Good morning everyone, this presentation talks about the latest evolutions brought into the SWIM products.

Results presented here are applicable to products delivered operationally in NRT to all users since October 12th of this year.

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

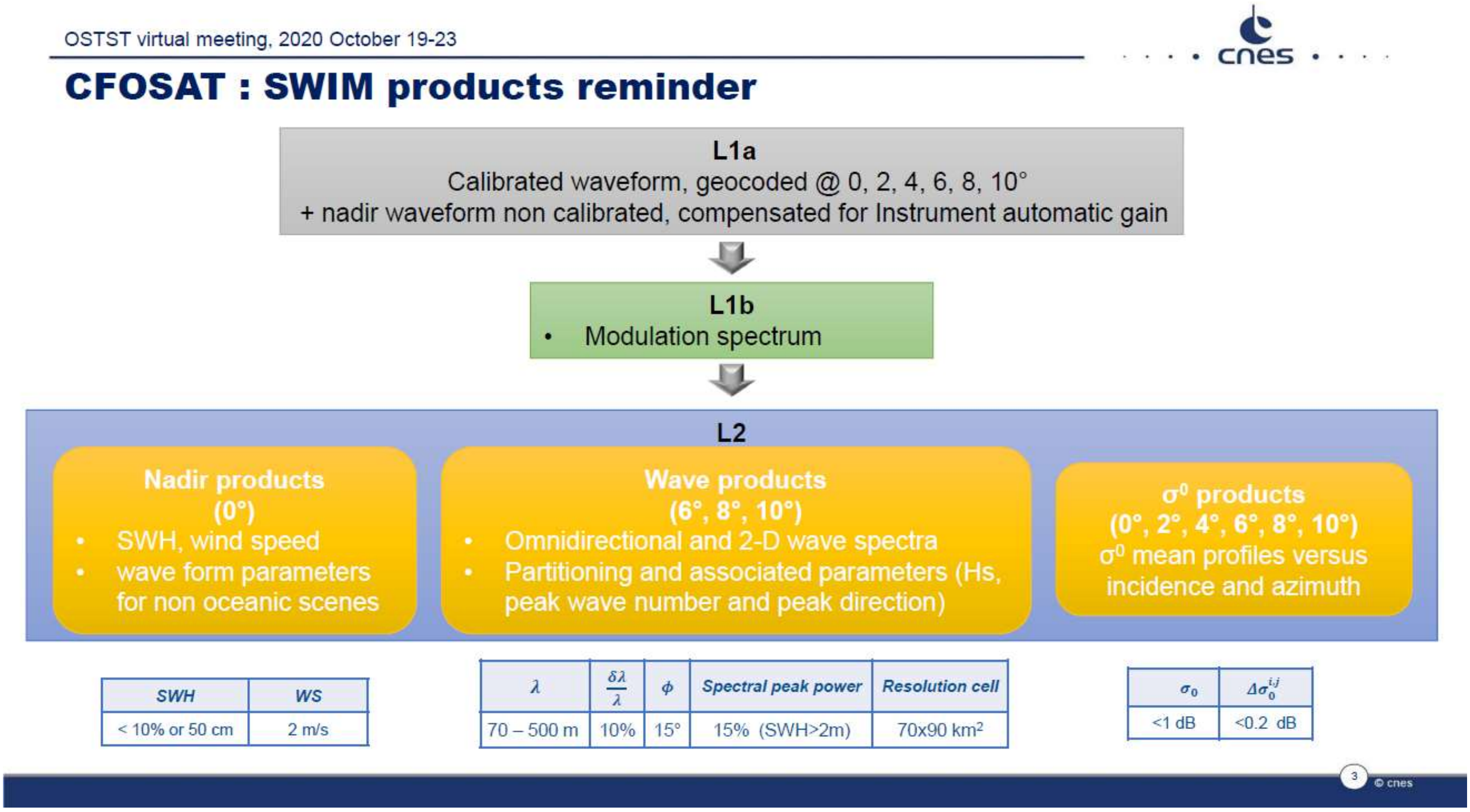
CFOSAT is a China/France mission for oceanography. It is a world première as it aims to measure simultaneously ocean surface wind and wave spectral properties.

The satellite embarks two instruments: a wind scatterometer SCAT, provided by China (NSSC) and a wave scatterometer SWIM, provided by France (manufactured by Thales).

- **SCAT** is as instrument based on a fan beam concept, combining the advantages of a large swath and a rotating antenna. It operates for incidences between 26° and about 50°. It provides sigma0 and ocean wind vectors.

- **SWIM** is a new instrument; it is a real aperture radar which operates in KU band.
  It illuminates scenes sequentially with 6 incidence angles, from nadir to 10°. The SWIM rotating antenna allows to get information in all azimuth directions.
  SWIM can thus provide **mean sigma0 profiles** for incidences **from 0 to 10°,** in all azimuths.

