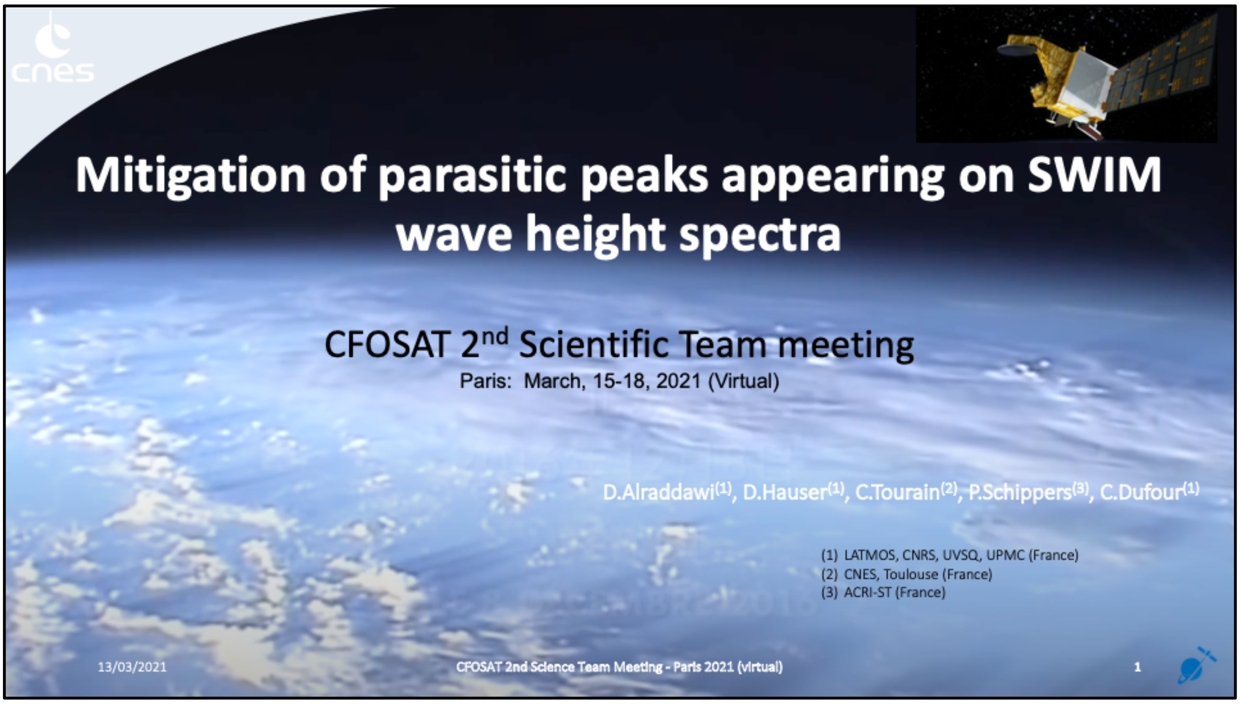

Hello everybody!
This presentation talks about one of the latest evolutions suggested by the CAL/VAL french team to be considered for improving the operational SWIM products provided by the NRT processing chains.

I would like to acknowledge my co-authors and all the teams implied in the analysis.
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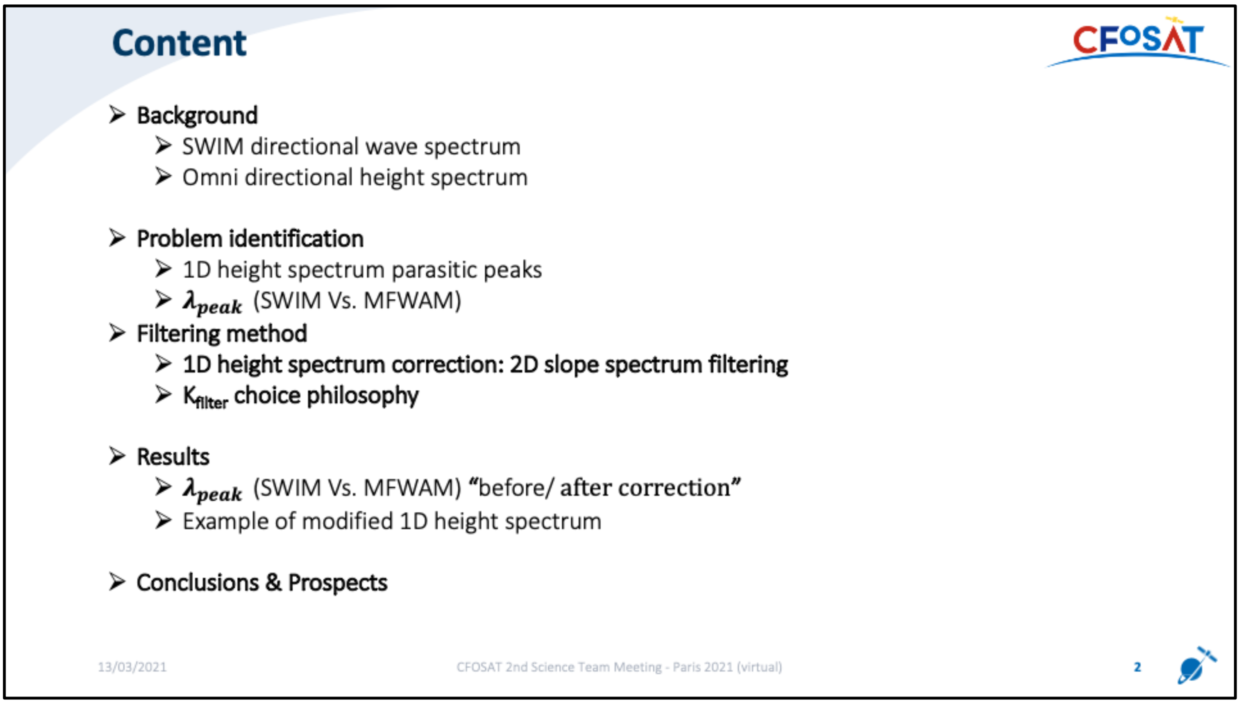


The current presentation consists of 5 main sections:

- Starting by a **background**:
 on the directional wave spectrum generation schema followed by
 the omnidirectional height spectrum estimation method and thereby the peak wavelength

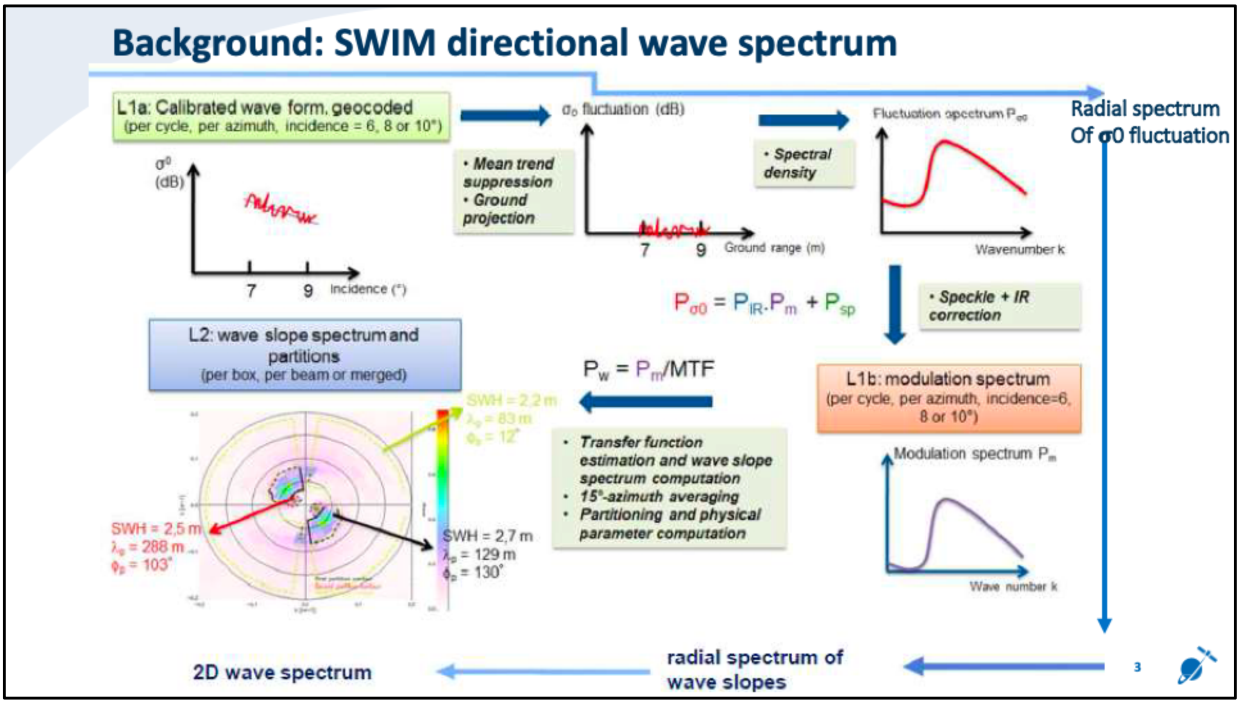
- Next we **identified the problem of**
  - **Parasitic peaks on the SWIM 1D height spectrum** which are found when
 This later is compared to Meteo France Wave model MFWAM, those peaks thought to make some outliers of
  - **SWIM peak wavelength compared to MFWAM**

