Directional and frequency spread of surface ocean waves from SWIM measurements

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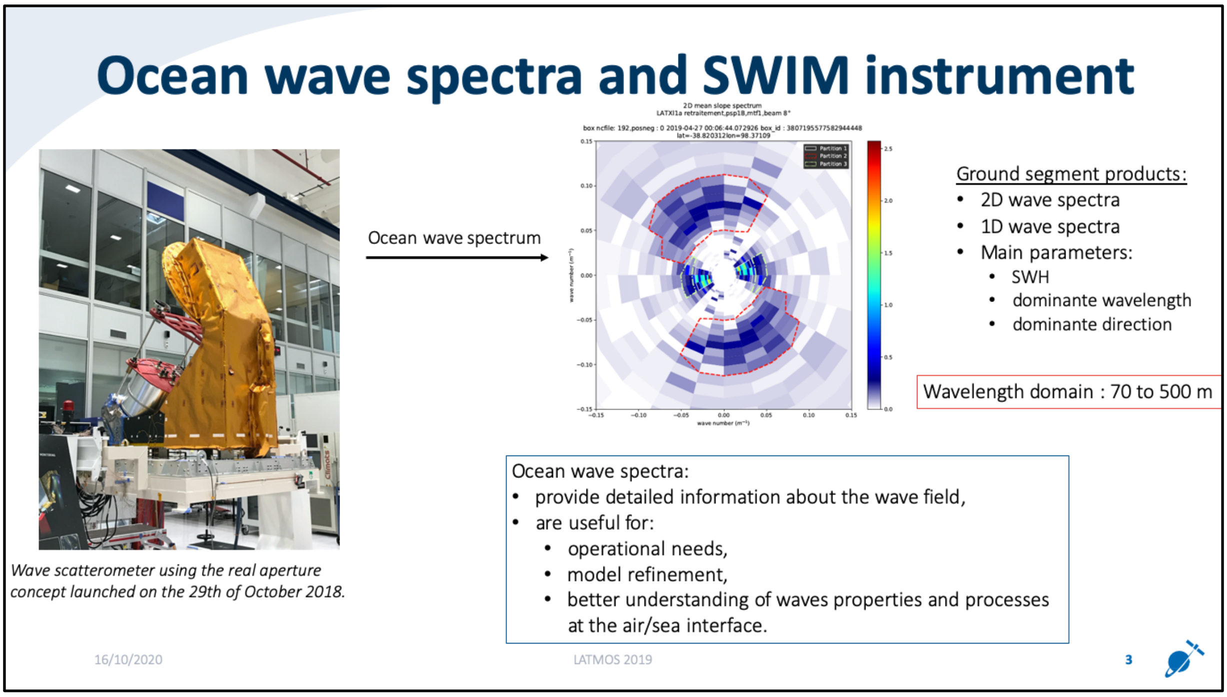
Outline

- Presentation of spectral shape parameters
- Analysis of spectral shape parameters and comparisons with the MFWAM wave model
- Study about the Benjamin Feir Index
- Focus on the Southern Ocean
- Conclusions and perspectives



SWIM is the first space wave scatterometer that uses the real aperture concept. It allows to compute ocean wave spectra which give very detailed information about the wave filed. SWIM measures wave with wavelengths between 70 and 500 m.

Parameters computed from wave spectra

Frequency width

- Calculated from 1D wave height spectra :

$$\Delta f = \frac{\left[\int_{-\infty}^{+\infty} F(f)\, df\right]^2}{\int_{-\infty}^{+\infty} F^2(f)\, df}$$

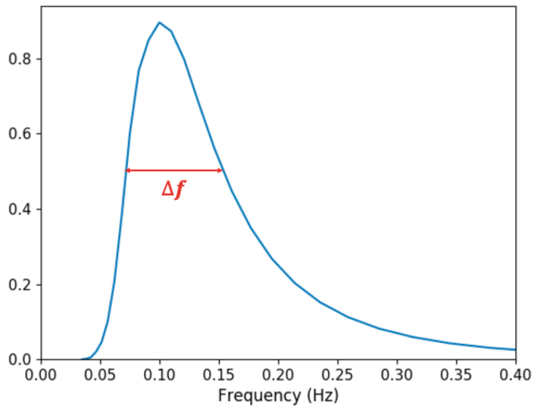
Blackman & Tukey (1959)

