Observation of high-resolution fetch-limited wave growth using CFOSAT near-nadir measurements

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Talk structure

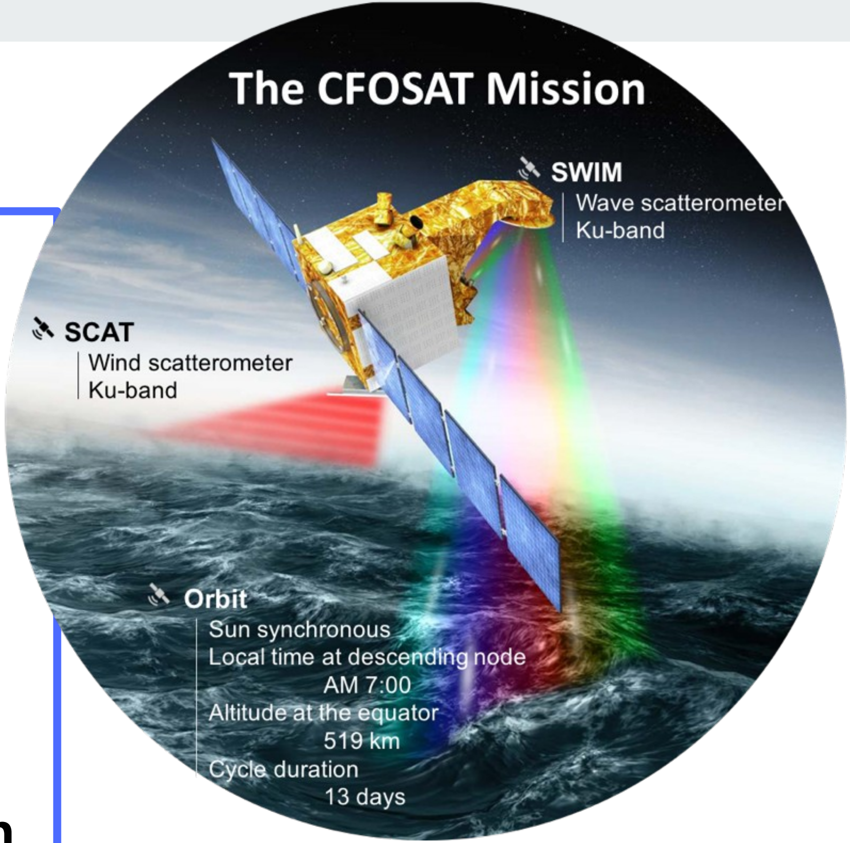
- **Understanding of SWIM measurements**
- **Speckle corrections**
- **Cross-comparison with Wave Watch 3 model**
- **Evaluation of the SWIM measurements, calibration approach**
- **Application of SWIM measurement for the geophysical measurements**
- **Example of Tramontane wind fetch-dependent wave growth**
- **Conclusions**

CFOSAT mission

CFOSAT: A China/France joint satellite oceanographic mission.

Joint measurements of surface wind and wave

- ✔ a wind scatteromerer (SCAT)
  => **ocean surface wind vector**
- ✔ a wave scatteromer (SWIM)
  => **directional spectrum of ocean waves + wind and Hs from nadir**

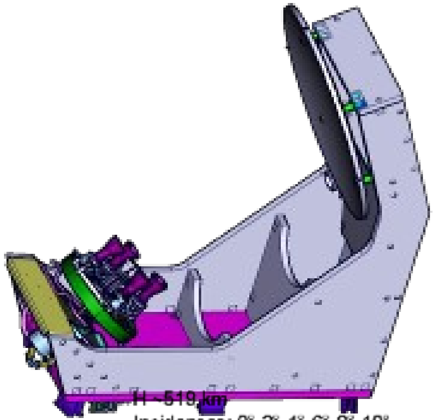


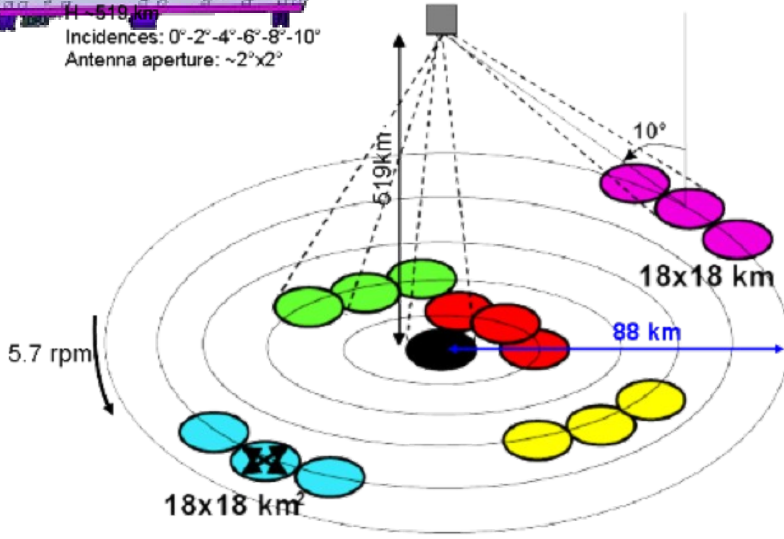
Instruments

SWIM

Wave scatterometer

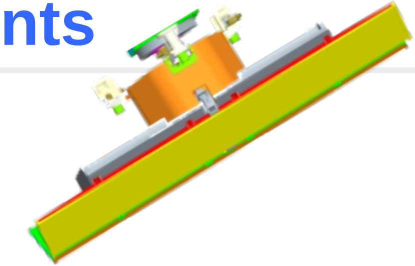
- Ku band real aperture radar
- Sequential illumination with 6 incidence angles :
  - Beams 0°, 2°, 4°, 6°, 8°, 10°
- Rotating antenna (all azimuth direction acquisition): 5,6 rpm
- Provides :
  - Directional wave spectra
  - Significant wave height and wind speed
  - σ_0 mean profiles, 0 to 10º

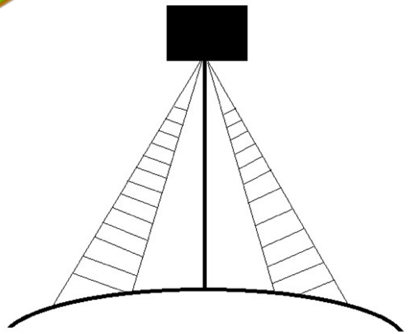




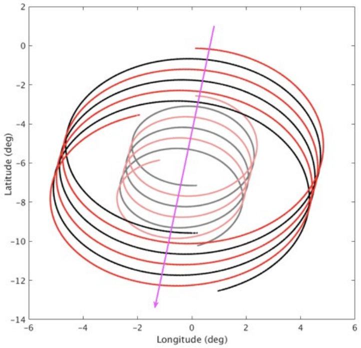
SCAT

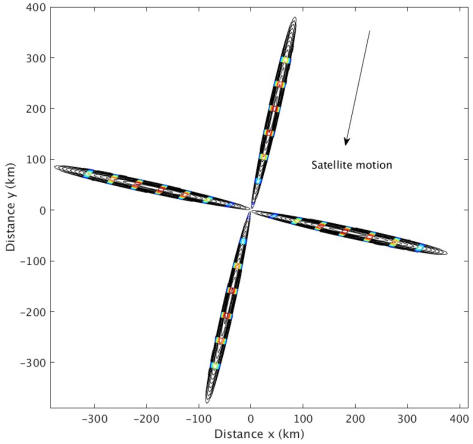
Wind scatterometer





- rotating fan beam concept with dual antenna system
- ⇒ Combines advantages :
  - Large swath and multiple viewing geometry
  - Rotating antenna: 3 rpm
- Incidences between 26° and ~52°
- Provides
  - σ0
  - Ocean wind vector at the scale of ≈ 25 km x 25 km
  - Swath ~ 900 km





Understanding of SWIM measuremets

SWIM σ^0 variation profiles converted to fluctuation spectrum which is related to the spectrum of sea surface waves