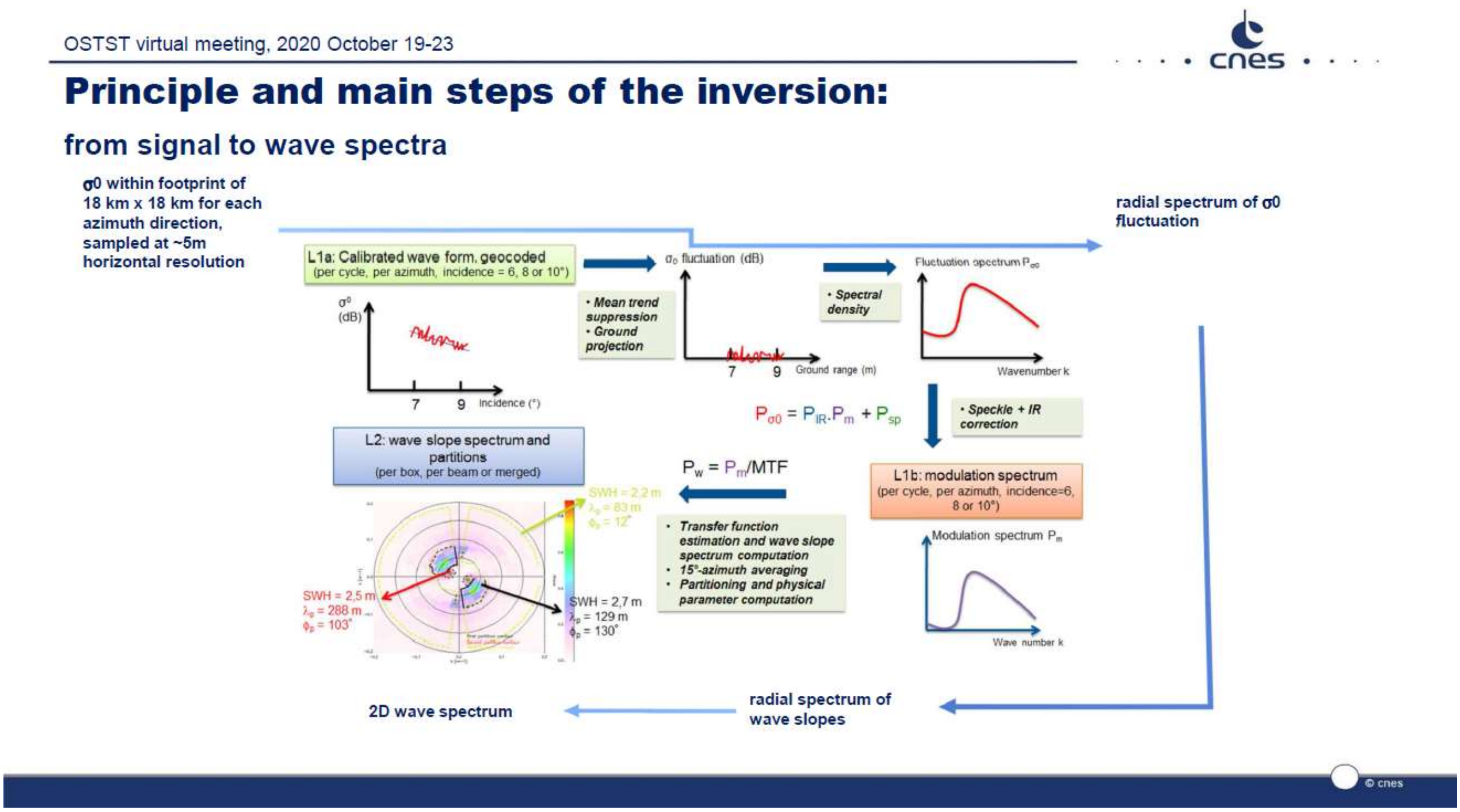
  It has been shown that for incidence around 8°, for Ku band, the radar cross-section variations are quite insensitive to wind speed, and radar cross-section modulation spectrum is proportional to wave slope spectrum.
  This allows to provide **directional wave slope spectra** from **beams 6,8 and 10°** (call spectrum beams).
  As SWIM presents a **nadir beams**, it also delivers significant wave height and wind speed, as conventional altimeters.



The SWIM products are generated by the CNES Wind and Wave Instrument Center (CWWIC) in Toulouse, France.

- **Level 1a** products contain calibrated and geocoded waveform in radar geometry for all beams from 0 to 10°.
- **Level 1b** provides signal modulation in the ground geometry and modulation spectrum for spectrum beams : 6, 8 and 10°.
- Finally, at **level 2** data are processed by ‘boxes’ which are 70km by 90 km resolution cells. for each box, data are cumulated and treated by azimuth to get:
  - Sigma0 mean profiles for incidences from 0 to 10°,
  - Omnidirectional wave spectra,
  - 2D wave spectra, from 6, 8 and 10° beams data, and associated wave parameters : Significant Wave Height, peak wave number and peak direction.

  Nadir beam data are retracked to get Significant Wave Height and wind speed.



Here we give a reminder of the main steps of the 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).