Goda parameter («*Peakedness parameter*»)

$$Qp = \frac{2\int_{-\infty}^{+\infty} f S(f)^2\, df}{\left[\int_{-\infty}^{+\infty} S(f)\, df\right]^2}$$

Goda (1970)

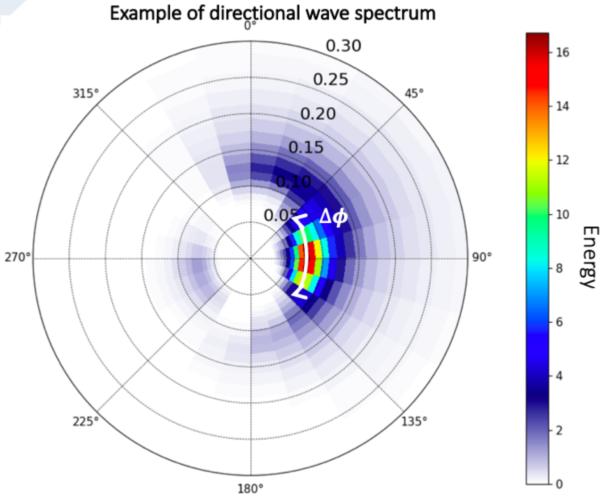
Example of an omni-directional spectrum



Thanks to the ocean wave spectra we can compute several parameters. Principle ones are significant wave height (Hs), dominant wavelength and dominant direction. We can also compute shape spectrum parameters. The frequency width and the Goda parameter indicate the spread and the peakedness of the spectrum in frequency.

Parameters computed from wave spectra

Example of directional wave spectrum



Longuet-Higgins et al., (1963)

Directional spread

- Using buoy computation:

$$\Delta\phi(f) = \sqrt{2 \times \left(1 - \sqrt{a_1(f)^2 + b_1(f)^2}\right)}$$

With the first pair of Fourier coefficients:

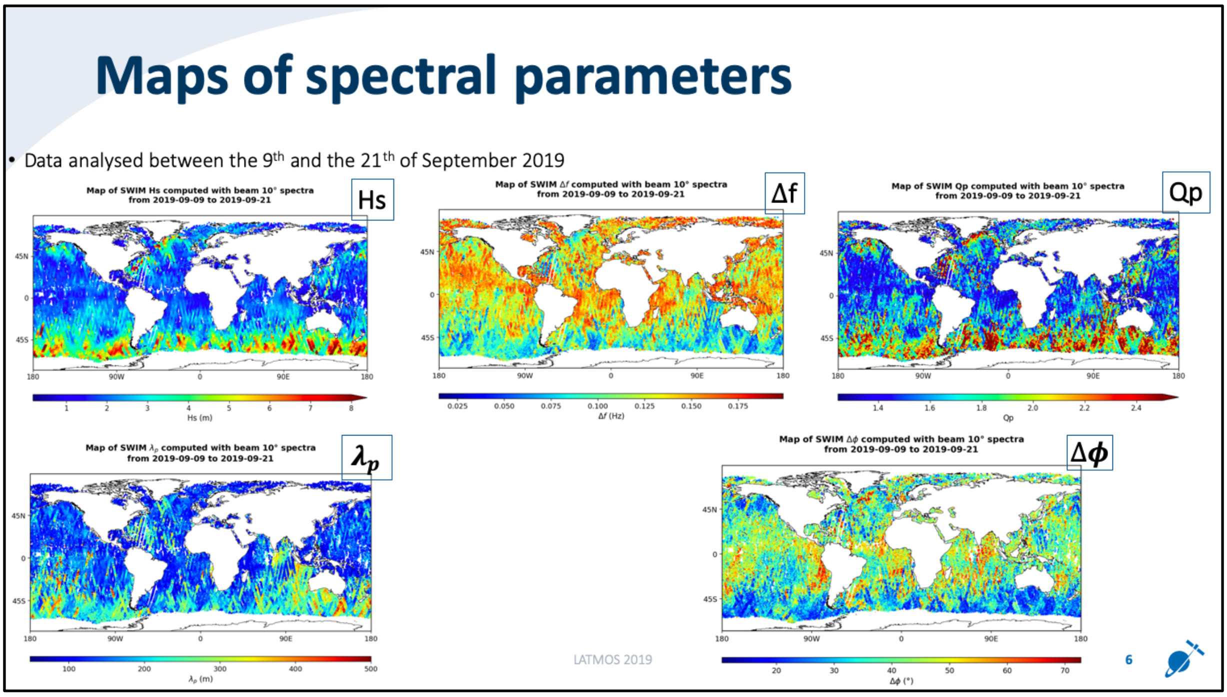
$$a_1(f) = Q_{12}(f) \Big/ \sqrt{(C_{22}(f) + C_{33}(f)) \times C_{11}(f)}$$

