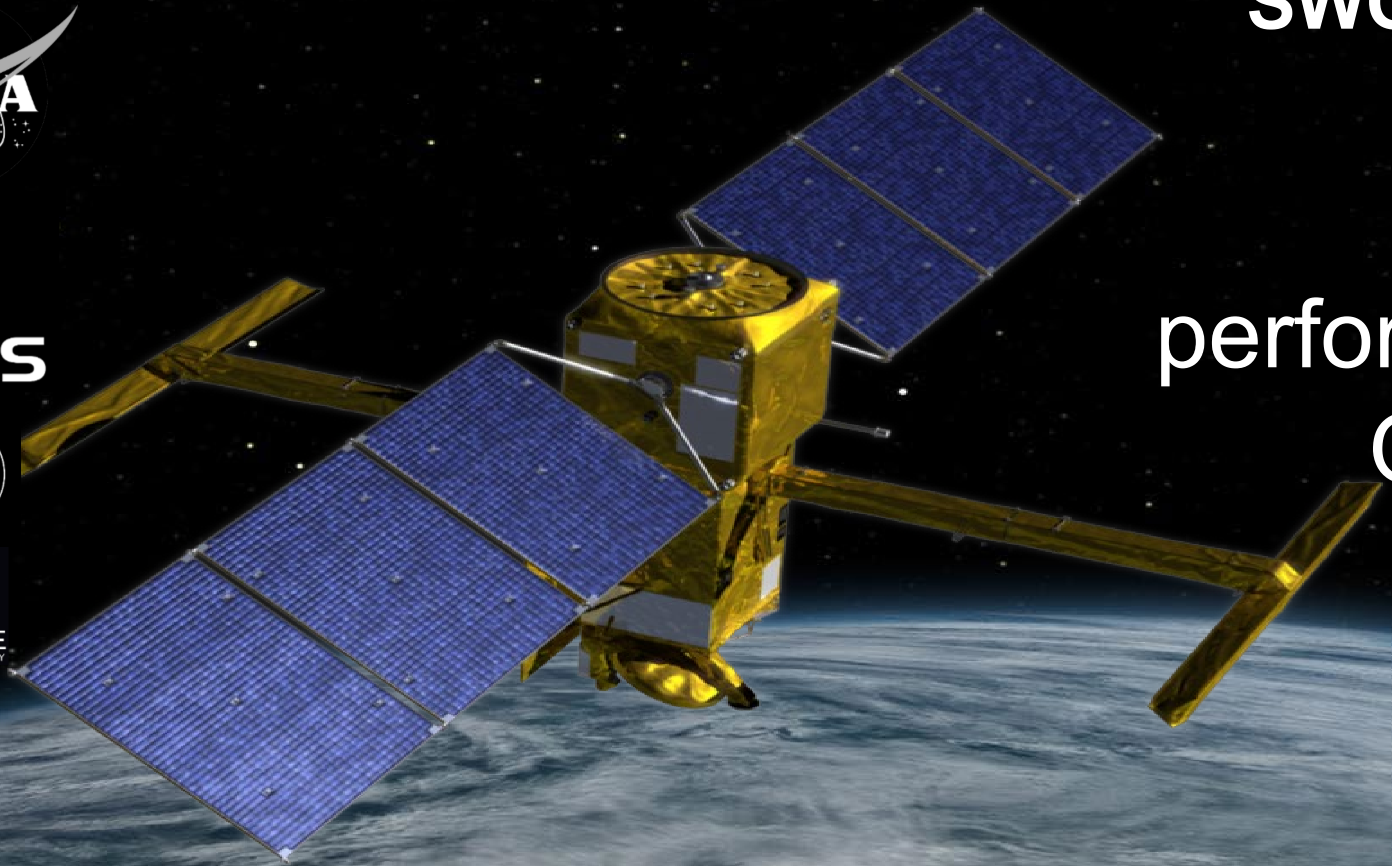
SWOT validation meeting

17-21 June 2024

KaRIn performances and validation Over Open Ocean



CNES : Matthias Raynal, Alejandro Bohe, Nicolas Picot, Gérald Dibarboure

CLS : Pierre Prandi, Francesco Nencioli, Emeline Cadier, Antoine Delepoulle

DATLAS : Clément Ubelmann

Fluctus : Bruno Picard

JPL: Curtis Chen, Albert Chen, Shailen Desaï, Bryan Stiles

OUTLINE

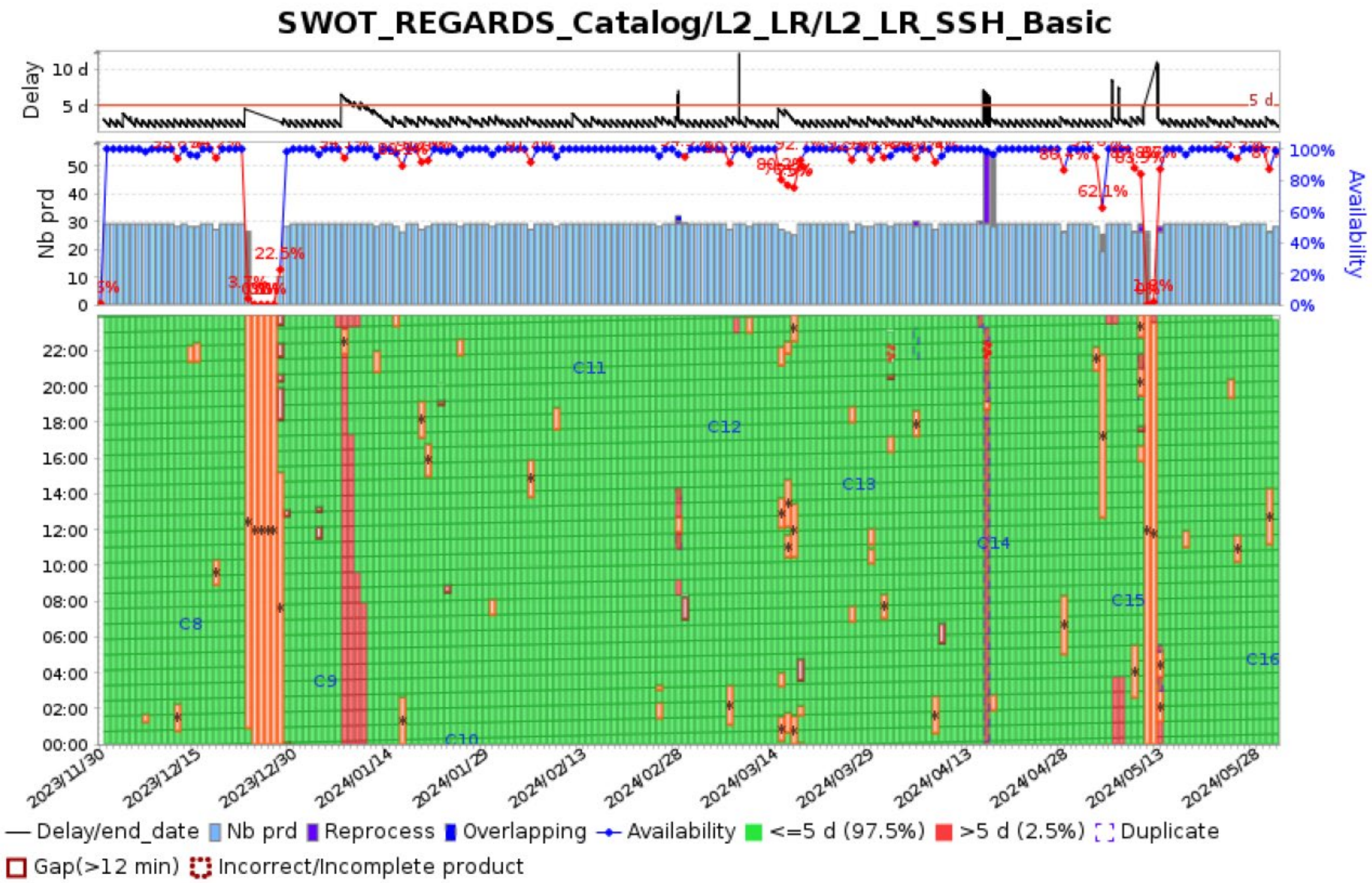
- KaRIn Global performances over Ocean
  - Data availability
  - Valid measurements & outliers
  - SSHA validation & Comparison with nadir altimetry
  - Wind speed & SWH respectively addressed in A. Chen and A. Bohe ‘s presentations

- (Sub-) mesoscale SSHA observability
  - Qualitative observations
  - Quantitative characterization

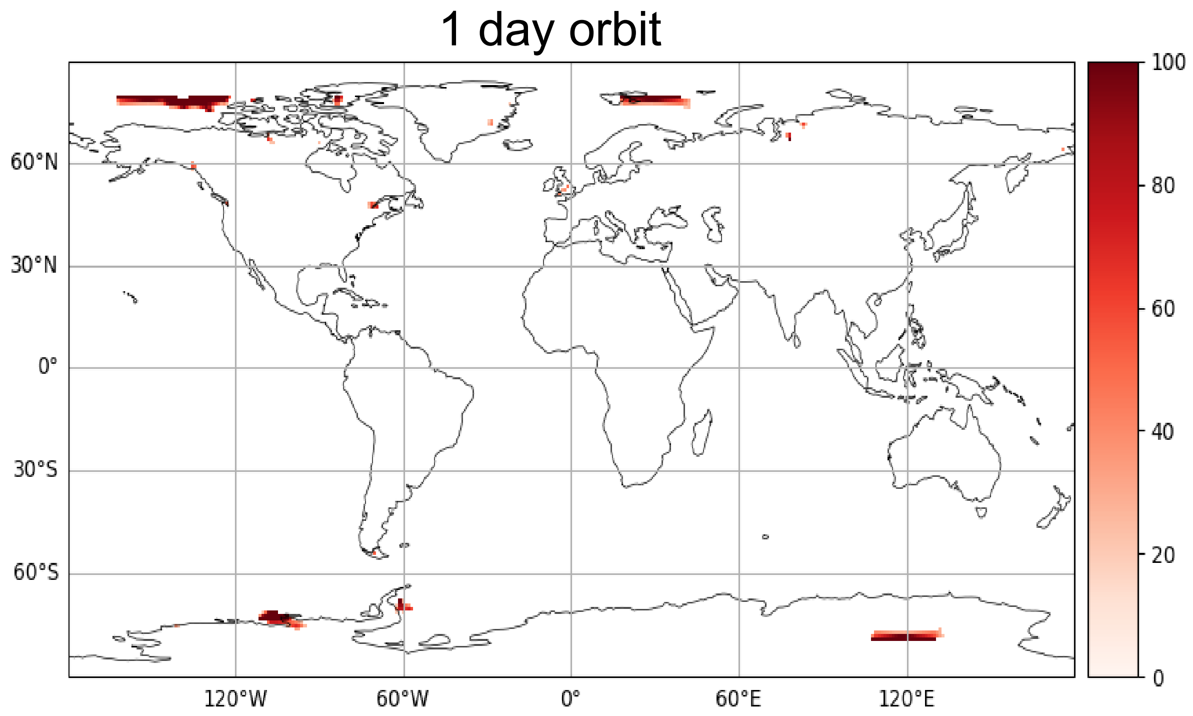
Data availability

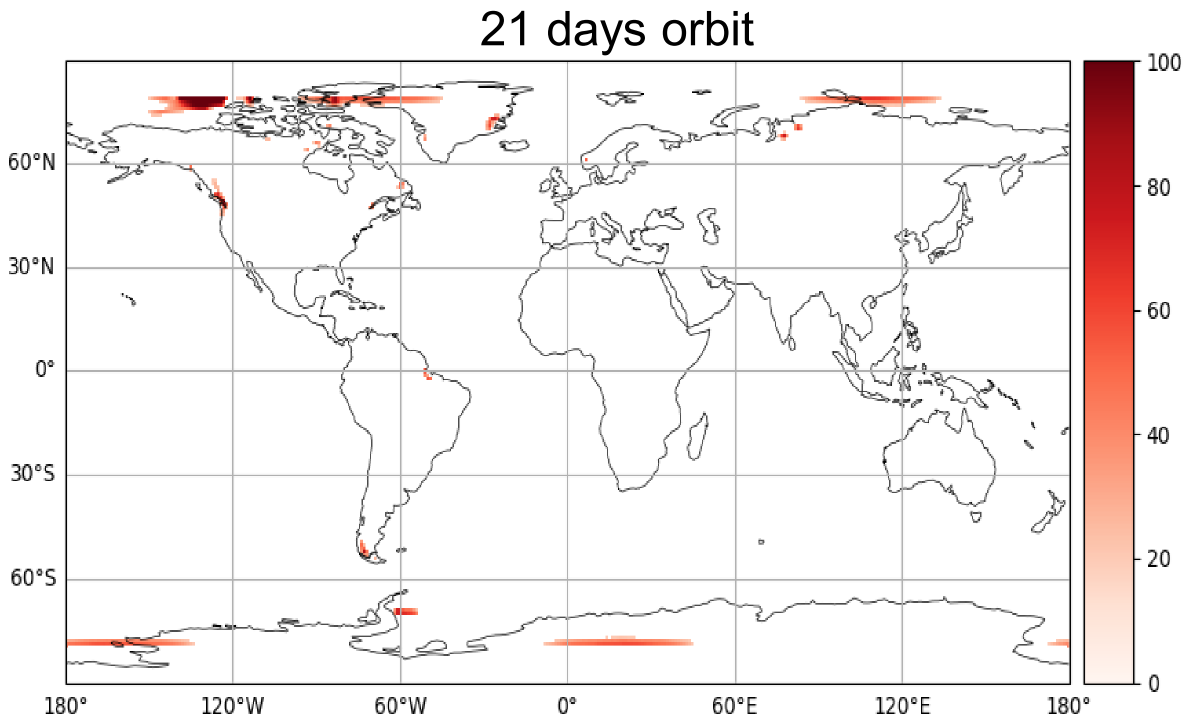
- **Excellent data coverage**
  - **93.8 %**
  - **(95 % for nadir IGDR products)**

- **Most of the degraded cases are related to**
  - **Mission manoeuvers**
  - **SSR issues**
  - **Ground stations events**



Data availability

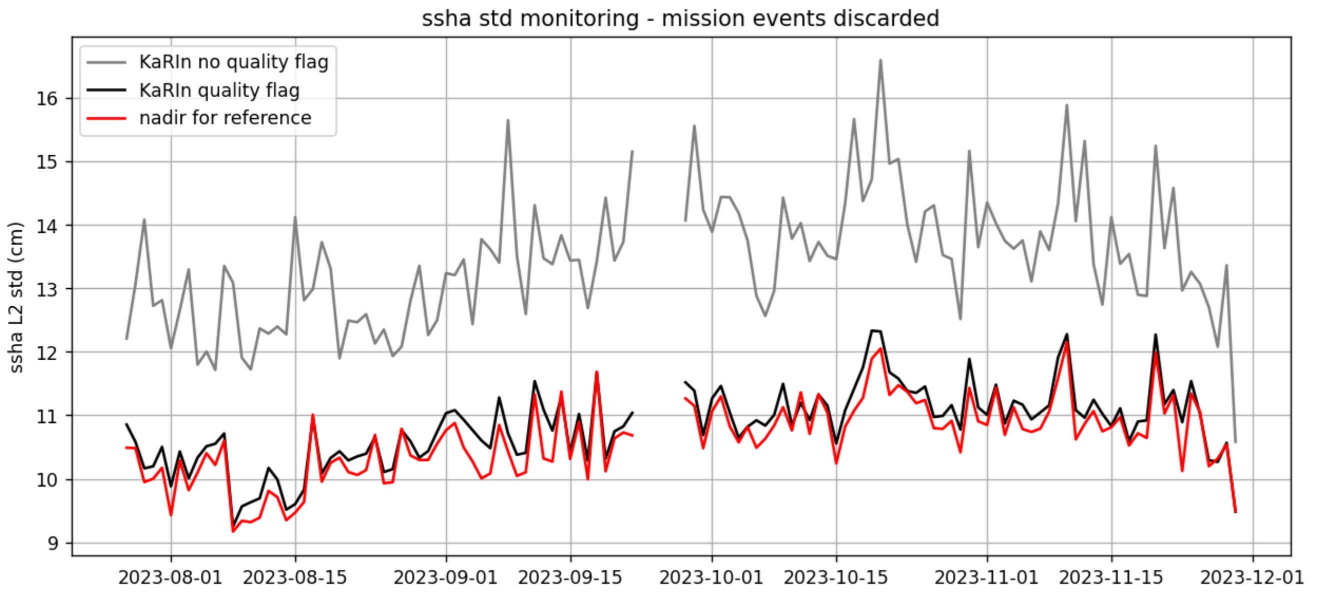


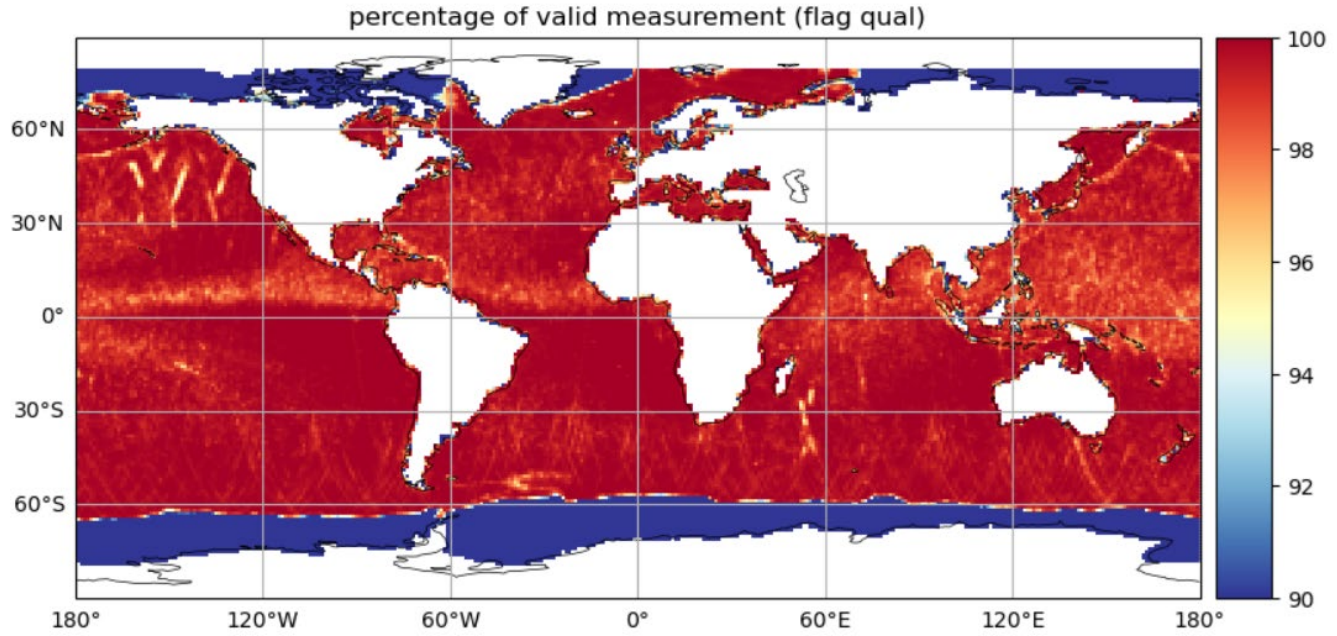


- Some specific areas for which KaRIn SSHA is undefined
  - Mainly located in arctic & coastal complex regions
- Mostly due to the reference surface used in LR L1B processing (see A. Chen 's presentation)
- These data are not permanently lost, should be recovered with next reprocessing (for now recommendation is to use HR products over these specific areas)