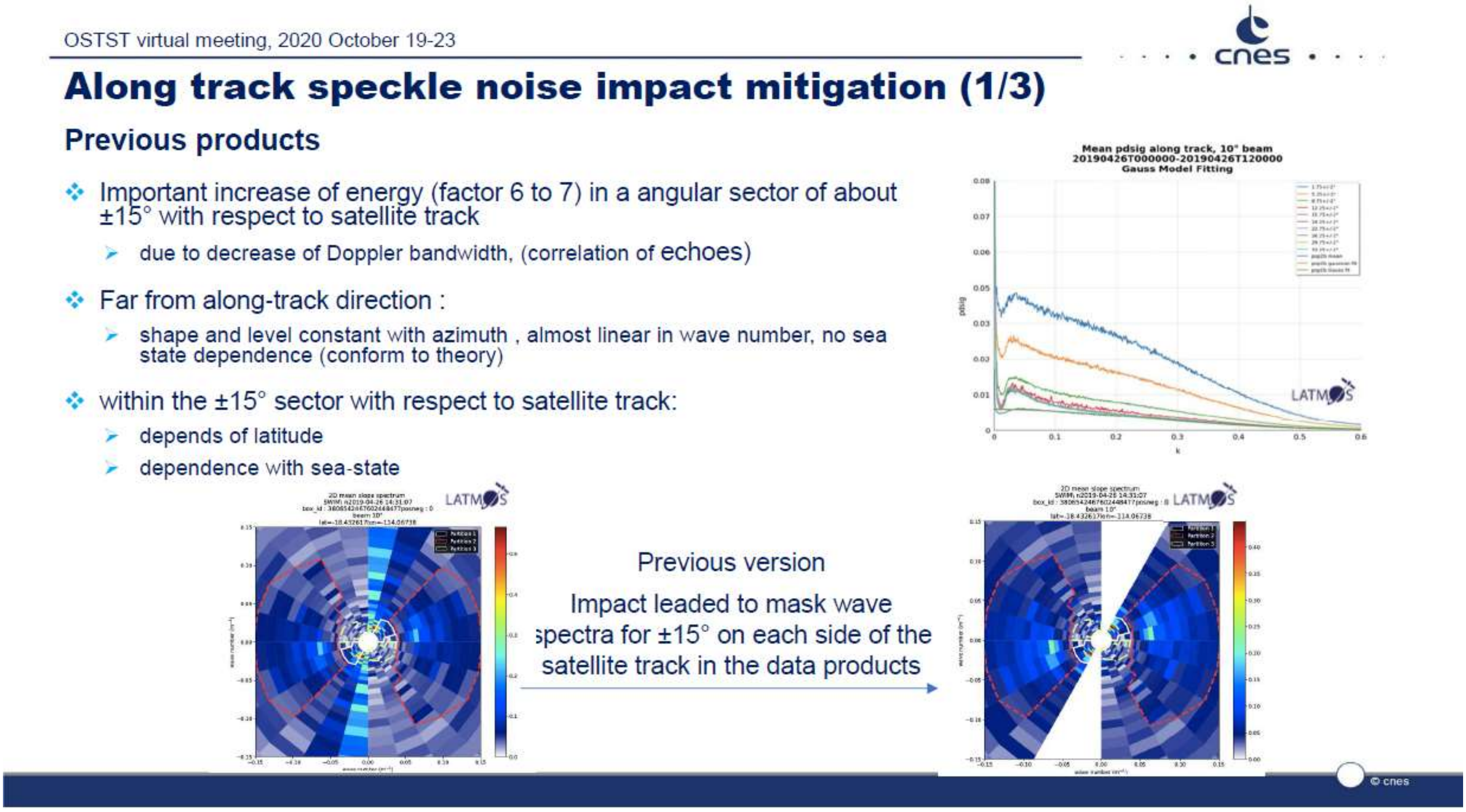
- Modulation spectra are combined and resampled to obtain directional modulation spectra at the scale of the SWIM boxes (70km * 90km) defined over azimuth bins and wave number bins.

  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.

SWIM products new version : evolutions and improvements

After these different reminders, we will now present the main latest evolutions implemented in the SWIM products and describe improvements implied.



As described previously, the first correction applied to modulation spectrum is the speckle noise correction.

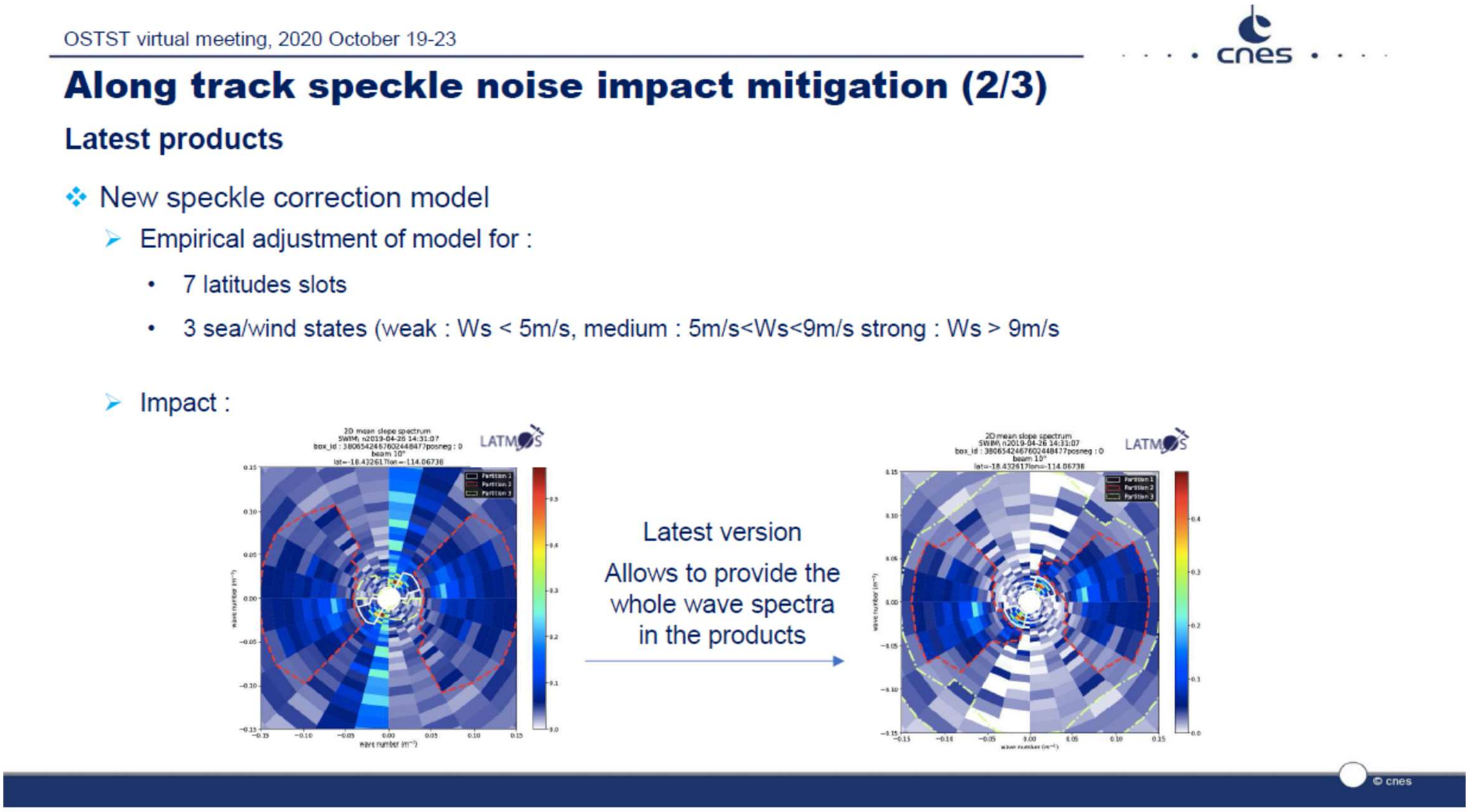
With the previous speckle noise correction, we observed an important increase of energy in an angular sector about ±15° around the satellite along track direction.

