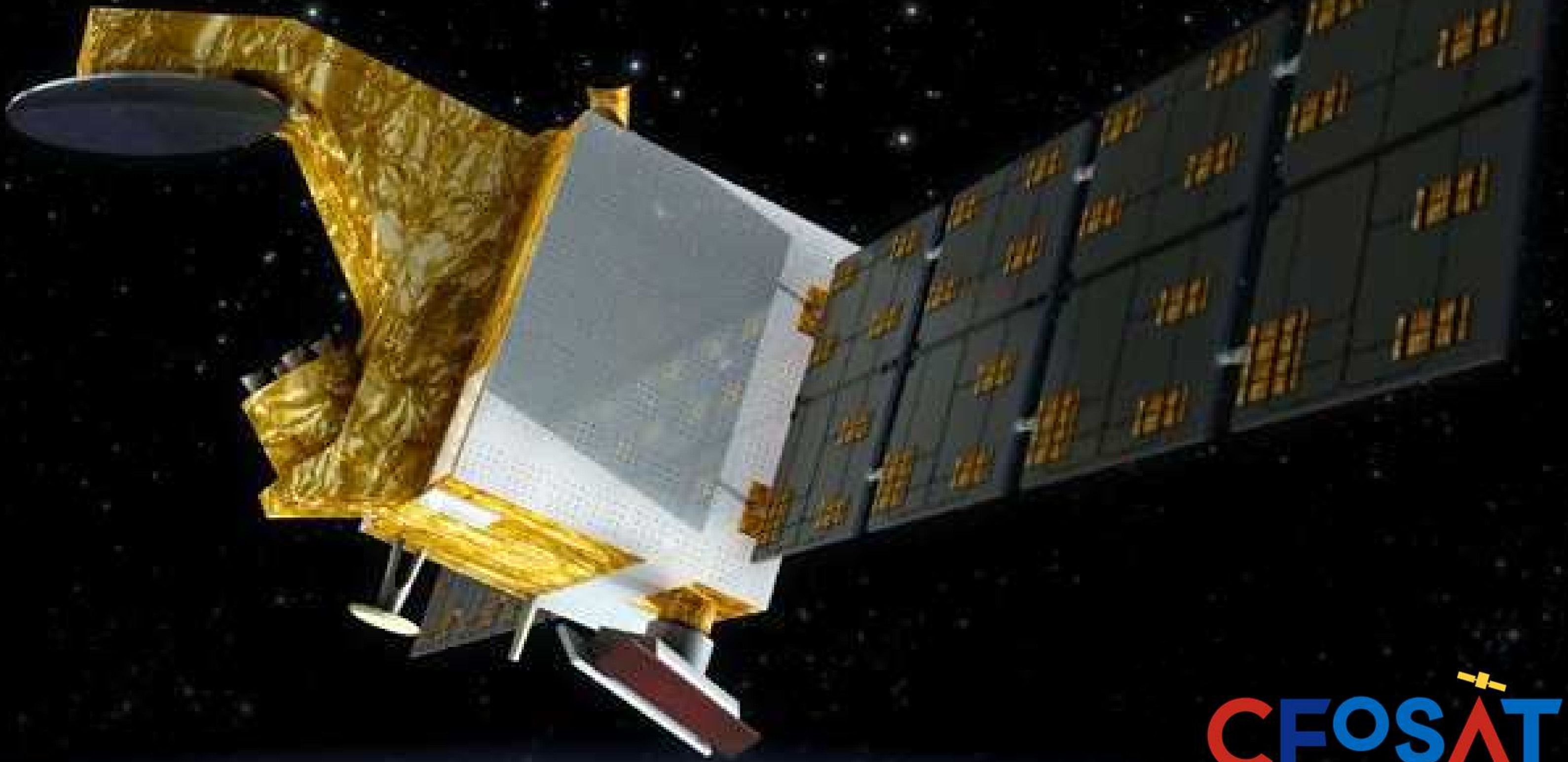
Surface Measurements for Oceanographic Satellites: the SUMOS in-situ and airborne campaign



