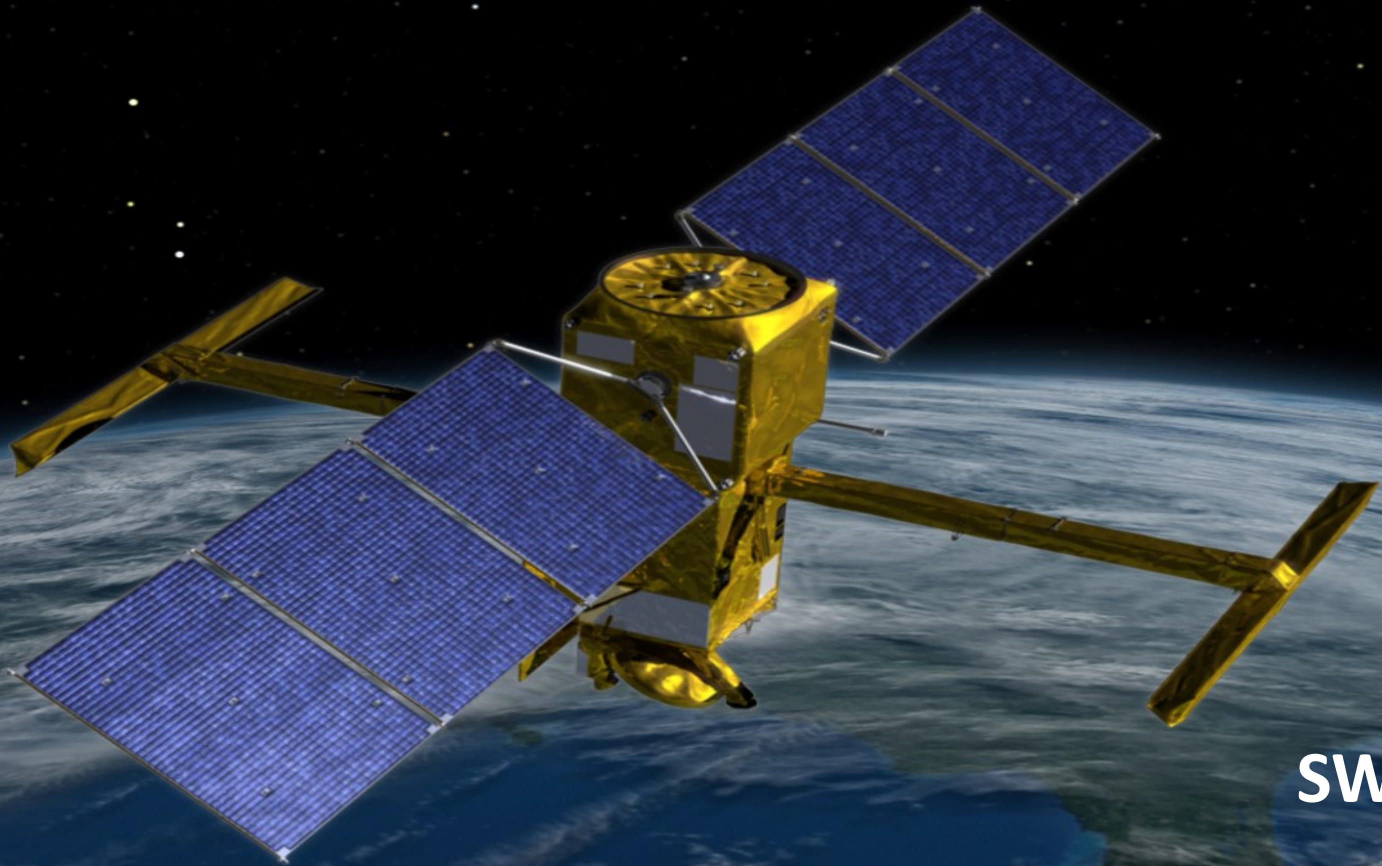
16 - KaRIn SWH Validation

June 18th, 2024



SWOT Validation meeting

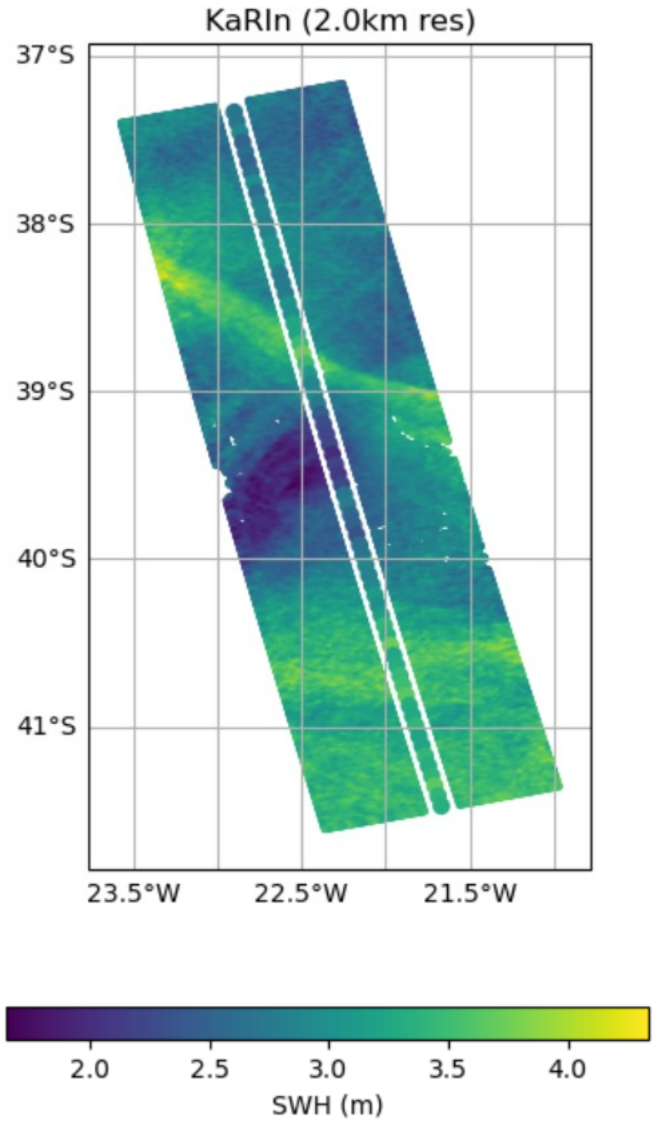
Alejandro Bohe (CNES),

on behalf of the CNES/JPL algorithm team

Outline

1. Principle of the SWH measurement with KaRIn and characterization of instrumental sources of decorrelation

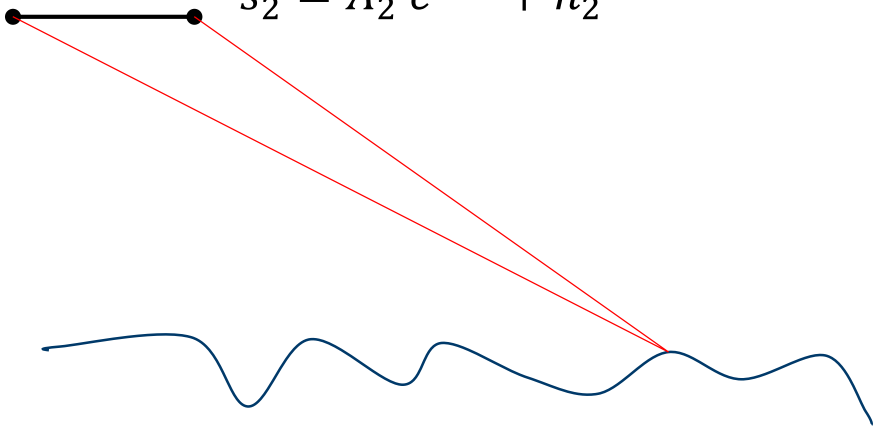
2. Validation against independent data



SWOT primary … and secondary measurements

$$s_1 = A_1\, e^{i\varphi_1} + n_1$$

$$s_2 = A_2\, e^{i\varphi_2} + n_2$$



- **SWOT is primarily a topography mission ! Surface height images are derived from the phase difference between the two KaRIn antennas.**

- This is « only » one of the four independent real combinations that can be formed using the two complex signals at each antenna.

- The **single-channel powers** can be **processed** (to remove instrumental contributions such as antenna gains) **to obtain NRCS images**, **from which we can infer wind speed** (other physical processes such as waves, currents or biological films also create sigma0 modulations, although they are in general sub dominant).

- **A fourth independent combination** of the complex received signals is the **interferometric correlation** (sometimes referred to as coherence).

$$arg < s_1\, s_2^* > = \varphi_2 - \varphi_1 \rightarrow height$$

$$< |s_1|^2 > , < |s_2|^2 > \rightarrow \sigma_0$$

$$\gamma = \frac{|< s_1 s_2^* >|}{\sqrt{< |s_1|^2 >< |s_2|^2 >}}$$

SWH from KaRIn : (idealized) inversion method

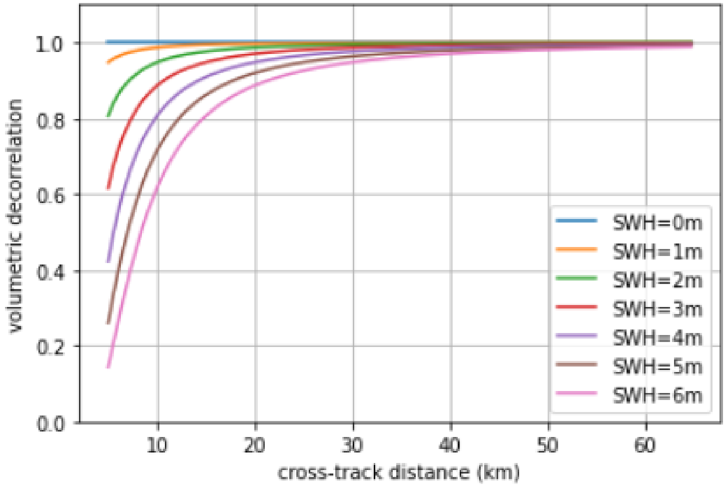
- Waves introduce interferometric decorrelation. The effect increases with SWH and decreases with incidence angle (cross-track distance).

- There are other sources of decorrelation :

  - Geometric/angular decorrelation only depends on the geometry of the acquisition and the instrument characteristics.

  - Computing SNR decorrelation requires a measurement of SNR. This is estimated by measuring the power in the noise alone and substracting it from the total received power (noise+signal).

- Dividing the total measured coherence by those two contributions, one obtains a measurement of volumetric decorrelation, which can be inverted to measure the SWH.