- Third section presents the suggested **filtering method** to delete carefully these wired peaks starting from the
  - **2D slope wave spectrum conditional screening** &
  - **Wave number filtering thershold**

- The fourth section shows the **after filtering improvements (Results)**, possibly

examined when the corrected
- **SWIM peak wavelengths are compared again to MFWAM,** Also we show
- **an example of the modified 1D wave spectrum**

- Finally, main **conclusions & Prospects**



SWIM radar cross-section variations are quite insensitive to wind speed for incidence around 8°, & Ku band,

So the radar cross-section modulation spectrum is proportional to wave slope spectrum.

This allows to provide directional wave slope spectra from beams 6,8 and 10° (call spectrum beams).

Here we give a reminder of the main steps of the SWIM signal processing leading to the wave slope spectrum.

- From L1a products, calibrated and geocoded waveforms from the so called spectrum beams 6°, 8° and 10°are
transformed into sigma0 fluctuation.

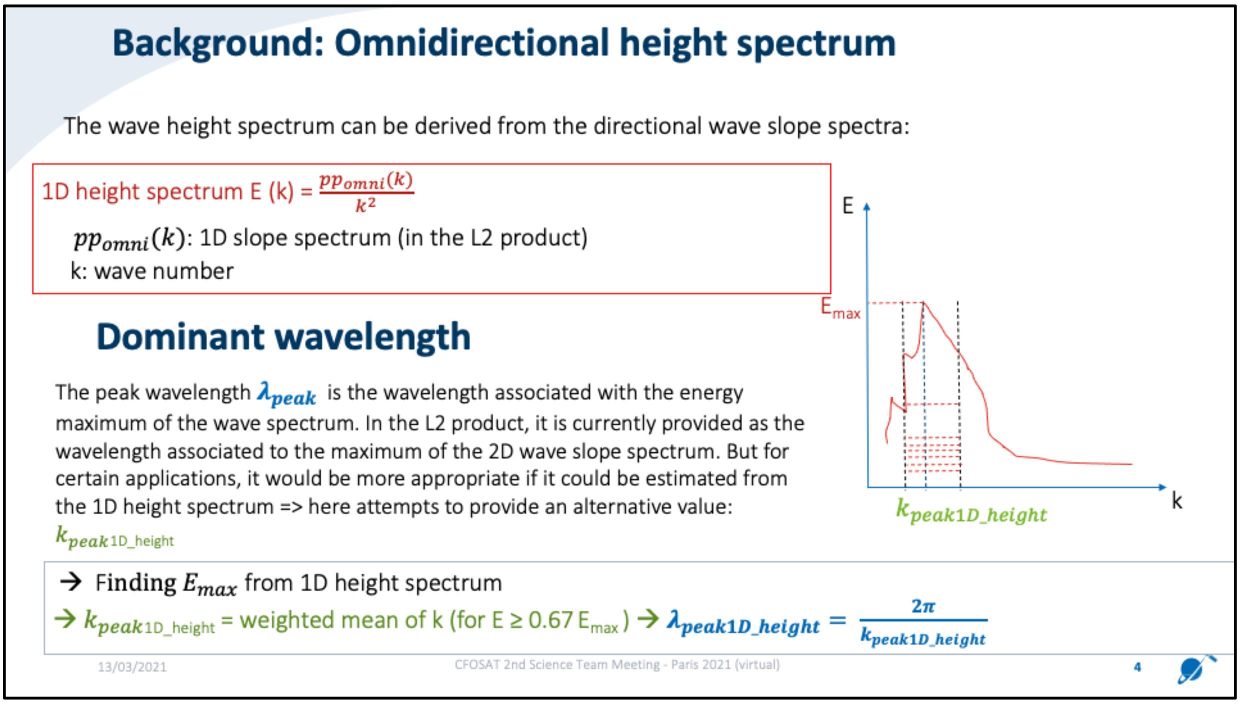
This is done by subtracting the mean trend to sigma0 profile. During this step, the signal, originally in radar
geometry, is projected to ground geometry.

-Then this modulation is transferred into the spectral domain, via a Fourier transform.

-The fluctuation spectrum obtained is then corrected from the speckle noise correction, and compensated for the
point target response.

The resulting modulation spectrum is provided in L1B product, per cycle of

measurement, per azimuth and per
incidence (corresponding to spectrum beams).
- Modulation spectra are combined and resampled to obtain directional modulation spectra at the scale of the SWIM
boxes (70km * 90km) defined over azimuth bins and wave number bins.
- A modulation Transfer Function (MTF) is then applied to get the directional wave slope spectra.
Finally, a partitioning process is applied on each wave slope spectra to identify the different wave partitions, and
associated wave parameters: Significant Wave Height, wave wavelength and wave direction are determined.



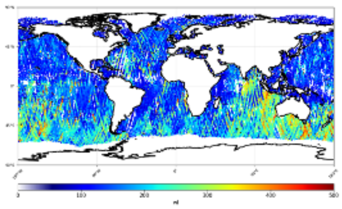
The wave height spectrum can be derived from the directional wave slope spectra (2D called pp_{mean} or 1D called pp_{omni} in the operational product) when dividing by K^2 , k: is the wave number

The omnidirectional height spectrum is the most frequently analyzed quantity in the "waves" community (even more than the slope spectrum). It is directly proportional to the energy spectrum of the waves.
In particular the significant height (Hs), the period or the dominant wavelength (and the resulting wave age) are generally estimated from the peak of this omni-directional height spectrum.

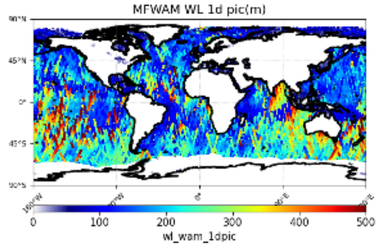
In the L2 product, the dominant wavelength is currently provided as the wavelength at the maximum of the 2D wave slope spectrum. But for certain applications, it would be more appropriate if it could be estimated from the 1D height spectrum => here attempts to provide an alternative value **by using the 1D height spectrum.**

SWIM peak wavelength from the 2D slope spectrum (as in the L2 product) compared to parameters in the MFWAM (wave model from Meteo-France)