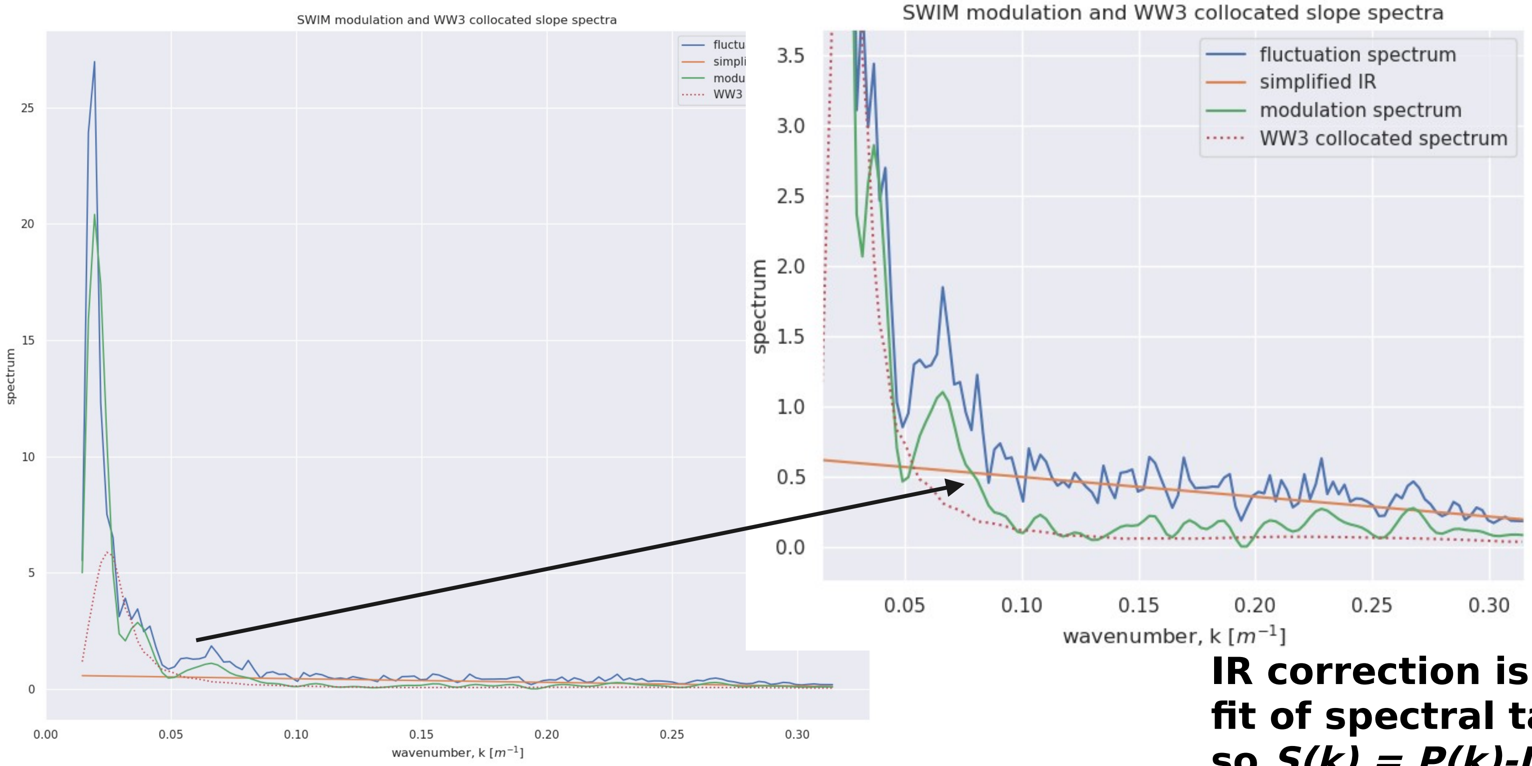
$$P_f(k) = S(k) * P_m(k)$$

$$P_m \approx MTF(k) k^2 F(k)$$

S(k) is the speckle and noise unknown function which varies with wave number and depends on instrument performance, antenna azimuth, satellite orbit position and geophysical conditions.

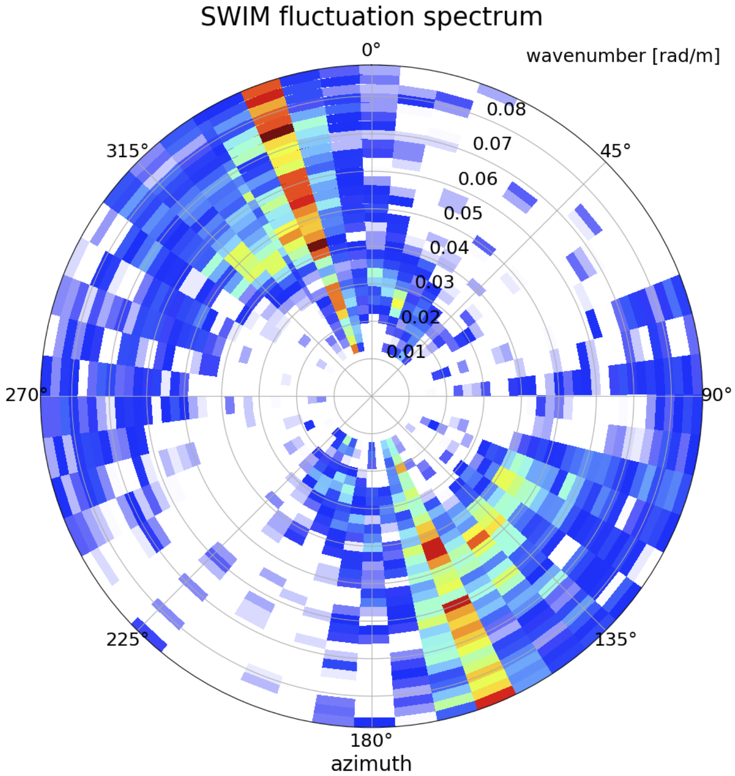
Speckle and noise correction is the first step of SWIM spectral analysis. This could be done with L2S products of IWWOC center.

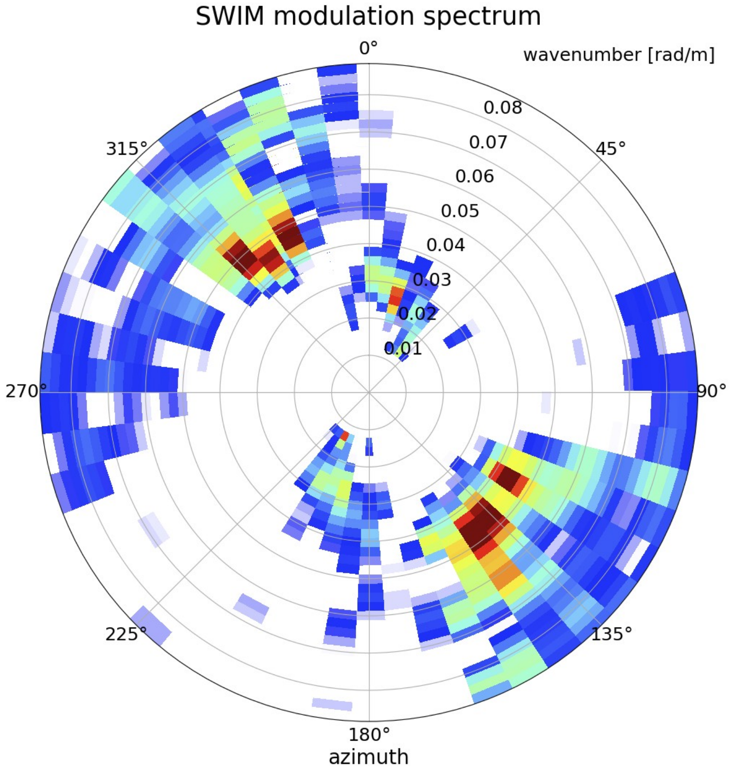
Fluctuation spectrum correction (simplified approach)



IR correction is the linear fit of spectral tail (λ<40 m), so *S(k) = P(k)-IR(k)*

Fluctuation spectrum correction (results of IR correction)





Modulation transfer function: The linear tilt model

The general form of MTF is the complex nonlinear function of wave slope and wave height spectrum, radar antenna swath configuration and range gate resolution, sea slope probability distribution and other geometrical statistical properties of sea surface.