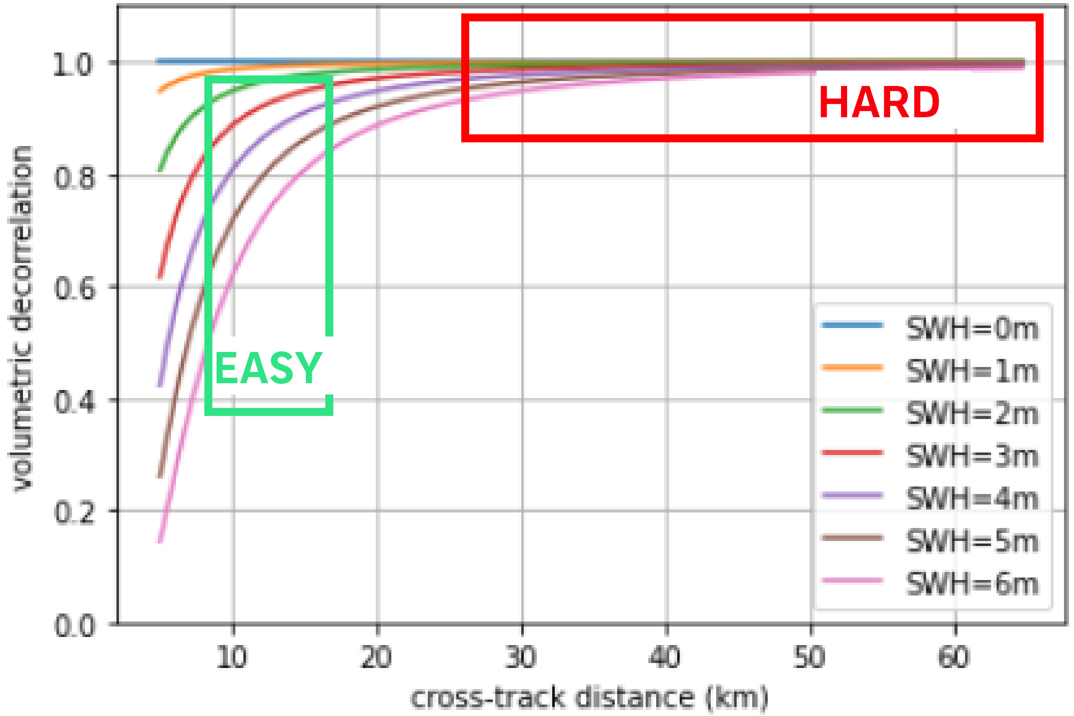


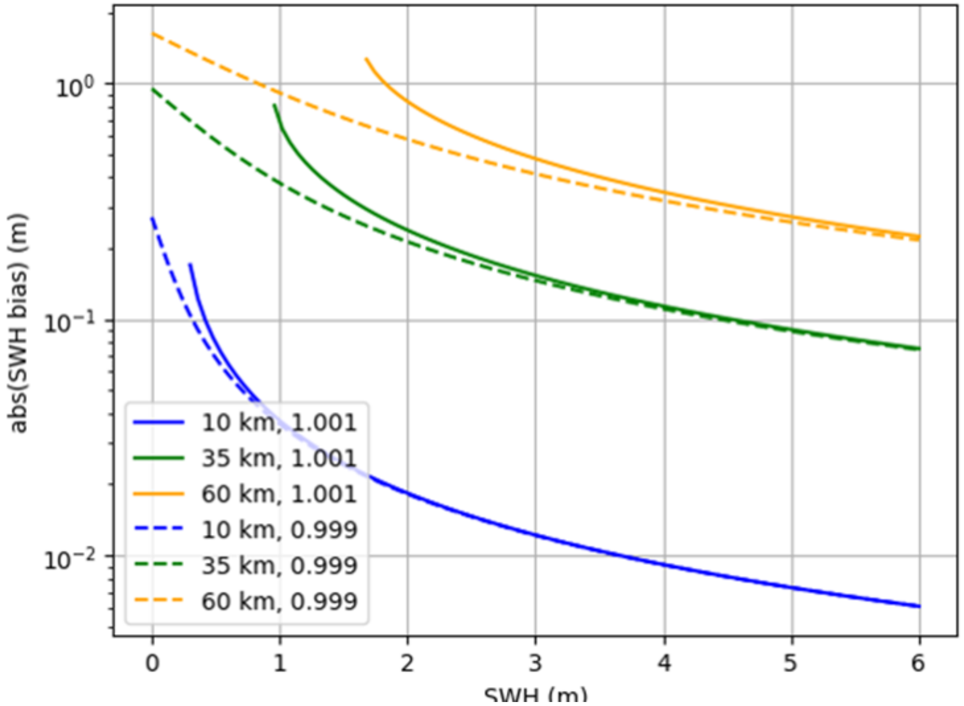
$$\gamma = \gamma_{SNR}\,\gamma_{geo}\,\gamma_{ang}\,\gamma_{vol}(SWH)$$

measure on data (γ, γ_{SNR})

compute from system params and geometry (γ_{geo}, γ_{ang})

SWH from KaRIn : inversion sensitivity and required accuracy on γ



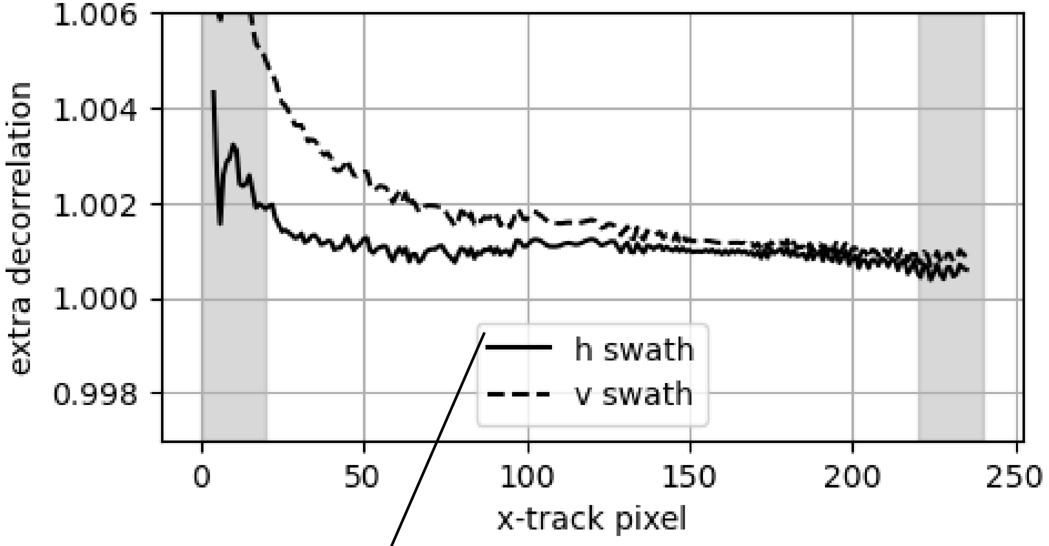


- The SWH inversion is most sensitive in the near range and for high SWH. **Most straightforward regimes for SWH measurements from KaRIn.**

- **In the far range, or for low values of SWH**, tiny errors in the decorrelation (e.g. 10^-3 chosen in the right plot) can lead to tens of cm of error on SWH. These are the **most challenging regimes for SWH measurements from KaRIn.**

SWH from KaRIn : inversion method (with static calibration)

- In real life, minute instrumental effects and approximations in our estimates of the « known » decorrelation terms introduce coherence modulations at the 10^{-3} level.
- Static errors can easily be calibrated empirically. Time-evolving errors are often complex and are much better corrected for if understood from first principles.
- By analyzing flight data, we have managed to understand the dominant instrumental effects varying along the orbit, and therefore correct them down to a few 10^{-4}. No longer timescale (beta angle) effects have been indentified.
- A static empirical calibration has been derived by using the SWH measurement from the nadir altimeter as statistical ground truth.
- This **static correction on decorrelation (not on SWH) is computed offline once and for all from a few passes of data. It only depends on cross-track distance (one profile per swath).**
- **To be clear : the nadir SWH is not used dynamically to estimate the SWH from KaRIn.**



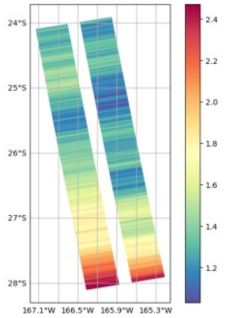
$$\gamma = \gamma_{cal}\,\gamma_{SNR}\,\gamma_{geo}\,\gamma_{ang}\,\gamma_{vol}(SWH)$$

measure on data

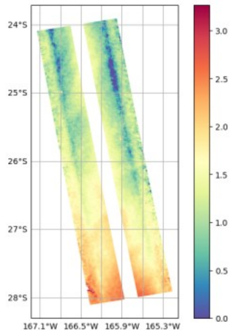
compute from system params and geometry

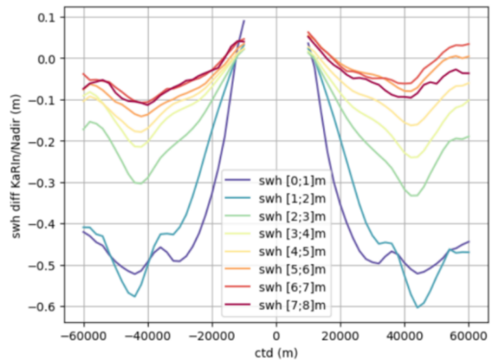
swh_karin throughout the product versions

- **Versions A and B :**
  - **Only 1D inversion** : one single SWH value per xtrack line (SWH only evolves in along track)
  - Several dynamical instrumental effects not accounted for
  - No static calibration

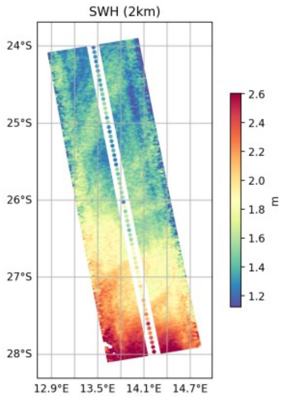


- **Version C (current) :**
  - 2D inversion
  - several dynamical instrumental effects impacting coherence NOT accounted for : errors evolving in along track
  - initial static calibration, suboptimal for the science orbit
  - tens of cm of biases on SWH (both SWH, xtrack dependent)

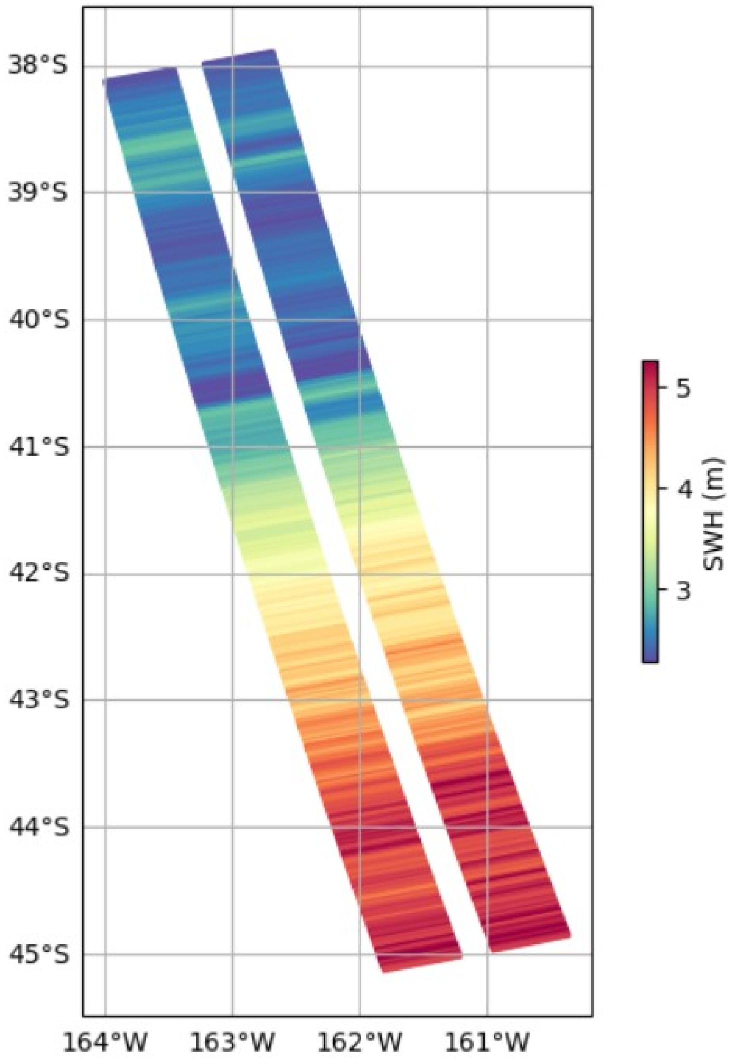




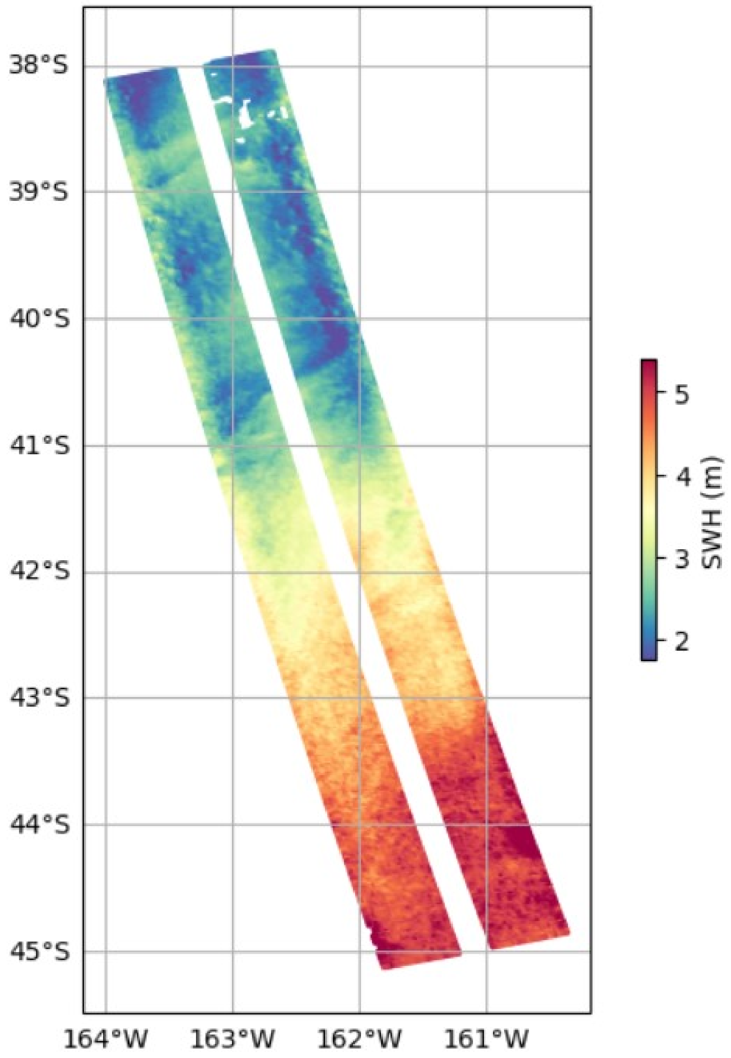
- **Developmental (next version) :**
  - 2D inversion
  - accounts for important dynamical instrumental effects
  - static calibration valid for both orbits
  - Results shown below correspond to this version