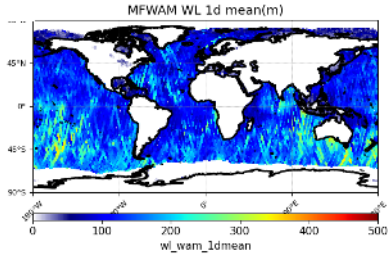
SWIM



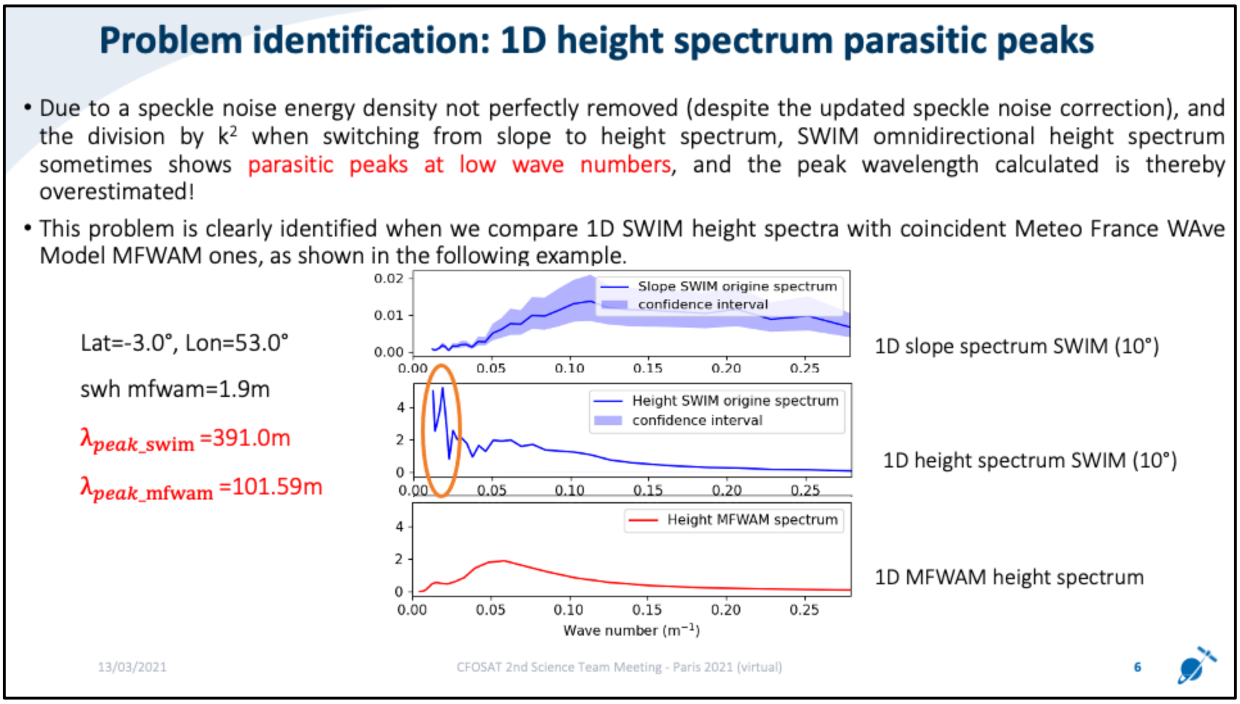
MFWAM peak wavelength (from the peak period of the 1D height spectrum)



MFWAM mean wavelength (from the mean period)

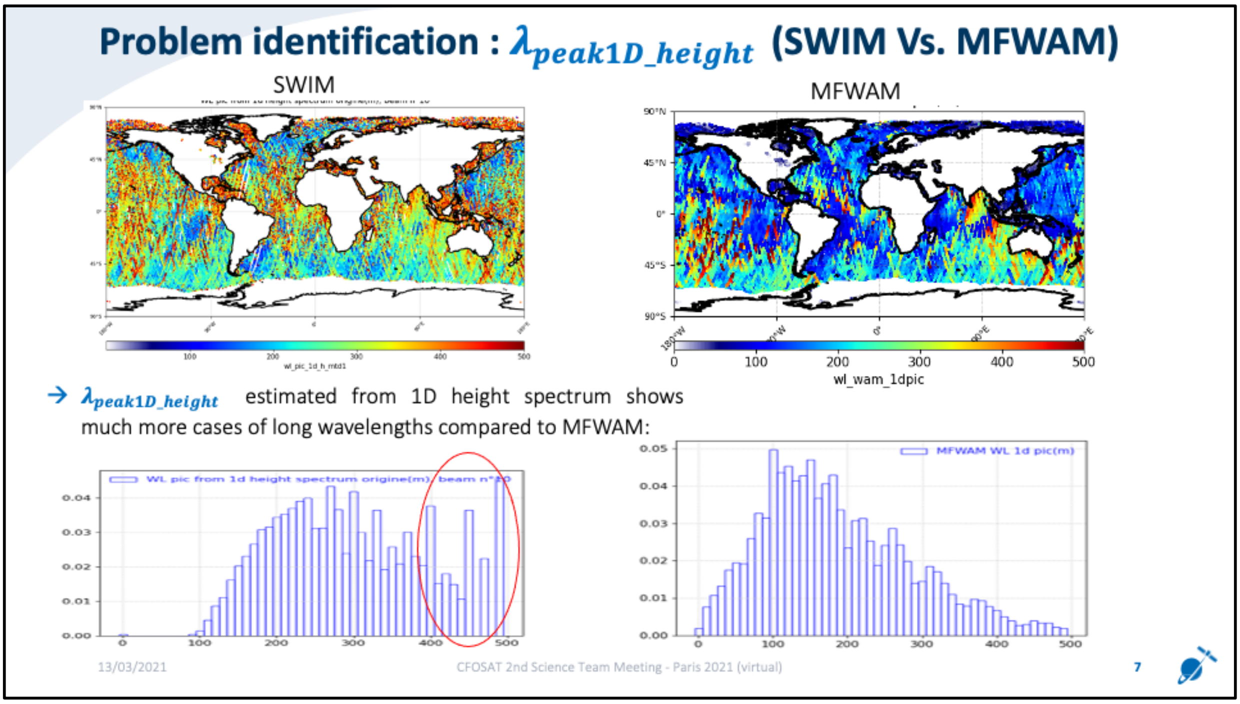


=> Reasonable agreement but not the same definition of dominant wavelength !! => =>
needs to consider peak wavelength from SWIM wave height spectra



The directional spectrum of wave slopes is directly related to the directional spectrum of signal modulation, after subtracting the speckle density spectrum. From this directional wave slope spectrum, the omni-directional spectrum of wave height spectrum can be derived. However, 1D height wave spectrum shows some parasitic peaks appearing at low wave numbers (long wavelengths), particularly for low sea state conditions. These spurious peaks are due the amplification of the noise floor at small wave numbers when converting SWIM wave slope spectra to wave height spectra. Even if the speckle correction is appropriate in the mean, some variability of speckle noise induces non-zero values of the noise floor [1]. When long waves are present, this noise contribution is negligible compared to the wave energy, but otherwise (and mainly for low sea-state conditions), after conversion in wave height spectra, this problem generates spurious peaks in the height spectra, which hampers to use these height spectra to characterize the peak wavelength (or peak frequency).
Here we show an example of an omni directional slope wave spectrum at latitude=-3.0 , longitude=53.0 & for a small significant wave height case (swh<2 m)
Top: SWIM 1D slope spectrum,
Middle: SWIM 1D height spectrum, the orange circle marks parasitic peak (due to the amplification when slope spectrum is divided by k^2 to get height spectrum one's) of the spectre.

Bottom: corresponding MFWAM omnidirectional height spectrum
Where : SWIM peak wavelength (of this example) is 390m , compared to 101m for MFWAM's



More generally, here on the left are presented a map and a histogram of λ_{peak} estimated from 1D SWIM height spectra over 13 days of data all over the globe . The corresponding map and histogram for MFWAM are presented on the right. Clearly compared to MFWAM, the SWIM data show a large number of long wavelengths which seems inconsistent compared to MFWAM . Note that in the case of MFWAM the peak wavelengths are derived by conversion of the peak periods of the 1D wave height MFWAM spectrum. The point by point difference between SWIM and MFWAM is Illustrated in the next slide.