$$b_1(f) = Q_{13}(f) \Big/ \sqrt{(C_{22}(f) + C_{33}(f)) \times C_{11}(f)}$$

→ Cross spectra are computed using the directional SWIM spectra

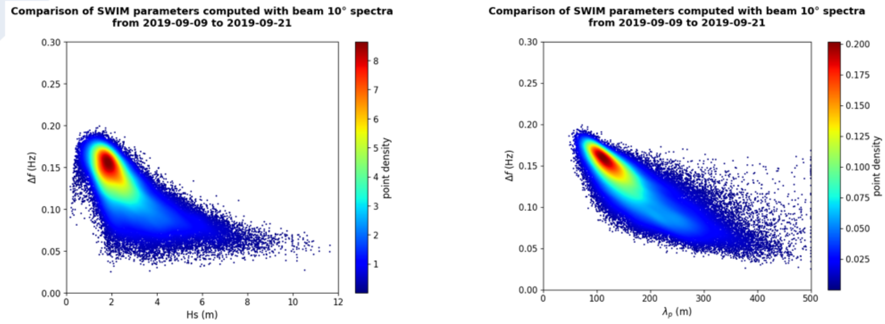
Directional spread calculated at the peak of the spectra

The directional spread is used to describe the directional shape of the wave spectrum. Its computation is the same as the one used with the buoy data. It is computed using the first pair of the Fourier coefficients. The directional spread can be calculated at each frequency of the spectrum. The



The maps on the left represent the principle parameters (Hs at the top and peak wavelength ($\boldsymbol{\lambda_p}$) at the bottom) and the maps on the right show the spectral shape parameters in frequency (Δ**f** and Qp at the top) and in direction ($\Delta\boldsymbol{\phi}$ at the bottom). We can see that the highest Hs are in the Southern ocean and near the coasts of Greenland. The areas of highest significant wave height and long wavelengths correspond to areas of smallest frequency spread and directional spread. In these regions, the peakedness parameter (Qp) is the highest. Hence, from CFOSAT data alone, there appear to be relationships between principle parameters and spectral shape parameters which seem qualitatively compatible with what we know from the wave spectra evolution during growth and dissipation.

Relationship between principal and spread parameters



Frequency spread of the omnidirectional spectrum

- Relationship between frequency spread and Hs (and dominant wavelength):
  - high values of frequency spread → low Hs and small $\boldsymbol{\lambda_p}$,
  - the frequency spread decreases as the sea state develops,
  - part of the distribution of **Δf** contant around 0.05 Hz for any value of Hs → probably associated to swell conditions.

- These relationships are in qualitative agreement with our knowledge of wave evolution during and after their generation by the wind.