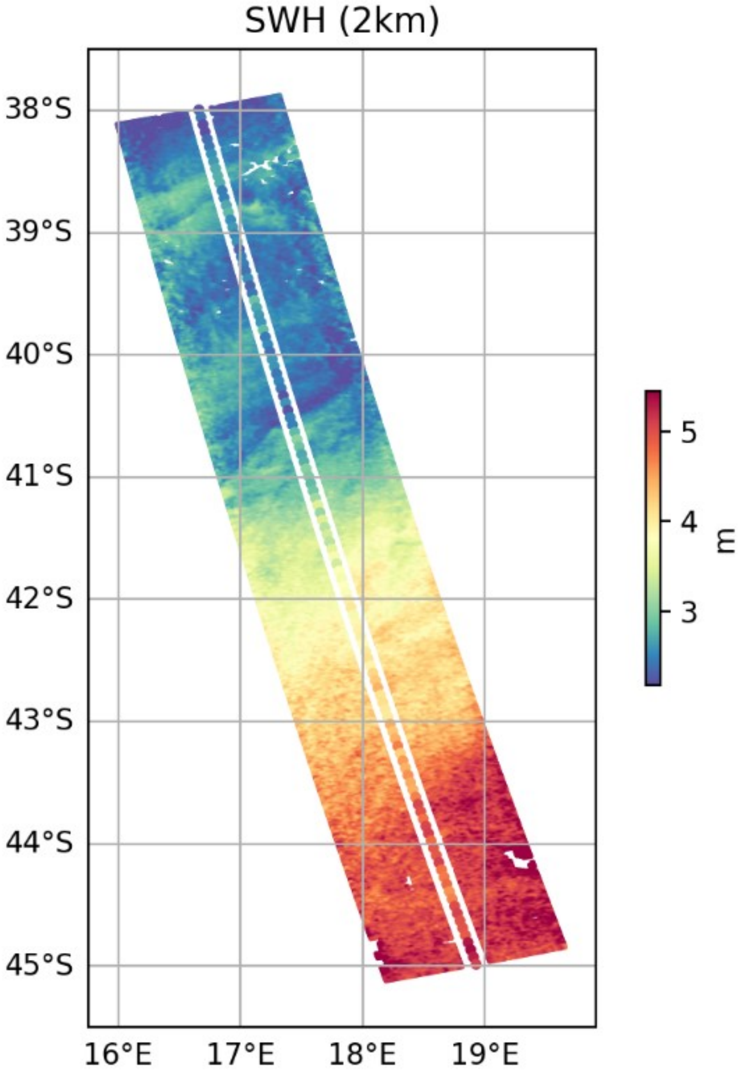
Product versions



Versions A and B



Version C

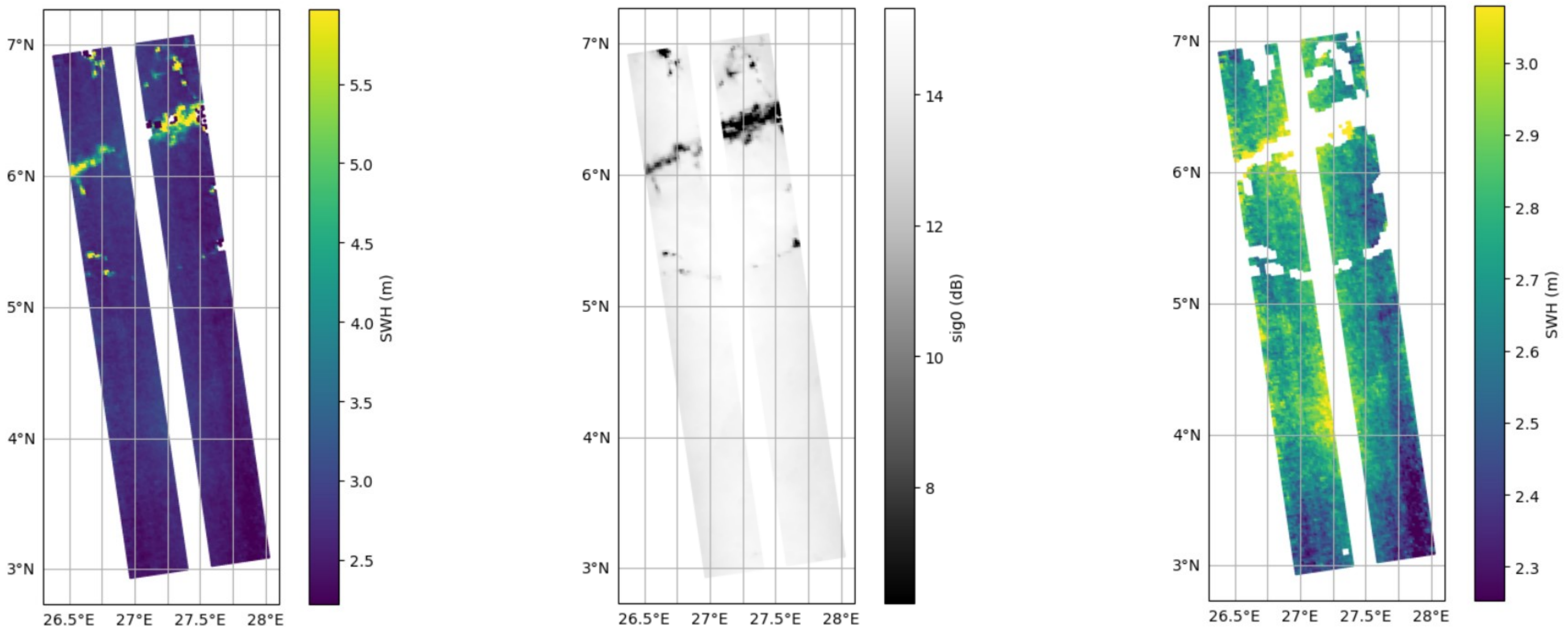


Developmental version

swh_qual flag

- Just like any other measured quantity in the L2 products, SWH comes with a quality flag attempting to signal corrupted measurements

- One particular source of corruption is rain cells, which have huge impacts on coherence and create huge biases on the retrieved SWH