Problem identification: SWIM λ_{peak1D_height} over-estimating

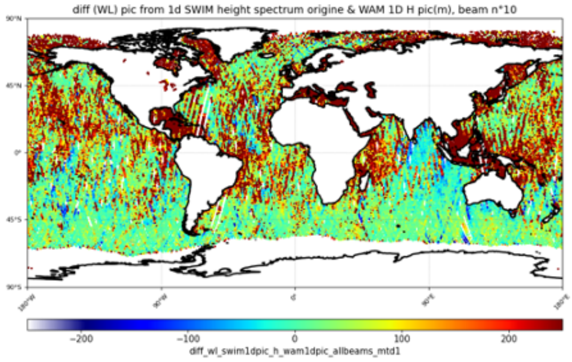
→ Strong positive bias is observed compared to MFWAM, especially under low sea state conditions

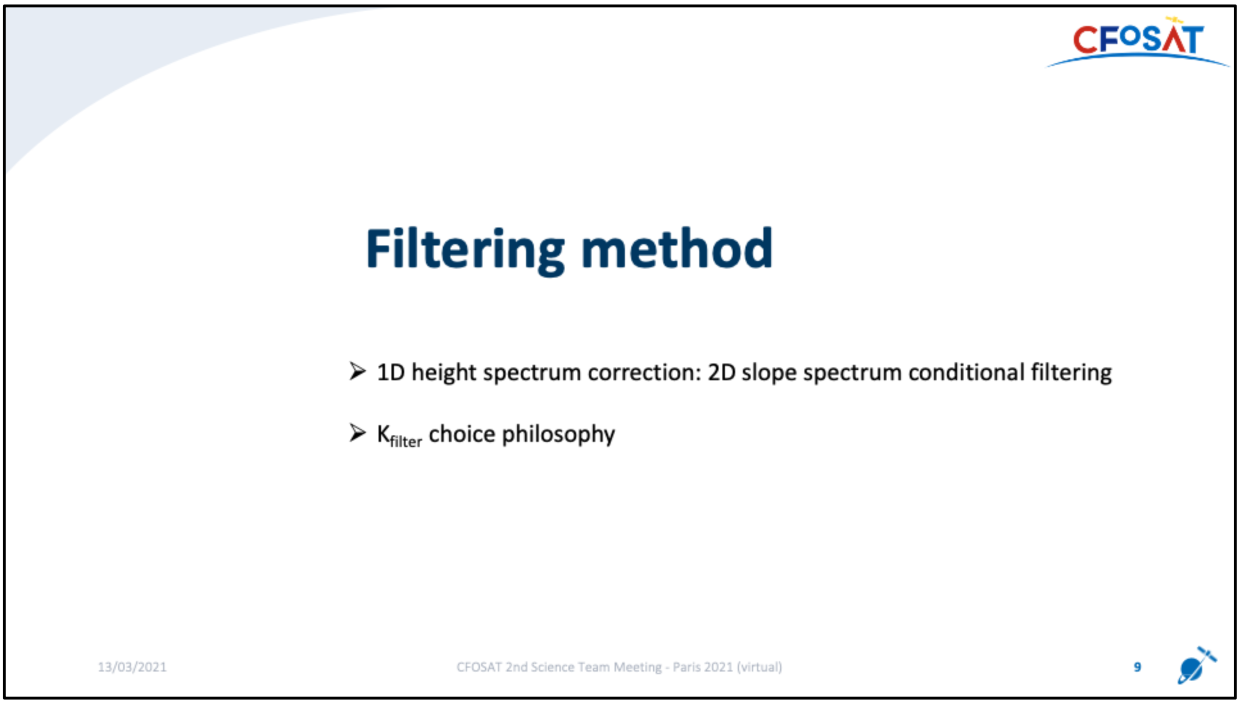
→**1D height spectrum correction is required to enable a correct characterization of** peak wavelength (or peak frequency) to **remedy this over-estimating!**

The following analysis uses:

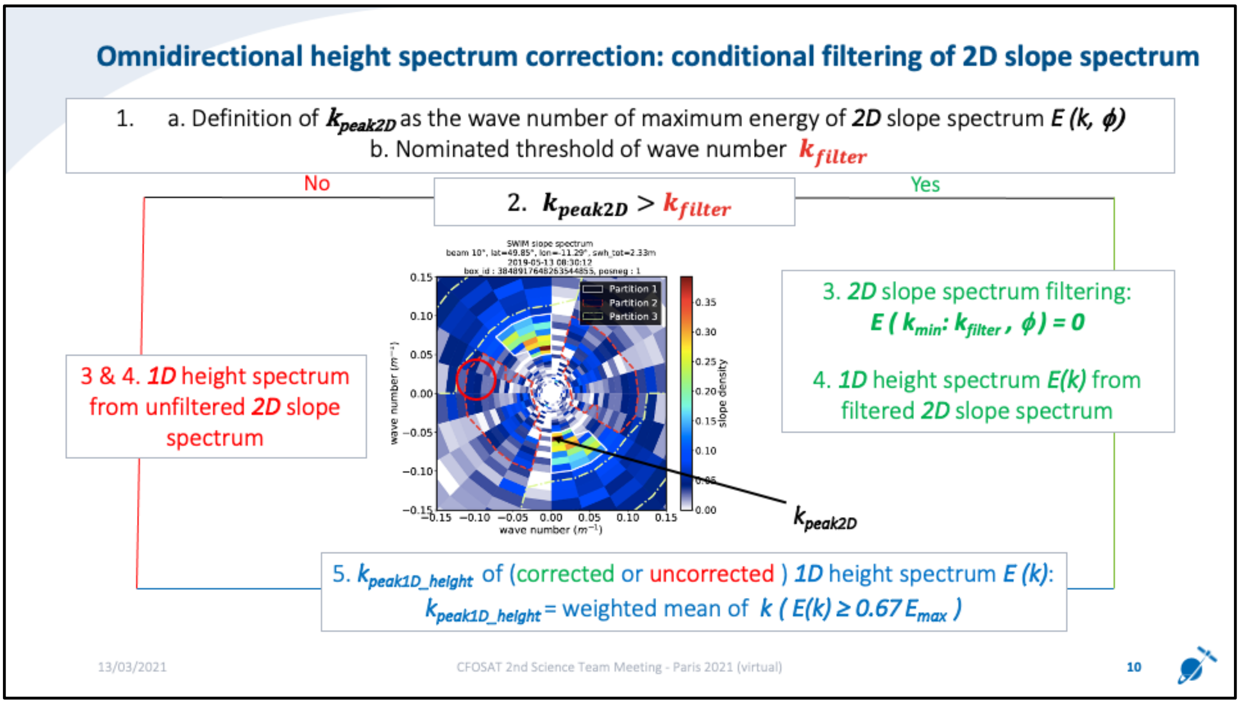
- SWIM dataset from version 5.0 (speckle psb1 & MTF3), from 10 to 22 september 2019.

$\lambda_{peak\_1D\_height}\,SWIM - \lambda_{peak}\,MFWAM$





- This section presents the suggested **filtering method** to delete carefully the parasitic peaks starting from the
  - **2D slope wave spectrum conditional screening** & and the wise choice of a
  - **Wave number filtering threshold** K_{filter}



1D height spectrum parasitic peaks are observed at small wave numbers and low sea state conditions, removing them means that we need to filter the energy of the noise at the small wave numbers (long wavelengths) while keeping the energy when real long waves (swell) are present.

The method under tuning consist in:

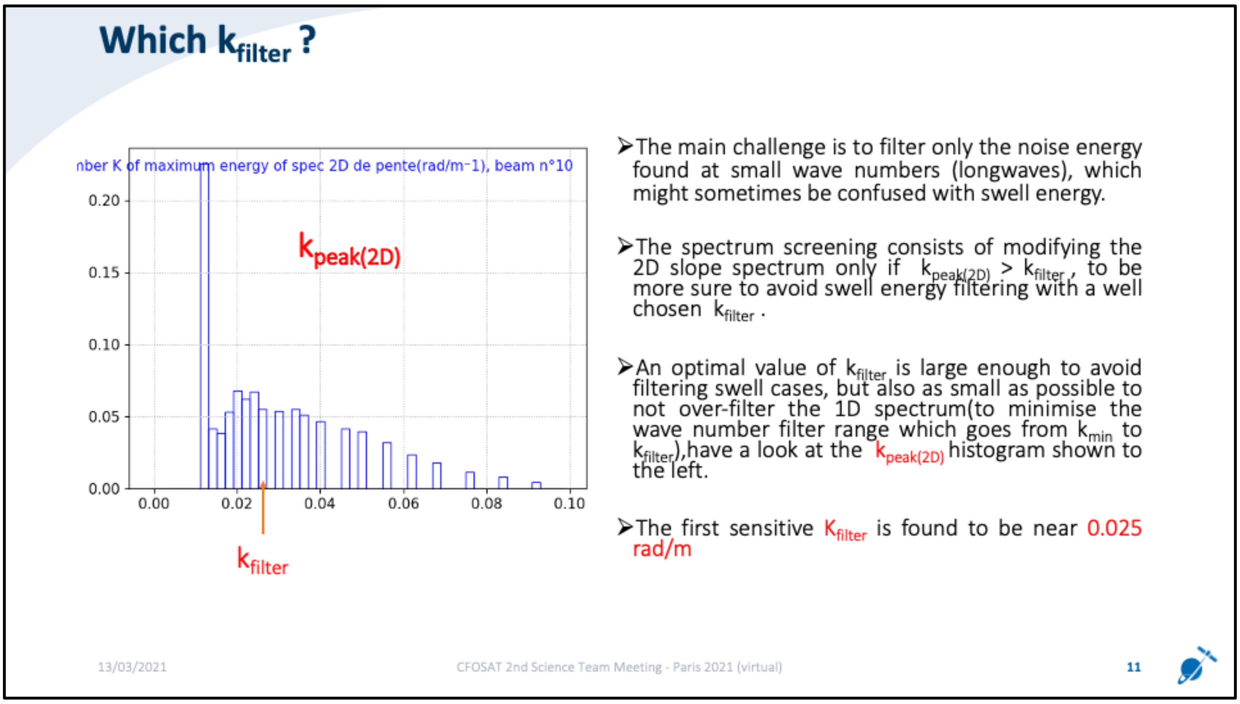
i) choosing a wave number limit (called k_{filter} currently chosen as 0.025 rad/m, see next slide for more details) .

ii) comparing the peak wave number k_{peak2D} from the 2D slope spectra (not affected by these parasitic peaks) to a suggested (Following several tests) threshold of wave number, hereafter called k_{filter} .