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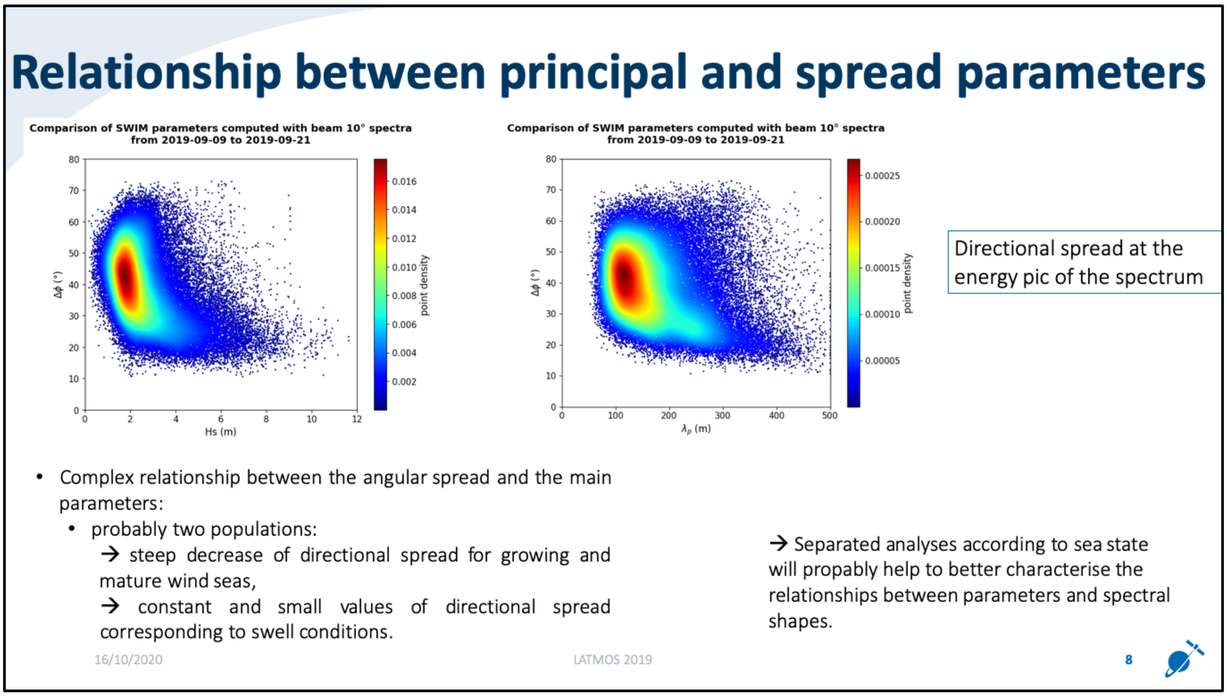
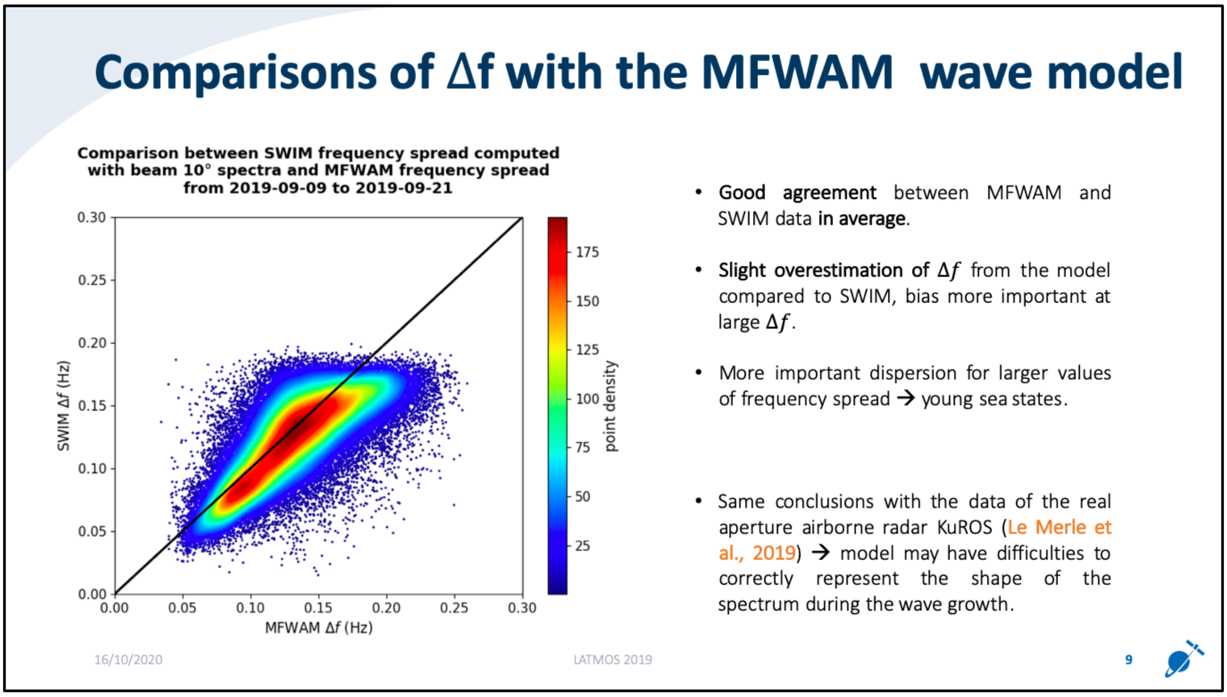
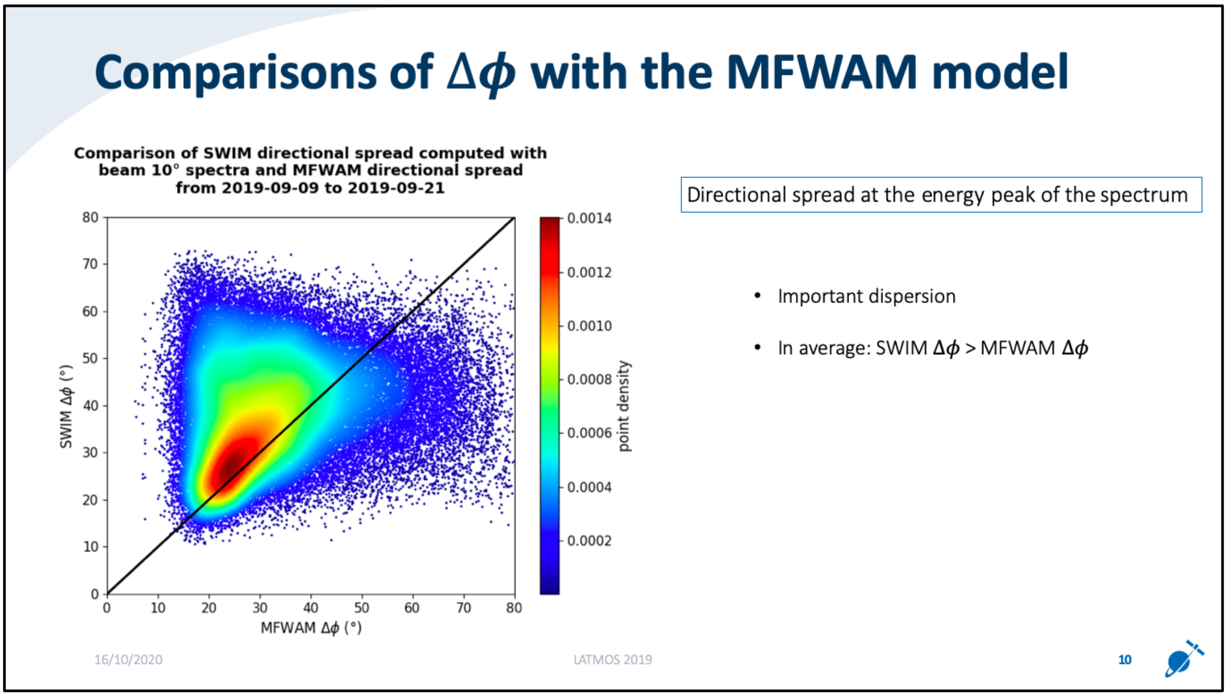
The scatter plots indicate the variation of the frequency spread as a function of Hs (left) and the dominant wavelength (right) measured with the SWIM instrument. High values of frequency spread correspond to sea states with low Hs and small $\boldsymbol{\lambda_p}$. These cases characterise generally the wind waves and more particularly the young wind waves. When the sea state is growing under the wind forcing: Hs and $\boldsymbol{\lambda_p}$ increase and the spectrum becomes more narrow. This plots indicate with observed data what we already know of the wave growth laws. For swell conditions in opposite the frequency spread of the spectrum does not vary significantly with Hs, whereas it continues to decrease with the dominant wavelength. This conclusion will be further verified in the future after we apply a classification on the sea state conditions (wind sea or swell).