The linear model of MTF was proposed by Jackson 81, 83
Accordingly, the linear range reflectivity variation term is:

$$\frac{\delta\sigma}{\sigma} = \left(\cot(\theta) + \frac{2\tan(\theta)}{mss}\right)\frac{\partial\eta}{\partial x}.$$

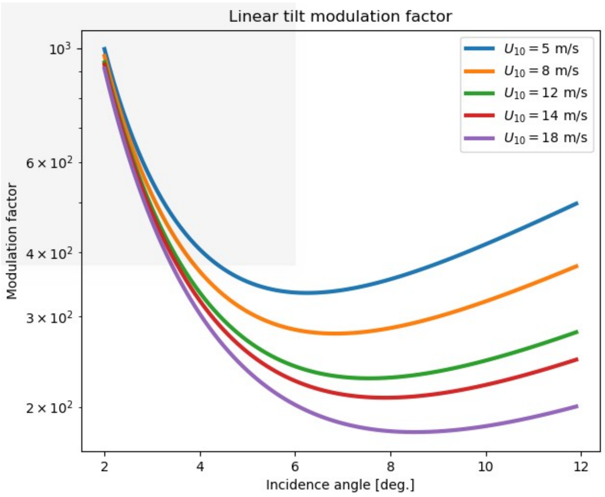
Modulation spectrum is:

$$P(k) = \frac{l_y\sqrt{2\pi}}{L_y}\,k^2\,F(k)\,\alpha^2$$

Where linear modulation factor is

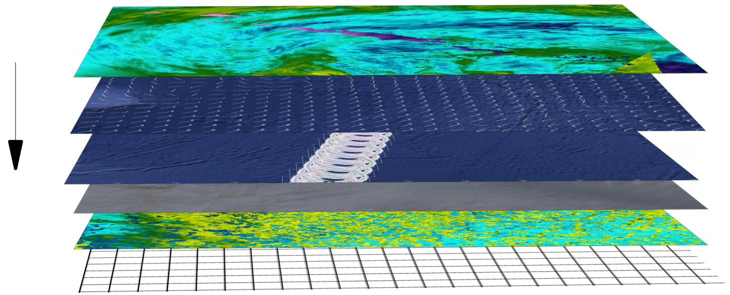
$$\alpha = \cot(\theta) + \frac{2\tan(\theta)}{\text{mss}}$$

Linear modulation factor for different wind speeds



Data set

IWWOC SWIM and SWIM/SCAT products

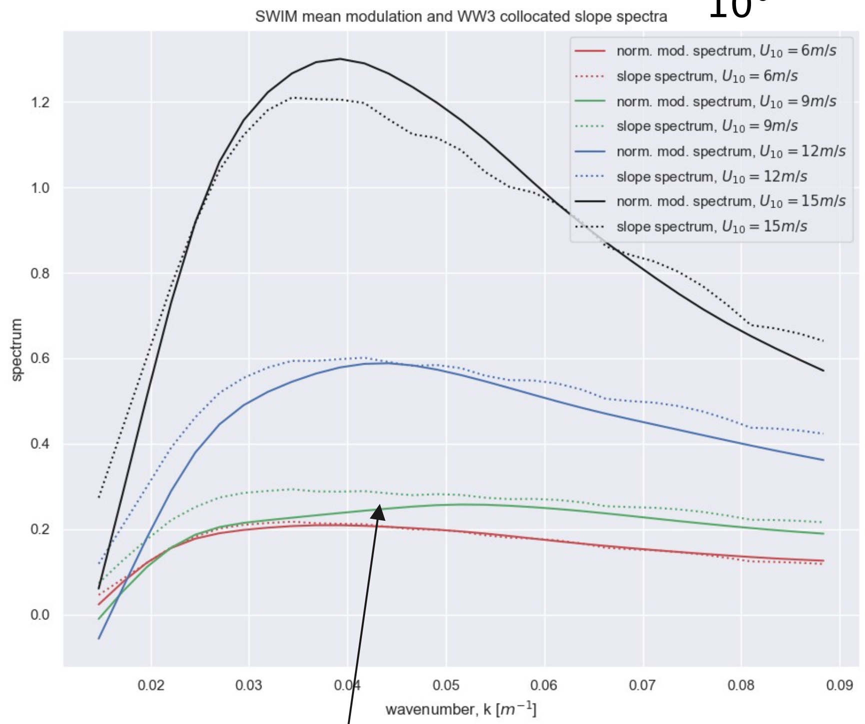


Product	Definition	Timeliness
SWI_L2S____	2D wave spectra and partitions along the satellite track, per incidence. (cf. Gilles Guitton presentation about results)	Delayed mode (+5 days because of ice mask)
SWI_L3_____	Wind and wave statistics	Quarterly yearly
SWI_L4_____	Propagated swells (“fireworks”), later possibly combined with other wave measuring instruments	Delayed mode
SWISCA_L2S___ _	2D wave spectra and partitions along the satellite track and wind vectors, using combined information from SCAT and SWIM	Delayed mode (+1 or 2 days)

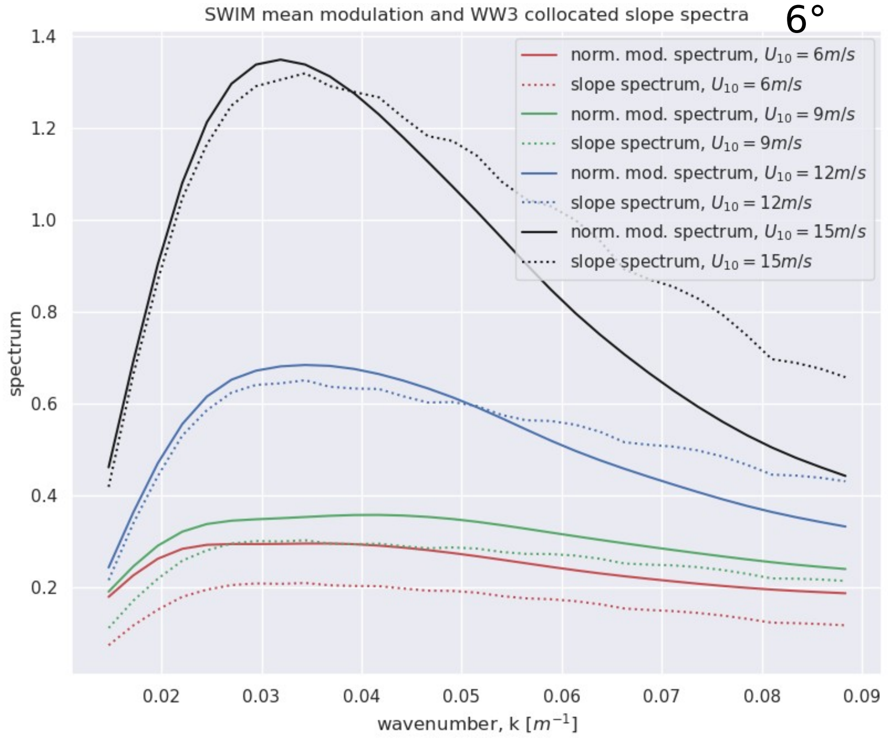
This study is based on 12 days of observations (SWIM L2S)
About $3x10^6$ valid observations for each beam

Validation of the linear MTF inversion

10°



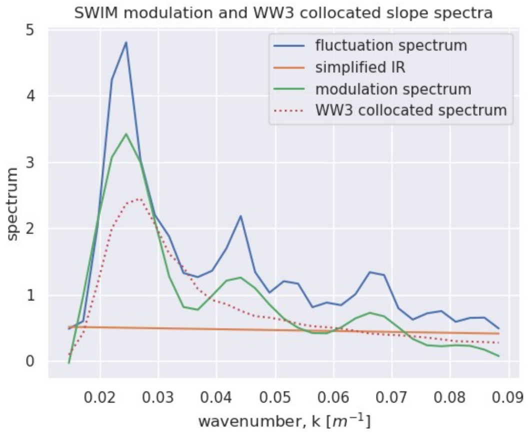
6°

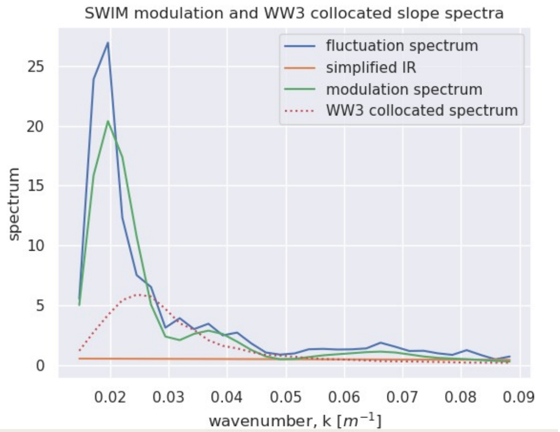


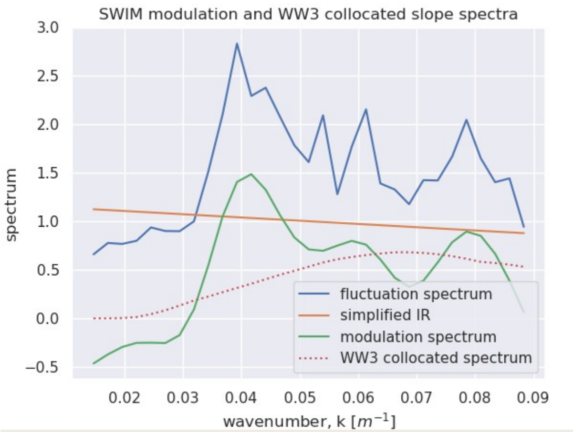
Spectra effected by wind waves (IR correction needs to be improved)

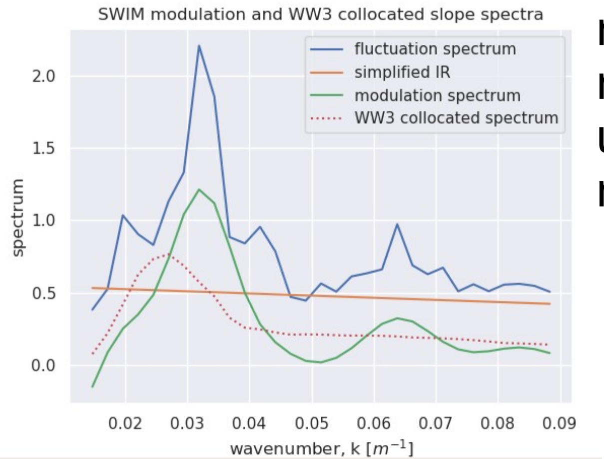
Mean spectra (12 days) could be compared with collocated WW3 model (part of IWWOC L2S product)

Examples of collocated measurements.