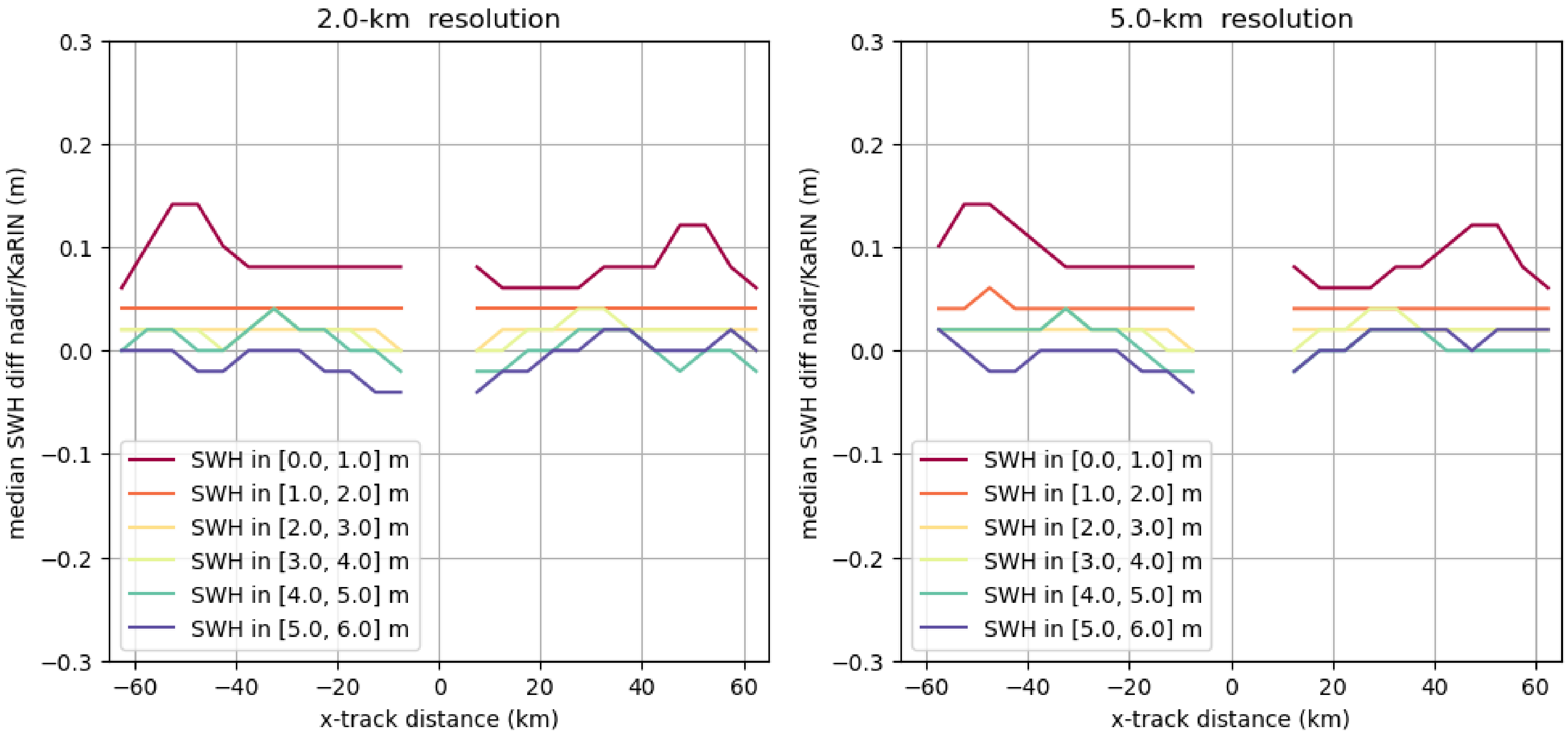


2. Validation against external data

SWH 2D maps from KaRIn : global validation against SWOT's nadir

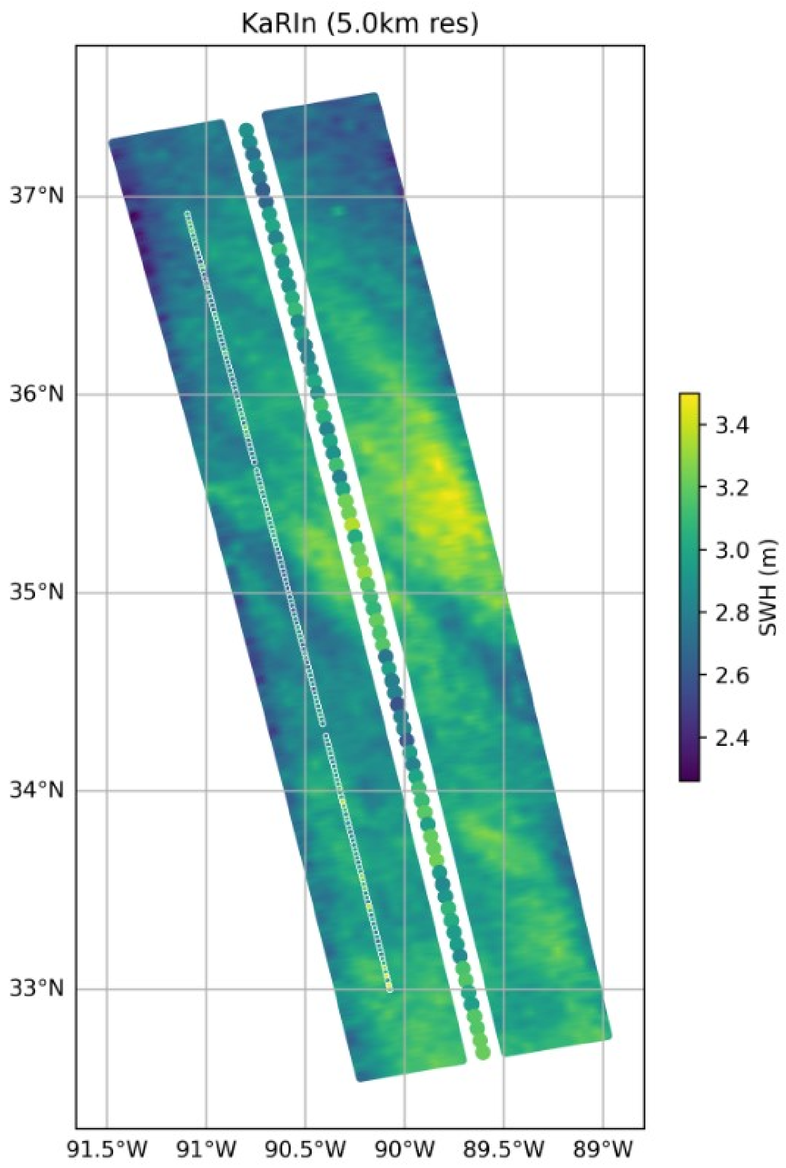
cnes

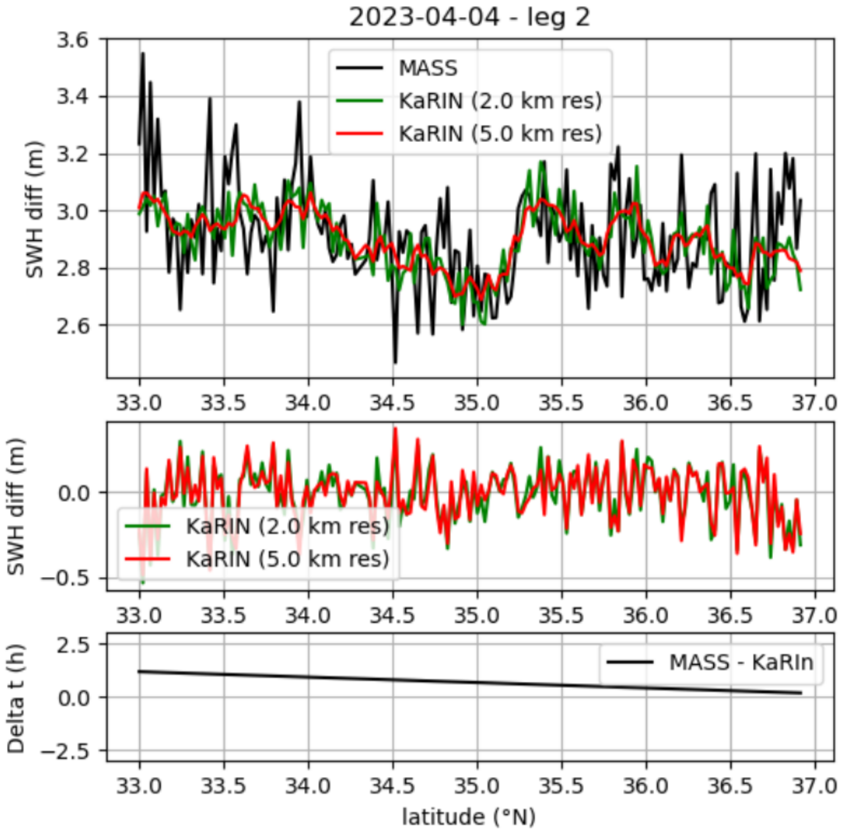
- **Median difference between SWH measurements by SWOT's nadir and by KaRIn, as a function of cross-track distance.**
- Statistics accumulated over ~200 passes from the 1-day phase.
- Assumption behind this validation : cross-track geophysical variability of the SWH field is zero on average (positive and negative differences cancel out on average).

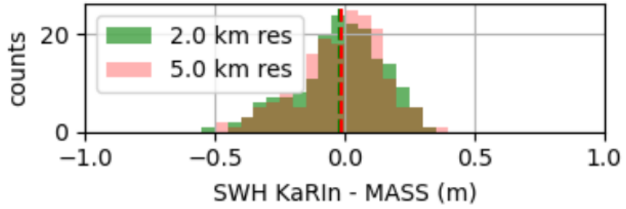


- **For SWH>1m, biases remain of the order of a few cm throughout the swath, indicating that instrumental effects have been correctly accounted for**.
- Biases become larger (~10cm) for very low values of SWH (<1m). This is excpected as this is the most challenging regime.

SWH 2D maps from KaRIn : validation against airborne lidar data (MASS)





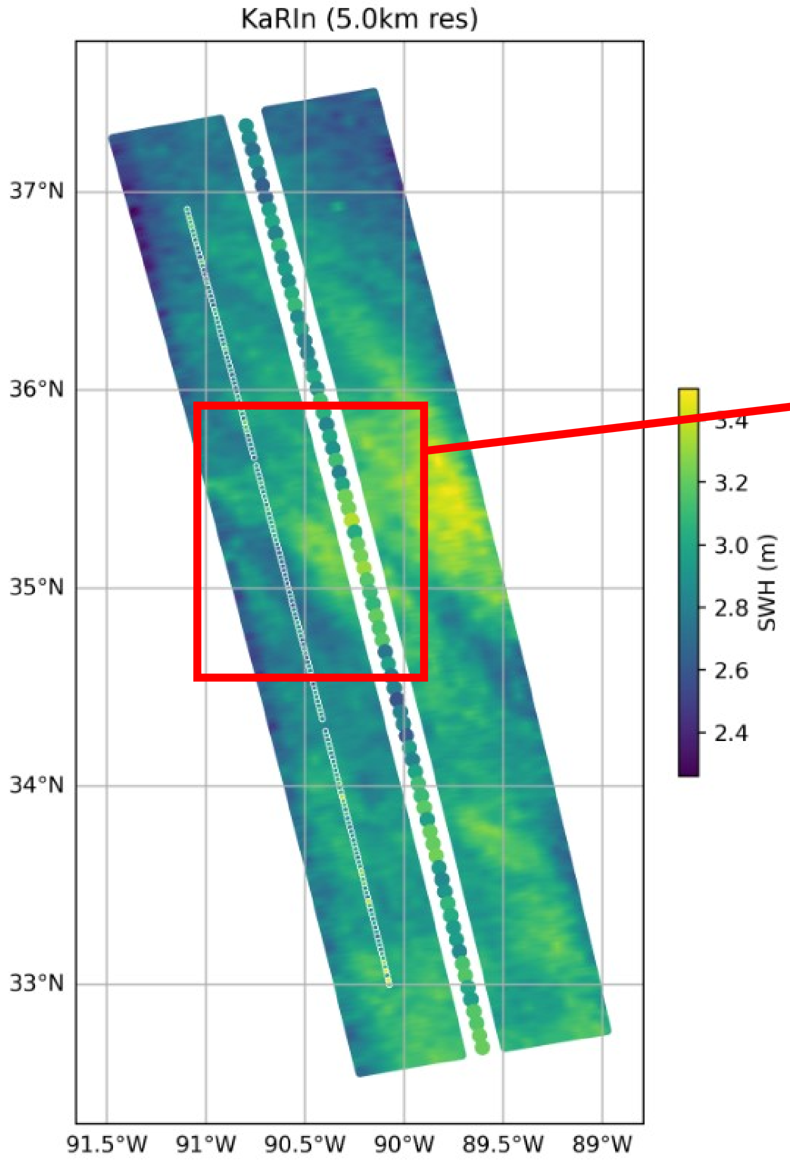


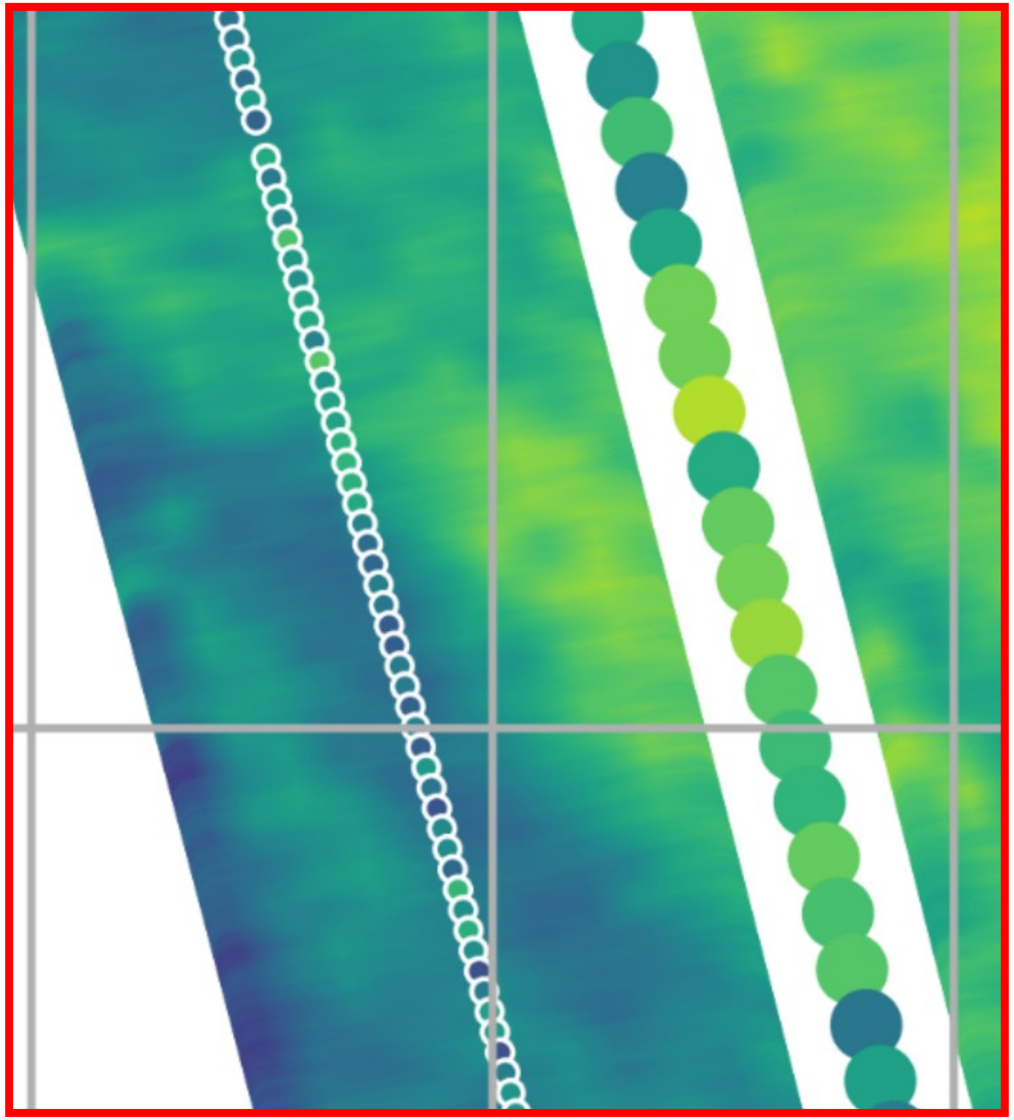
- Left plot :
  - KaRin 2D SWH map @5km resolution,
  - nadir SWH (dots in between the KaRIn swaths)
  - MASS SWH (overlay, white contour markers)

- Excellent agreement throughout the leg

- For example, 30cm sharp variation over ~25 km (around 35°N)

SWH 2D maps from KaRIn : validation against lidar data (MASS)



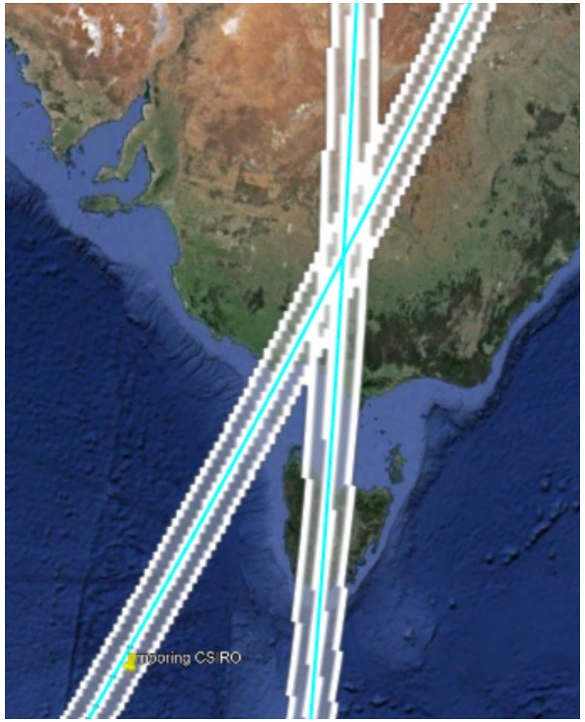


SWH 2D maps from KaRIn : validation against buoy data (SOFS)