The scatter plots indicate the variation of the frequency spread as a function of Hs (left) and the dominant wavelength (right) measured with the SWIM instrument. There are no visible relationships which indicates that links between the principle parameters and the spectral shape in direction are complex. However, we can see that situations with high Hs and long dominant wavelength correspond to small values of angular spread with less dispersion. Separation of sea state will probably help to better characterise the relationships between parameters and spectral shapes.



This plot shows the comparison of the frequency spread between SWIM and MFWAM data. There is a good agreement in average. However, we can see a slight overestimation of the MFWAM data compared to the SWIM data, especially for the largest frequency spread values (above 0.15 Hz), which correspond to young sea states. These conclusions were the same with a study carried out with airborne observations (KuROS radar, airborne simulator of SWIM) in the Mediterranean sea during fetch-limited conditions. This seems to indicate that the MFWAM model may have difficulties to correctly represent the spectral shape of the wave spectra during the growth processes.



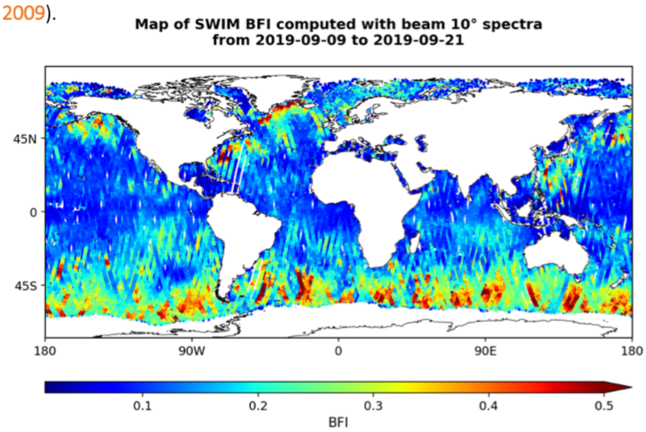
Here we show the comparison of the directional spread computed at the peak of the spectrum between the MFWAM and the SWIM data. There is an important dispersion, particularly for the highest values of the directional spread parameter. Directional spread is a parameter which may be affected by noise effects in the measured spectrum. The reason of this dispersion will be further investigated in the future. However, if we concentrate on values where the dispersion remains limited, this plot shows that in the mean, the wave energy is spread over a wider angular sector for SWIM observations than for the model.

First map of the Benjamin-Feir Index (BFI)

The Benjamin-Feir index has been proposed in the literature as an **appropriate indicator** of **non-linearities of wave interactions** and **probability of occurrence of extreme waves** (Janssen and Bidlot, 2009).

$$\mathrm{BFI} = k_0\sqrt{m_0}\,Q_p\sqrt{2\pi}$$

Significant slope ($k_0\sqrt{m_0}$) — Peakedness parameter (Q_p)



- First map of BFI at the global scale obtained exclusively with observations.
- Higher values of BFI in the Southern Ocean:
  → extreme sea states.

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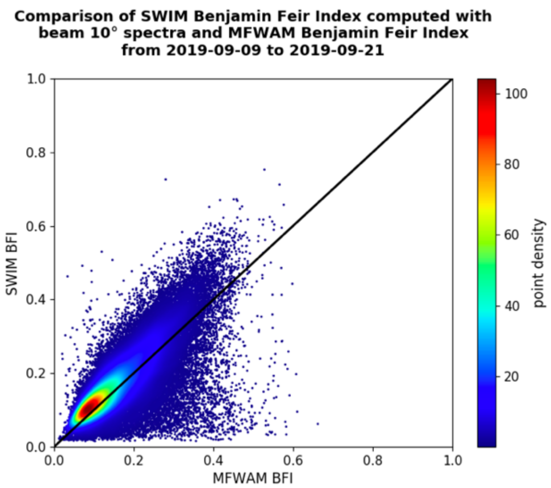
The Benjamin Feir Index (BFI) has been proposed in the literature as an appropriate indicator of non-linearities of wave interactions and probability of occurrence of freak waves. Its values span between 0 and 1, and the highest it is, more the probability that a freak wave occurs is important. Here we show a map of BFI computed with the observed data by the SWIM instrument. We can see that the higher BFI are observed in the Southern Ocean and near the Greenland coasts. It correspond to the more extreme situations over this period.

Comparison of BFI with the MFWAM model



- Good agreement between SWIM and MFWAM data.
- SWIM gives access to **new information** that is important for **operational oceanography** and wave **climate statistics**.