Valid / corrupted KaRIn pixels

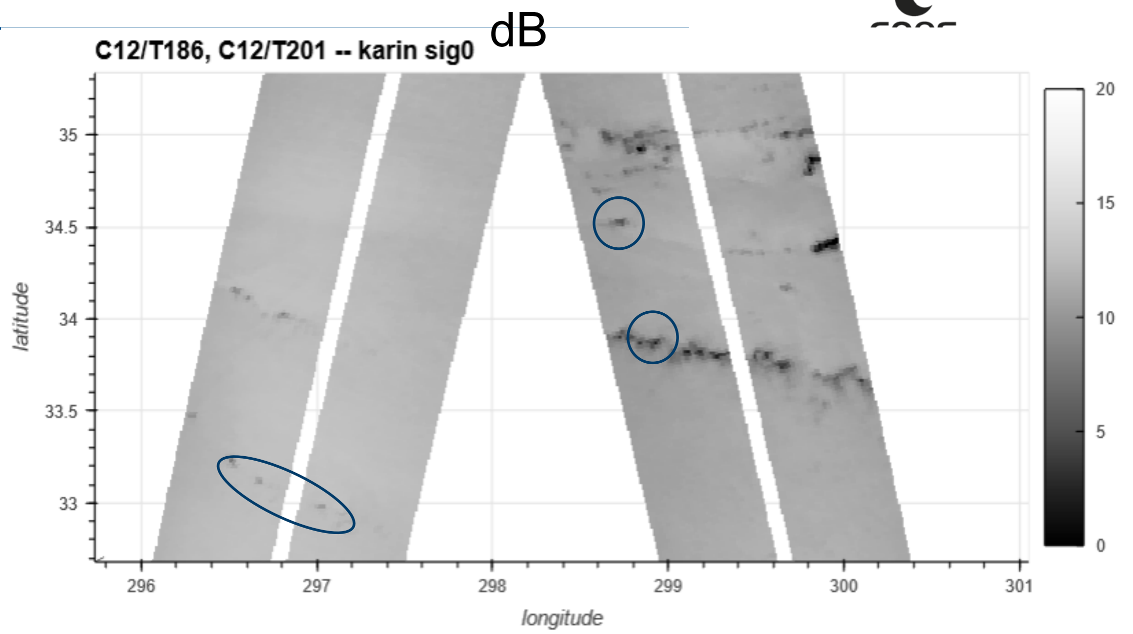
- Use of the KaRIn SSHA quality flag(s) to identify & remove outliers
- Expected positive impact on SSHA with a significative reduction of the SSHA variance
- Very high number of valid measurements
  - 98% of valid measurements over Ocean
  - (97% usually observed for nadir missions)
- Most of the outliers are located in:
  - ITCZ (Inter Tropical Convergence Zone) where rain cells impact the measures quality
  - Strong sea states areas
  - Coastal areas

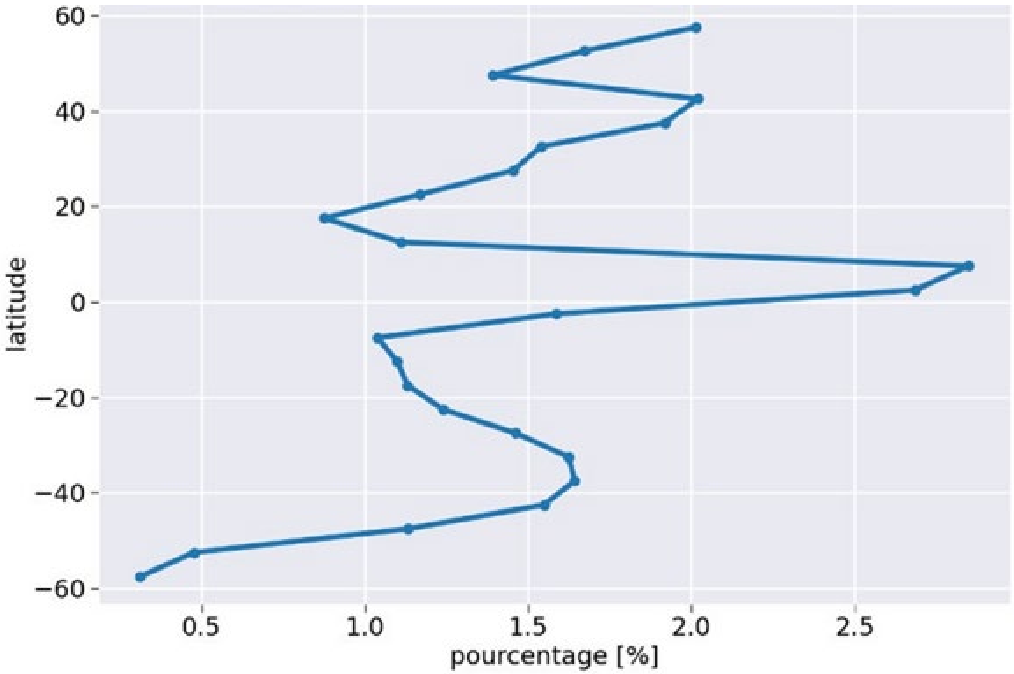


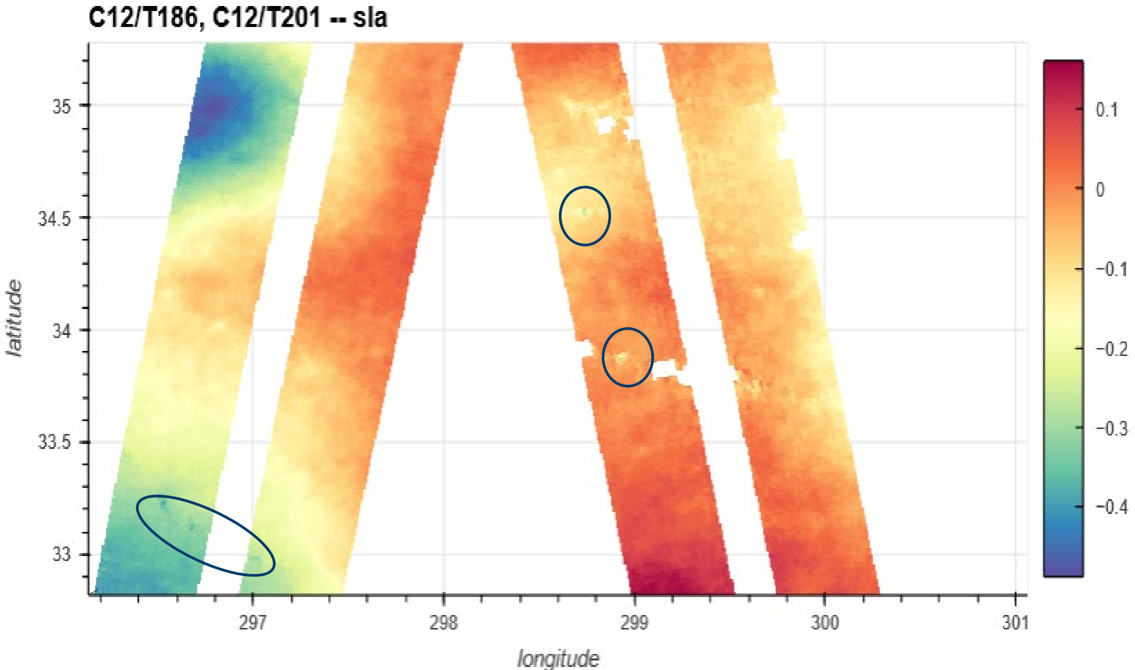


Valid / corrupted KaRIn pixels: the specific case of rain cells

- Current quality flag definition (ssha_Karin_2_qual) misses some rain events that impact the KaRIn SSHA
- Ongoing development of a new rain flag based on KaRIn sigma0 attenuation (and AMR a priori)
  - Rain flag (based on ECMWF model) available in the products is not accurate enough
- Up to 2% of valid measurements (based on quality flags) are flagged as rain
  - These residual non-identified outliers have a potential impact on SSHA quality







Valid / corrupted KaRIn pixels: the specific case of high SWH

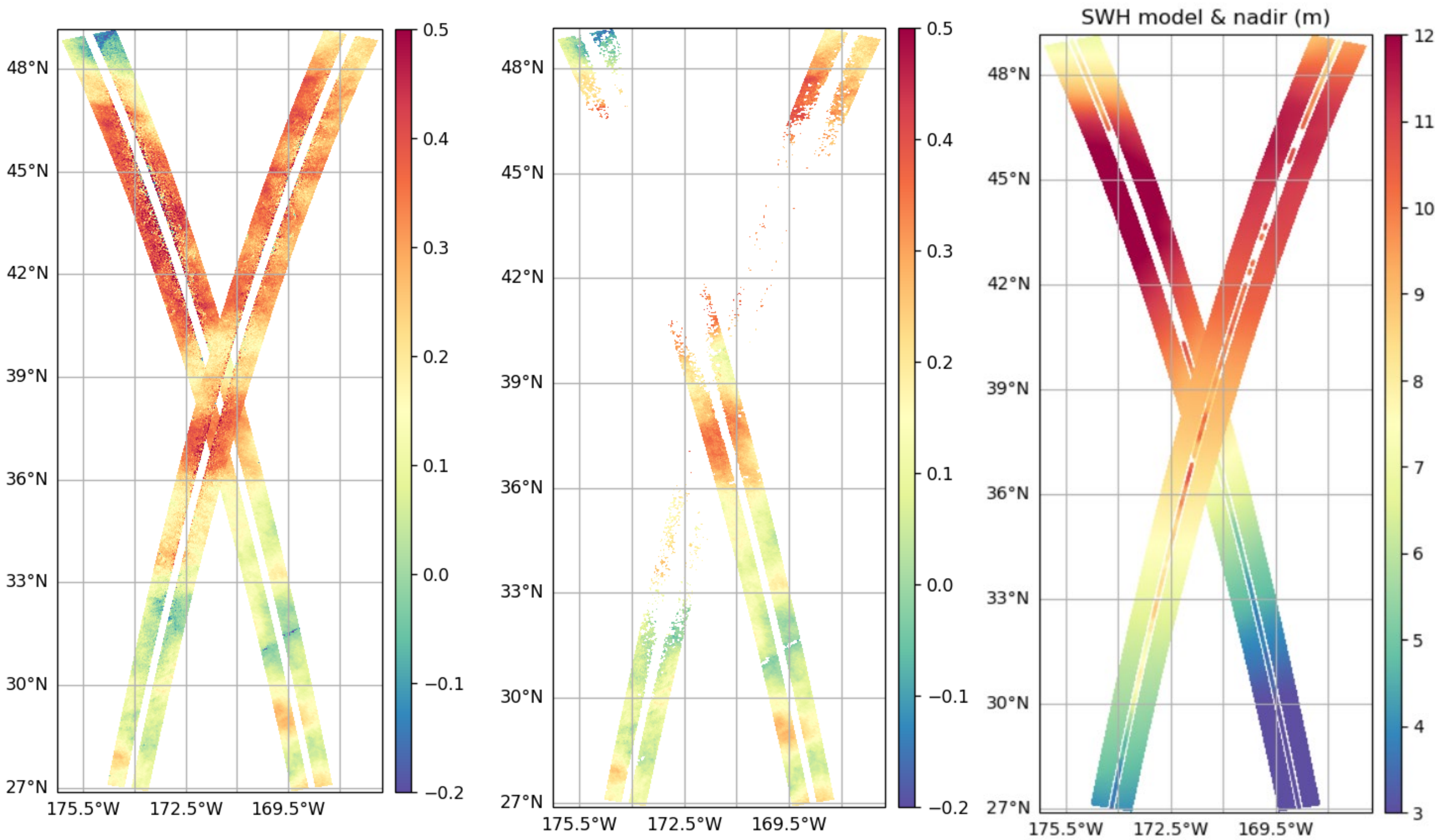
The current editing strategy (ssha_Karin_2_qual == 0) includes a threshold (10cm currently) on the variable ssh_uncertainty (which estimates the random noise from the measured coherence).

•For extreme sea states the random noise significantly increases (as expected, with more impacts in the near range). This leads to a significant increase of edited measurements starting at SWH>6m.

•It reaches more than 30% of edited pixels for SWH>10m. However this amounts to a small overall number of edited pixels at the global scale since these extreme SWH values are very punctual and local : SWH > 8m only represents 0.4% of the data.

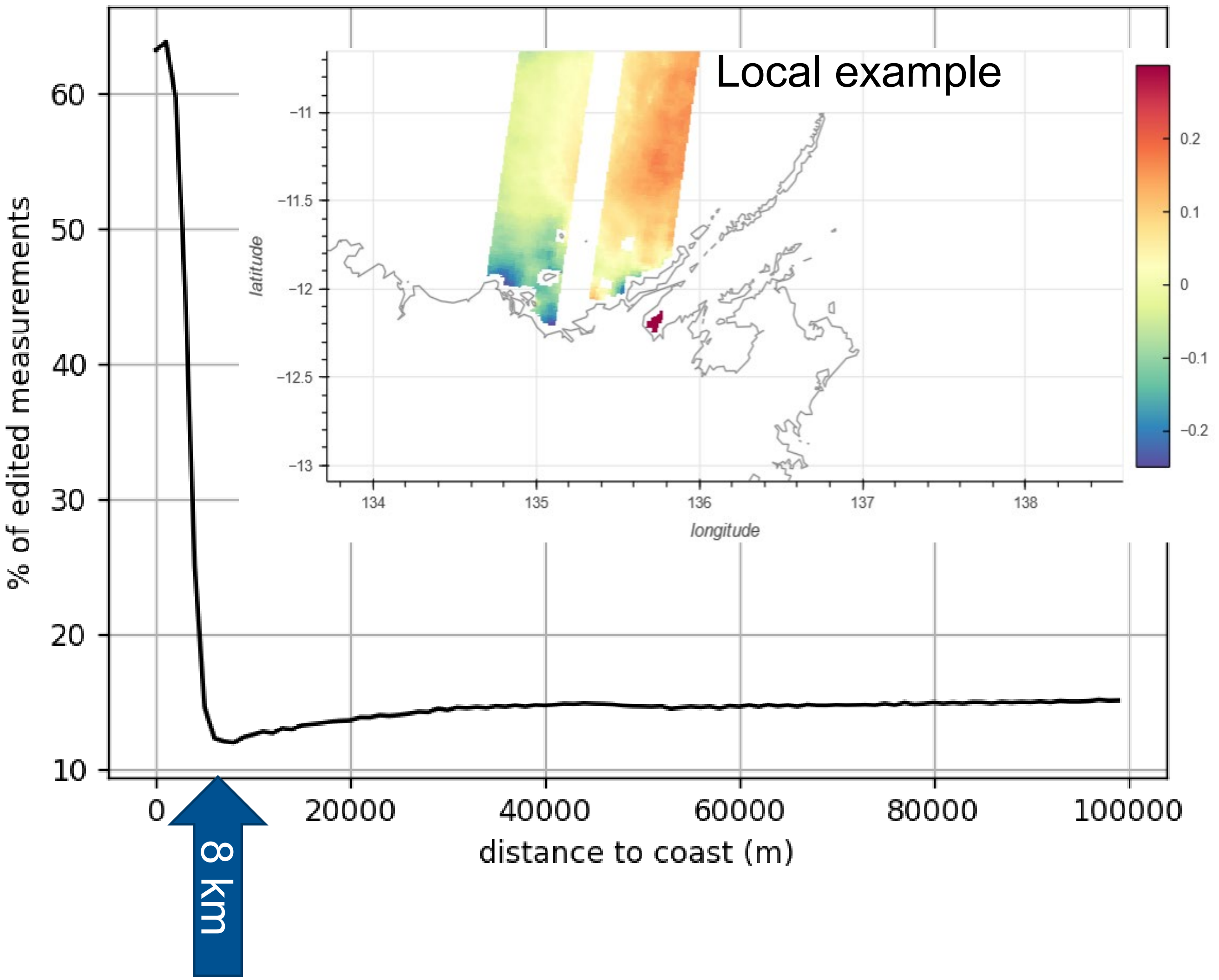
•Although the random noise is higher in those extreme sea states (as expected), the SSHA signal still seems to contain valuable information (see example), so in the long term, not editing these pixels would likely be beneficial.