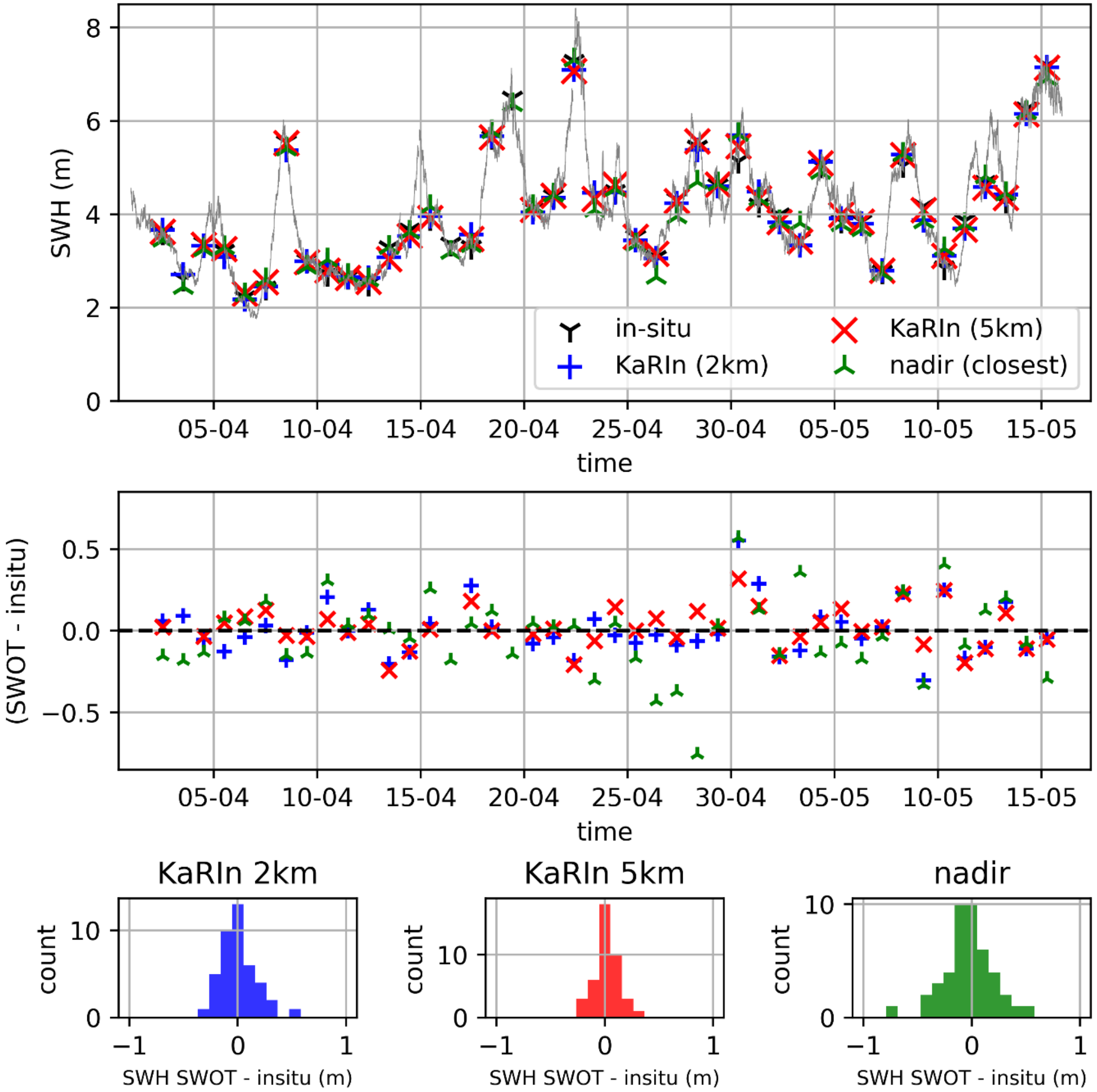
The Southern Ocean Station Time Series (SOTS) mooring GNSS data contains in situ observations of the sea surface for each yearly deployment of the mooring (47°S, 141°E) and was covered by the 1-day repeat phase of SWOT.

Data used here : 2-minute observations of SWH.

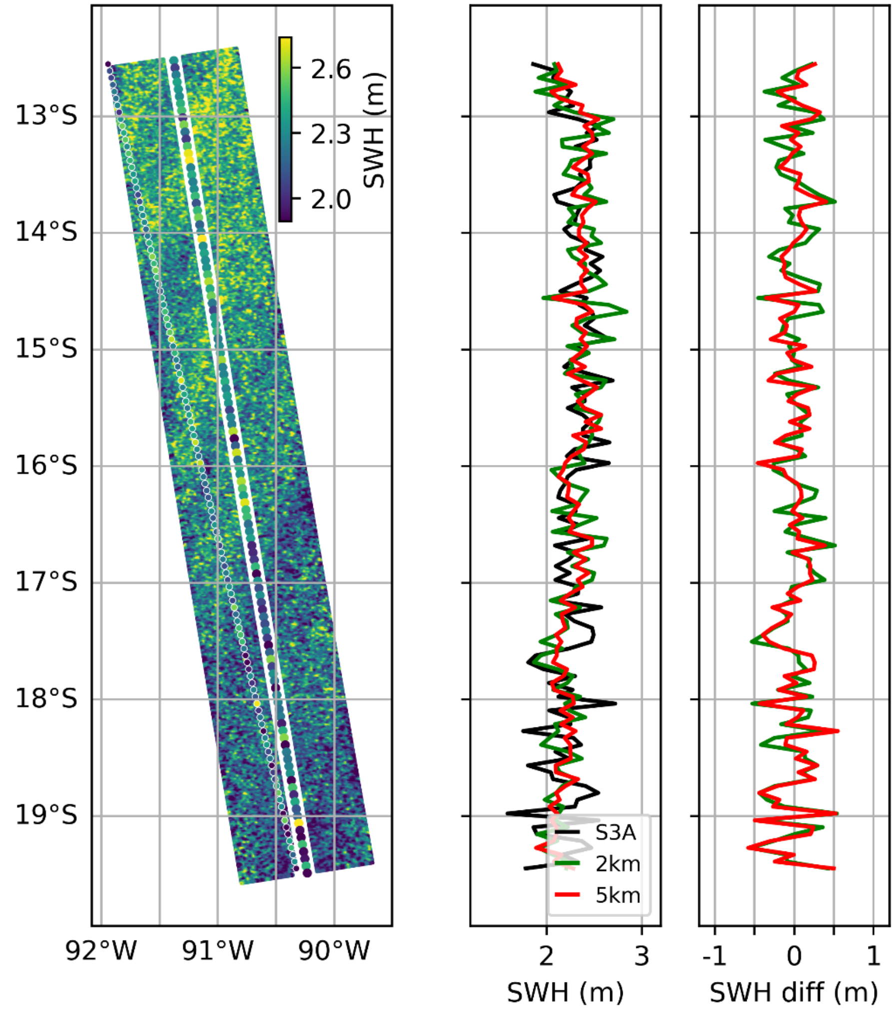
Hay et al. 2023, https://doi.org/10.1175/JTECH-D-23-0031.1



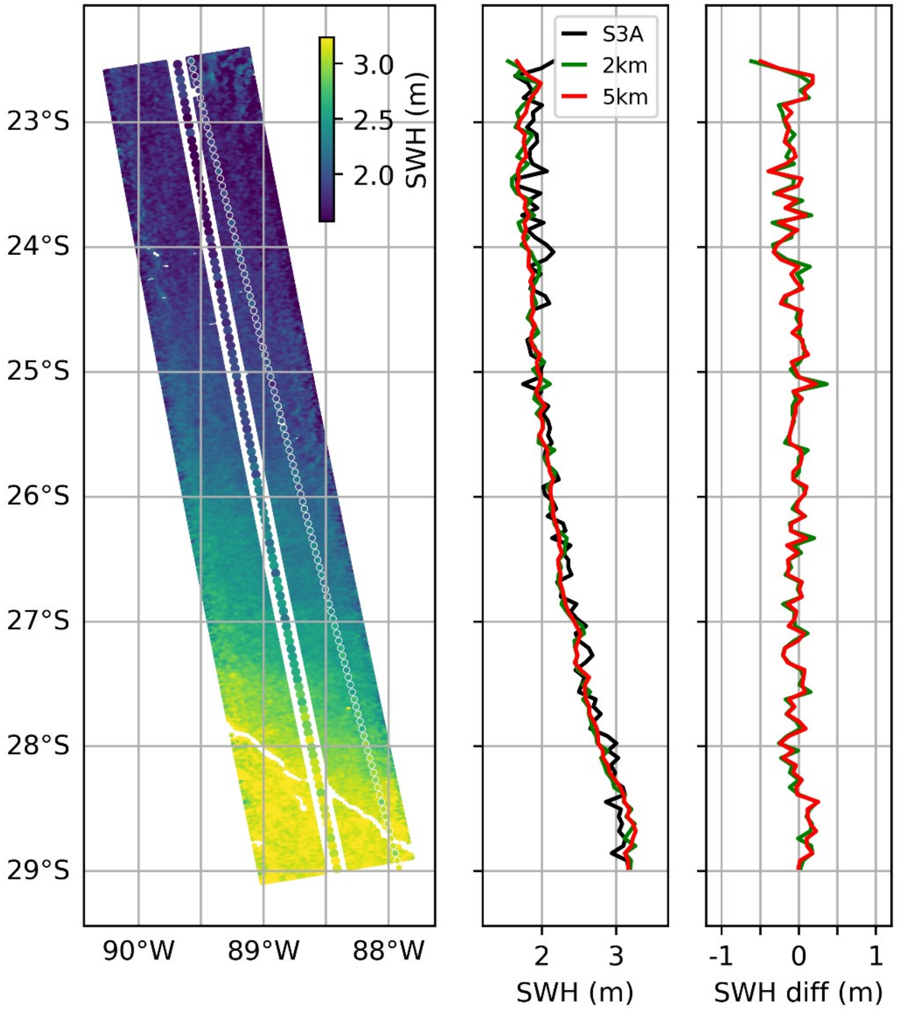
Timeseries used here covers one month and a half: from end of KaRIn's commissioning phase until last available in-situ measurement (in-situ data is retrieved on a yearly basis)



SWH 2D maps from KaRIn : validation against Sentinel3

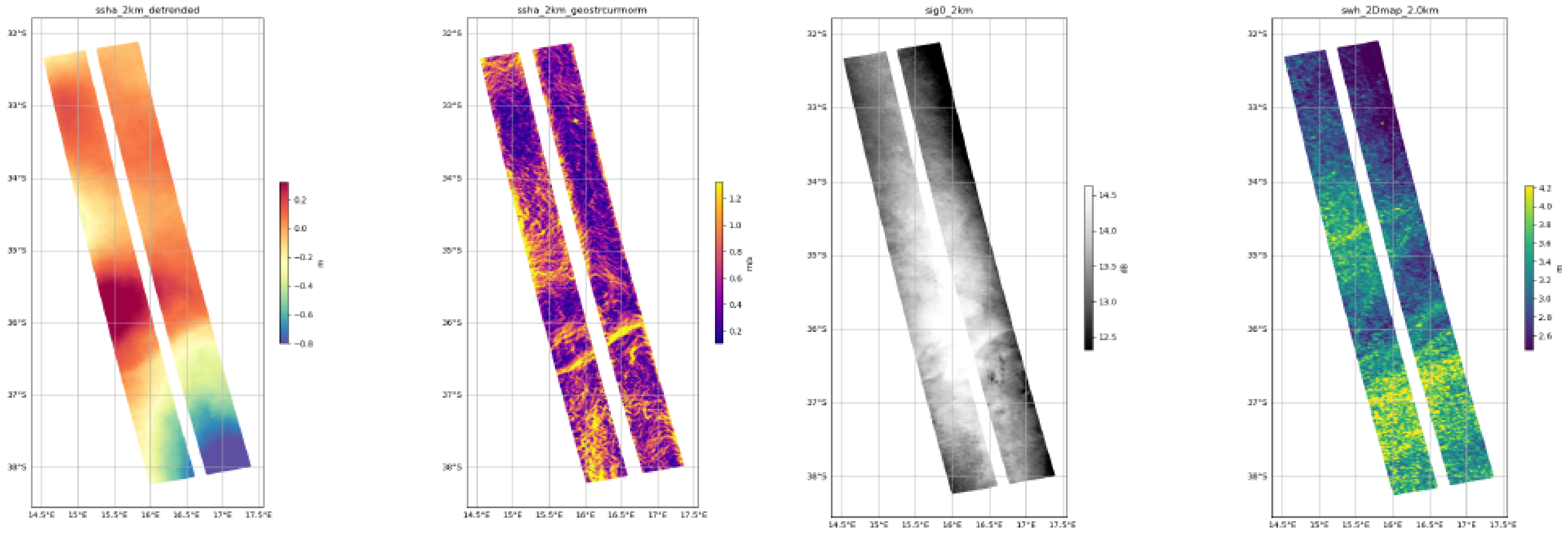


Strong group modulations (peaky wave spectrum case)



Smooth N/S gradient picked up by all instruments

SWOT : a new window on ocean dynamics at km scales



(a) ssha (b) geostrophic current (c) σ_0 (d) SWH

SWOT provides simultaneous 2D maps at kilometric scales of surface topography (->geostrophic part of the currents), backscatter (wind dominated, with other physical signatures) and Significant Wave Height fields.