This is due to the decrease of Doppler bandwidth for measurements preformed in this area: the number of uncorrelated echoes reduces drastically, so the integration of the received signals does not allow to reduce the speckle noise by averaging them any more.

Consequently, in these directions, the speckle noise introduces non geophysical energy in the spectrum for all wave numbers. This phenomenon was expected, but such a high impact was not .
For directions far from the along track direction, observations are compliant with the theory: speckle noise has a constant shape and level with azimuth, is almost linear in wave number, and shows no sea state dependency.
Further investigations show that within the ±15° sector with respect to the along track direction, the level of speckle noise depends of latitude and also shows a sea-state dependency.

This phenomenon implied a pollution of the wave slope spectra, and affected the wave parameters determination.
This leaded to a masking of this specific area in the wave slope spectra, in order to only keep significant geophysical information.

Work has been performed to reduce the impact of this phenomenon and leaded to a mitigation presented hereafter.



To mitigate the impact of the speckle noise within the ±15° sector with respect to the along track direction, a new speckle correction model is implemented.

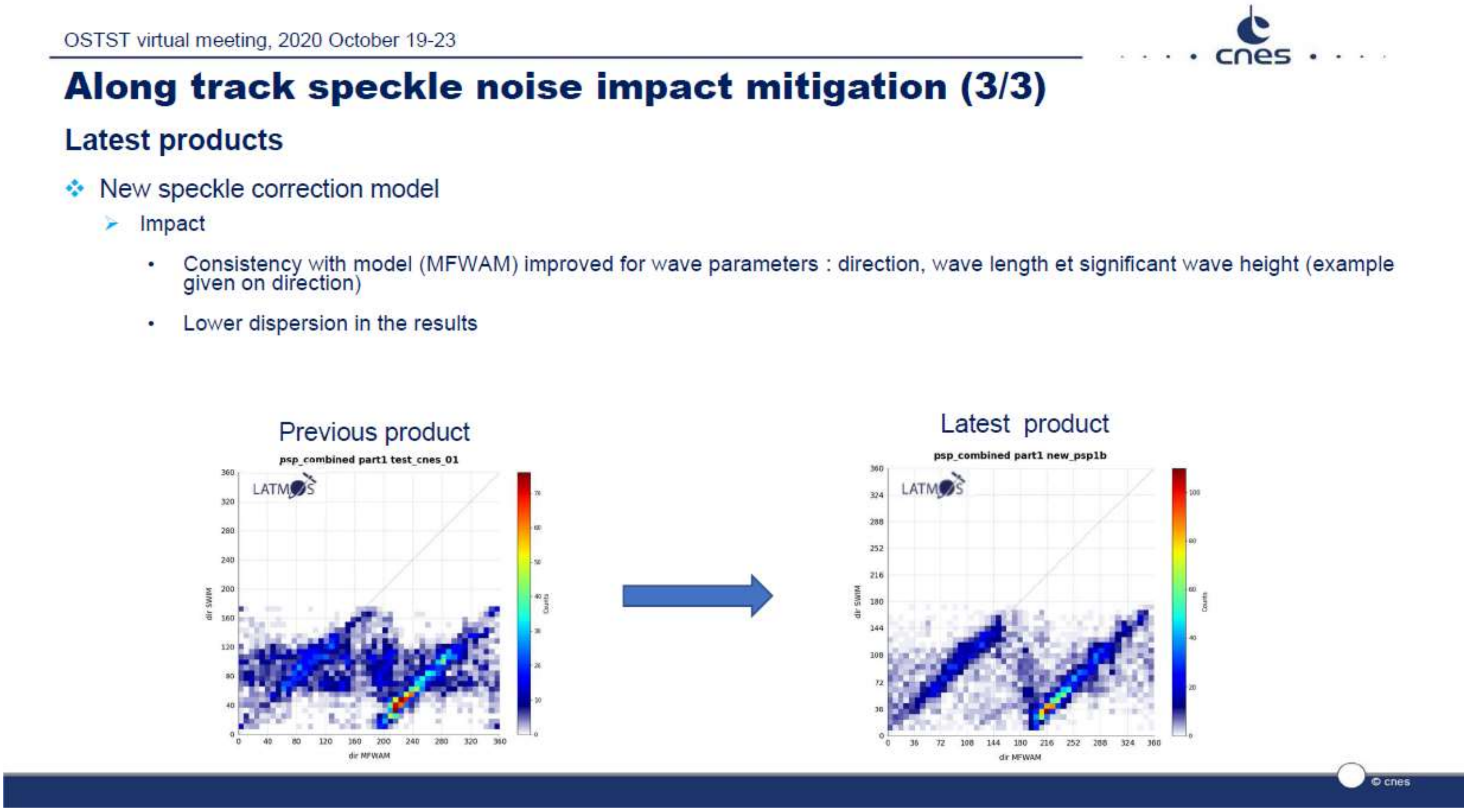
As dependencies with latitude and sea-state were observed, the correction model, based on the previous one, was empirically adjusted for the ±15° sector with respect to the along track direction. This adjustment was performed accounting for:

- 7 latitudes slots
  [-70°,-50°], [-50°,-30°], [-30°,-10°], [-10°,10°],[10°,30°],[30°,50°],[50°,70°]

- 3 sea/wind states :
  weak: Ws < 5m/s,
  medium: 5m/s<Ws<9m/s
  strong: Ws > 9m/s

The impact is directly visible on the wave slope spectra, as illustrated on an example for one spectrum. The strong energy in the 0 -15° area, due to speckle noise, is largely reduced in the new product.