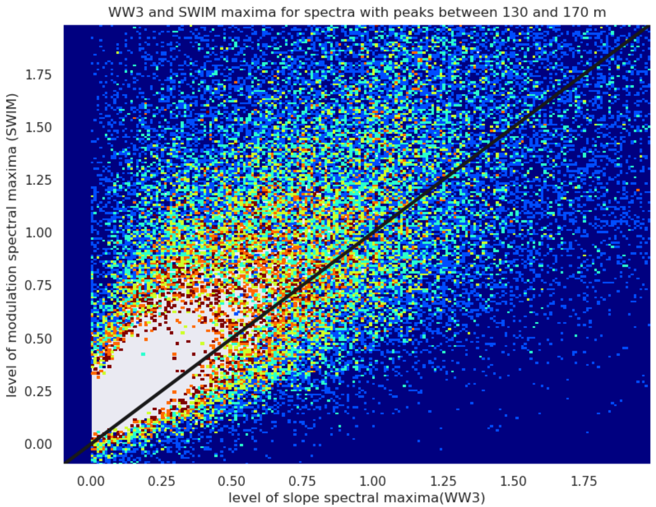


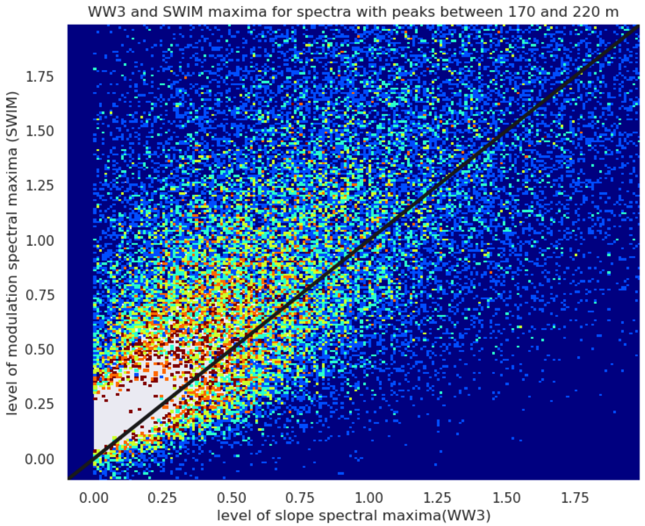




While in the mean the linear inversion works well, in every particular case deviations are systematical caused by different reasons: spectrum randomization, nonlinear MTF manifestation, uncorrected speckle, models errors etc.

Collocated slope spectrum maxima; Probability distribution

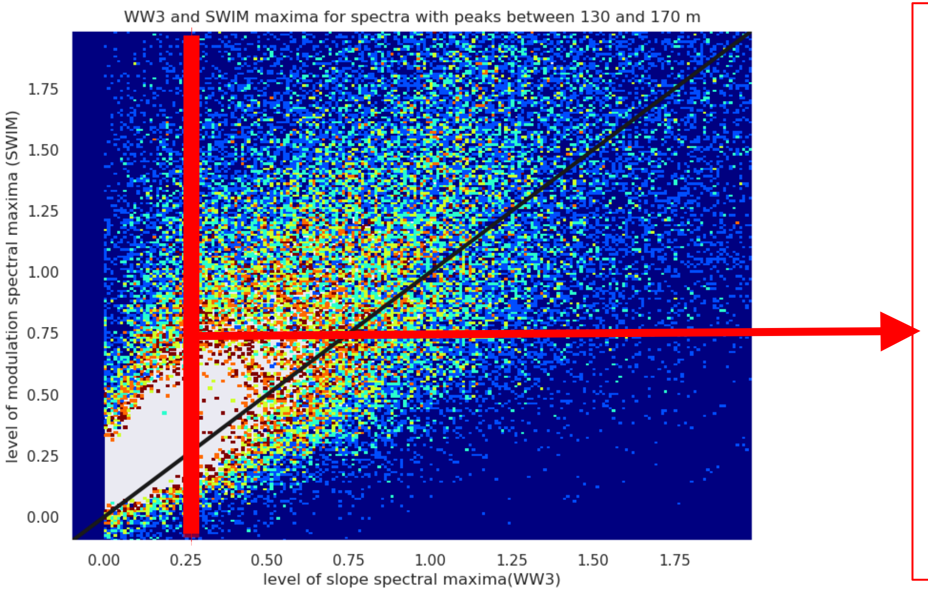


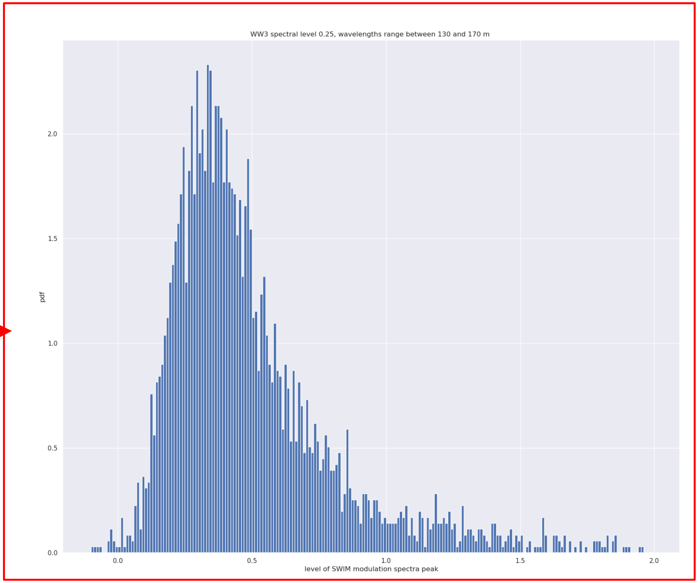


The probability density of collocated SWIM and WW3 spectrum maxima could be involved for the calibration and validation of the inversion algorithm

wind speed 10 m/s

Collocated measurements distribution profiles





The cross-section of the distribution has very table shape for every spectral energy level

Collocated measurements distribution interpretation

For relatively short interval of wind speeds the global wave height distribution follows Rayleigh law and wave energy (spectral slopes) will follow exponential distribution law.

$$P_i(s) = P_i(\xi^2) = \frac{1}{2\sigma_i^2} \exp\left(-\frac{s}{2\sigma_i^2}\right) = E_g(s)$$

So spectral maxima distribution is exponential (geophysical variation): $\boldsymbol{E_g(s)}$

From the other side signal processing/instrumental errors introduced by Gaussian distribution:

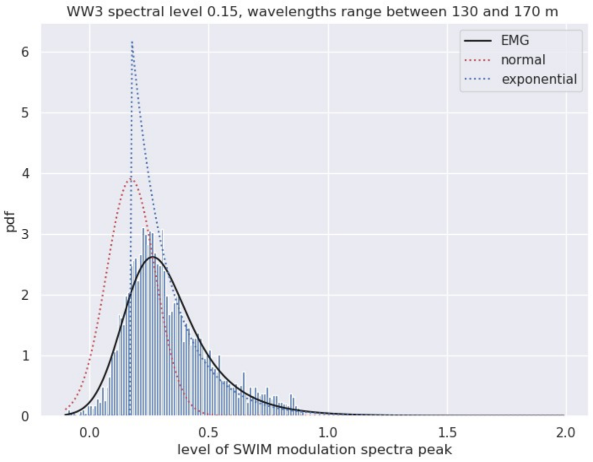
$$P_N(s) = \frac{1}{\sigma} \exp\left(\frac{s-\mu}{2\sigma^2}\right) = G_\alpha(s)$$