Summary

- **2D maps of SWH with kilometric resolution can be inferred from KaRIn measurements.**

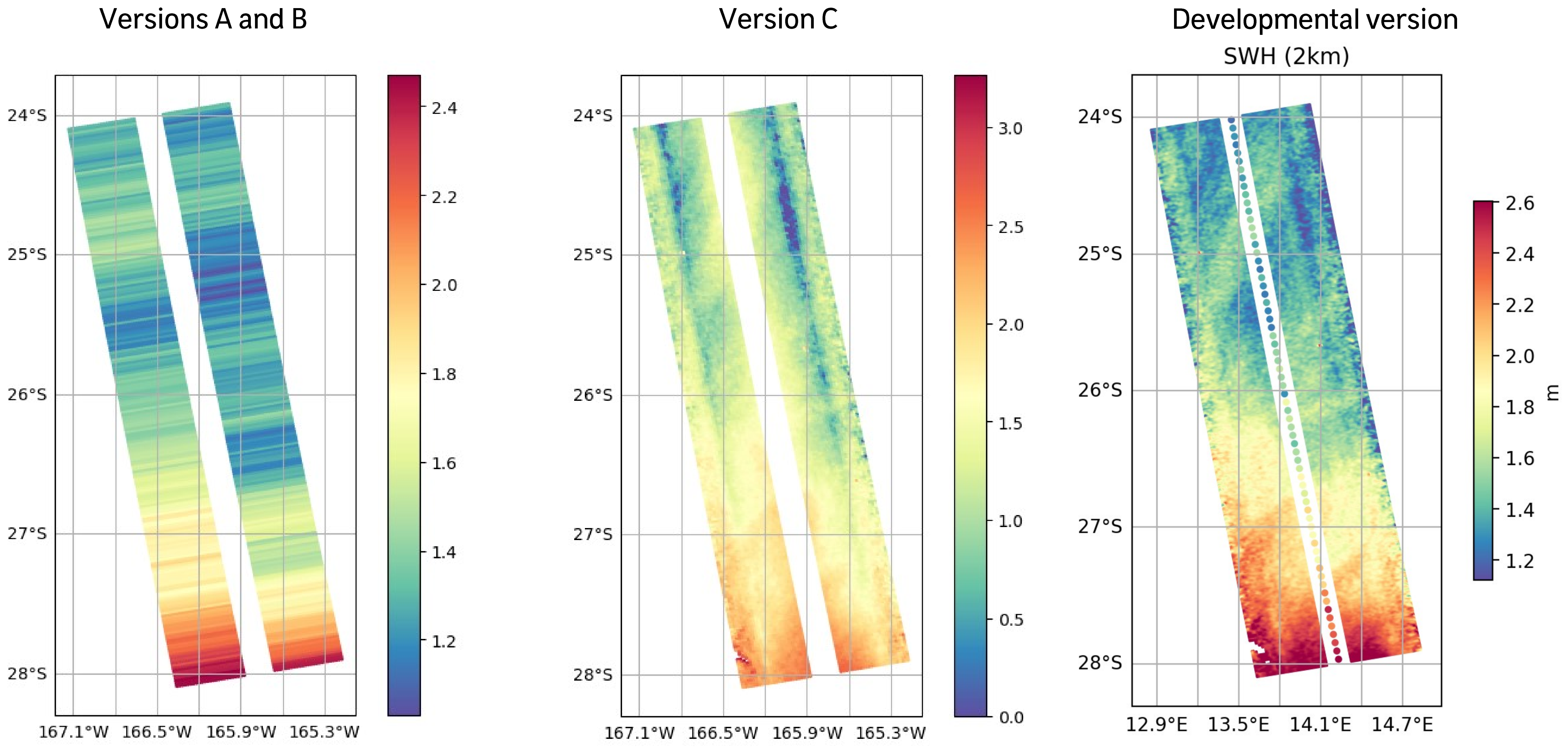
- This required understanding the impact on interferometric correlation of extremely small but dynamical instrumental effects (negligible for topography measurements) : pushing the instrument beyond its requirements

- KaRIn's SWH estimates show **excellent consistency with independent measurements** from
  - SWOT's nadir (global validation)
  - Sentinel3, the MASS lidar, in-situ buoys (local validation)

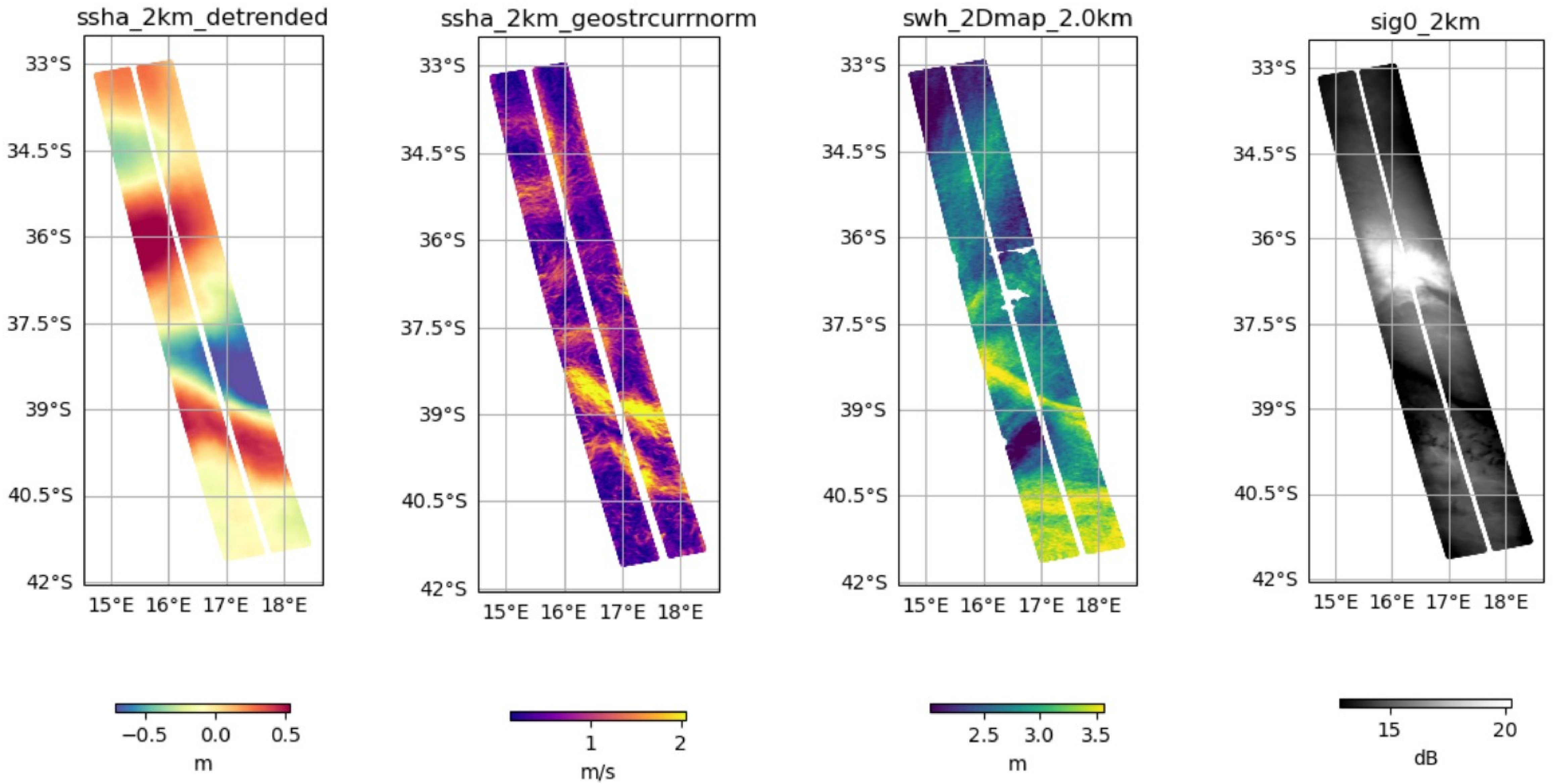
- KaRIn provides, **for the first time and at a global scale**, **simultaneous measurements at kilometric scales** of surface **topography** (from which the **geostrophic** part of the **currents** can be derived), backscatter (**wind** dominated, with other physical signatures) and **Significant Wave Height** fields.

- **This should open the door to a lot of new science**. In particular, for sea state : quantitative studies of **wave/currents interactions**, **effect of local winds at small scales** and **modulations from groups of waves…**