•This however requires more work on choosing the right threshold. This is not straightforward as it is an important factor in our ability to detect measurements contaminated by rain.

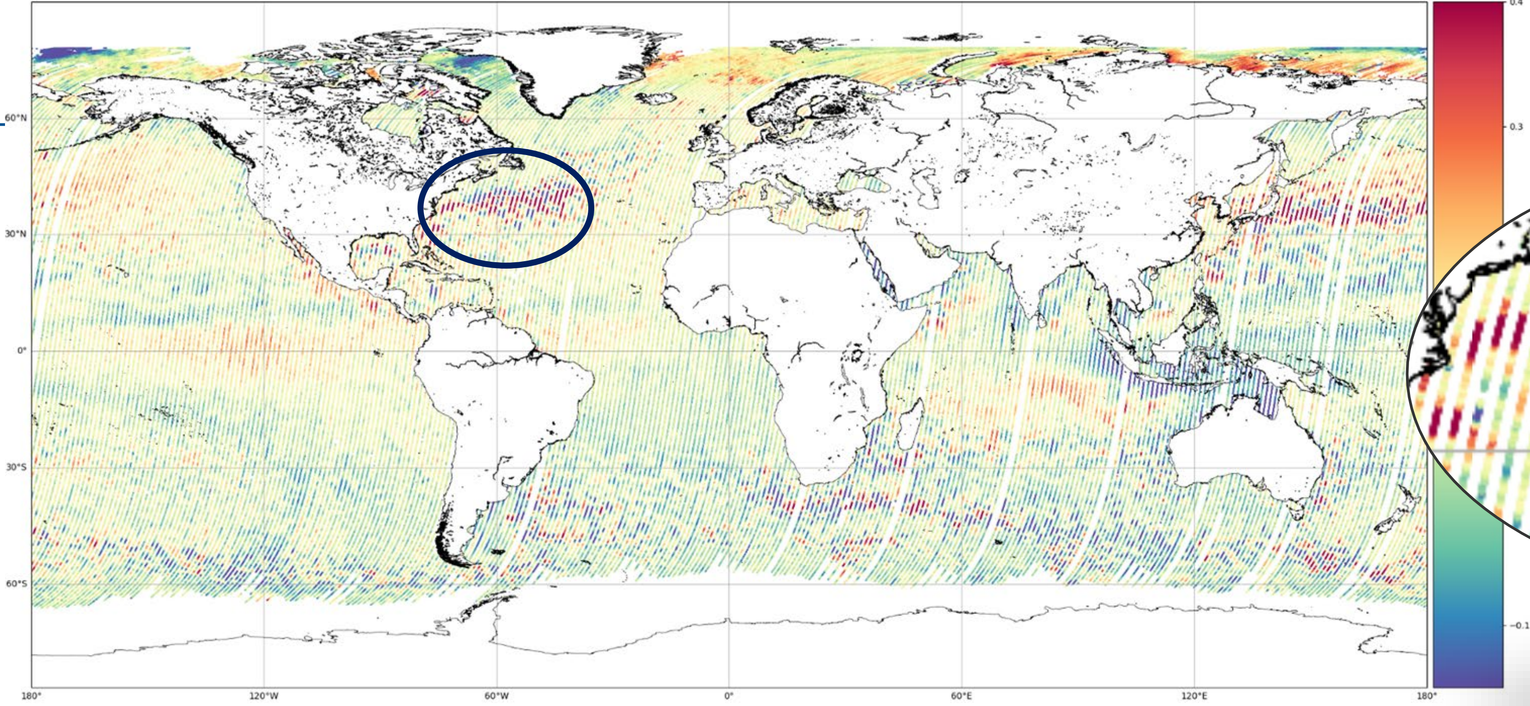


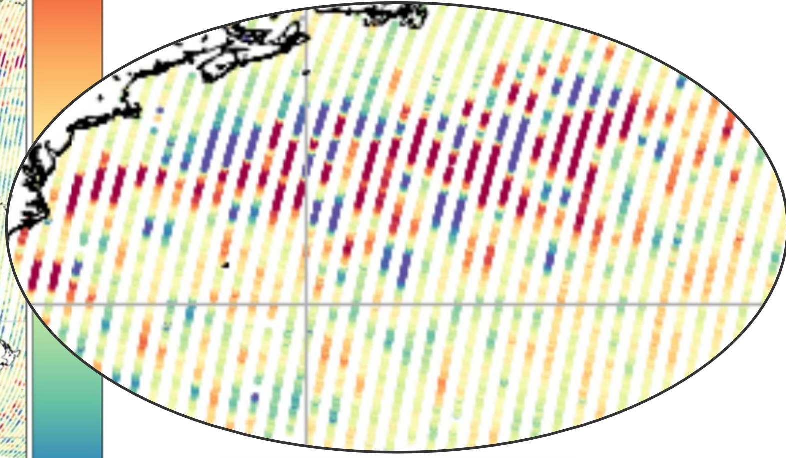
Valid / corrupted KaRIn pixels: the specific case of Coastal areas

- **L2 LR SSH products not designed for coastal (first kms) studies.**
  - See A. Chen ‘s presentation for details on processing limitations
  - % of valid measurements decreases from 8 km to the coast
  - More than 60% of the measurements edited near the shore
- **The specific case of coastal areas will be further studied to improve the data quality in these regions**

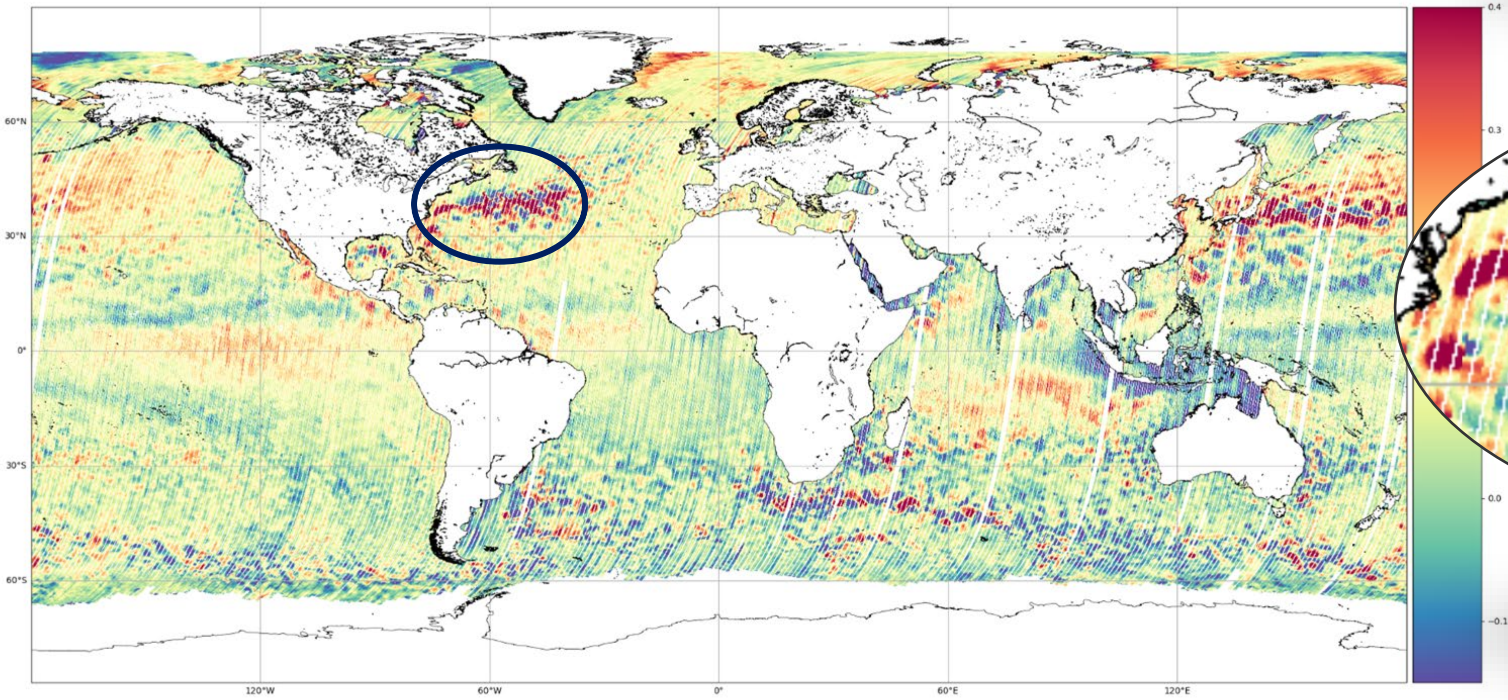


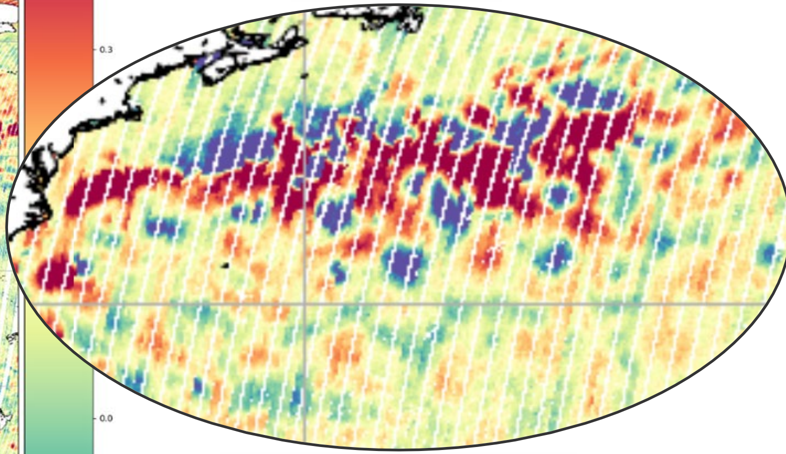
SWOT nadir SSHA





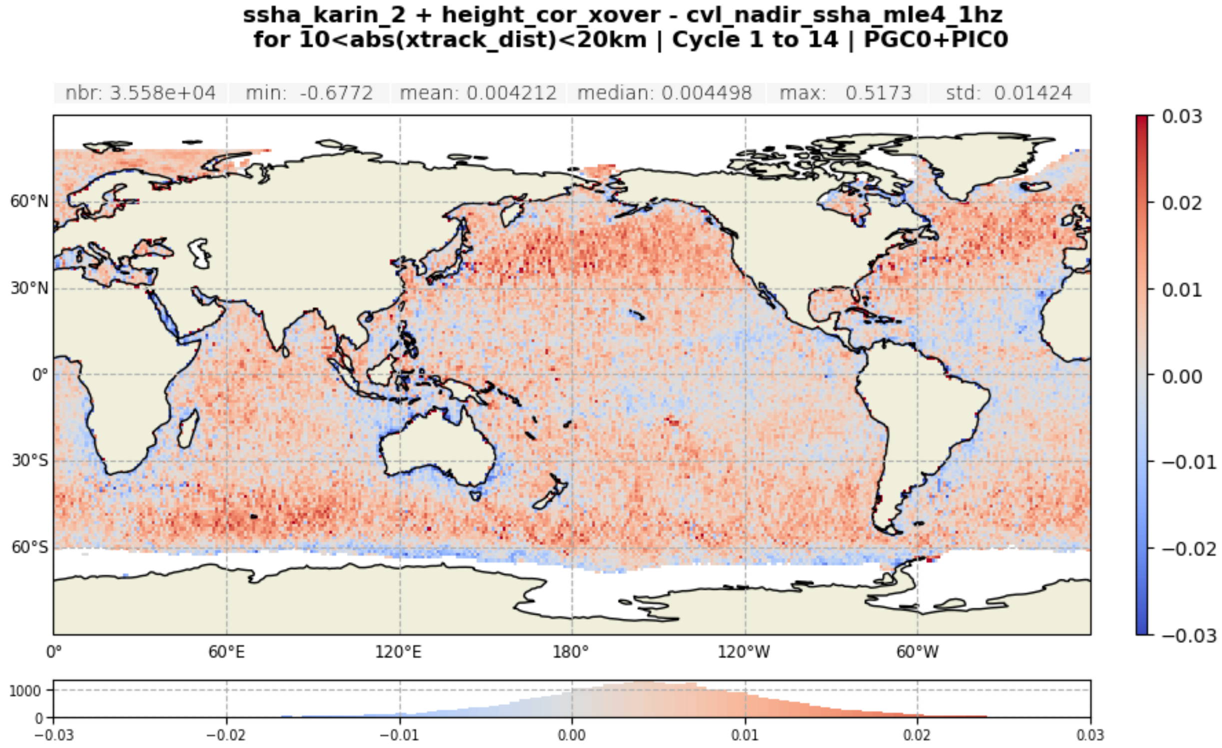
KaRIn SSHA

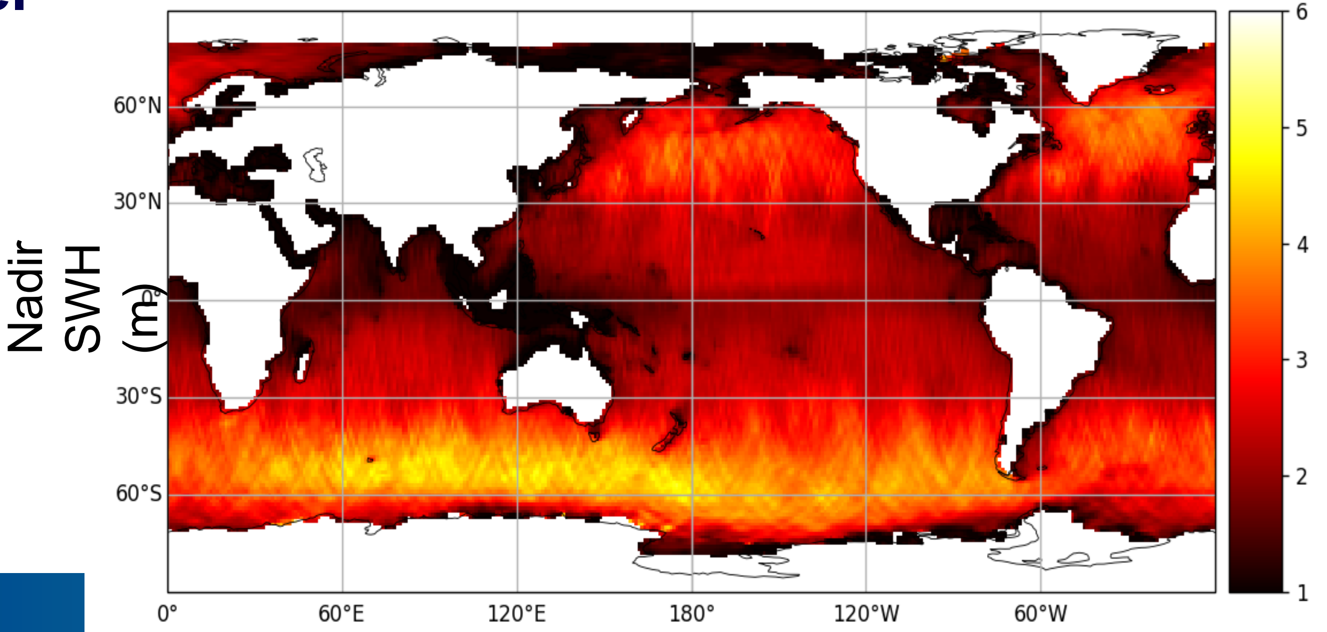




KaRIn/SWOT_nadir comparisons

- **Excellent agreement between KaRIn & SWOT nadir at long wavelengths**
  - ~4mm mean bias
  - Differences ranged from -1 to 2 cm
- **At first order, spatial correlation of differences with nadir SWH**
  - SSB solution used (based on model inputs) is the first suspect
  - Need to refine the current SSB solution (inputs + model)
  - Estimation of the real, total SSB error is not straightforward as part of the error is absorbed by the L2 XCAL at scales > 7000 km