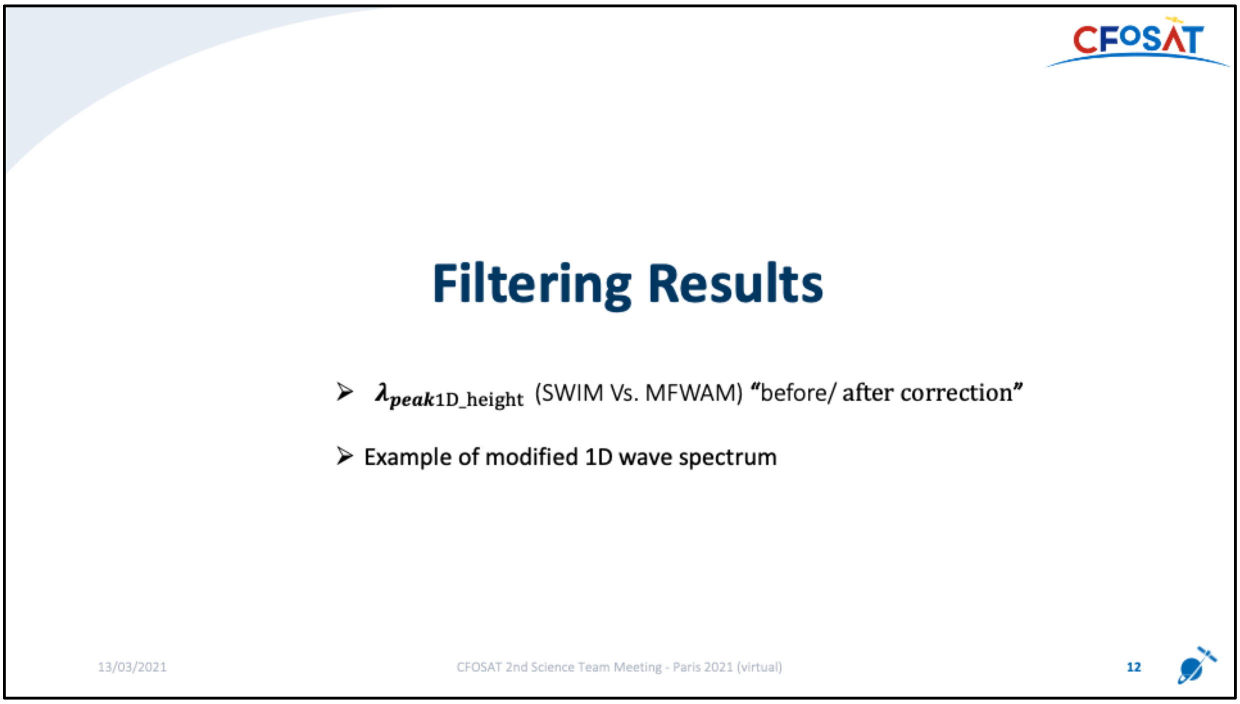
iii) only when k_{peak2D} is larger than k_{filter} (wavelengths of waves smaller than $2p/k_{filter}$), impose a zero value to the 2D wave slope spectrum energy for all k less than k_{filter} .

iv) calculating the omni-directional wave height spectrum $\mathbf{E(k)}$ from the filtered 2D wave slope spectrum.

v) Calculating the peak wave number of the omni-directional wave height spectrum $\mathbf{E(k)}$, this value is used later to calculate the new value of peak wavelength $\boldsymbol{\lambda_{peak\_1D\_\mathrm{height}}}$. This latter is compared in the folllowing slides to MFWAM's peak wavelength to validate the method.



Here we present the distribution of peak wave numbers of the maximum energy of the 2D slopes spectrums examined within the studied period, called previously $k_{peak(2D)}$,
the filter can be applied on the 2D slope spectre only if $k_{peak(2D)} > k_{filter}$, so the modified 1D height spectres & thereby their modified λ_{peak} are only for these cases,
That means also: all 2D slope spectrums where $k_{peak(2D)}$ is too small to be bigger than k_{filter} are not modified (i.e: swells,..).
After testing many k_{filter} values, the most suitable k_{filter} value to acheive the previous objectives is found to be near 0.025 rad/m



- In the following section, we will evaluate the validation results of the comparison between SWIM peak wavelength and MFWAM one's, with objective to examine the **after filtering improvements, the study evaluates:**
  - $\lambda_{\mathrm{peak(1D)}}$ **(**SWIM vs. MFWAM) before & after correction
  - an example of the modified 1D wave spectrum

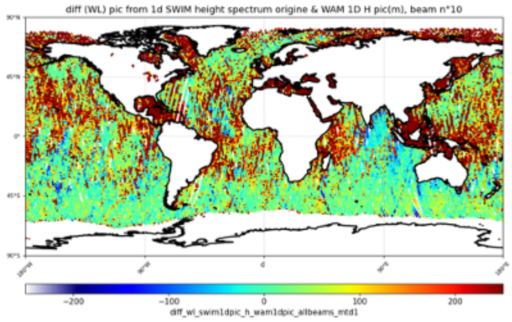
Results: $\lambda_{peak(1D\_height)}$ SWIM $- \lambda_{peak(1D\_height)}$ MFWAM

$$\lambda_{peak1D\_height} = \frac{2\pi}{k_{peak1D\_height}}$$

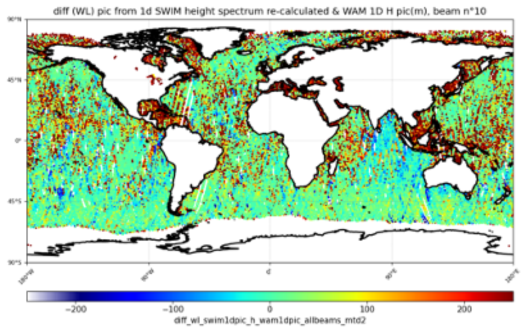
k_{peak1D_height} : peak wave number of SWIM 1D height spectrum (before/after filtering)

Then the differences of λ_{peak1D_height}(SWIM, MFWAM) are presented in the two maps below