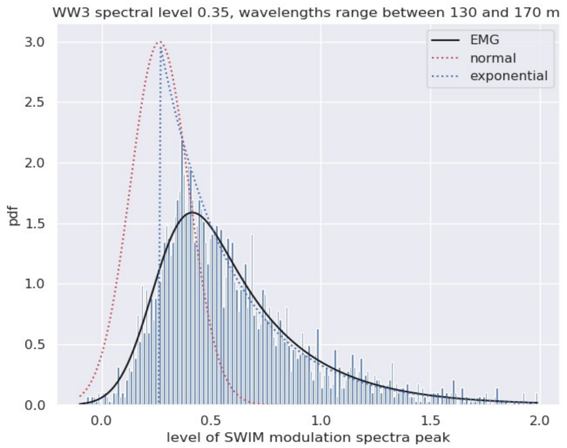
The common pdf is the convolution of two distributions:

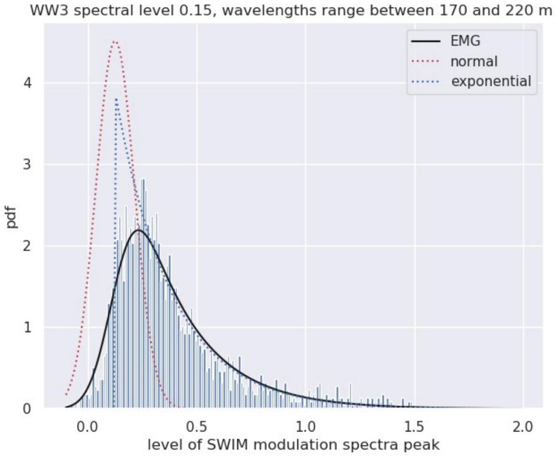
$$P_{SWIM}(s) = E_g * G_\alpha = \frac{1}{\sigma\lambda}\sqrt{\frac{\pi}{2}} \exp\left(\frac{1}{2}\left(\frac{\sigma}{\lambda}\right)^2 - \left(\frac{s-\mu}{\lambda}\right)\right) \mathrm{erfc}\left(\frac{1}{\sqrt{2}}\left(\frac{\mu}{\lambda} - \frac{s-\mu}{\sigma}\right)\right)$$

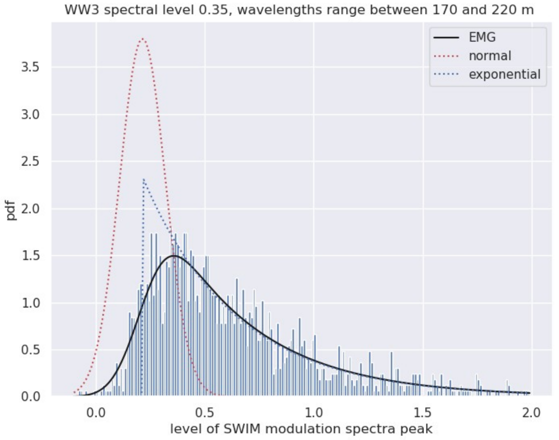
This is exponentially modified Gaussian distribution which can be fitted using MLE approach. Three principal parameters give exponential growth rate (geophysical part) and shape of Gaussian component (this is the error we want to minimize)

Examples of fitted distributions





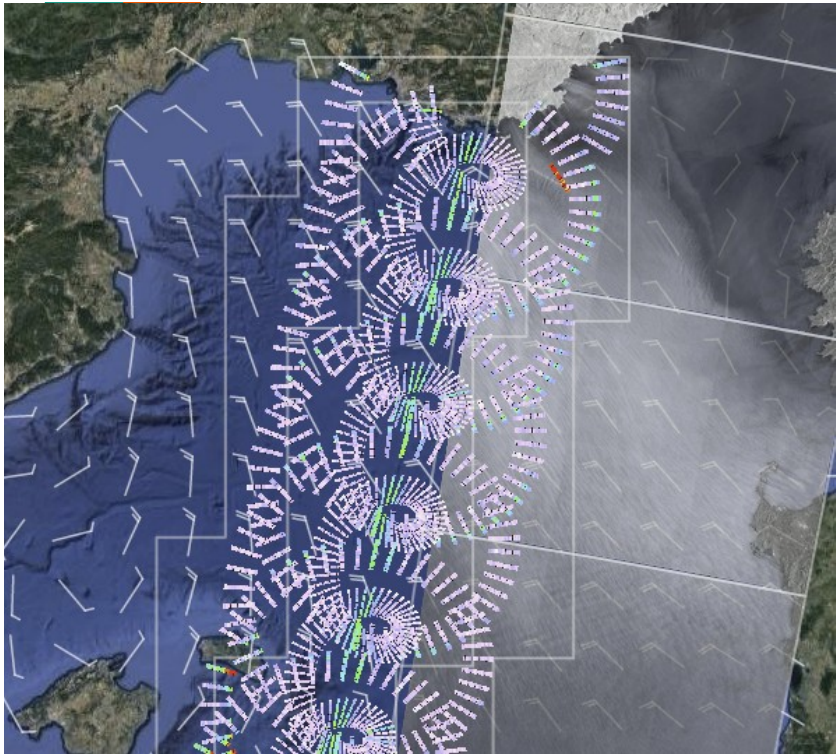




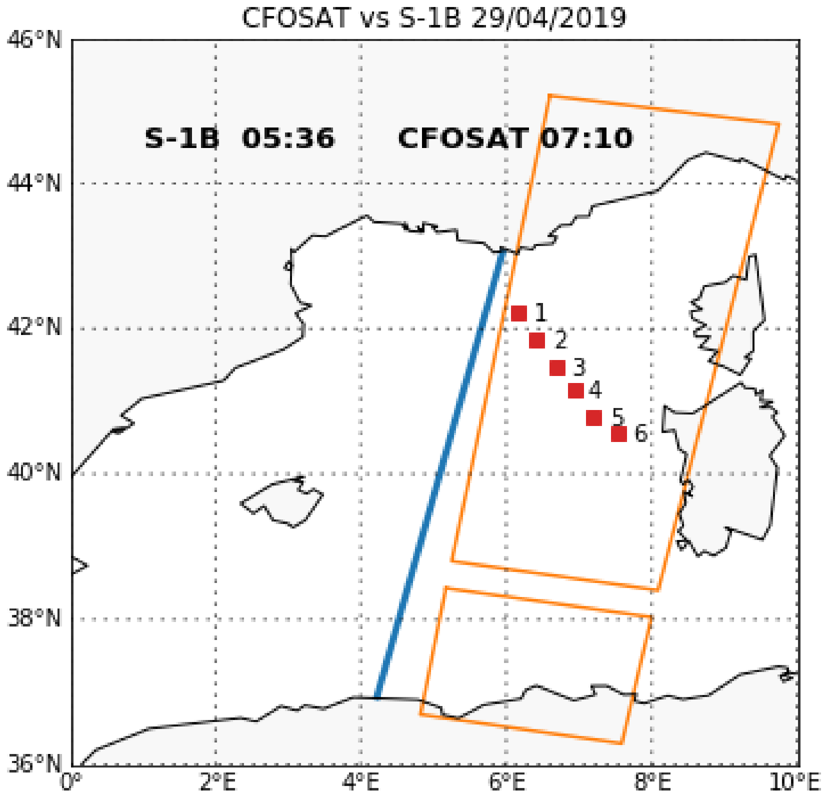
Using SWIM in geophysical applications

- The level and shape of inverse SWIM spectrum is the subject of ongoing research works
- The direction of detected waves and wavenumber of spectral maximum (in some cases) seems to be relevant and can be used for oceanographic tasks
- The examples of such works: wave spectral growth study, the detection of wave systems in the ocean