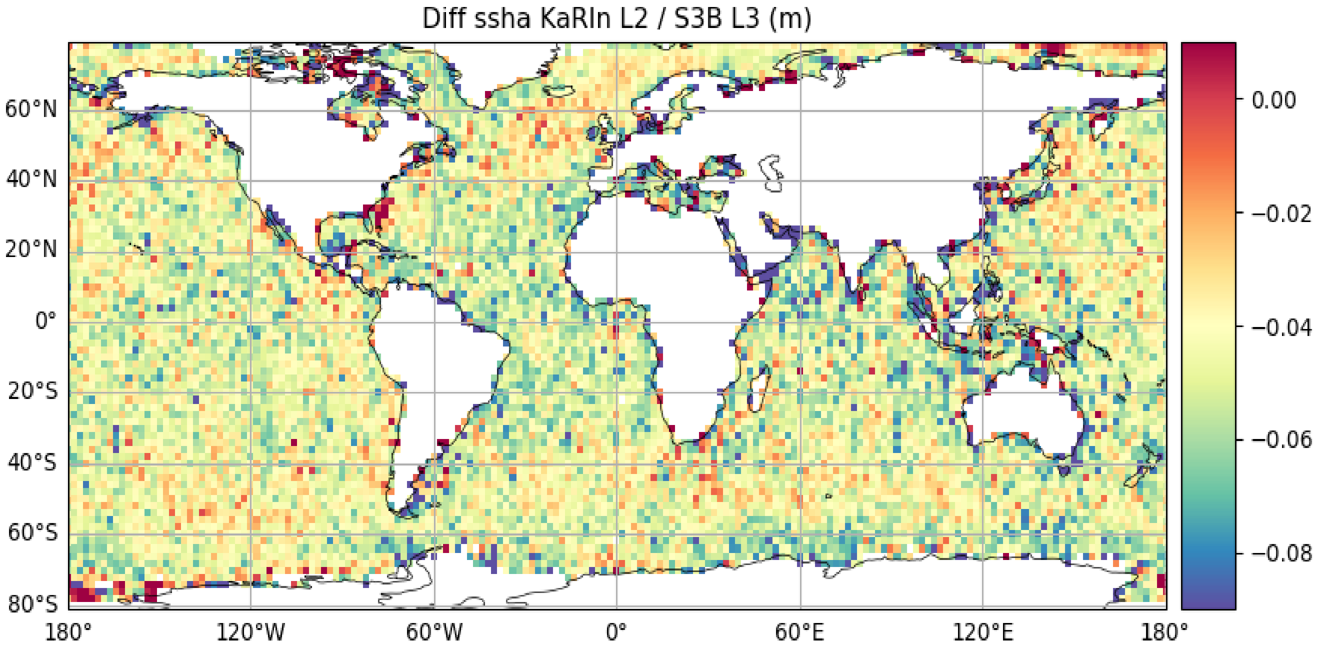


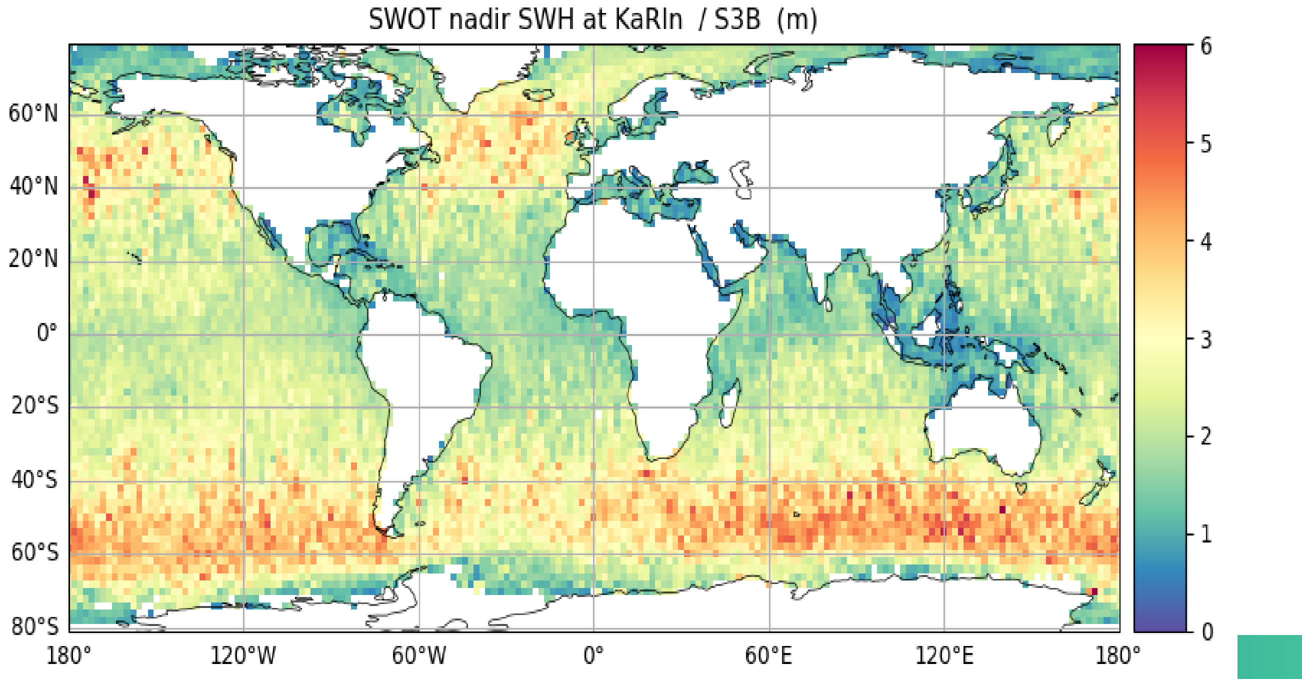
KaRIn/Sentinel-3 comparisons

- Same kind of analysis performed with respect to Sentinel-3
  - Differences computed at crossovers with time lag <= 1 day)

- Again excellent agreement observed

- Residual patterns also correlated with SWH geographical distribution
  - Confirms that most of the SSB residual error comes from KaRIn measurements.





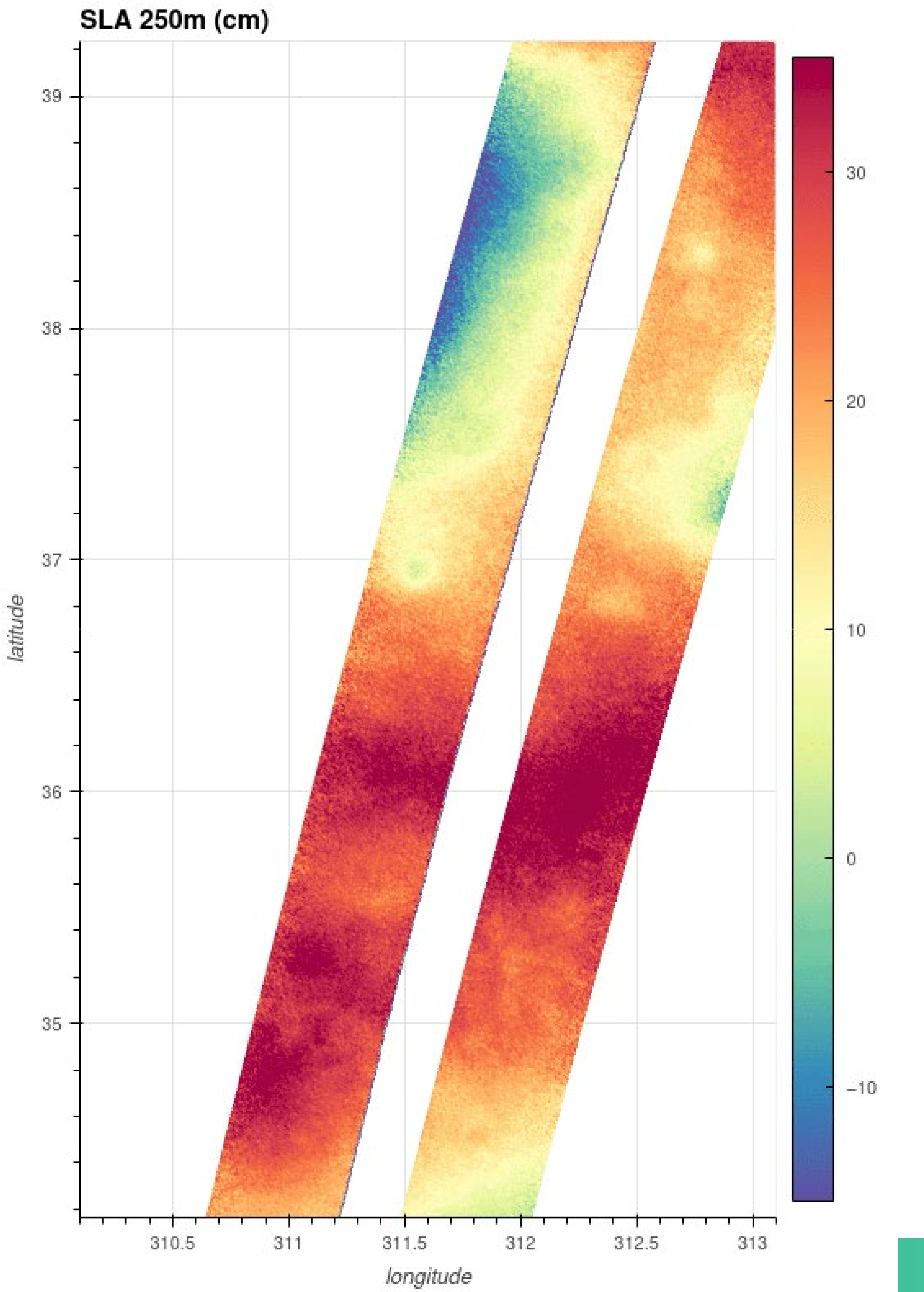
OUTLINE

- KaRIn Global performances over Ocean
  - Data availability
  - Valid measurements & outliers
  - SSHA validation & Comparison with nadir altimetry

- **(Sub-) mesoscale observability**
  - **Qualitative observations**
  - **Quantitative characterization**

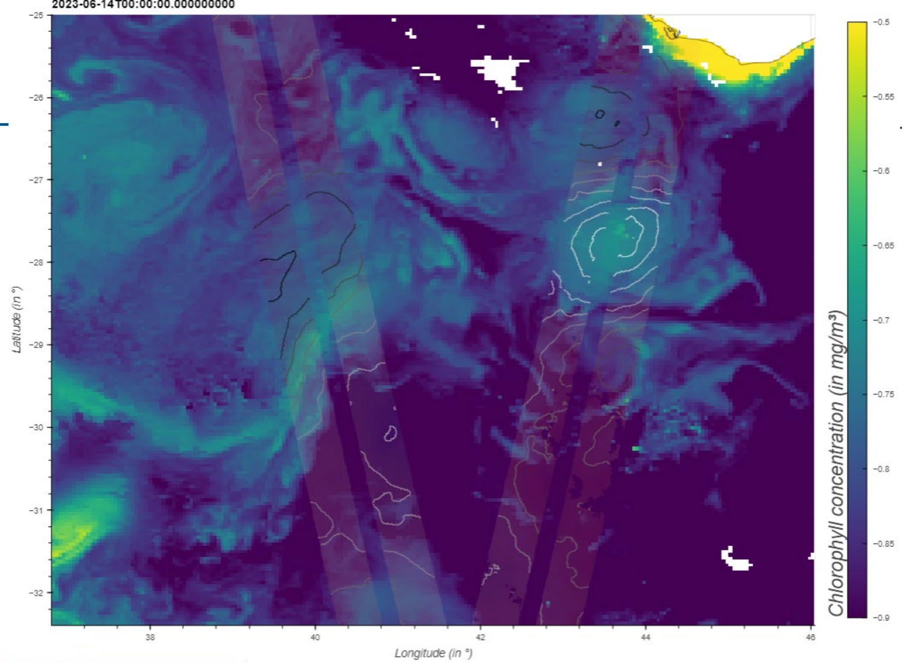
KaRIn SSHA (sub)mesoscales self-consistency

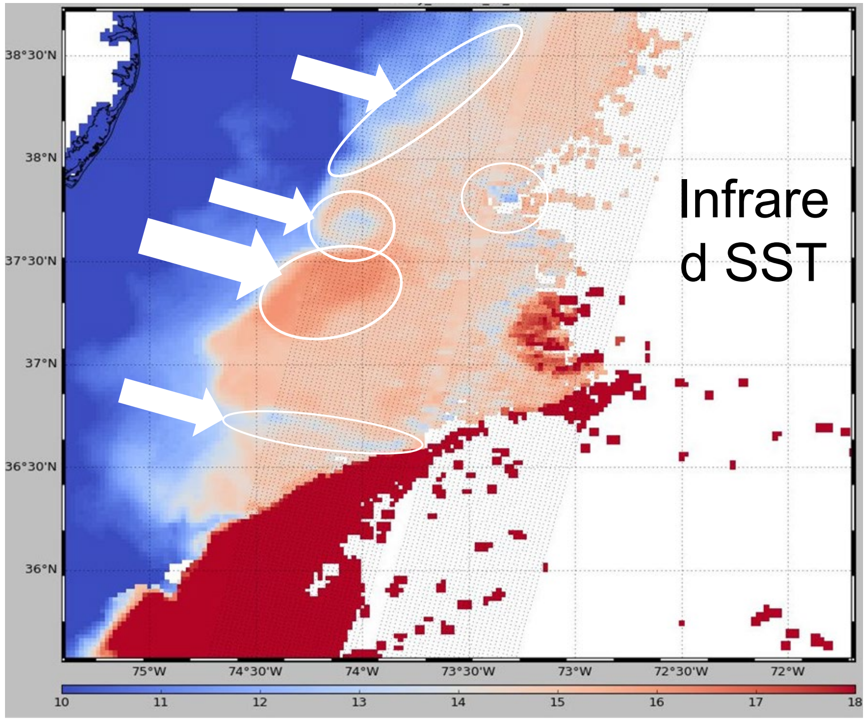
- **KaRIN topography animated**
  - One month of data
  - One snapshot every 12h
  - Full resolution of LR mode (250m)
- **Extreme self-consistency test (large eddy, eddies travelling between swaths, etc.)**
- **Longevity of massive cyclonic eddy**
- **Very fast transformation of nearby circulation**
- **Small eddies splitting/merging**
- **Expected limitations**
  - Some days with rain artefacts (glitchy areas)
  - Some days with calibration problems (bias)
  - Some days with noisy images (high waves)

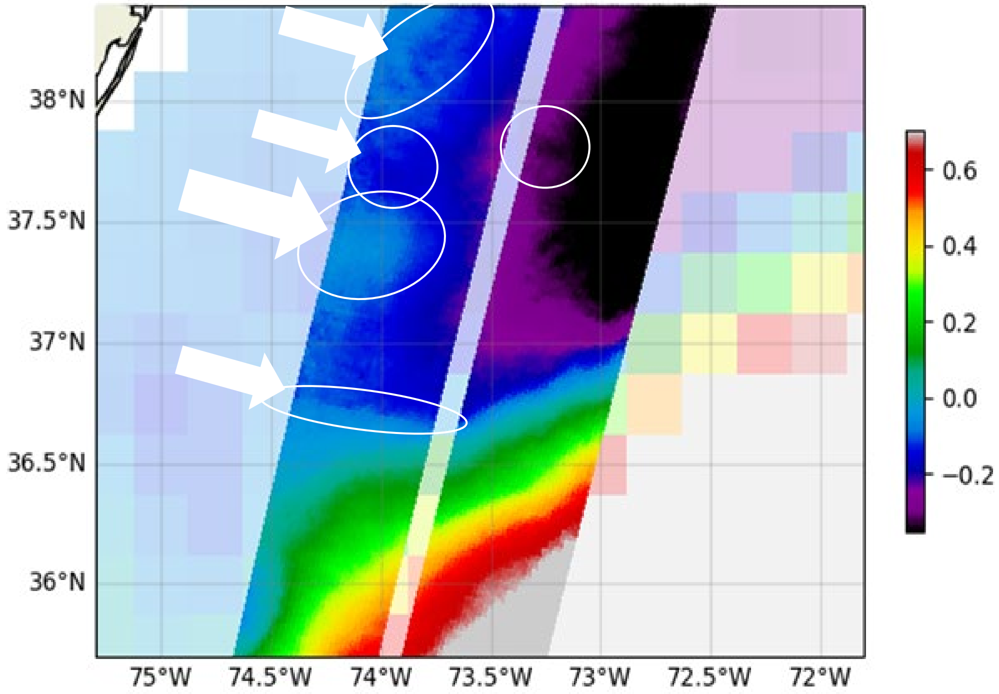


KaRIn SSHA (sub)mesoscales multi-sensors comparison

- Local validation of KaRIn SSHA structures using independent sensors
- Excellent agreement on the location of eddies and fronts
- Ongoing study to assess the global spatial correlation for scales <= 100 km
- Does not validate the amplitude of structure seen by KaRIn