R. Rodriguez-Suquet, C. Tourain[1], D. Hauser[2], P. Sutherland[3], L. Marié[3]

(1) CNES, Toulouse, France

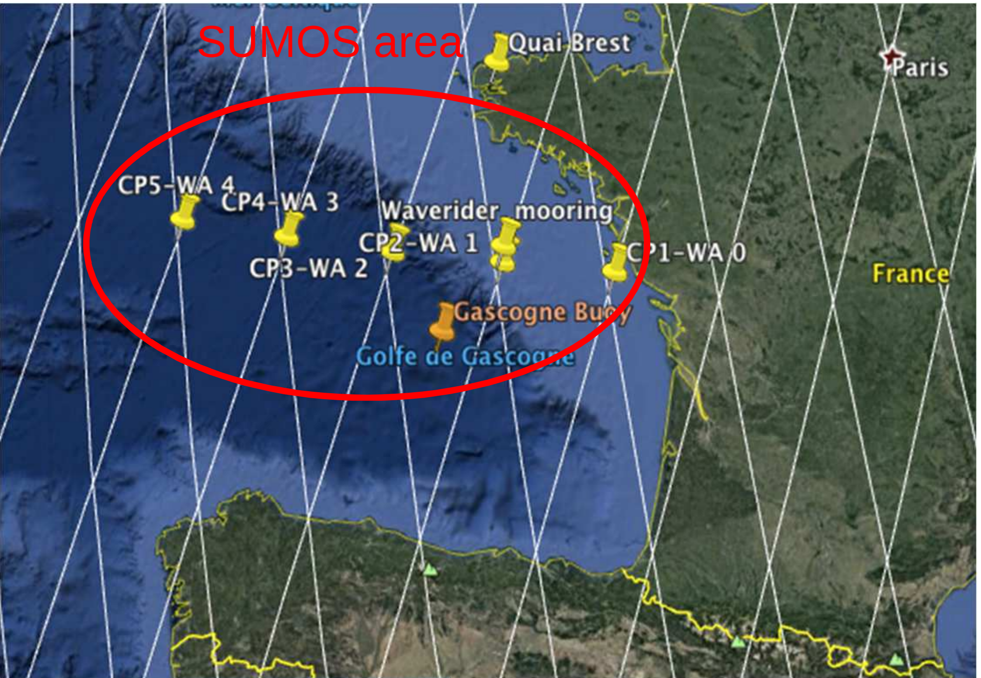
(2) LATMOS, CNRS, UVSQ, UPMC, Guyancourt, France

(3) IFREMER, Brest , France

SUMOS campaign

- Context
  - Field campaign proposed by French research groups (LATMOS,LOPS; PIs : P. Sutherland and D. Hauser) , supported by CNES to contribute to the CFOSAT product assessment
    - Project manager at CNES: Raquel Rodriguez Suquet
    - For several reasons (among which Covid Crisis) could only be carried in spring 2021 (~2,5 years after launch)
- Objectives of SUMOS
  - Gather comprehensive set of collocated observations on wind, waves and related parameters(in situ, remotely sensed)
  - Contribute to continuous improvement of the SWIM data inversion, identify limitations
  - Study wave hydrodynamics and wind/wave/fluxes relationships in condition of high sea-state
  - Prepare SKIM-like missions (surface current and waves)

SUMOS OPERATION PLAN



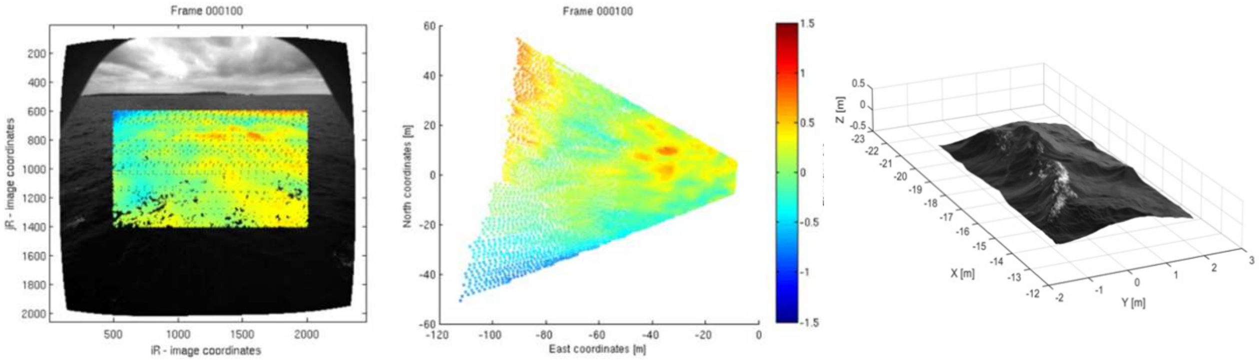
SUMOS operation plan was carried out from 9th February to 10th March 2021

- **2 national platforms deployed from Bay of Biscay**
  - Research vessel Atalante from 10th of February to 9th March
  - Research aircraft ATR42 from 15th February to 4th March
- **SUMOS measured winds and waves along the CFOSAT ground track during 14 satellite passes.**
- **Flight program in perfect coordination with in-situ measurements and satellite passes.**
  - 17 flights in total
    - 13 used for SUMOS campaign and synchronised with 14 CFOSAT passes
    - 4 used for SKIM
  - In-situ measurements on board the L'Atalante vessel and drifting buoys deployed from the vessel at different positions according to satellite's passes.