This has a direct impact on wave parameters retrieval, as we will see in the following slide.



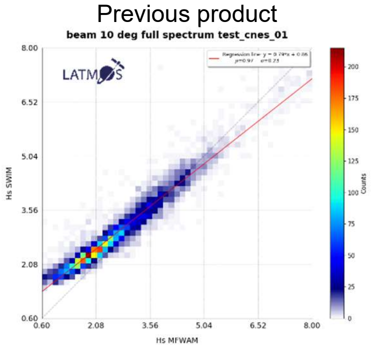
Application of the new speckle correction improves all the wave parameters:

When comparing to model, here MFWAM, we observe:

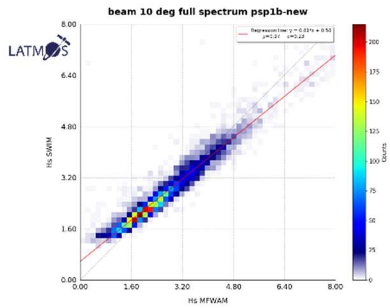
- As shown above, a better consistency for **wave direction**.
  We also observe a decrease of the dispersion, this can be attributed to the elimination of the energy in the ±15° sector with respect to the along track direction, which biased the restitution
- **Significant Wave Height** from wave spectra is also improved: the over estimation at low wave height is reduced.

SWIM Significant wave height form 10° beam vs MFWAM

Previous product



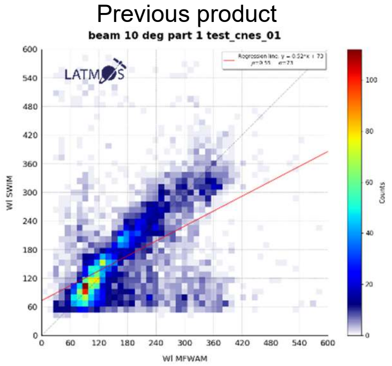
Latest product



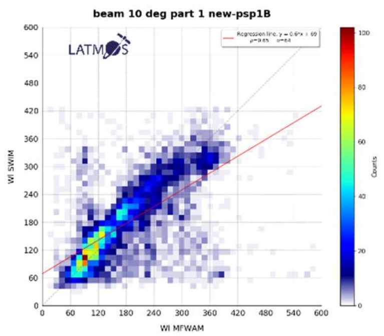
- **Wave wavelength** present a better consistency, and part of the outliers are eliminated.

SWIM wave wavelength form 10° beam vs MFWAM

Previous product



Latest product



Modulation Transfer Function (1/5)

Function to transform the modulation spectrum into wave slope spectrum

- Previous product :
  - so called MTF1 azimuth dependent with an analysis of σ_0 over several beams (0°-10°) for each azimuth
  - $MTF(\theta,\phi) = \frac{\sqrt{2\pi}}{L_y}\alpha^2(\theta)$
    - L_y : azimuth length of the footprint ;
    - α : sensitivity factor $= cotan(\theta) - \frac{1}{\sigma_0}\frac{\partial\sigma_0}{\partial\theta}$ with : θ : incidence angle

- Latest product :
  - so called MTF3 : using the SWH from L2a nadir products to normalize the energy of the spectrum.
  - $MTF = \left(\frac{4}{SWH}\right)^2 \iint P_m(k,\phi)\frac{1}{k}dkd\phi$
    - P_m :density of modulation spectrum for k : wavenumber and ϕ : azimut angle;
    - SWH : Significant Wave Height