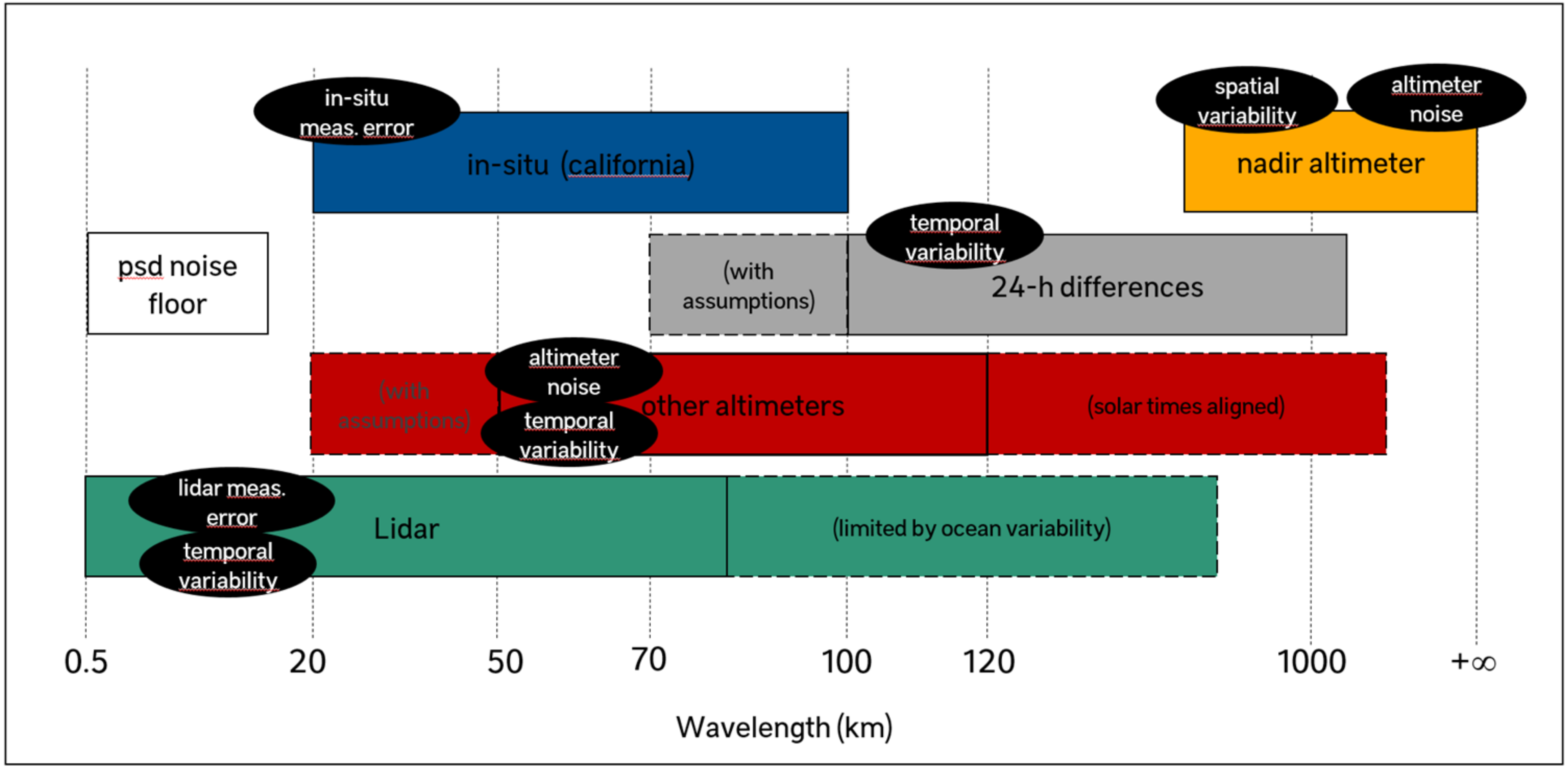






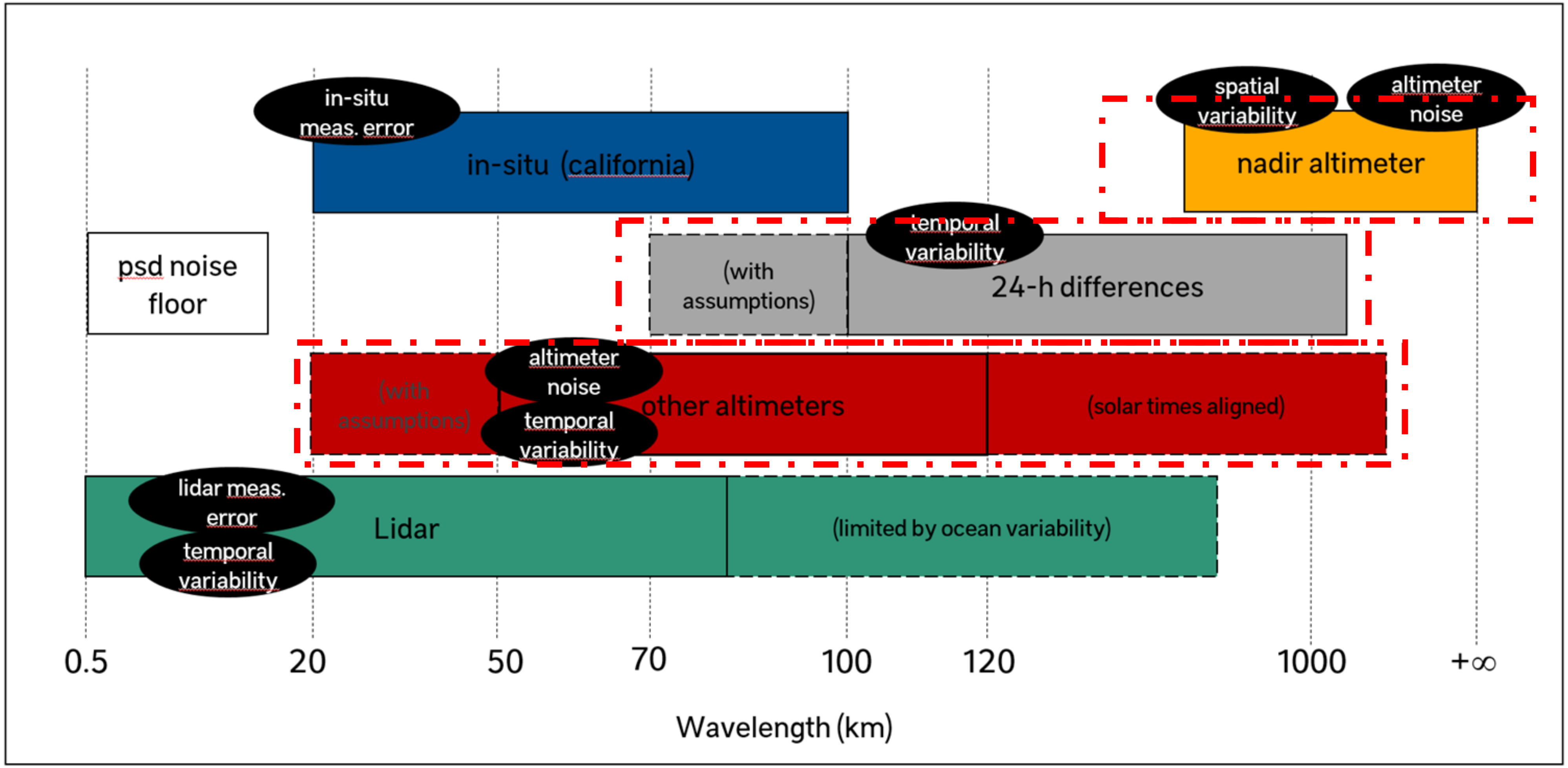
KaRIn SSHA (sub)mesoscale validation

- Different methods to evaluate the KaRIn SSHA performances
- Different assets and drawbacks



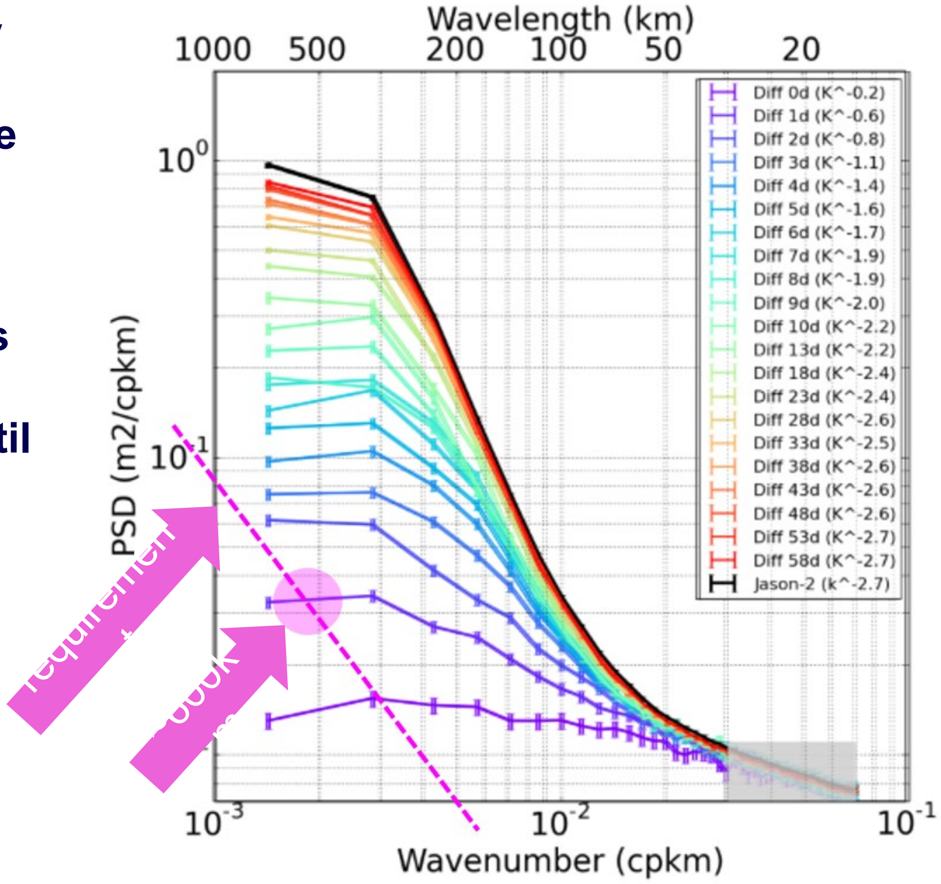
KaRIn SSHA (sub)mesoscale validation

- **Focus on the 3 global methods**
- **Dedicated paper led by F. Nencioli to be submitted in coming days.**

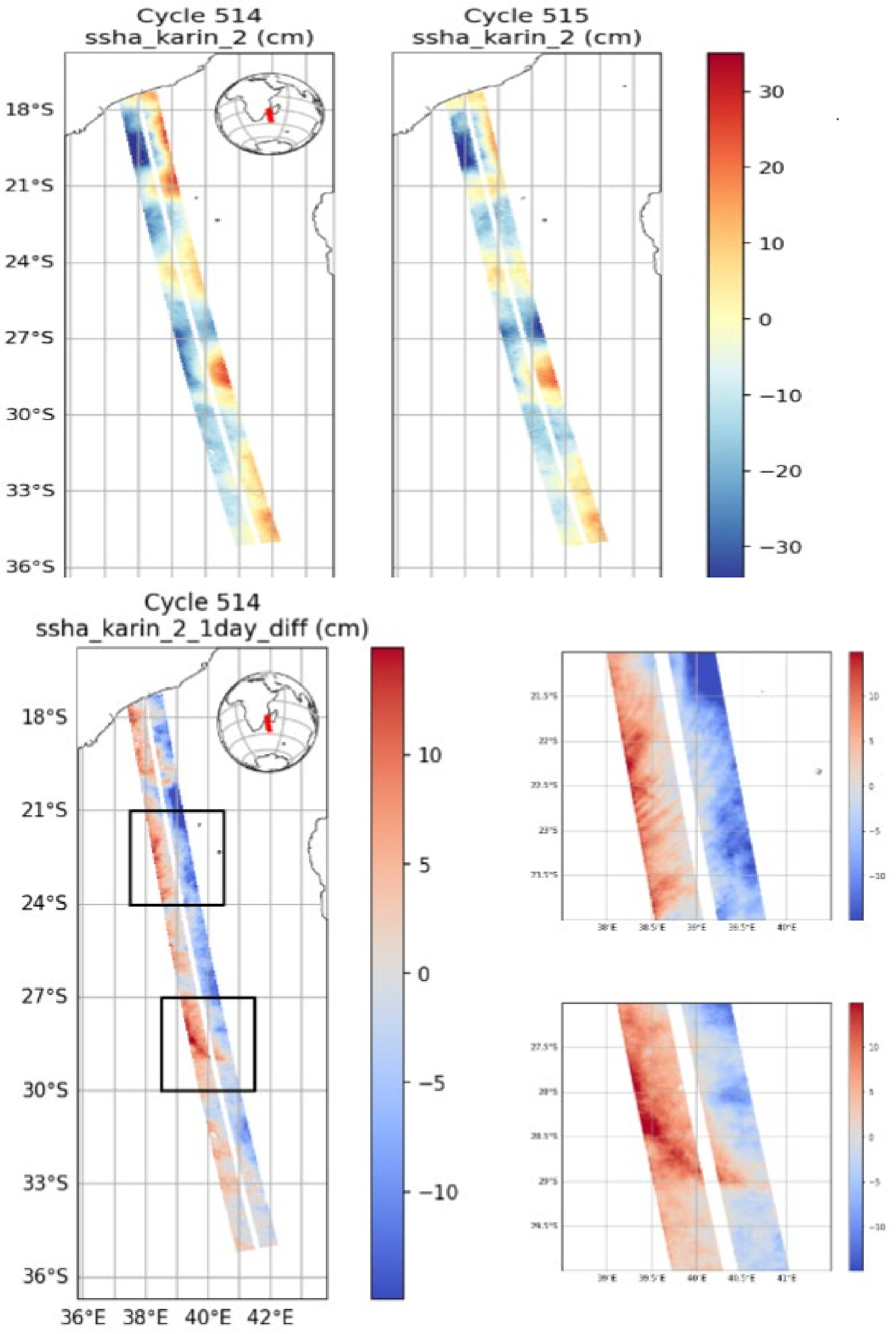


24h diff Method: limiting factor

- Natural oceanic variability significantly increases the variance when computing a time difference
- For 24hours differences, it prevents the validation of the SWOT requirement until ~600 km.
- Need to estimate this contribution



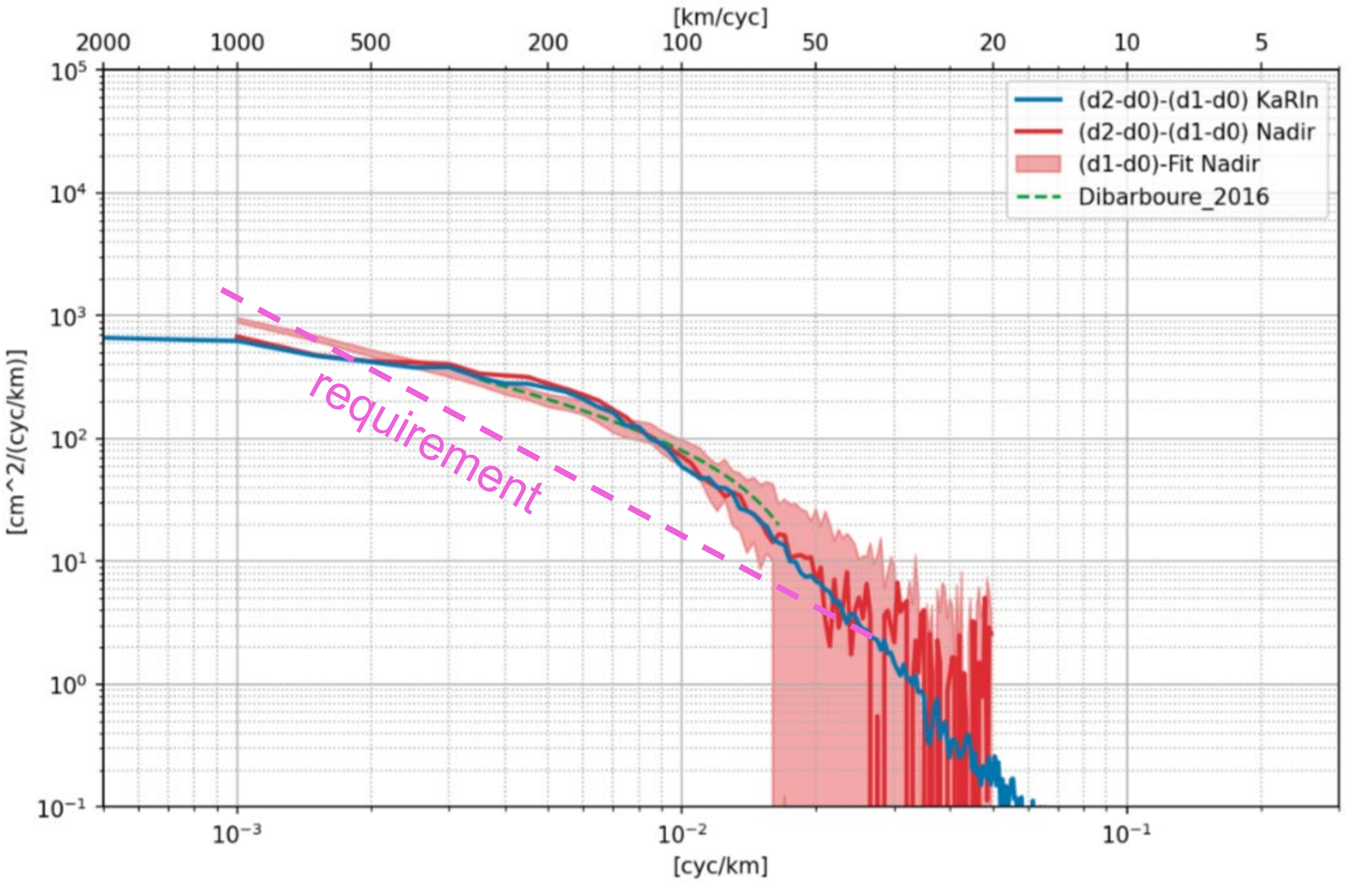
From Dibarboure & Morrow, 2016



24h diff Method: Estimation of the 24hour oceanic variability

3 different methods provide very consistent results:

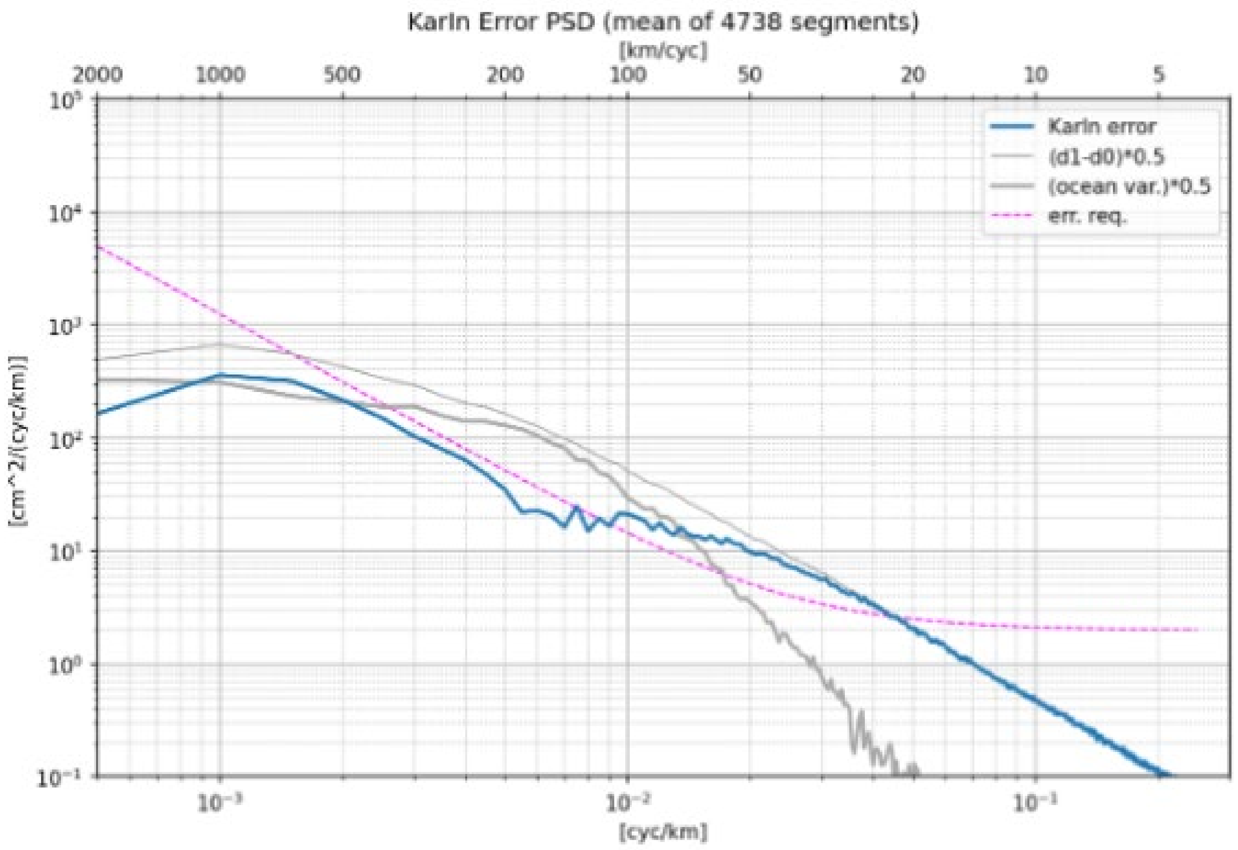
- Dibarboure & Morrow (2016) based on colocated differences bewteen Jason-1 (geodetic phase) and Jason-2.
- Estimation based on the increase of variance between 1day and 2 days differences
  - Only includes the mesoscale variability
  - Variance of oceanic signal decorrelated in 24hours is not included
  - Assume that the increase of oceanic variability is linear from 1day to 2 days (False !)
- Estimation from SWOT nadir based on the increase of variance of 24h differences / ssha noise floor.
  - Limitation from nadir random noise (estimation below ~70km cannot be trust)
  - Limitation on the nadir random error estimation



The SWOT requirement is higher than the 24h oceanic variability from 70 to 300 km by a factor of 2 to 4

24h diff Method: result

- **Result based on this method shows that the KaRIn SSH random errors is :**
  - **Below the requirements for scales >= 125km**
  - **Below 100 km result is an upper bound of the KaRIn error estimation:**
    - Part of high frequency oceanic variability leaks in the error estimation

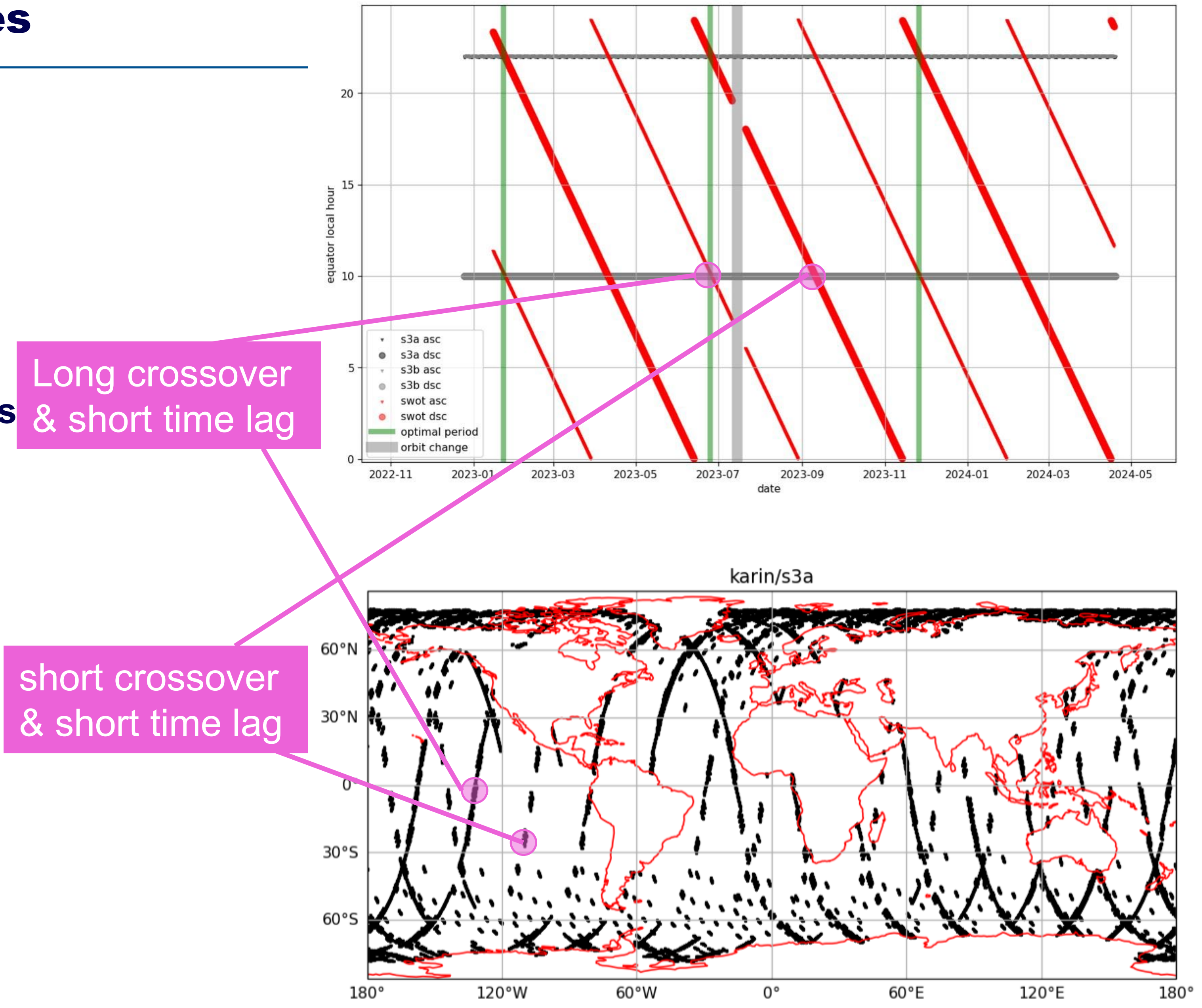


KaRIn / Sentinel-3 SSH differences

- **Optimal configurations when SWOT & Sentinel-3 solar time are aligned**
  - **See Dibarboure & al, ST2018 for more details about geometry & matchups properties**

Method:

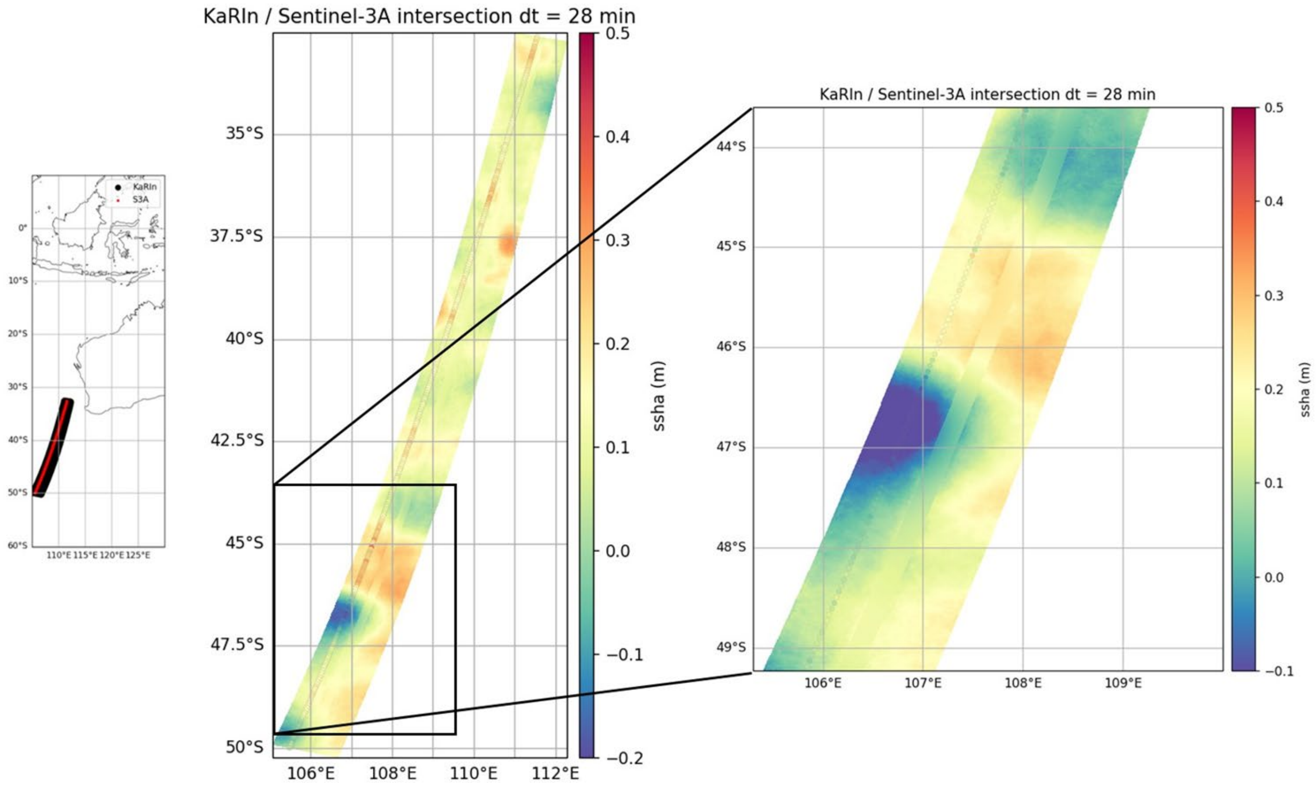
- **Merging of both Sentinel-3A & B datasets**
- **Compute match-ups with dt < 1h to limit the effect of natural oceanic variability**
- **Nearest neighbor interpolation of KaRIn pixels on Sentinel-3 measurements**
- **Compute PSDs from segments of different lengths**
- **Merge the individual PSDs to a mean Spectrum.**



1-day orbit matchups

KaRIn / Sentinel-3 SSH differences

- Optimal configurations when SWOT & Sentinel-3 solar time are aligned
  - See Dibarboure & al, ST2018 for more details about geometry & matchups properties



<u>**Method:**</u>

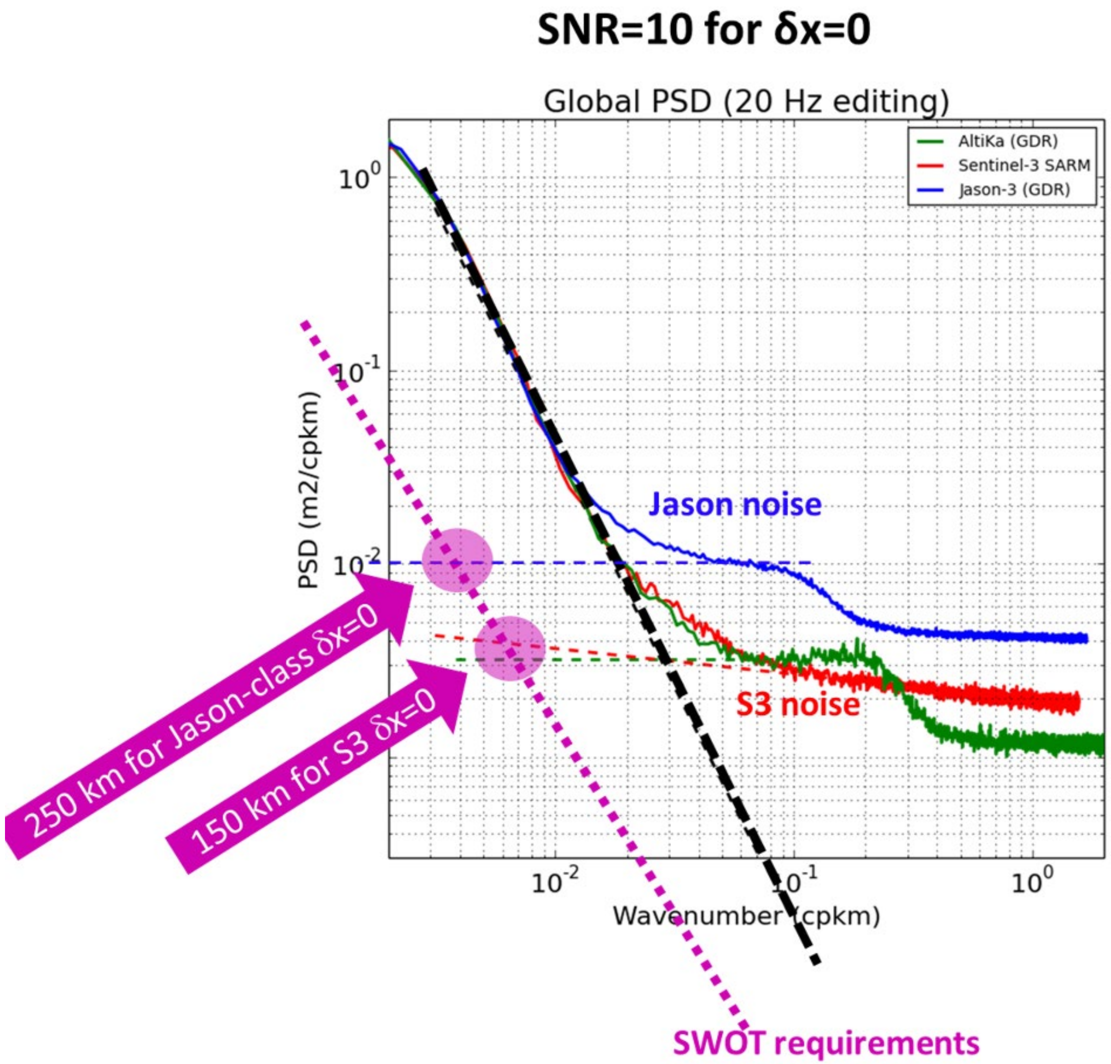
- Merging of both Sentinel-3A & B datasets
- Compute match-ups with dt < 1h to limit the effect of natural oceanic variability
- Nearest neighbor interpolation of KaRIn pixels on Sentinel-3 measurements
- Compute PSDs from segments of different lengths
- Merge the individual PSDs to a mean Spectrum.

KaRIn / Sentinel-3 SSH differences: limiting factor

- Both datasets are spatially co-located and time lag is limited to 1h

- The effect of oceanic variability is supposed to be small above tens of km.

- The limiting factor is the Sentinel-3 random noise that dominates at smaller scales
  - Prevents for validation up to ~150 km
  - If this contribution is removed, the residual signal drops below the requirement curve for scales from 20 to 1000 km.