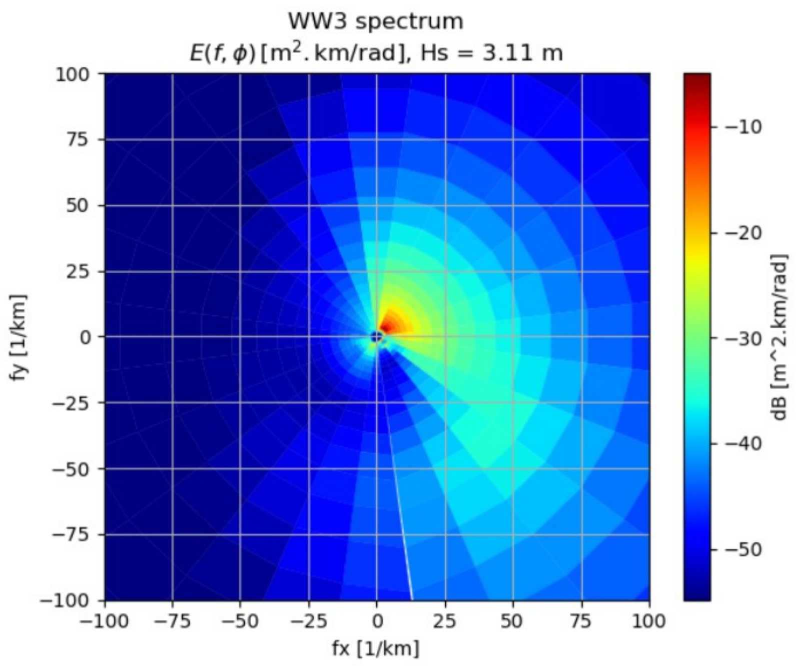
Product versions

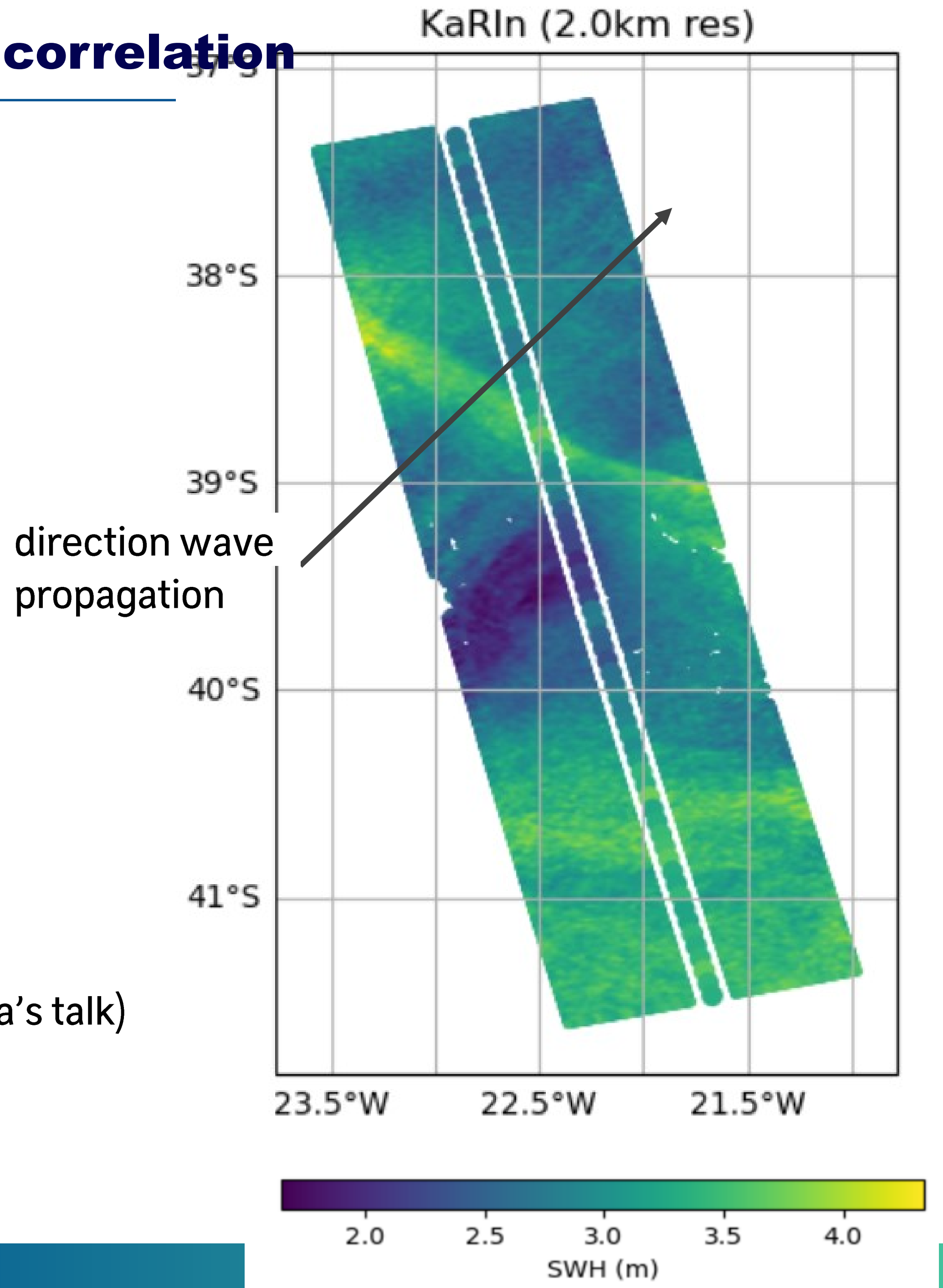


Agulhas current example (481, 16) : strong waves/current correlation



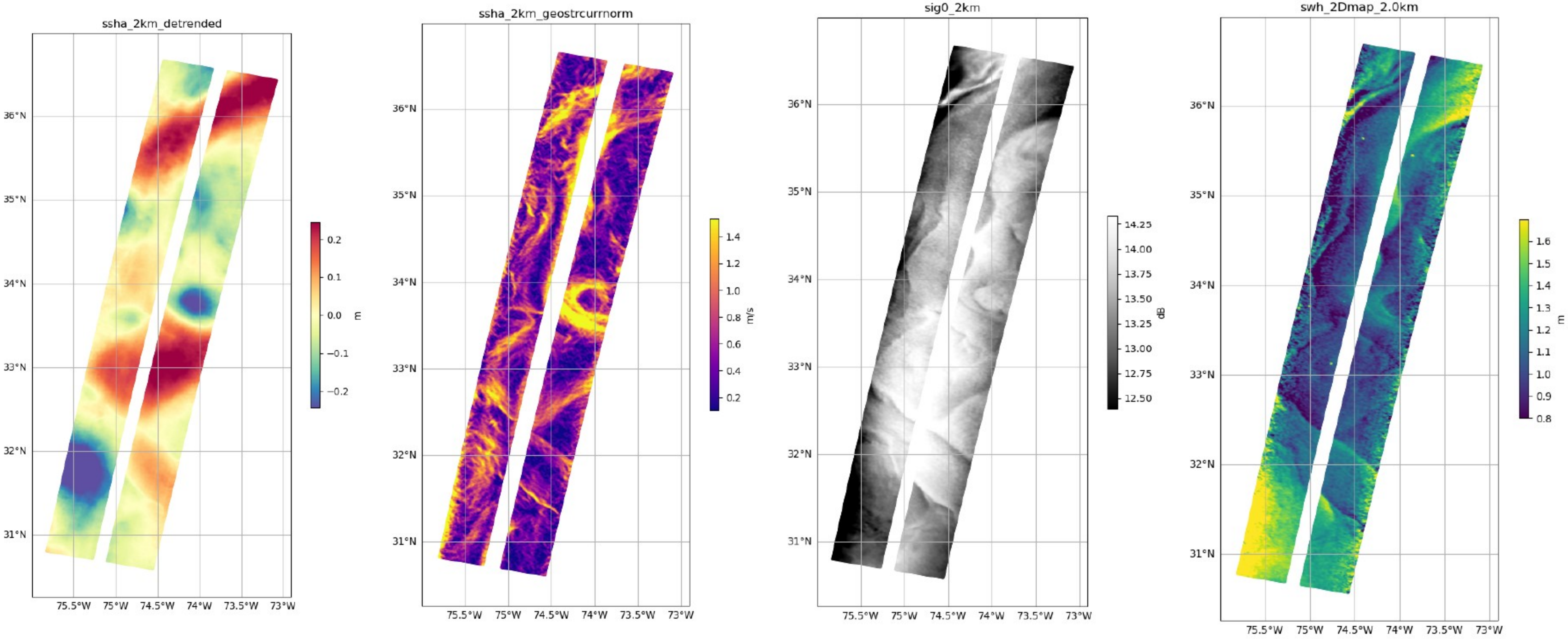
Agulhas current (481, 16) : strong waves/current correlation





SWH streaks aligned with direction of propagation of the waves (cf Bia's talk)

Example : strong wind/wave correlation ?



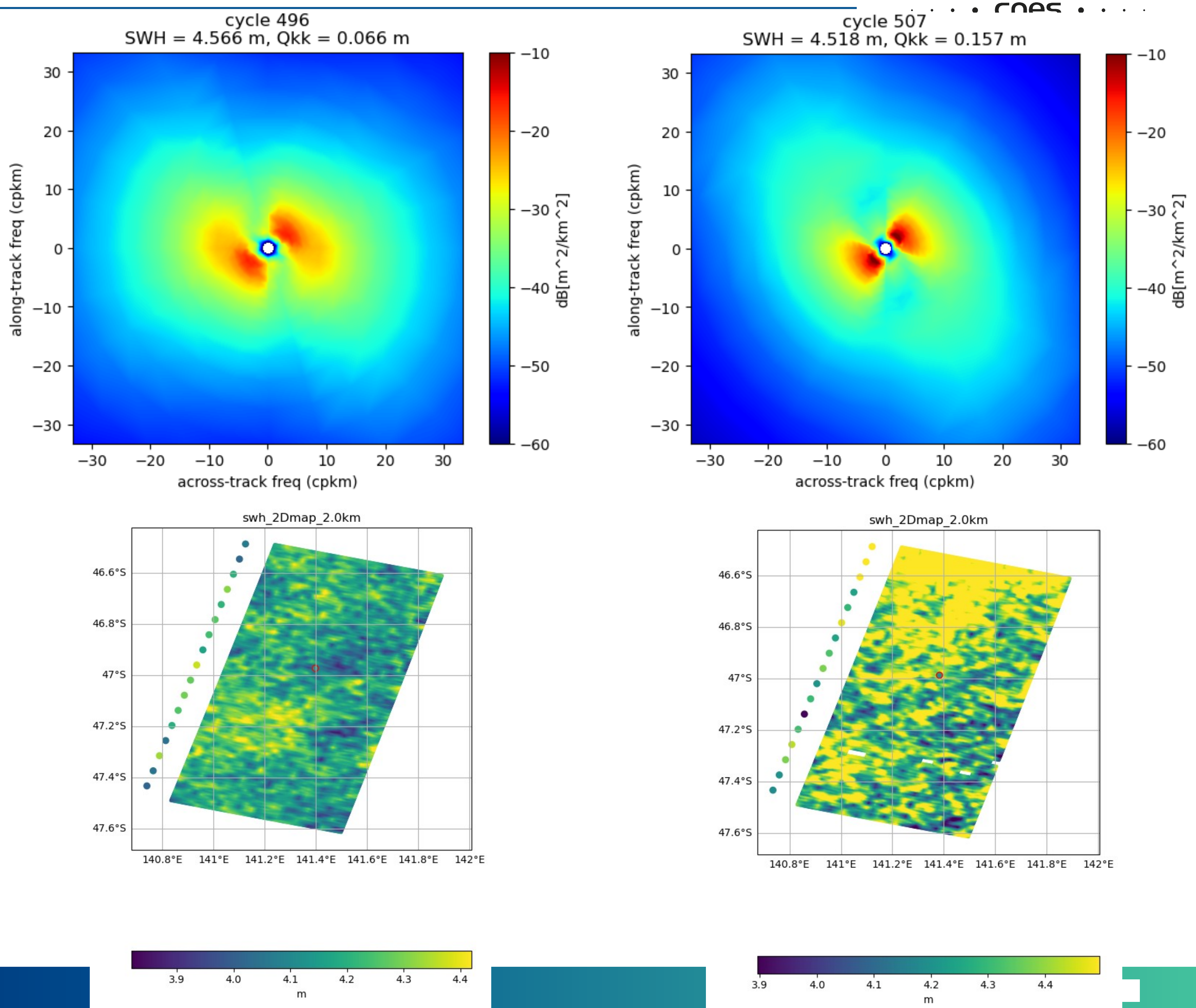
SWH modulation from wave groups

Example of two cases with almost identical SWH (as seen by the buoy, KaRIn and the nadir altimeter, and also predicted by the WW3) but different Qkk.

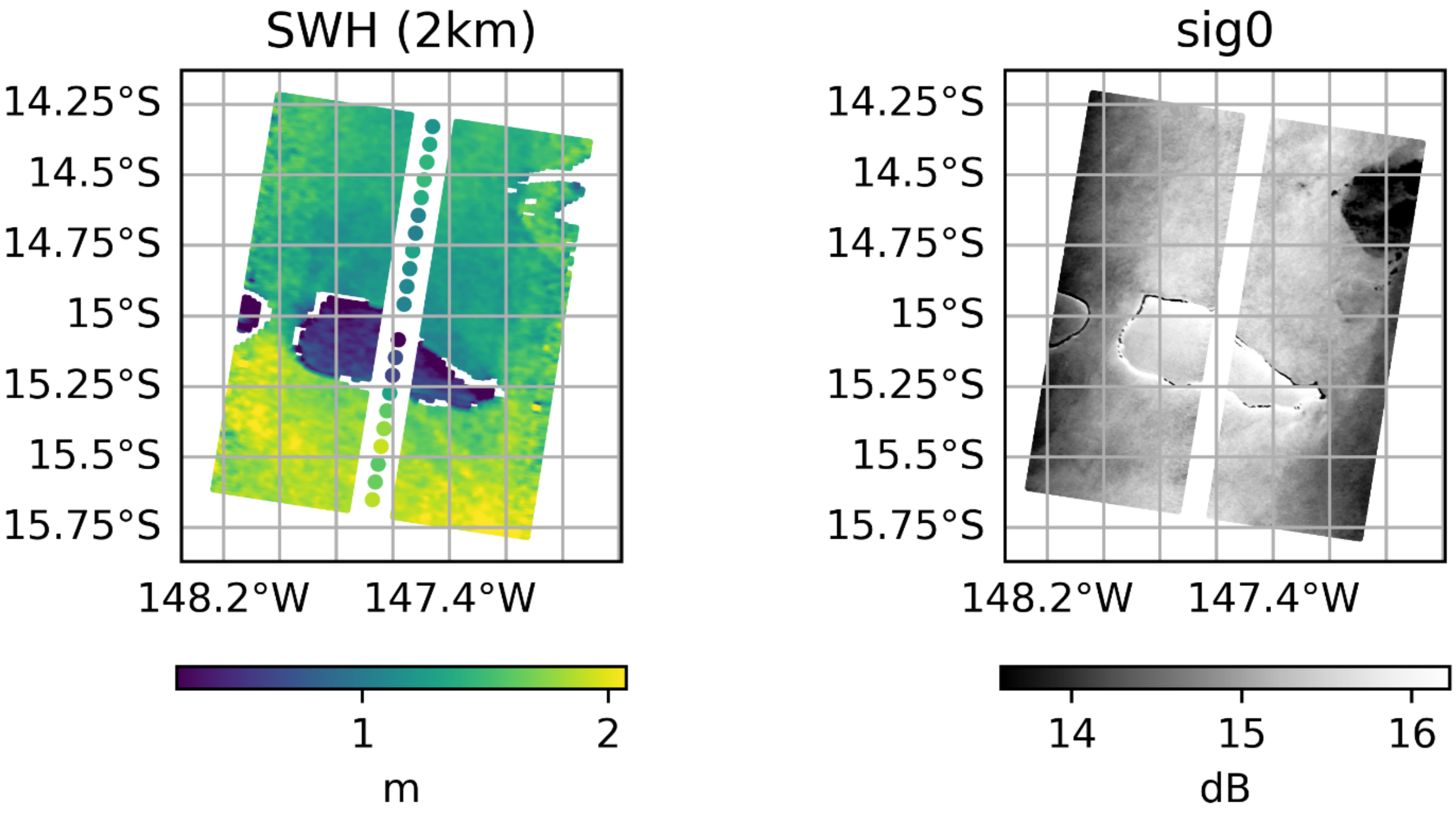
Cycle 507 has a narrower wave spectrum (based on WW3) and should exhibit stronger modulations of the local SWH from wave groups than cycle 496.