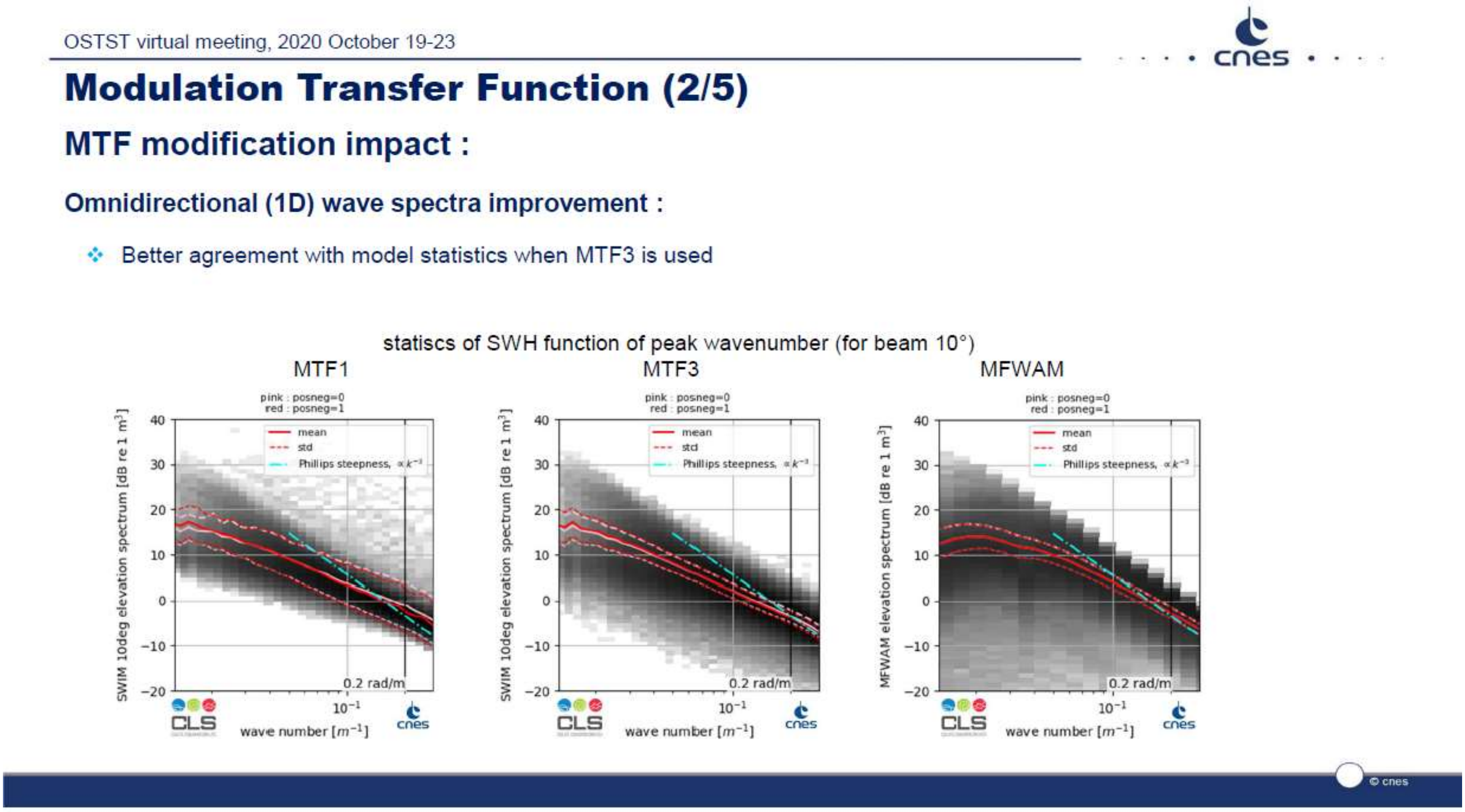
As described previously, directional modulation spectra are converted into wave slope spectra thanks to a modulation Transfer Function (MTF).
This MTF is the proportionality coefficient between the modulation spectrum and the wave slope spectrum.

Several MTF are implemented in the ground segment and can be activated via the process parametrization.

- For the previous products, the MTF applied was the so called **MTF1**:
  In this case, the sensitivity factor is estimated from the measurements by fitting the complete sigma0 profile (all beams except nadir) constructed by azimuth bins in one box. This fit gives the estimation of $\frac{1}{\sigma_0}\frac{\partial\sigma_0}{\partial\theta}(\theta,\phi)$.
  The MTF1 is given for each azimuth bins (15°) and each spectrum beams (6°, 8° and 10°) of each box.

- For the latest products, the so called **MTF3** is used:
  Here the MTF3 is determined for each spectrum beams (6°, 8° and 10°) at the box level (no azimuth dependency). It uses the SWH obtained from nadir beam data processing to normalize the energy spectrum and obtain a slope spectrum.

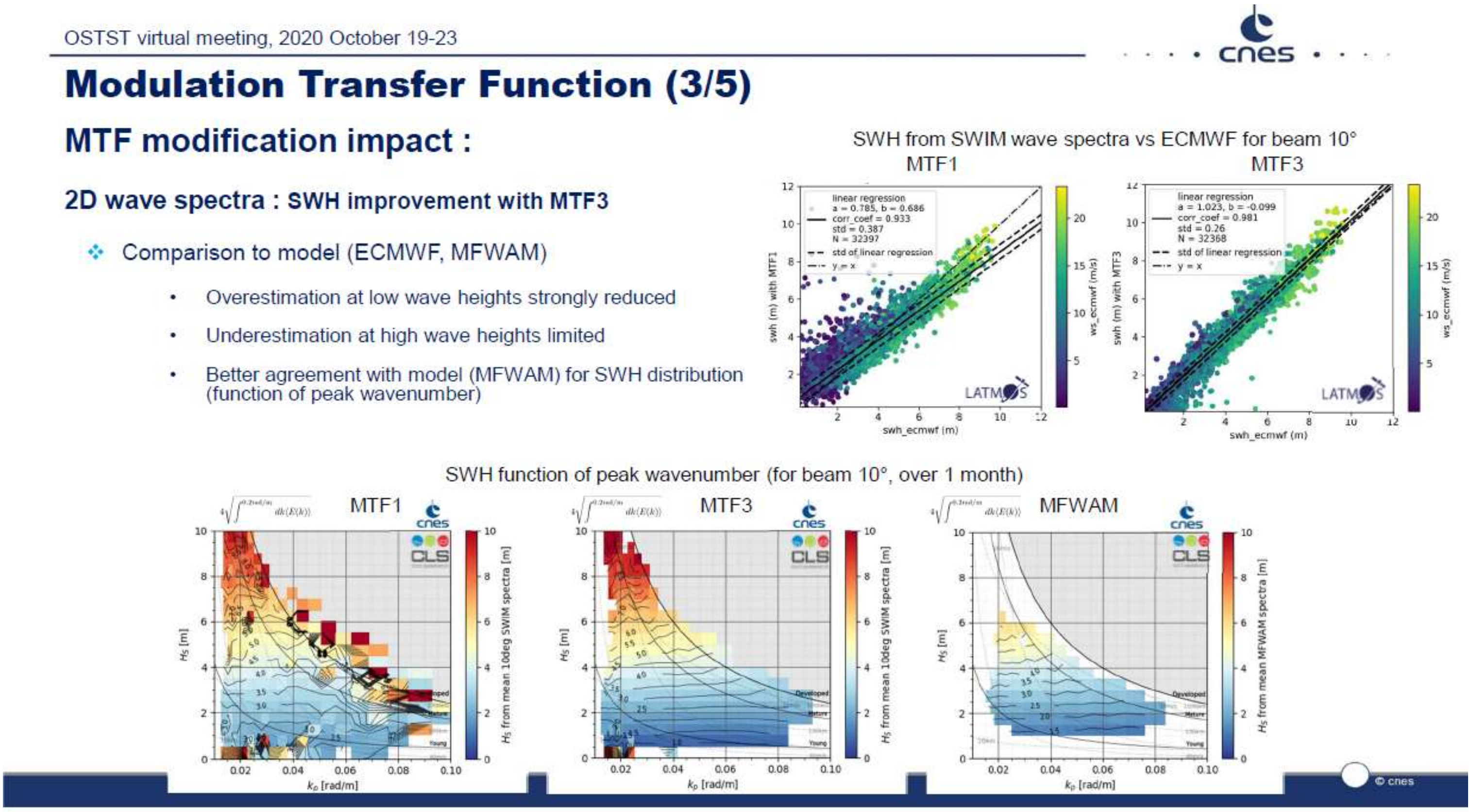
The MTF3 solves some issues encountered with MTF1, as shown later on.
Work is on-going on an azimuth dependent MTF, such as MTF1, to exploit as much directional information present in SWIM data as possible.