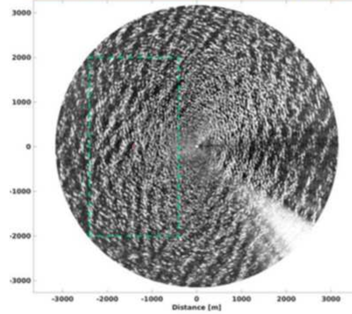
Instrumentation and measurements (1/4)

Shipboard instrumentation : PI = Peter Sutherland, LOPS

Video measurements: Stereo-video system, polarimetric imagery, and wide FOV camera.
=>Short waves properties (1cm-5m), wave breaking



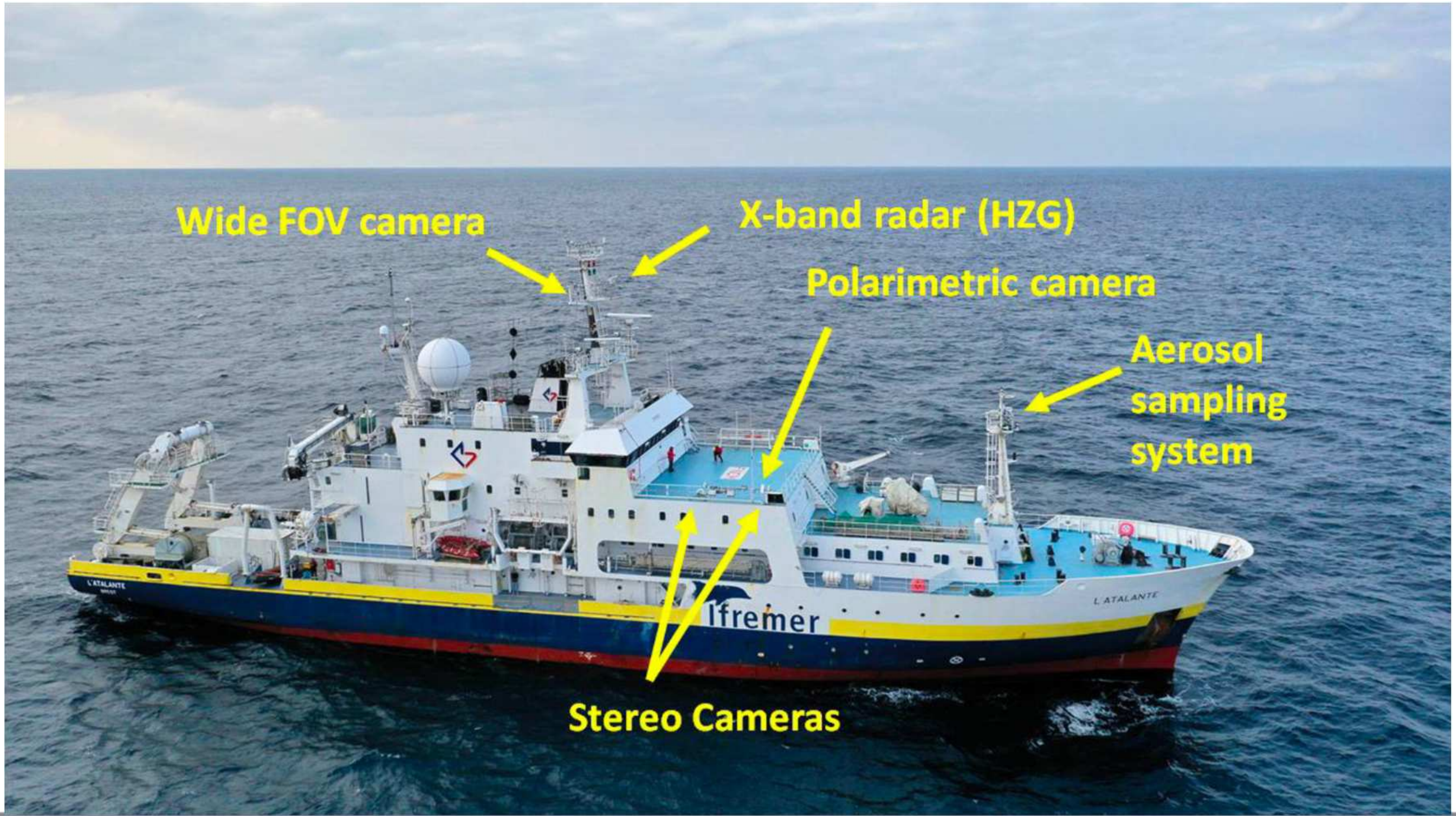
Helmholtz-Zentrum Hereon (Geesthacht, Germany)
=> Long-wave directional spectra (in wavenumber and frequency), current



Radar image from March 1st

Instrumentation and measurements (2/4)