The example of Tramontane wind fetch-dependent wave growth

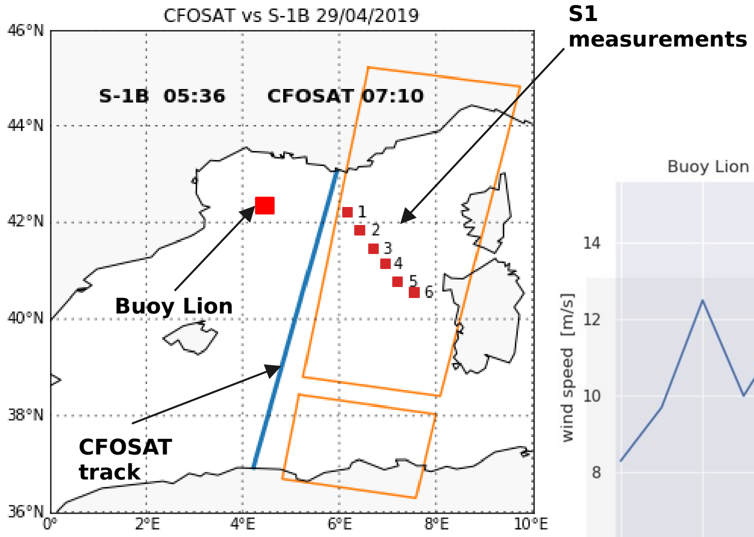


Gulf of Lion

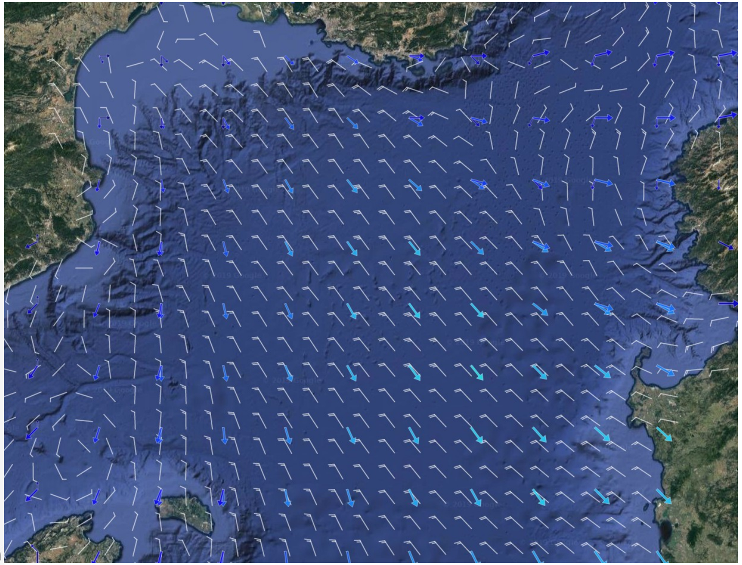


Meteorological conditions

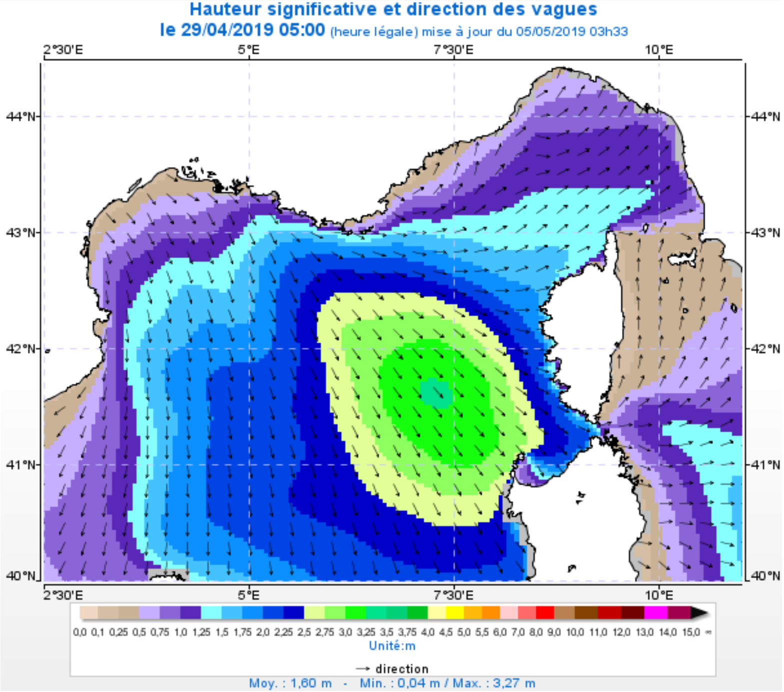
Date, time: 27 april 2019, 5h -7h
Wind speed: ~ 11.5 m/s