Impact of the MTF modification can be observed on the omnidirectional spectra.

If we look at statistics of SWH with respect to peak wave number, we observed a better consistency with the model (MFWAM) for MTF3:

- Dispersion is lower than MTF1 and closer to model one
- Distribution is more consistent, with the elimination of high values, and there is a better agreement for low values.



We can also see several improvements on the 2D wave spectra.

As expected, with the normalization of the energy spectrum with SWH from the nadir beam, the wave parameter SWH from spectrum beams processed with MTF3, is more consistent with the models (ECMWF, MFWAM).

- The overestimation at low wave heights is strongly reduced, we can see that it almost disappears.
- The underestimation at high wave heights is also largely limited.

The scatter plot of SWIM 10° beam SWH versus ECMWF SWH shows a good alignment (up right plot).

If we look at the distribution of SWH with respect to wave number (bottom plot), we observe a clear improvement of the consistency between the model and SWIM data for MTF3.

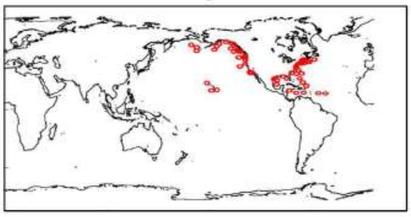
Modulation Transfer Function (3/5)

MTF modification impact :

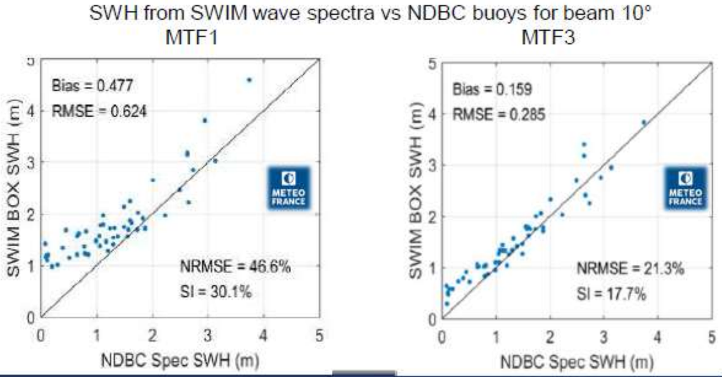
2D wave spectra : SWH improvement with MTF3

- Comparison to NDBC buoys
  - Same results :
    - Better alignment of SWIM SWH with NDBC buoys outputs