KaRIn / Sentinel-3 SSH differences: result

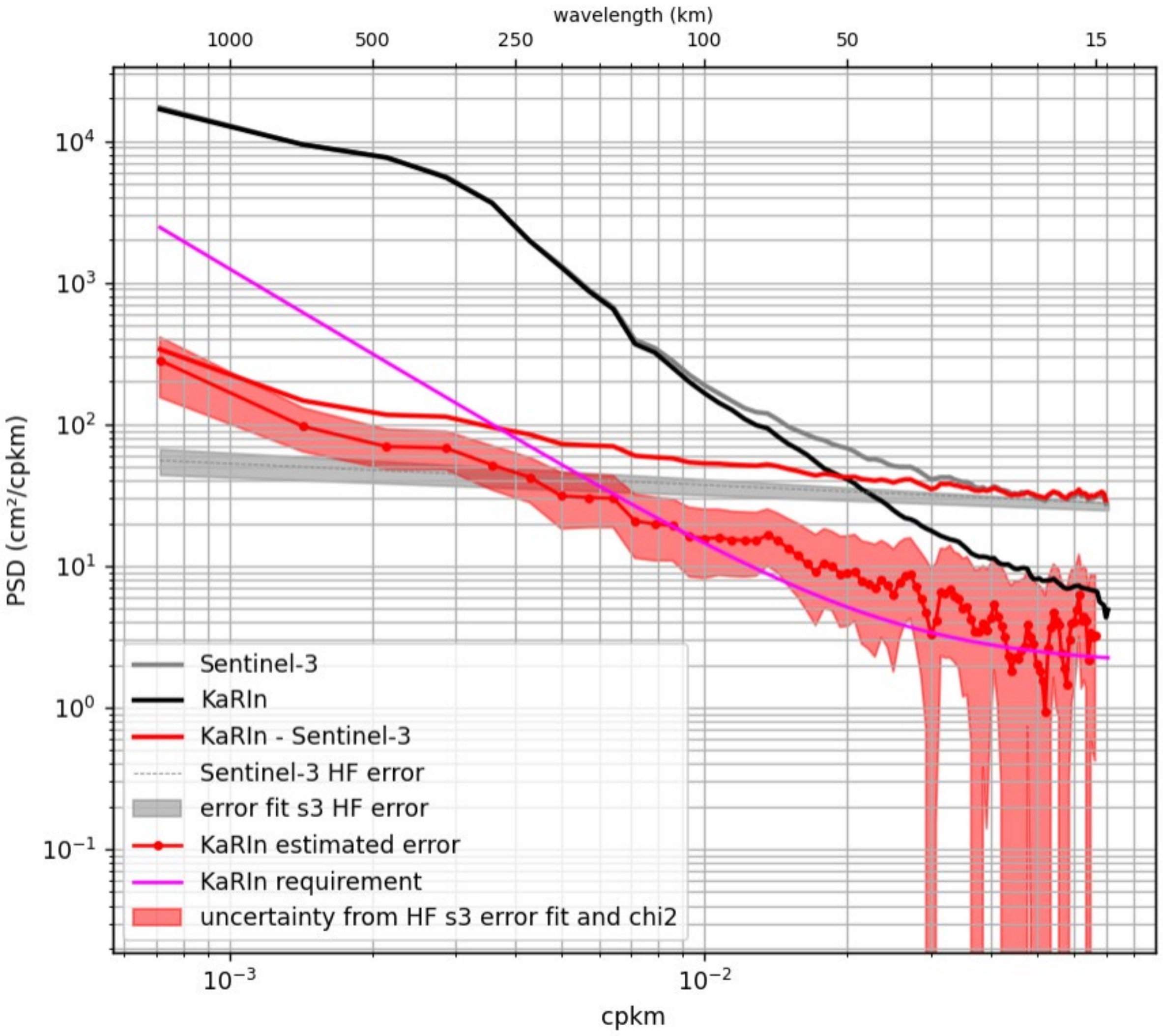
- Excellent agreement between S3 & KaRIn spectra for scales >= 125 km

- The spectrum of SSH differences (red continuous lines) is below the requirement for scales >= 270 km

  - A large part of the variance is induced by the nadir altimeter noise floor (red-colored spectrum for SARM altimetry)

- An estimation of this contribution is fitted and substracted to the PSD of differences (grey dashed line & gray envelop)

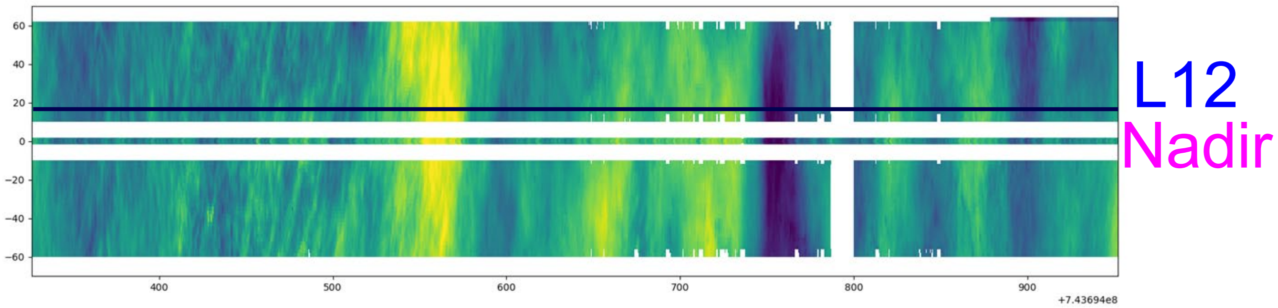
  - The requirement is verified for scales >= 100 km.
  - Below 100 km result is an upper bound of the KaRIn error estimation:
    - Part of high frequency oceanic variability leaks (below 1h) in the error estimation

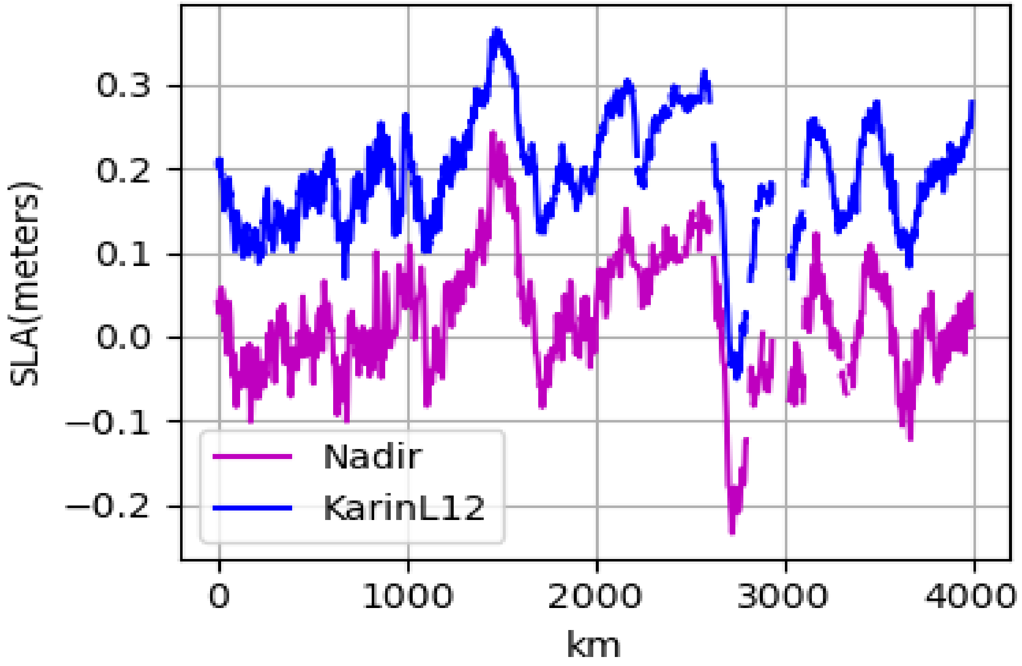


KaRIn / SWOT nadir SSHA differences

- Simple analysis of the differences between SWOT nadir and KaRIn near range (12 km pixel) SSHA

- The Nadir SSHA is interpolated (linear interpolation) on the KaRIn pixels (2 km sampling)

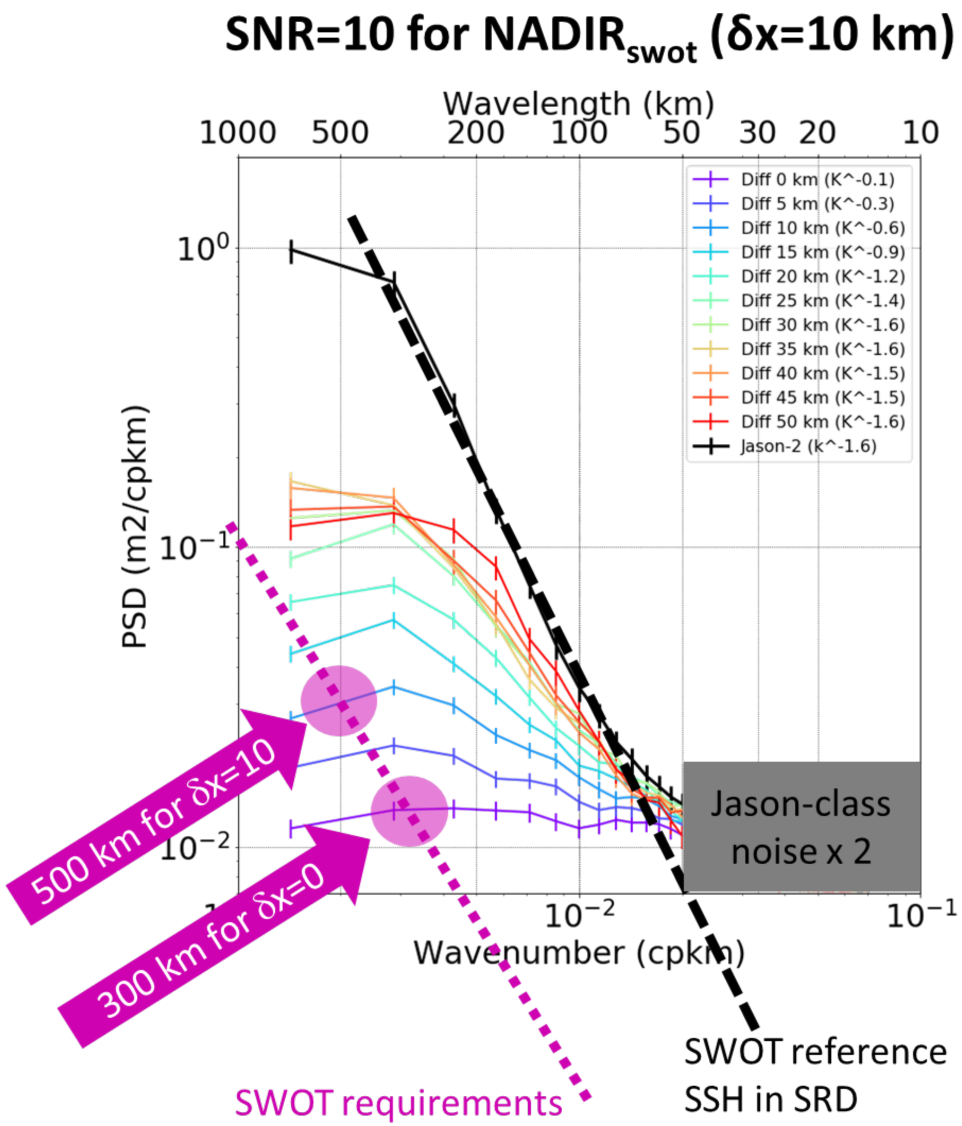




KaRIn / SWOT nadir SSHA differences: limiting factor

- **Two limiting factors identified**
  - **The nadir random error**
  - **The cross-track oceanic variability at 12km**

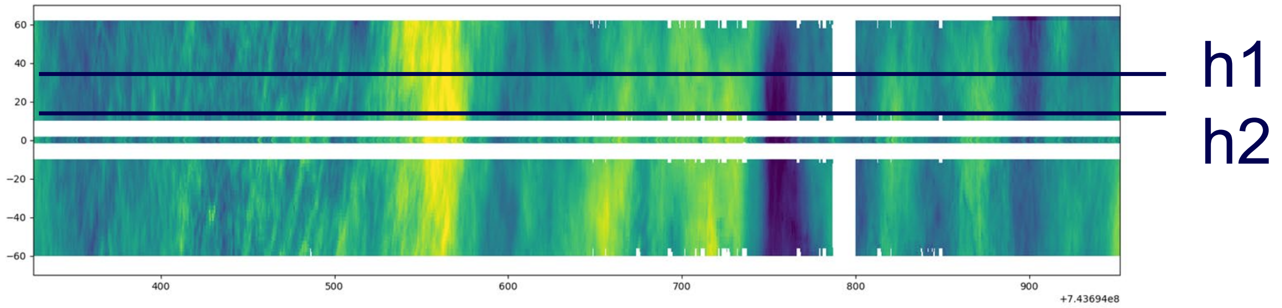
- **These two limitations prevent the validation of the requirement below ~500 km scales.**



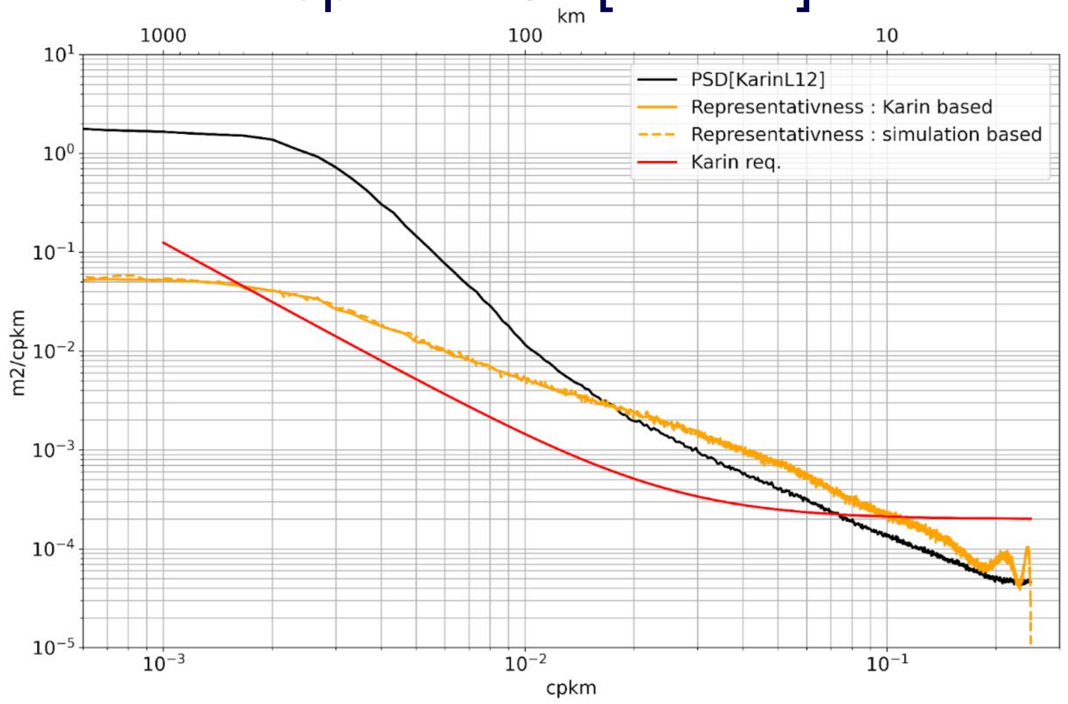
KaRIn / SWOT nadir SSHA differences: Estimation of the limiting factors

- **Nadir error term estimated from XSD method (Ubelmann et al.,2018)**
- **The contribution of cross-track oceanic variability is directly estimated from KaRIn measurements**
  - **Use of 1D along-track SSHA differences for colums spaced by 12 km apart**
  - **Does not account for cross-track noise variation & roll error □ very low variation for this xtrack distances and at these scales**
  - **Possible over-estimation in case of uncorrelated geophysical errors**
  - **Alternative method based on 2D synthetic signal provides a very similar representativness error spectrum**
- **The average spectrum of these differences gives an estimate of the cross-track oceanic variability @ 12km**
  - **Higher than requirement below 600 km scales**
  - **Twice the KaRIn signal for scales <= 50km □ uncorrelated signal**

From KarinL24 - KarinL12

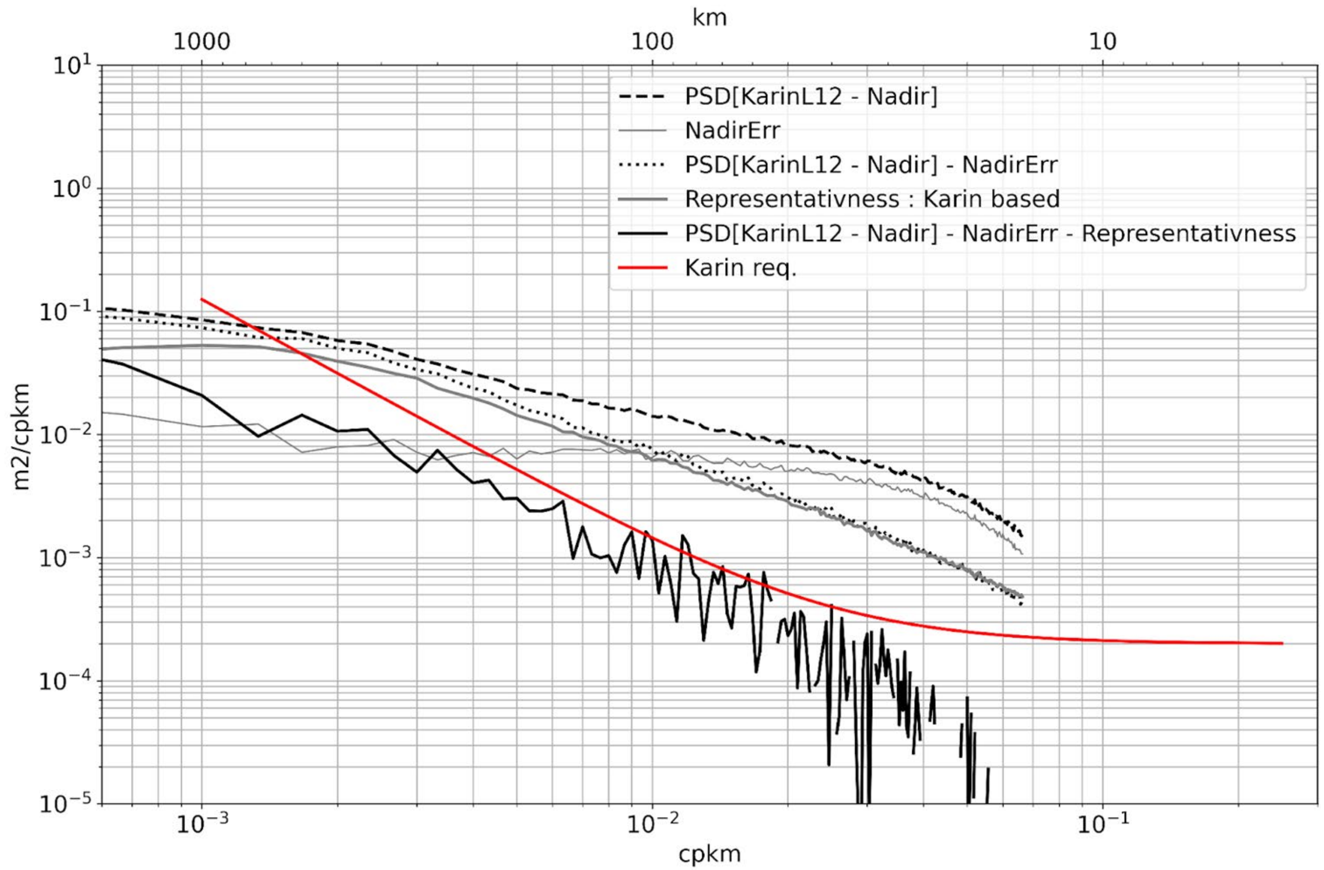


Rep. = PSD[h1- h2]



KaRIn / SWOT nadir SSHA differences: result

- **Under assumptions described in previous slide, the result obtained is below the requirement curve (noisier below 100 km)**



Synthesis

With these 3 methods we validate the KaRIn error requirement above 100 km scales.