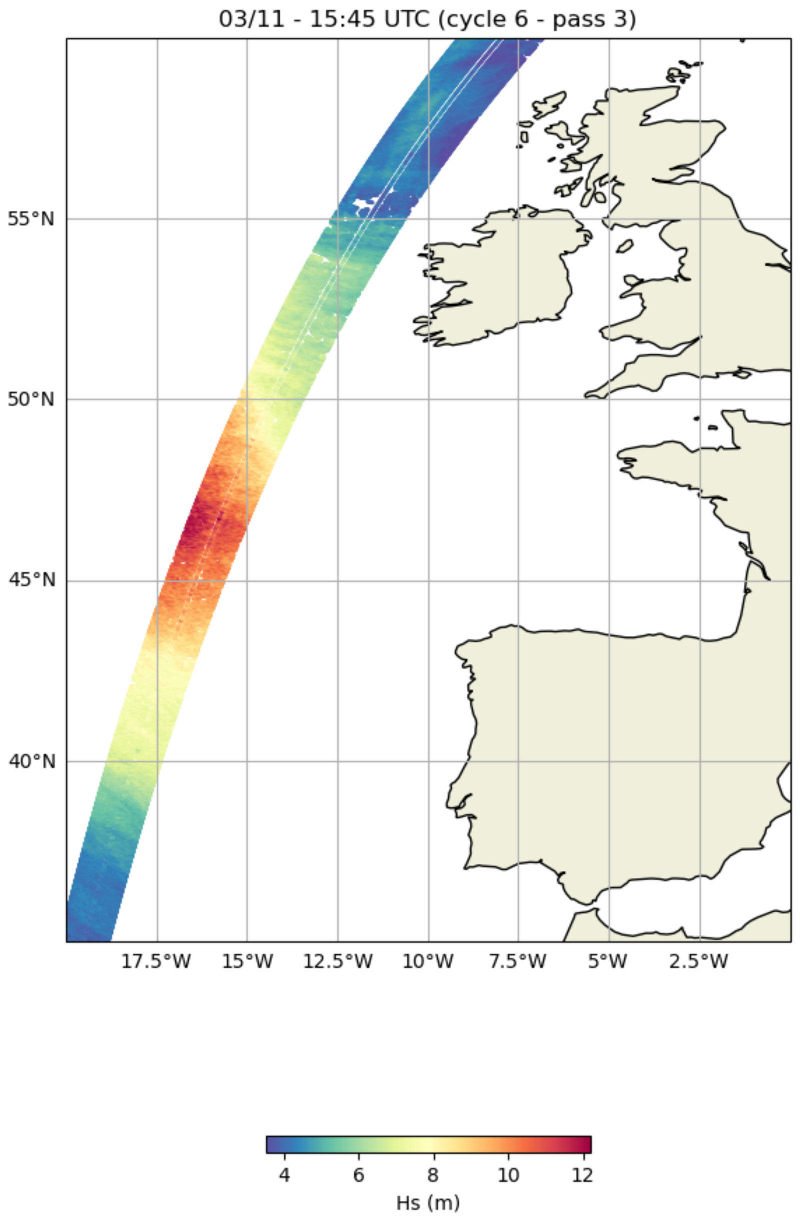
This is well captured in the SWH fields measured by KaRIn at 2km resolution (colorbar width is 60 cm in both bottom plots). The larger SWH modulations are also measured by the nadir altimeter (as expected, see De Carlo et al).

TO DO : predict spectrum of modulated SWH from WW3 spectrum and KaRIn resolution and compare to data.



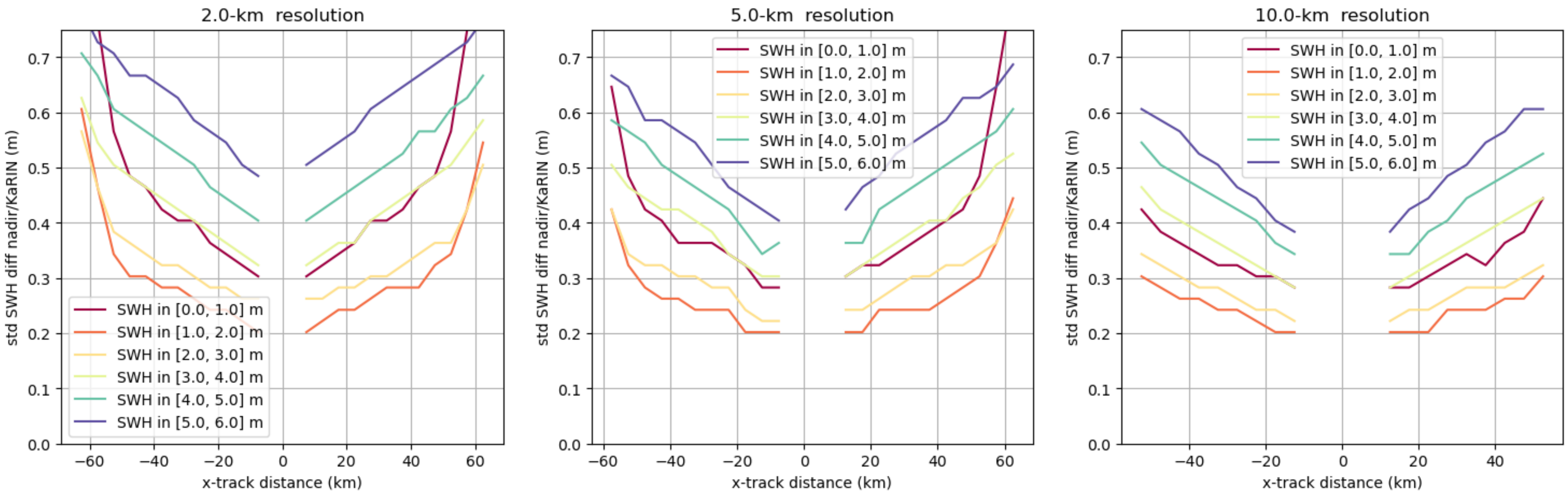
Cycle 3 - Pass 485





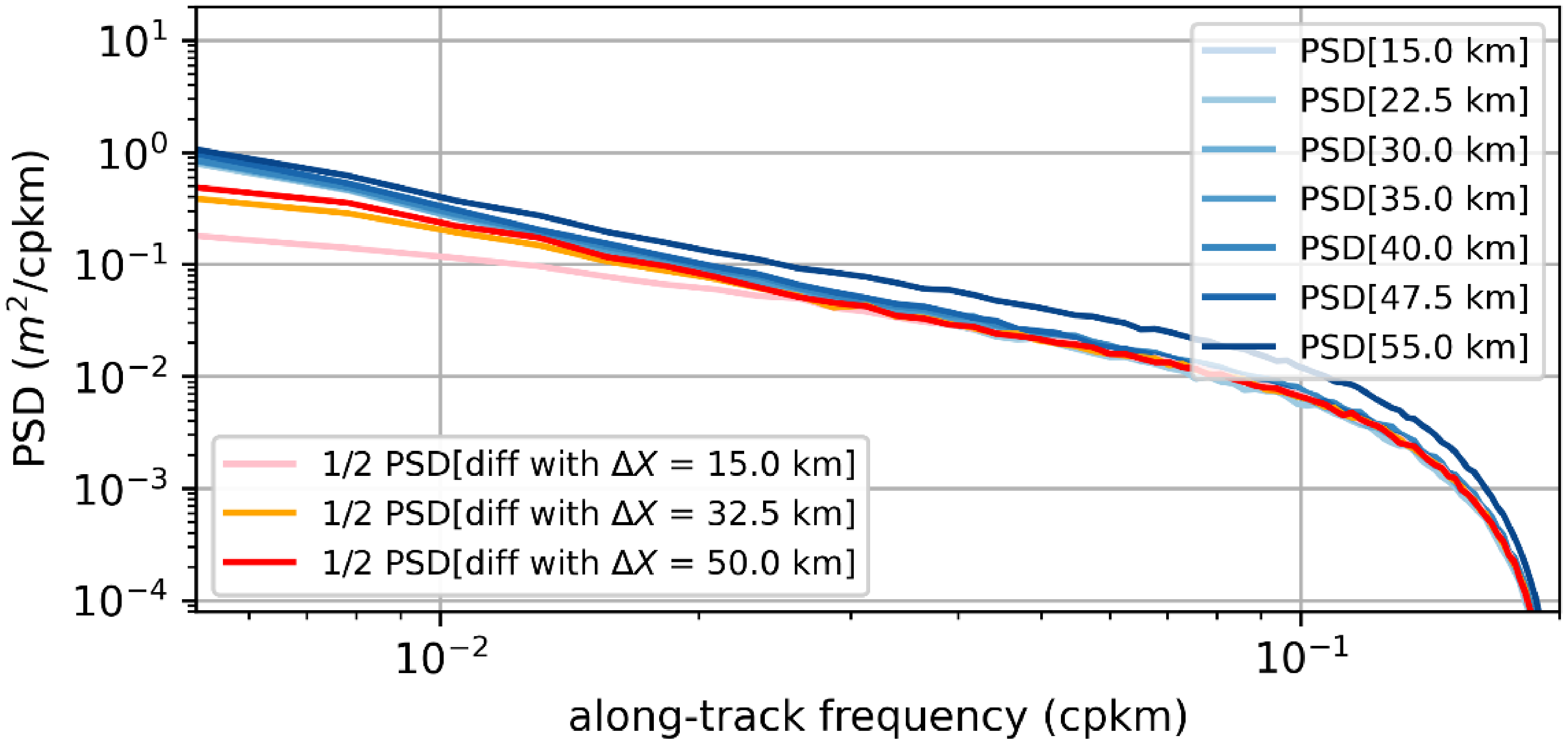
03/11 - 15:45 UTC (cycle 6 - pass 3)
55°N
50°N
45°N
40°N
17.5°W
15°W
12.5°W
10°W
7.5°W
5°W
2.5°W
4
6
8
10
12
Hs (m)

Nadir vs KaRIn : std of the difference



Contributors :

- KaRIn SWH noise
- nadir SWH noise
- cross-track geophysical variability (measurements not at the same location)
- small scale signal NOT resolved by nadir



PSD (m^2/cpkm)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
along-track frequency (cpkm)
PSD[15.0 km]
PSD[22.5 km]
PSD[30.0 km]
PSD[35.0 km]
PSD[40.0 km]
PSD[47.5 km]
PSD[55.0 km]
1/2 PSD[diff with ΔX = 15.0 km]
1/2 PSD[diff with ΔX = 32.5 km]
1/2 PSD[diff with ΔX = 50.0 km]