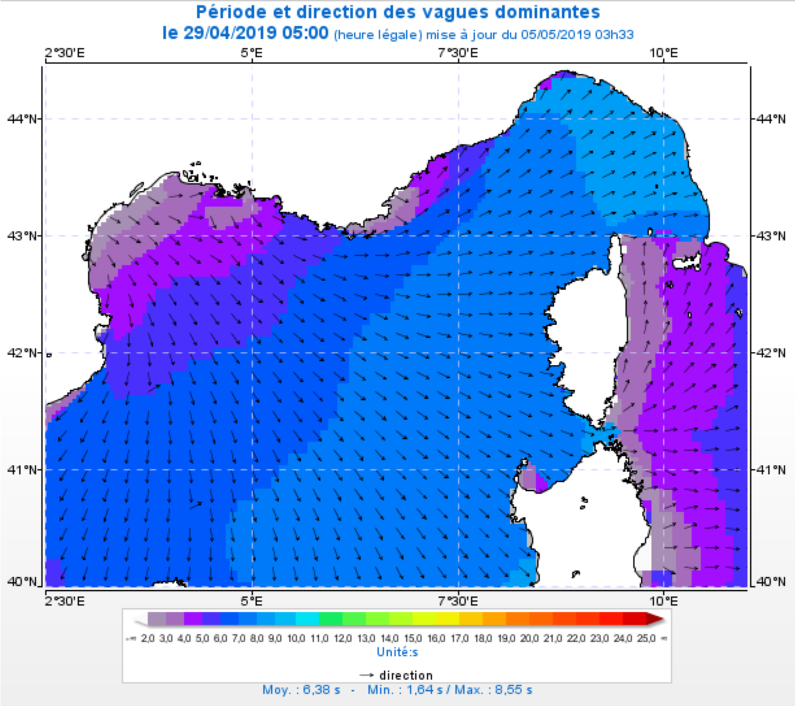


Wind and wave fields



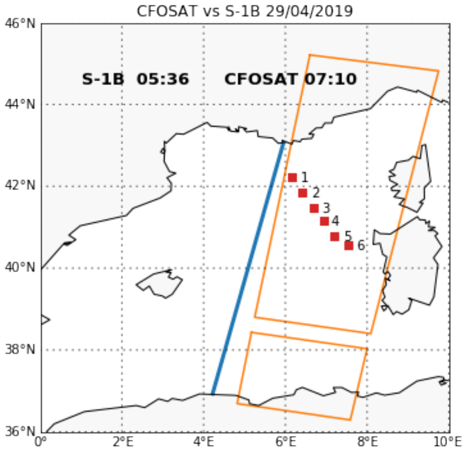
Wave conditions

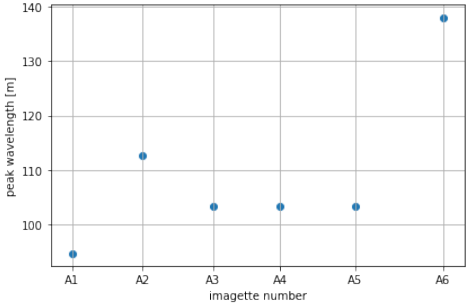




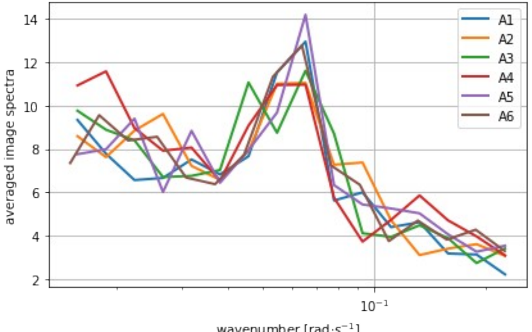
expected wavelengths: L_p=60 - 115 m

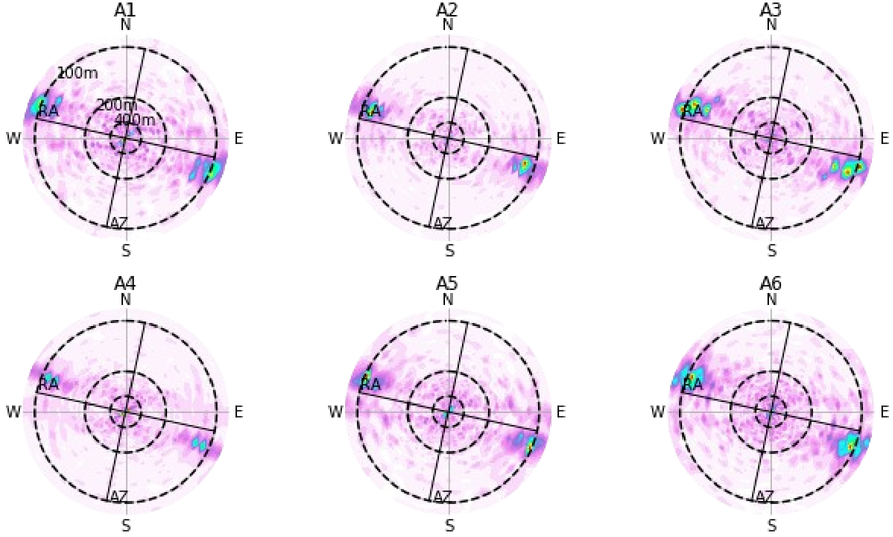
Sentinel-1 measurements





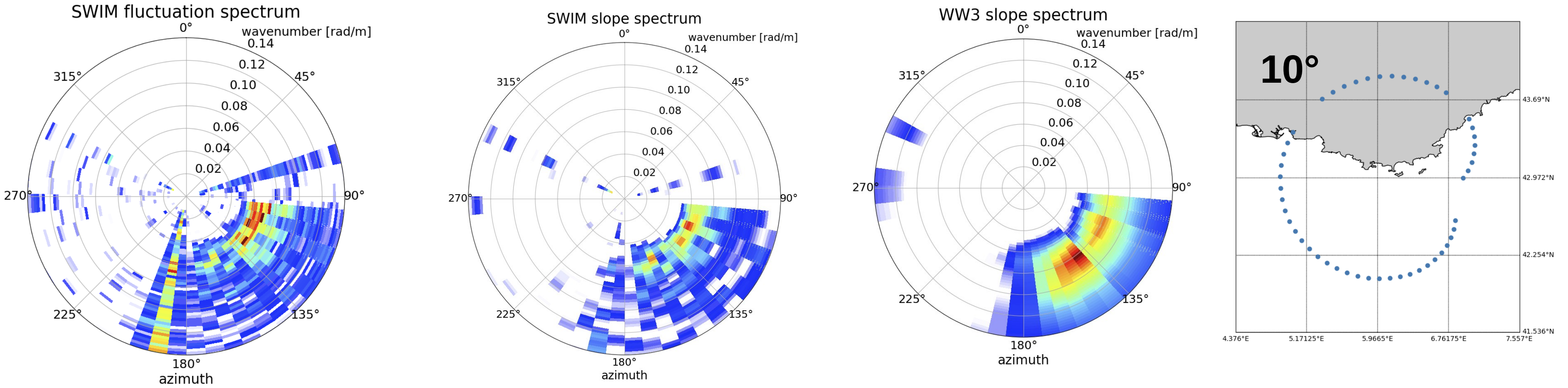
Wavelength evolution from SAR measurements