Before filtering

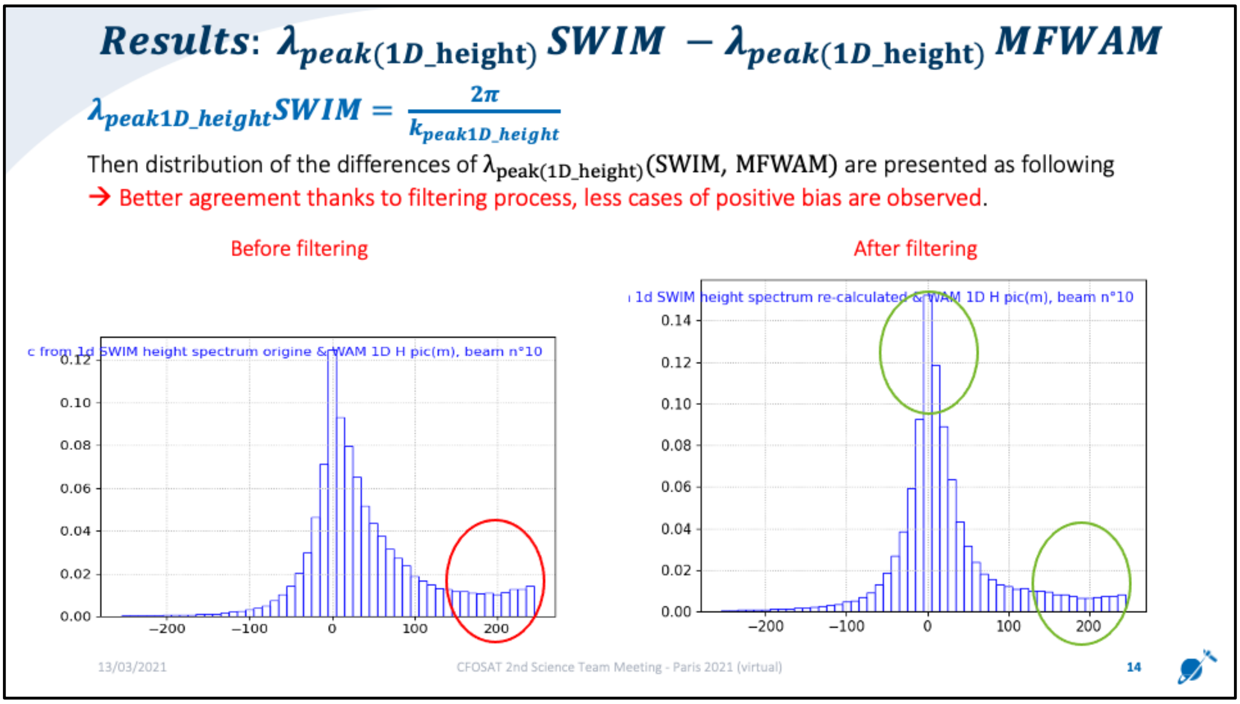


After filtering

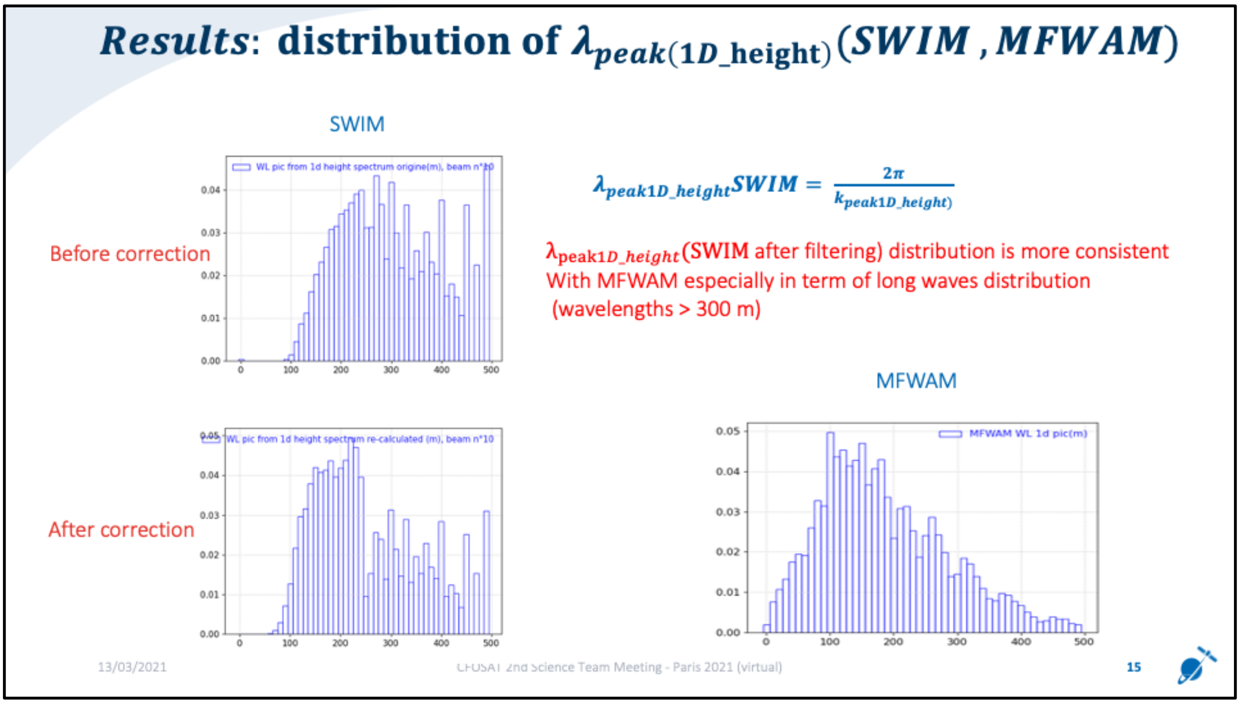


⇒ Less over-estimation of SWIM after filtering

⇒ Method needs more tuning to handle areas of small significant wave height



The presented histograms of differences of λ_{peak1D_height}(SWIM,MFWAM) show a better agreement thanks to filtering process, less positive bias are observed.