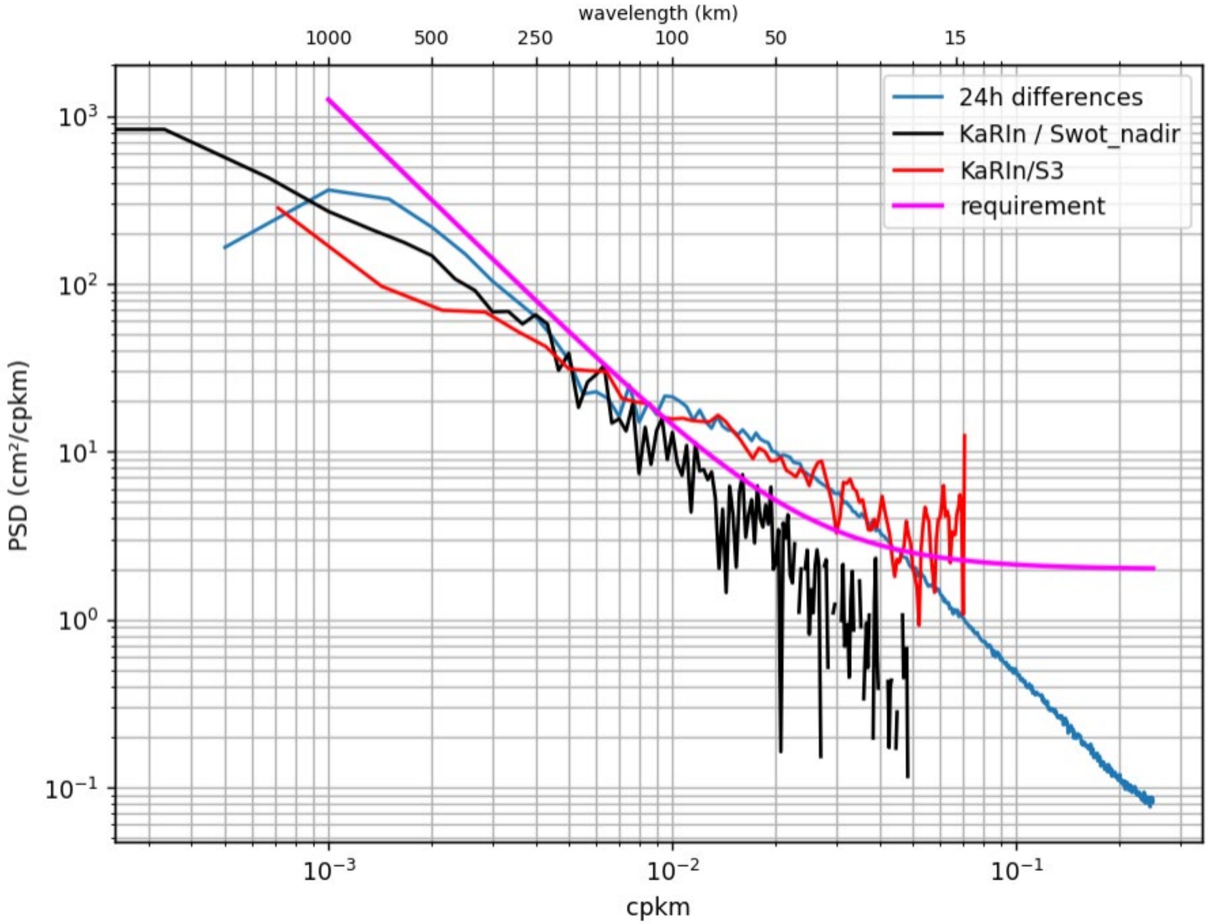
Below 100 km scales:

- **24h differences & KaRIn / S3 differences error estimations are consistent and above requirement by a factor ~2**
  - **These estimations are an upper bound of the KaRIn error:**
    - Do not account for the residual oceanic variability at shorter scales

- **The KaRIn / nadir comparison provides a better description of the oceanic variability contribution at scales below 100km. The KaRIn error estimated verifies the requirements**

Note that these different results were not obtained from the exact requirement framework:

- **Global sea state conditions (instead of selection below 2m) □ very low impact**
- **100 % of the segments contribute to the final error estimation (instead of using the 68th percentile of the spectral distribution)**

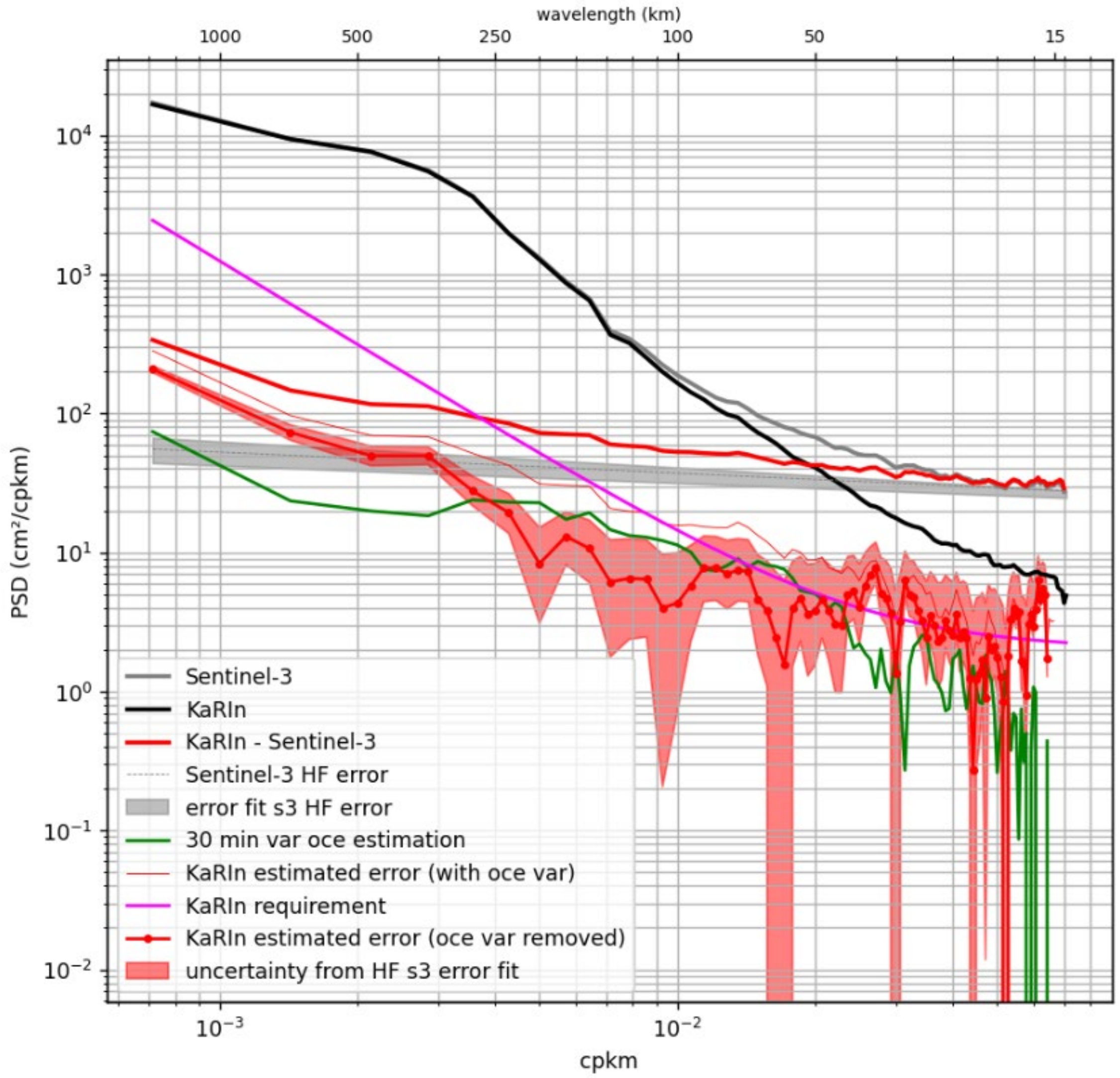


Conclusions

- **At global scales the performances of KaRIn L2 LR products is excellent and comparable with nadir altimetry:**
  - **Need to further work on SSB error characterization and potential solutions**
- **Most of the efforts were put on the KaRIn validation and improvements over open Ocean**
  - **Data quality in coastal areas presents some limitations**
  - **Further assessment and data quality improvements are expected in a near future**
- **Sub / mesoscales SSHA validation shows excellent performances:**
  - **Excellent spatial agreement with other variables from other sensors**
  - **The estimation of the SSHA error is challenging for scales below 100km because of the oceanic variability contribution.**
  - **Requirement is verified using some assumptions**

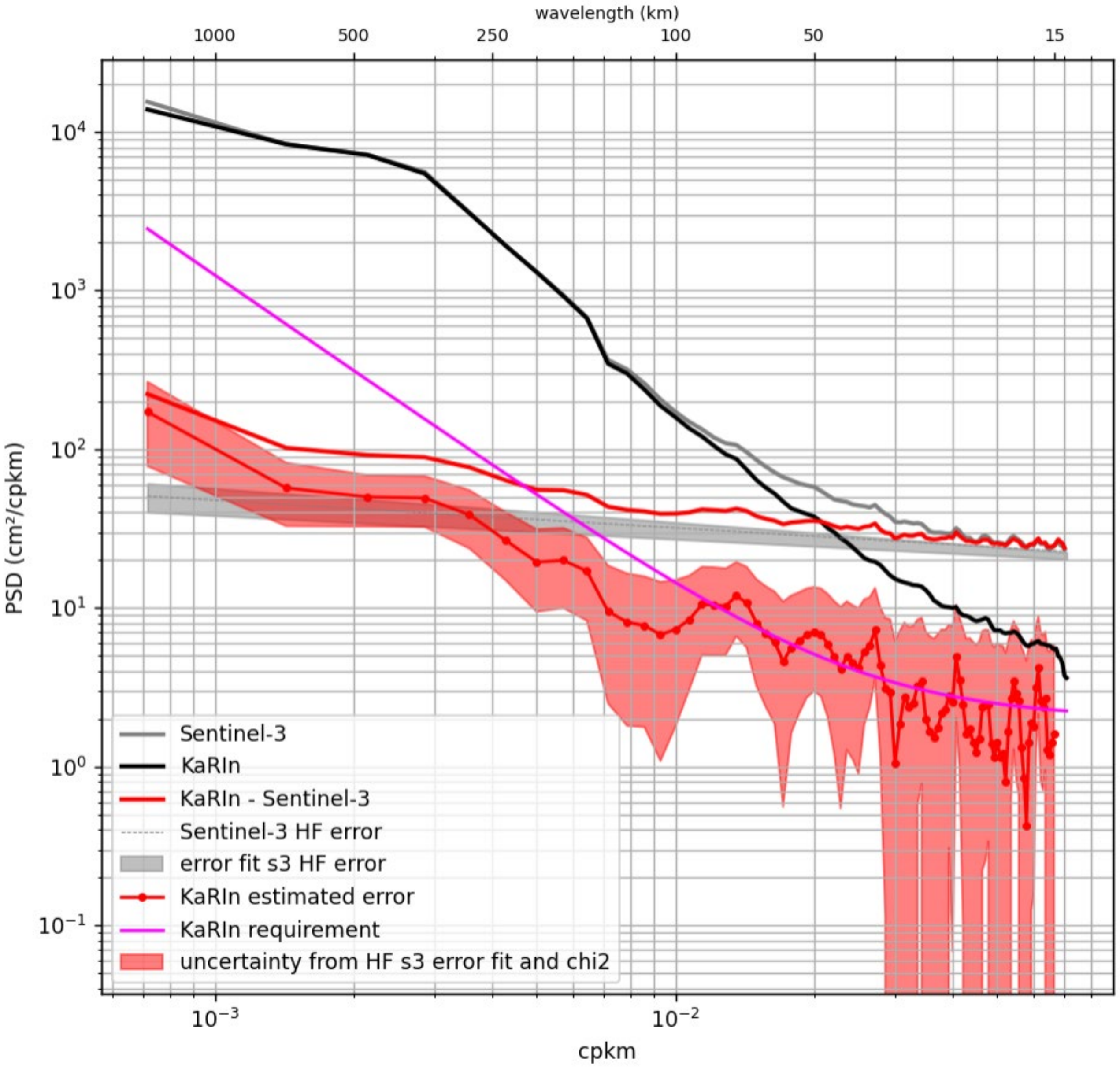
BACKUP

- **KaRIn/S3 analysis with 95% of the crossovers identified**
  - **Error estimated above requirement from 100 km scale**
- **Use of 1hour < dt < 2hours to estimate the 30 minutes ocean variability**

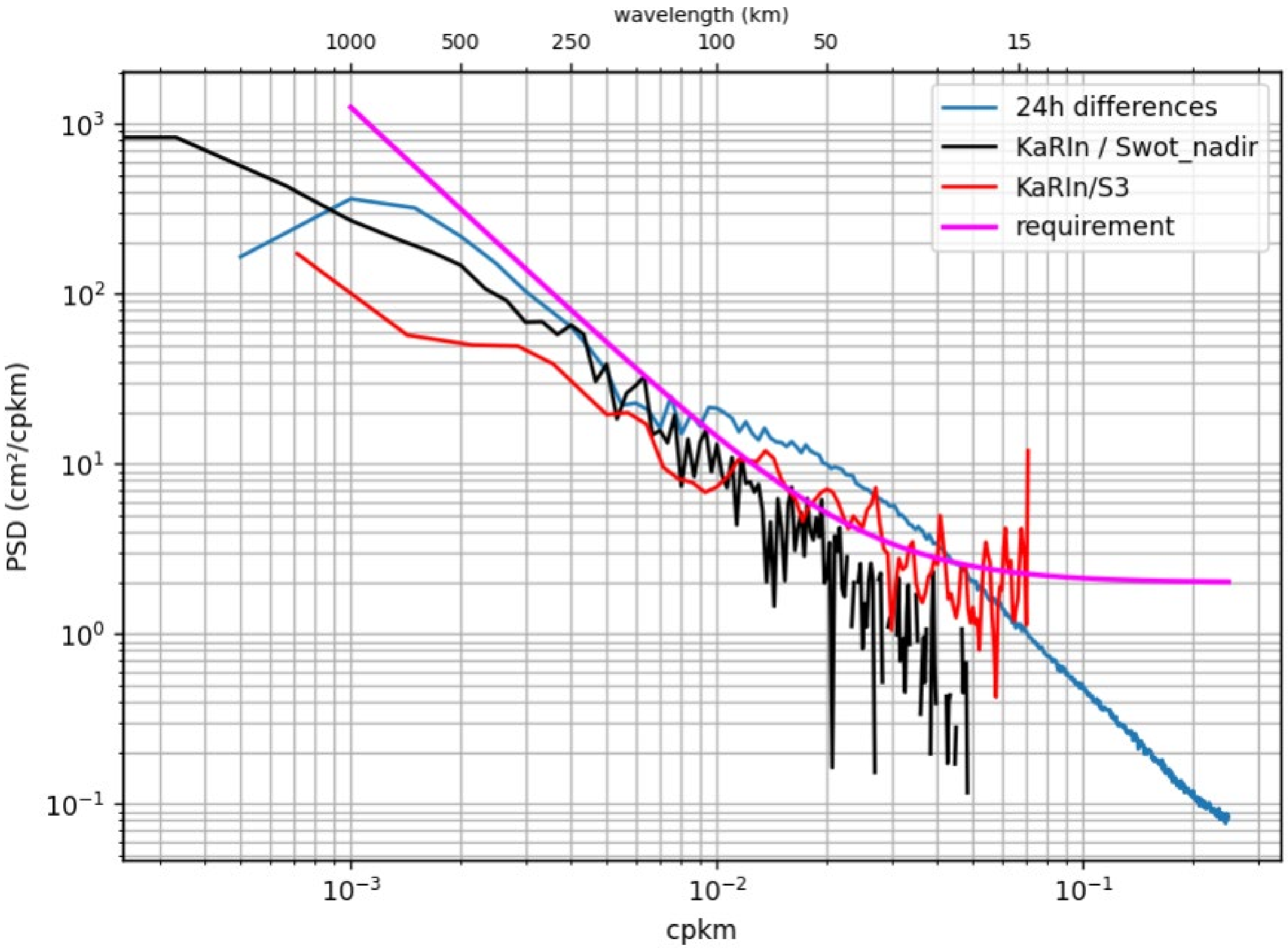


KaRIn / Sentinel-3 SSH differences: result

- **Excellent agreement between S3 & KaRIn spectra for scales >= 125 km**
- **The spectrum of SSH differences (red continuous lines) is below the requirement for scales >= 270 km**
  - **A large part of the variance is induced by the nadir altimeter noise floor (red-colored spectrum for SARM altimetry)**
- **An estimation of this contribution is fitted and substracted to the PSD of differences (grey dashed line & gray envelop)**
  - **The requirement is verified for scales >= 70 km.**
  - **Below 100 km result is an upper bound of the KaRIn error estimation:**
    - Part of high frequency oceanic variability leaks in the error estimation



Synthesis


wavelength (km)
1000
500
250
100
50
15
24h differences
KaRIn / Swot_nadir
KaRIn/S3
requirement
PSD (cm²/cpkm)
10^3
10^2
10^1
10^0
10^{-1}
10^{-3}
10^{-2}
10^{-1}
cpkm