NDBC buoys network



SWH from SWIM wave spectra vs NDBC buoys for beam 10°

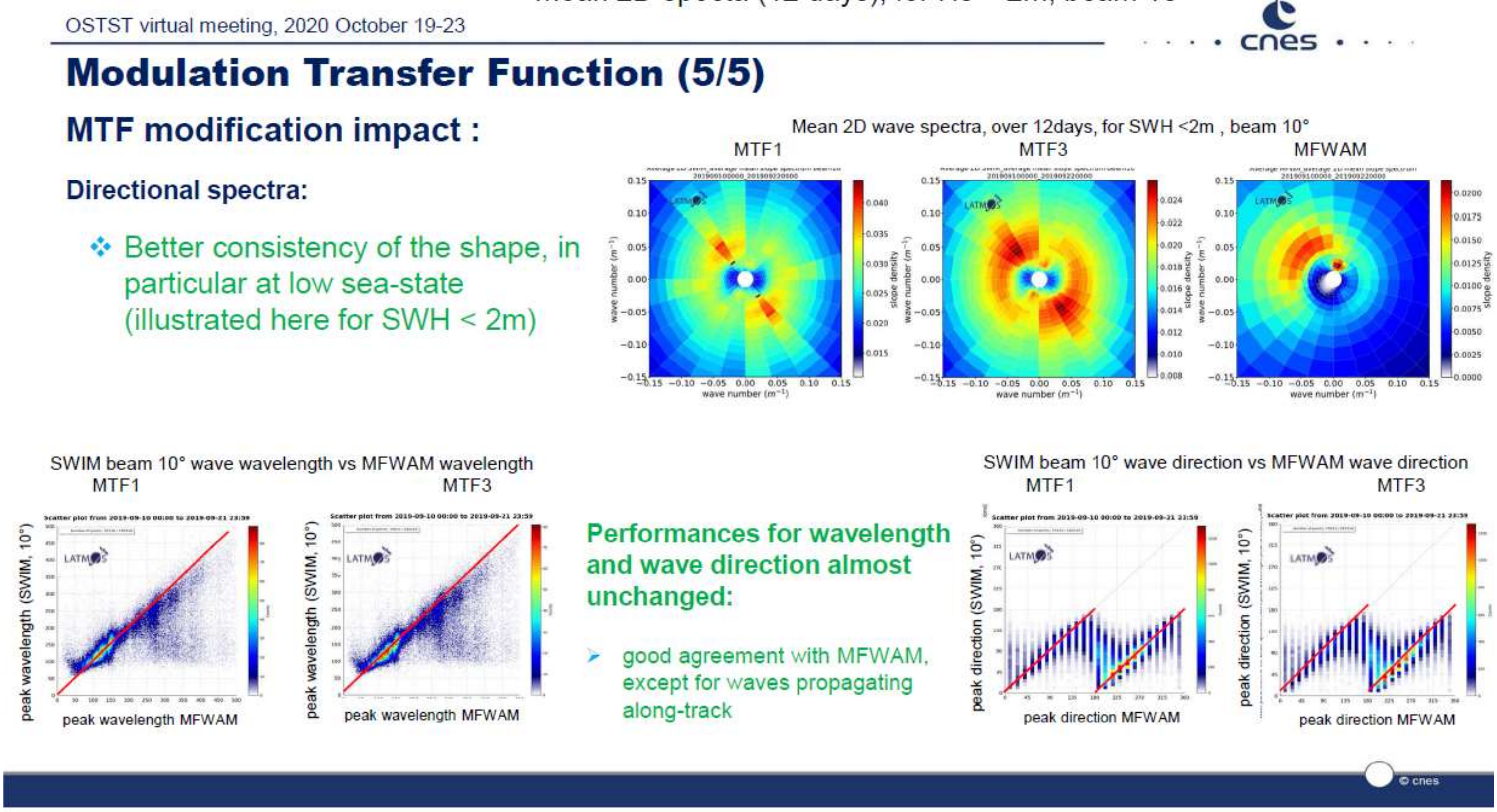


Same analysis can be performed with in situ data.

A comparison of SWIM SWH wave parameter with NDBC buoys SWH was performed.

We also observe a better consistency for wave parameter SWH from spectrum beams processed with MTF3. Once more, the overestimation at low wave heights is strongly reduced.
The limited amount of data does not allow to conclude on the underestimation at high wave heights.

mean 2D specta (12 days), for Hs < 2m, beam 10°



The improvement on the wave parameter Significant Wave Height determined from wave slope spectra was expected.

We then have to verify that for other diagnosis and for the two other wave parameters: wave wavelength and wave direction, performances are at least unchanged, and at best improved.

- Wave slope spectra have been analyzed by computing a mean spectrum, in this case over 12 days.
  We observed an improvement with the MTF3 when comparing SWIM mean wave slope spectra with MFWAM mean wave slope spectra. The shape is in better agreement and wave distribution (direction, peak energy) is more consistent.

- Concerning the wave direction and wave wavelength, values obtained with MTF1 were already in good agreement with the model.
  We observe that the performances with MTF3 are almost unchanged.
  So we keep the same level of performance for wave wavelength and wave direction

Conclusions

SWIM latest product issue OP05 shows consolidated performances and improvements

- 1D spectra improved, more consistent with model
- 2D spectra fully exploitable,
  - No more masking of near along track area
  - Good agreement with model for all wave parameters :
    - Direction
    - Wavelength
    - Significant Wave Height

Products available to all users since October 12th :

- https://www.aviso.altimetry.fr/fr/missions/missionsen-cours/cfosat.html
- Reprocessing campaign of all SWIM acquisitions since the beginning of the mission starting in November, completed by the end of the year (objective)
- NRT delivery to operational centers via Eumetcast
- **Basis for intern CMEMS product by the end of this year** (see presentation in APOP session : CMEMS WAVE-TAC, Recent upgrades and enrichment of the satellite constellation for near-real-time ocean waves characterization E. Charles, et al)

Interest of SWIM products for global and specific wave studies reinforced

Work on going to further improve product performances

As a conclusion, we can say that the latest product issue, so called OP05, shows consolidated performances and improvements:

- The Omnidirectional spectra is more consistent with the model

- **The whole 2D spectra** is now **exploitable:** no mask is applied anymore.

- The **3 wave parameters**:

  - Direction
  - Wavelength
  - Significant Wave Height

  are now **in good agreement with model**:

These products are available to all users since the 12th of October, they are produced operationally and available on aviso https://www.aviso.altimetry.fr/en/missions/current-missions/cfosat/access-to-data.html.

A reprocessing campaign of all SWIM acquisitions since the beginning of the mission is planned, and will start in November, with the objective of completing this reprocessing by the end of the year.

Near Real Time products, based on the same processing, are delivered to operational centers via Eumetcast.

This product issue is used to define and produce an intern CMEMS product by the end of this year (read presentation 'CMEMS WAVE-TAC, Recent upgrades and enrichment of the satellite constellation for near-real-time ocean waves characterization E. Charles, et al, in Application development for Operations)

With this new issue, the interest of SWIM products for global and specific wave studies takes a step forward.

The work of expert teams, that leaded to such improvements, is still on-going to further enhance SWIM products performances.

Thanks for reading, co-authors and myself are ready to answer questions.


Thank you for reading!
CFOSAT