Results: distribution of $\lambda_{peak(1D\_height)}(SWIM, MFWAM)$
SWIM
Before correction
WL pic from 1d height spectrum origine(m), beam n°10
After correction
WL pic from 1d height spectrum re-calculated (m), beam n°10
$\lambda_{peak1D\_height}SWIM = \frac{2\pi}{k_{peak1D\_height}}$
λ_{peak1D_height}(SWIM after filtering) distribution is more consistent
With MFWAM especially in term of long waves distribution
(wavelengths > 300 m)
MFWAM
MFWAM WL 1d pic(m)
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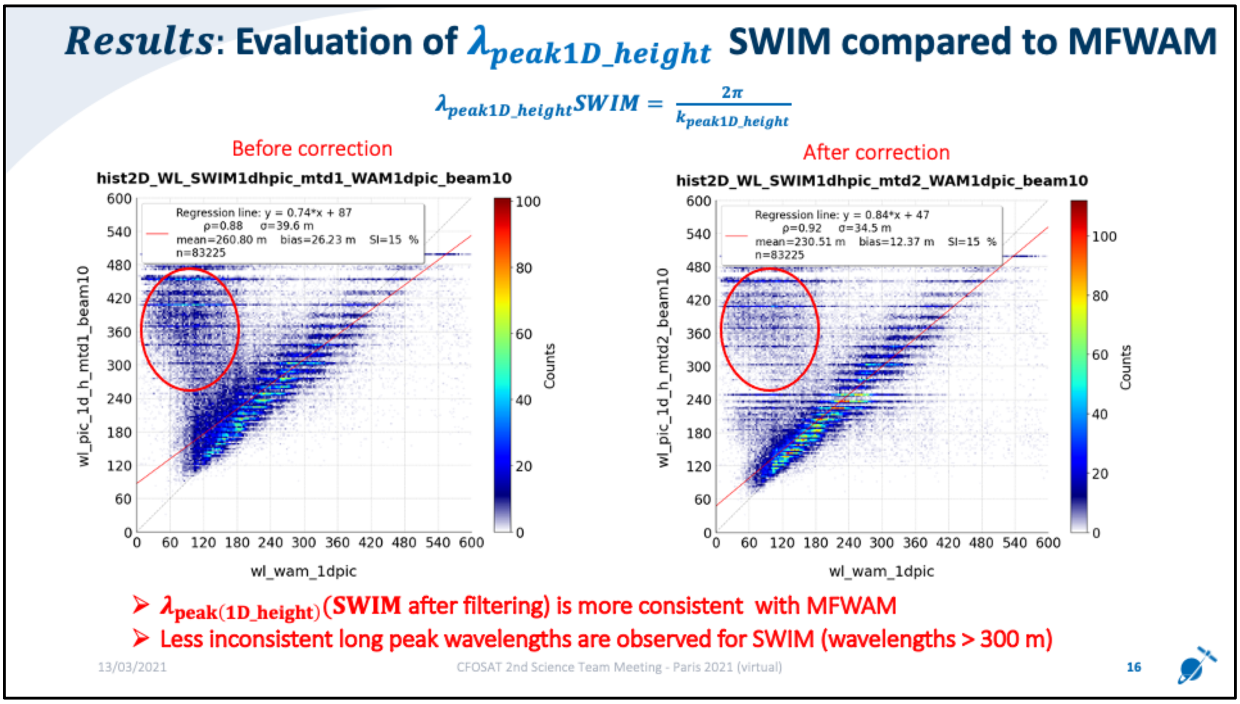
Results: Evaluation of λ_{peak1D_height} SWIM compared to MFWAM
$\lambda_{peak1D\_height}SWIM = \frac{2\pi}{k_{peak1D\_height}}$
Before correction
hist2D_WL_SWIM1dhpic_mtd1_WAM1dpic_beam10
Regression line: y = 0.74*x + 87
ρ=0.88 σ=39.6 m
mean=260.80 m bias=26.23 m SI=15 %
n=83225
wl_pic_1d_h_mtd1_beam10
wl_wam_1dpic
Counts
After correction
hist2D_WL_SWIM1dhpic_mtd2_WAM1dpic_beam10
Regression line: y = 0.84*x + 47
ρ=0.92 σ=34.5 m
mean=230.51 m bias=12.37 m SI=15 %
n=83225
wl_pic_1d_h_mtd2_beam10
wl_wam_1dpic
Counts
$\lambda_{peak(1D\_height)}$(SWIM after filtering) is more consistent with MFWAM
Less inconsistent long peak wavelengths are observed for SWIM (wavelengths > 300 m)
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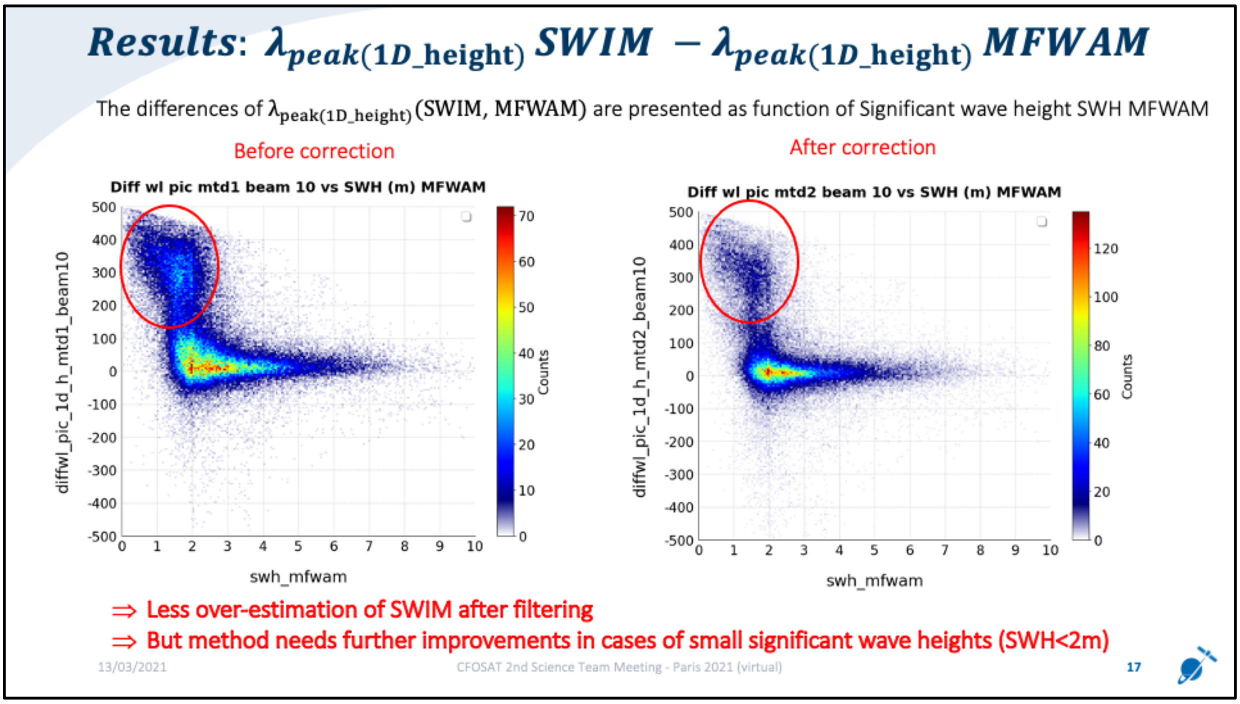
Results: $\lambda_{peak(1D\_height)}$ SWIM $- \lambda_{peak(1D\_height)}$ MFWAM
The differences of $\lambda_{peak(1D\_height)}$ (SWIM, MFWAM) are presented as function of Significant wave height SWH MFWAM
Before correction
After correction
Diff wl pic mtd1 beam 10 vs SWH (m) MFWAM
Diff wl pic mtd2 beam 10 vs SWH (m) MFWAM
diffwl_pic_1d_h_mtd1_beam10
diffwl_pic_1d_h_mtd2_beam10
swh_mfwam
Counts
⇒ Less over-estimation of SWIM after filtering
⇒ But method needs further improvements in cases of small significant wave heights (SWH<2m)
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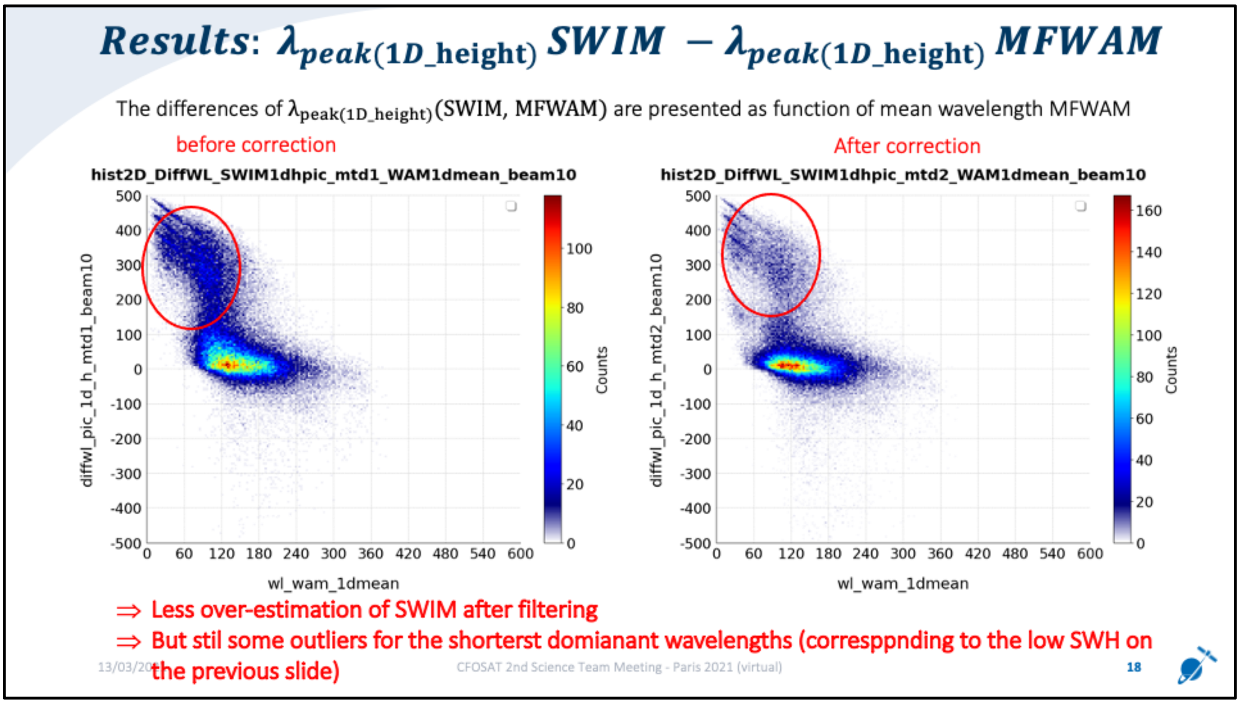
Results: $\lambda_{peak(1D\_height)}$ SWIM $- \lambda_{peak(1D\_height)}$ MFWAM
The differences of $\lambda_{peak(1D\_height)}$(SWIM, MFWAM) are presented as function of mean wavelength MFWAM
before correction
After correction
hist2D_DiffWL_SWIM1dhpic_mtd1_WAM1dmean_beam10
hist2D_DiffWL_SWIM1dhpic_mtd2_WAM1dmean_beam10
diffwl_pic_1d_h_mtd1_beam10
diffwl_pic_1d_h_mtd2_beam10
wl_wam_1dmean
Counts
⇒ Less over-estimation of SWIM after filtering
⇒ But stil some outliers for the shorterst domianant wavelengths (corresppnding to the low SWH on the previous slide)
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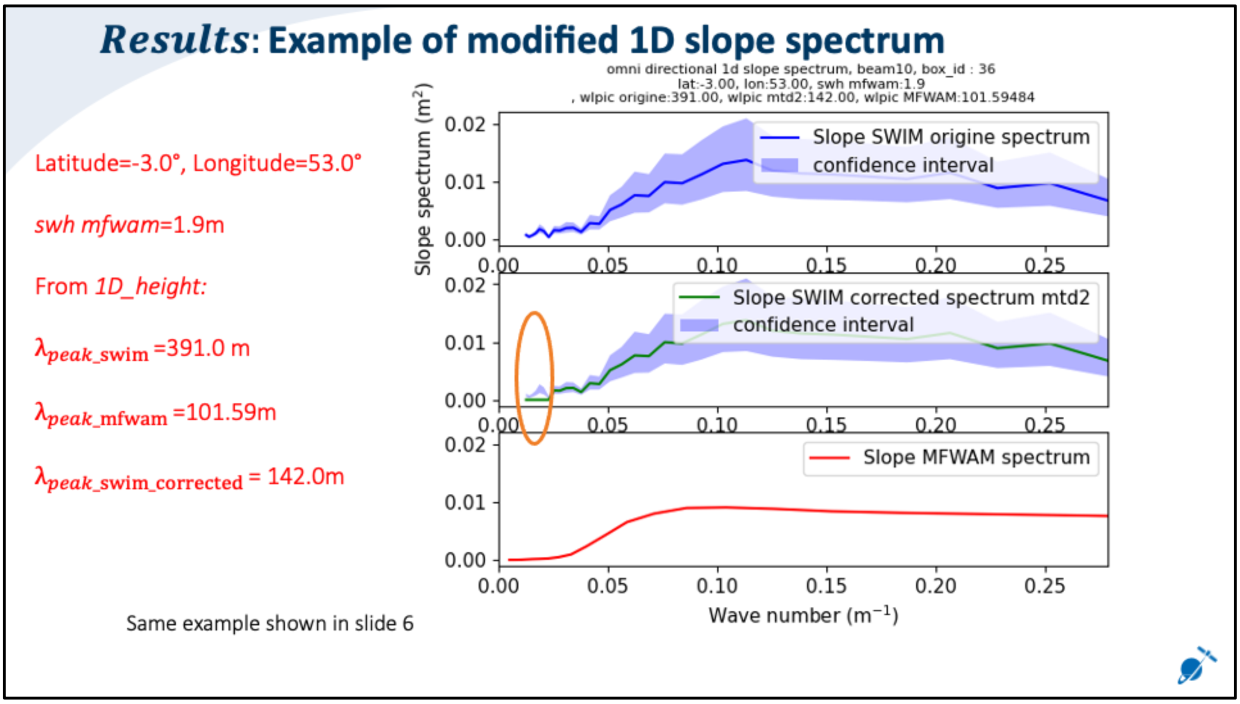
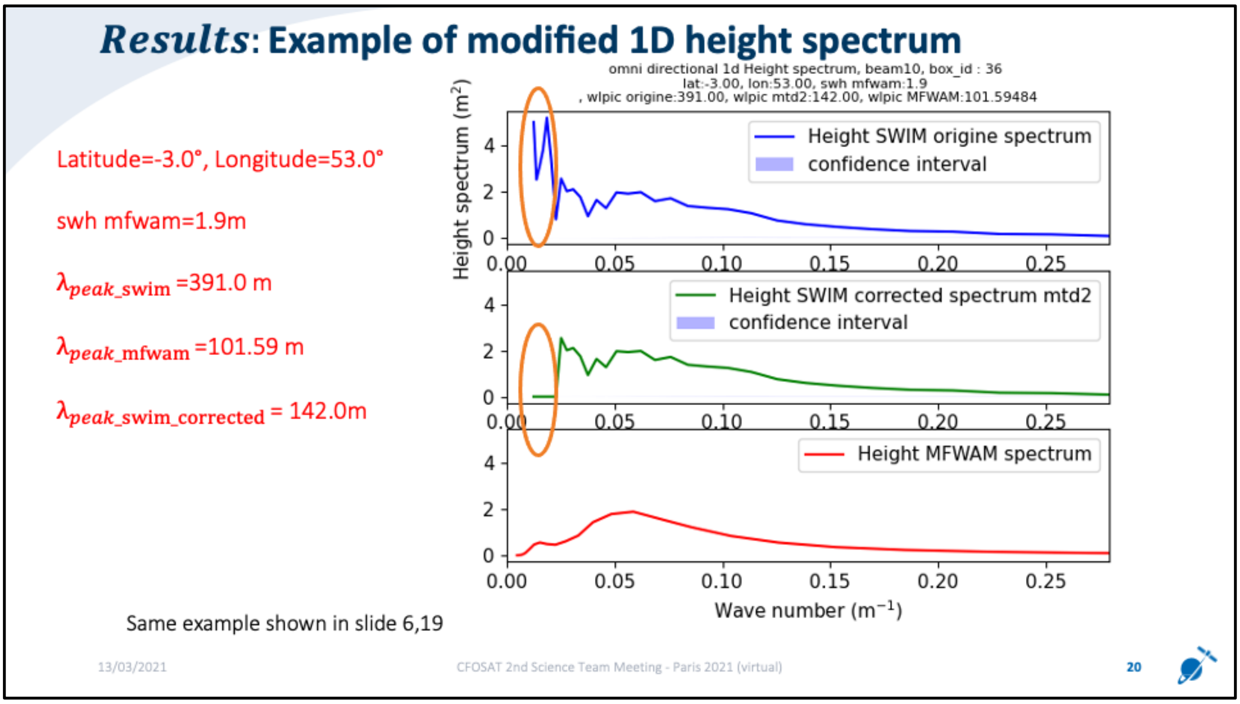