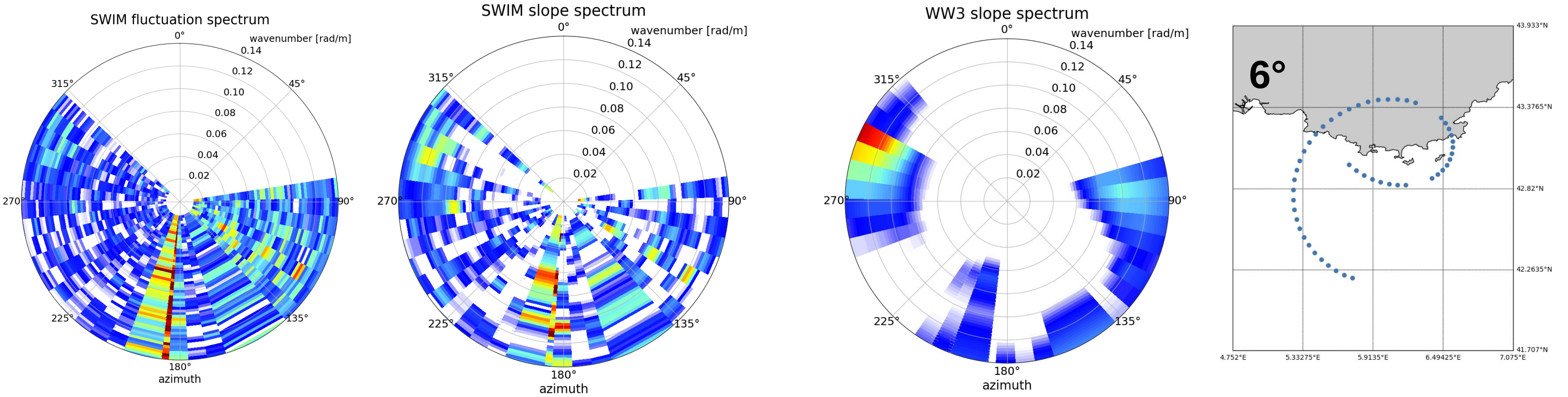




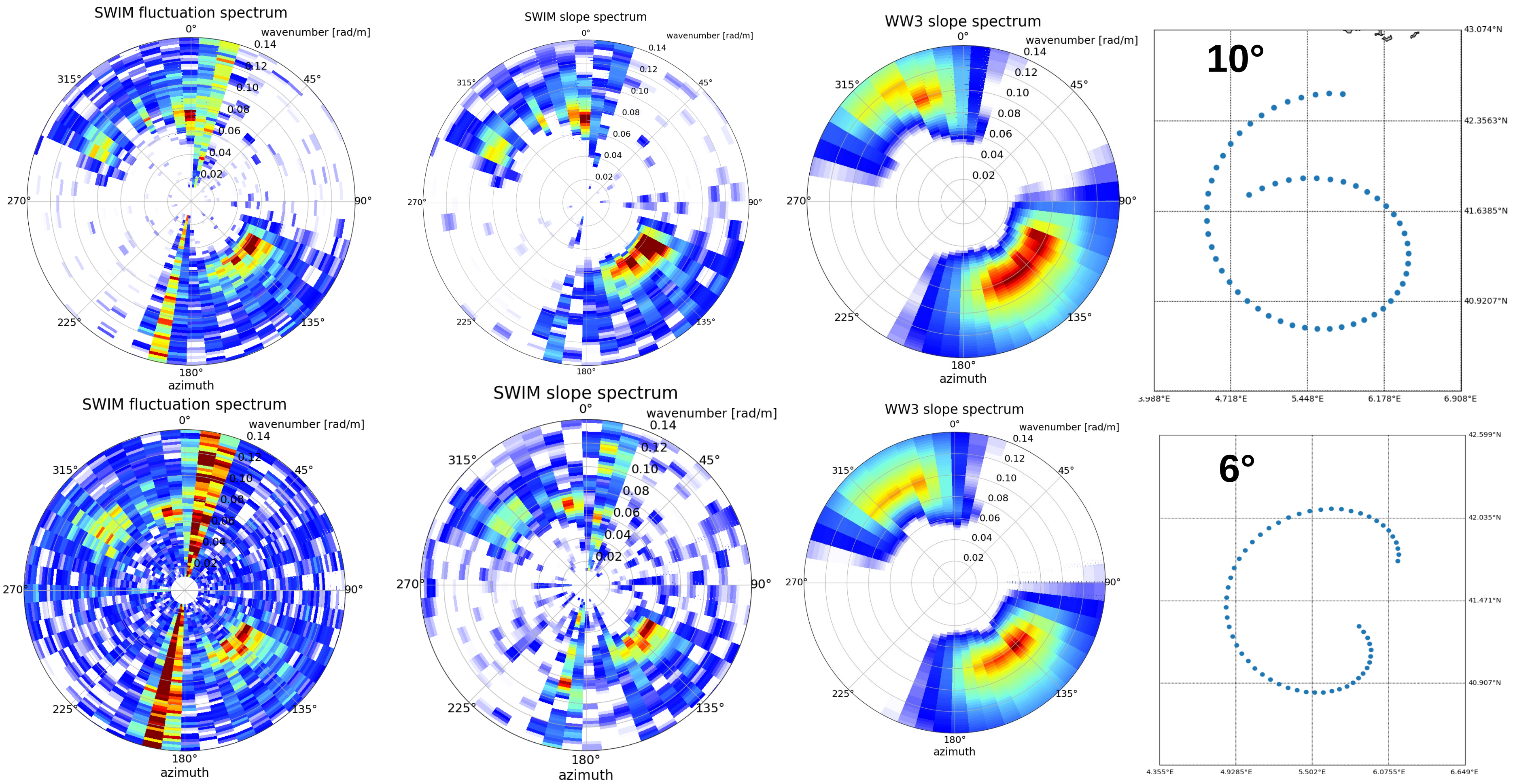
Directional wave spectra from SAR

SWIM directional wave spectrum

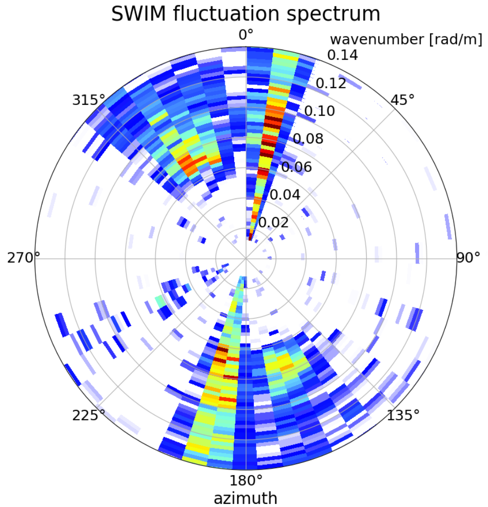


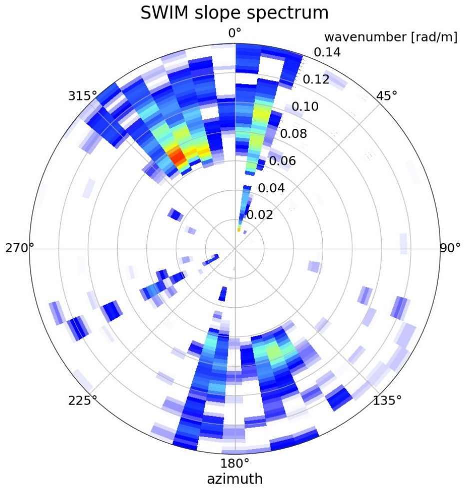


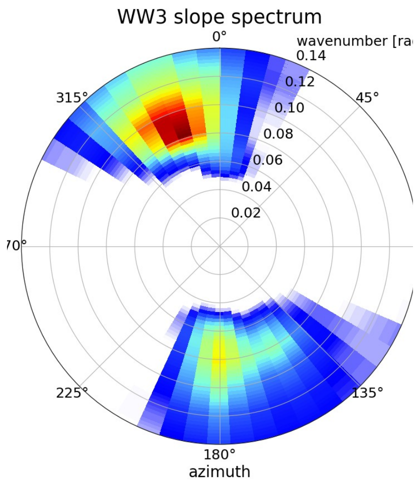
SWIM directional wave spectrum

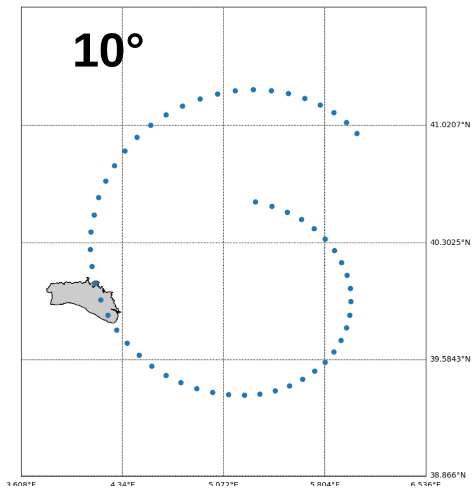


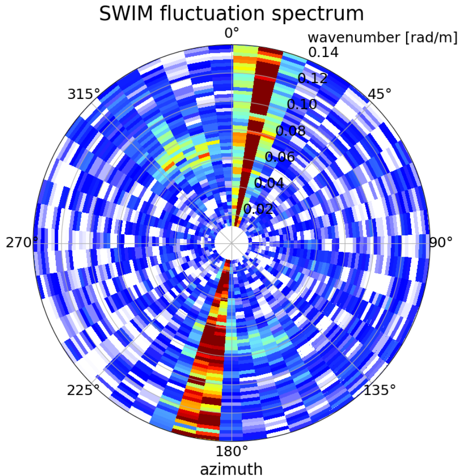
SWIM directional wave spectrum

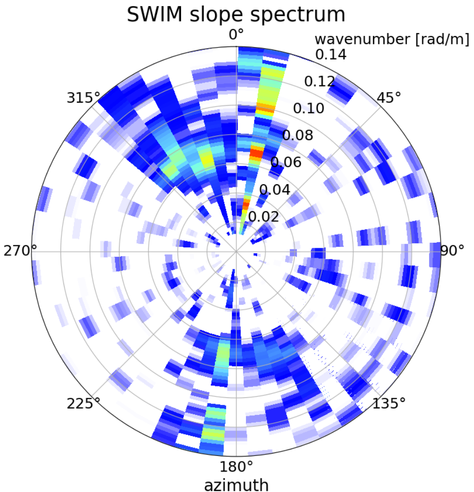


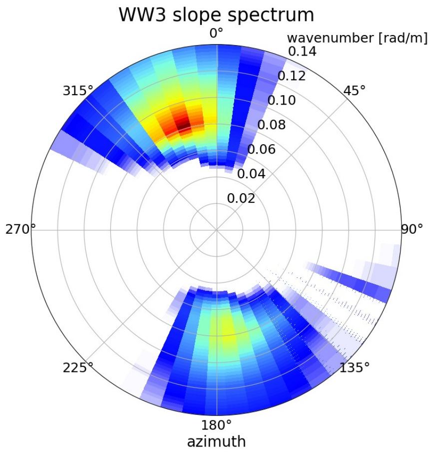


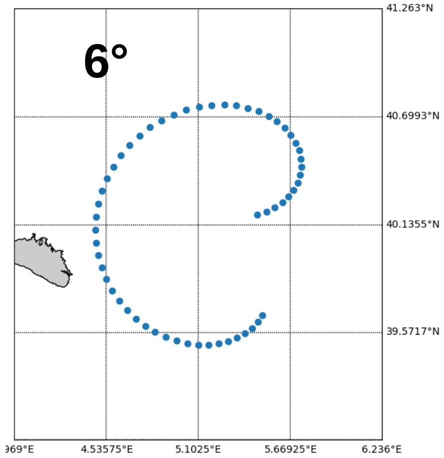




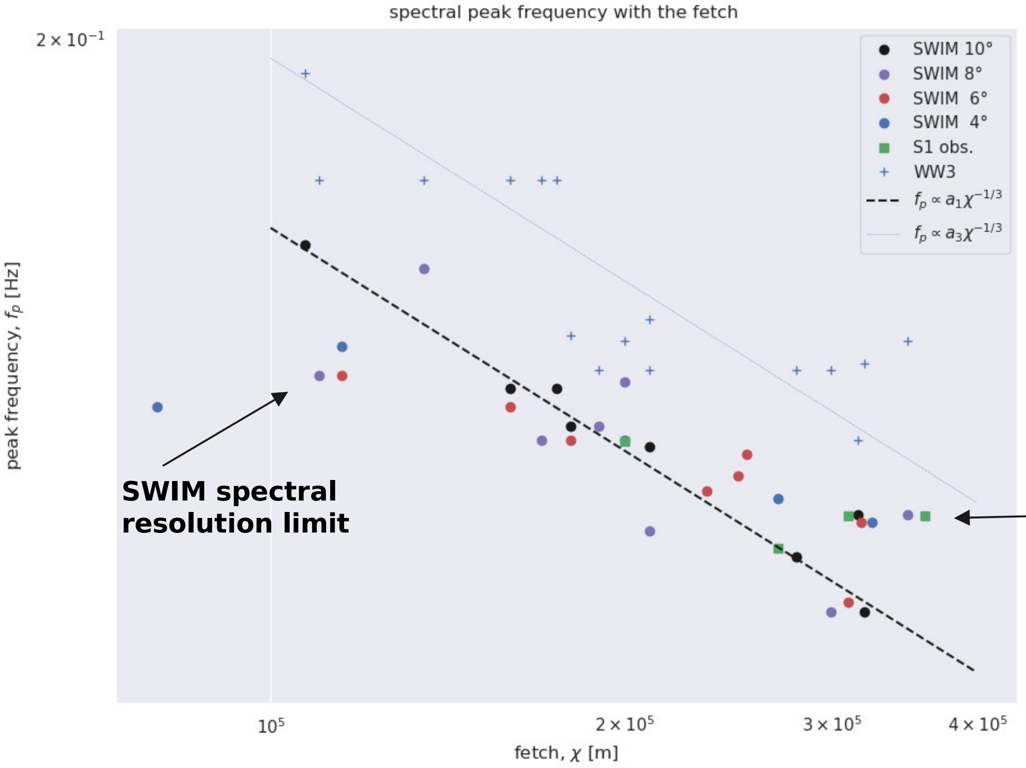








Evolution of wave spectral peak with the fetch



Classical JONSWAP relation for non-dimensional fetch :

$$f_p = 0.35\chi^{-\frac{1}{3}}$$

Conclusions

- SWIM is the effective ocean observation tool which potentially allows to have regular global high resolution information about directional wave spectra
- Like for any new instrument processing and correction algorithms need to be established and validated
- SWIM observation variation(deviation) statistics contains both geophysical and instrumental/processing components. Correct interpretation of observations is essential for the calibration and validation of the product
- Even if processing algorithms are under improvement, promising geophysical studies can be done with already existing data sets.