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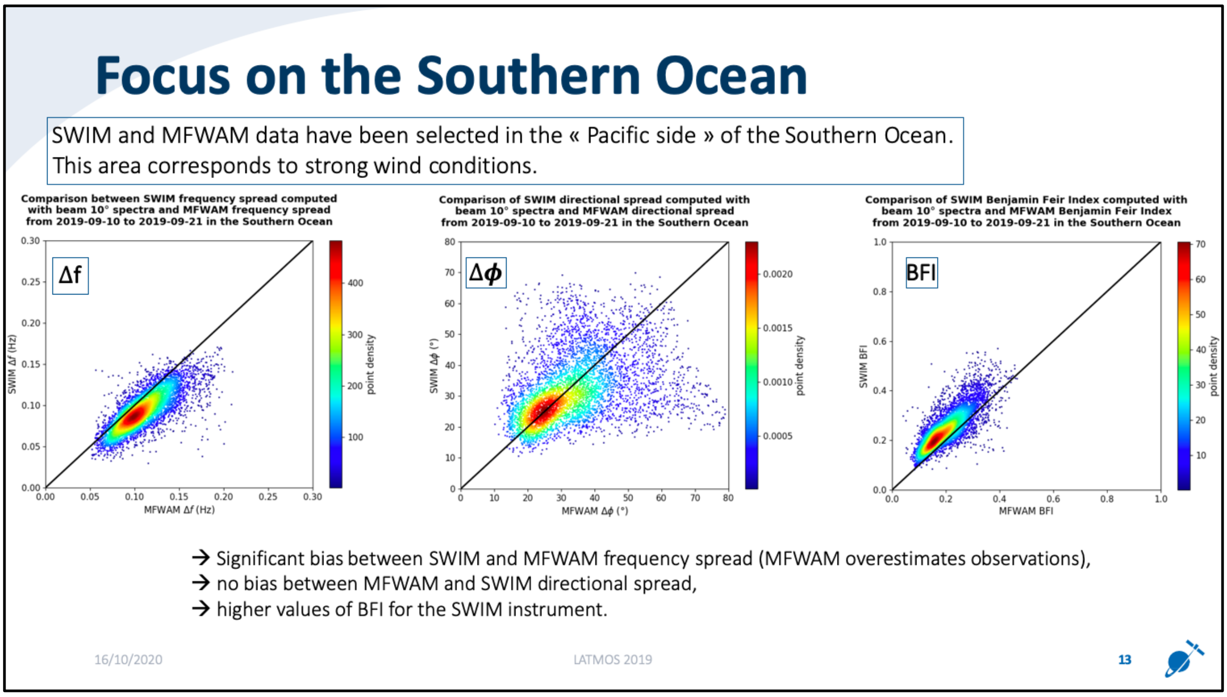
This scatter plot shows the comparison between the MFWAM and the SWIM data. We can see that in average there is a good agreement between the MFWAM and SWIM data. SWIM BFI are in average more important than MFWAM even if the bias is small. SWIM gives access to information that allow to compute indexes such as BFI which is important in the operational oceanography.



Here we focus on data in the Southern Ocean between latitudes -40° and -70°. Extreme winds and sea states occur in this area because of the strong storms moving toward East. These three scatter plots show comparison of the SWIM data with the MFWAM data for the frequency spread (left), the directional spread (middle) and BFI (right). Bias for Δ**f** and BFI are more obvious than comparisons at the global scale. It seems that in extreme situations, MFWAM spectra are wider in frequency than the SWIM spectra. In opposite, the comparison of the directional spread shows no bias between the SWIM and MFWAM data, even if the dispersion is still important. Due to the difference in the peakedness of the spectra (Qp) the BFI index is also different between SWIM and MFWAM with smaller values for SWIM than for MFWAM.

Conclusions (1/2)

- SWIM provides at the global scale very new observations:
  - detailed information on wave spectra (distribution of wave height with dominant direction, wavelength or frequency) for waves with wavelength in the range [70-500] m,
  - shape parameters of the wave spectra at the global scale,
  - indicators of probability of occurrence of freak waves → very usefull for maritim transport,
  - complementary information to altimeter and SAR observations.

- Geographical distributions and global statistics from satellite of shape parameters of wave spectra shown for the first time here.

Conclusions (2/2)

- Further assessment is needed to:
  - better characterise these parameters as a function of sea state conditions → young or mature wind seas and swell (in progress),
  - evaluate the impact of noise due to speckle on the shape parameter of the wave spectra.

- Analysis of shape spectra at the global scale is very promising for:
  - the assessment of model results and improvements in the model approximations,
  - providing indicators related to extreme wave probability (BFI),
  - evaluate the impact of wave current interactions.

Perspectives

- Study in-depth the shape of the ocean wave spectra:
  - separation of sea state,
  - study of the angular spread as a function of frequency,
  - use other formulations to computed shape spectrum parameters.

- Better quantify relationship between principal and shape spectrum parameters.

- Use this kind of parameter to assess parametrisation of the wave models.

Thank you for your attention

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