Here we show an example of an omni directional slope wave spectrum at latitude=-3 , longitude=53 & for a small significant wave height case (swh<2 m)
Top: SWIM 1D slope spectrum before filtering,
Middle: SWIM 1D slope spectrum after filtering, the orange circle marks the filtered parts of the spectre.
Bottom: corresponding MFWAM omnidirectional slope spectrum
Where : SWIM peak wavelength estimated from the 1D height spectrum before correction was 390m on this example , and it was reduced to 142m, compared to 101m for MFWAM



Same example, but this time we present the omnidirectional height wave spectrum (latitude=-3 , longitude=53 & for a small significant wave height case (swh<2 m))
Top: SWIM 1D height wave spectrum **before filtering,**
Middle: SWIM 1D height wave spectrum **after filtering**, the orange circle marks the filtered parts of the spectre.
Bottom: corresponding MFWAM omnidirectional height spectrum
Where : SWIM peak wavelength (of this example) before correction was 390m , and it was reduced to 142m (thanks to filtering), compared to 101m for MFWAM's

Conclusions & prospective

- Omnidirectional SWIM wave **height** spectra show some parasitic peaks at low wave numbers, and the peak wavelength estimated from the wave **height** spectra is thereby not fully reliable.

- These peaks are due to the amplification of the low level noise floor at low wavenumber when converting wave slope to wave height spectra. This issue is more frequent for low sea-state conditions.

- This issue can be remediated via a conditional filtering of the 2D slope spectrum after an appropriate choice of wave number limitation threshold.

- The suggested filtering enables to filter out the parasite peaks in the 1D height spectrum while preserving the information when long waves are present

  - In most of the cases, the corrected 1D height spectrums are cleaned from these parasitic peaks,
  - The associated SWIM peak wavelength (corrected) is more consistent with the MFWAM's, with less outliers is the long wave (>300m) range
  - Parastic peaks are no fully eliminated in cases of small wave heights & short dominant wavelengths => a future tuning which takes into account the sea-state condition might help to reduce them.

- Future Improvements
  - Conditionning the filter with significant wave height thresholds
  - Filtering the fluctuations rather than zeroing the slope spectrum parasitic peak parts (the current disadvantage is to suddenly cut the spectrum)

- To be confirmed: integration in the next version of the operatioonal chains (to be set up in the prototype software first)