Shipboard instrumentation : Atalante Vessel accomadation

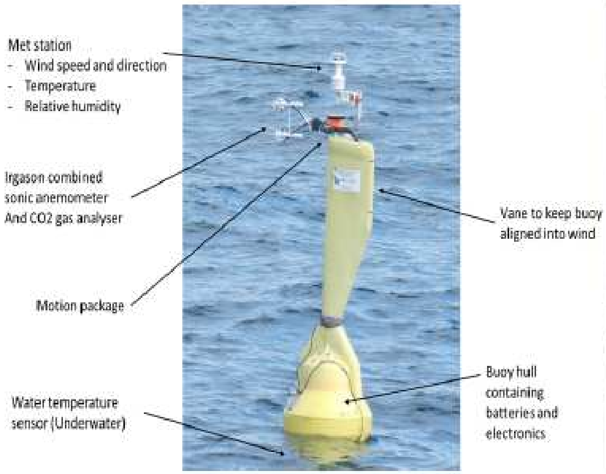


Instrumentation and measurements (3/4)

Instrumentation deployed by the R/V L'Atalante near CFOSAT crossover points
PI = Peter Sutherland, LOPS

FLAME buoy (full and Lite version)
instrumented platform
=> wind, turbulent fluxes, waves

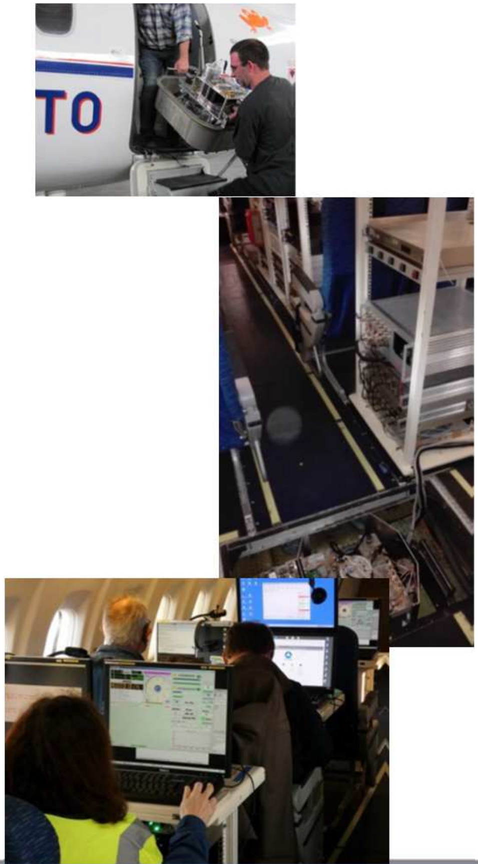
Spotter drifting buoy (from Spoondrift) directional wave rider
=> Directional wave spectrum



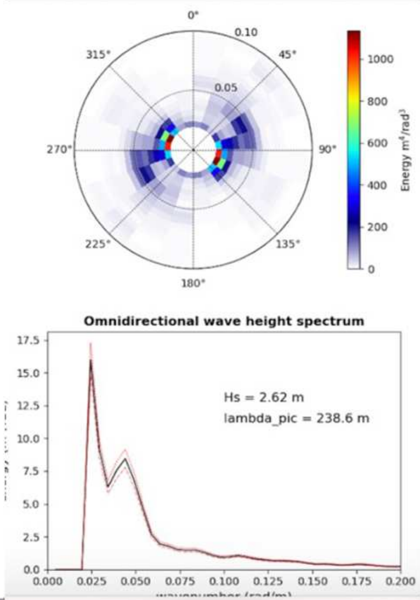
Instrumentation and measurements (4/4)

Airborne observations: KuROS radar (Ku Band)
PI: D. Hauser, LATMOS

=> Directional spectra of long waves (30-300m) and normalized radar cross-section along the flight track and along and across- SWIM swath

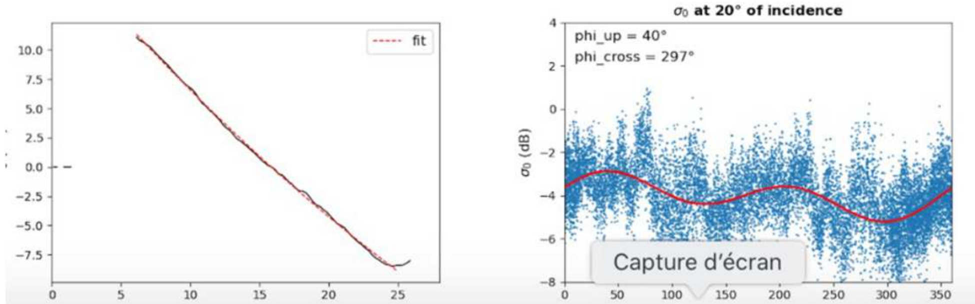


KuROS wave spectrum
(2D and omni-directionnal)



Example from
16 February 2021- 17:03-19:38 UTC

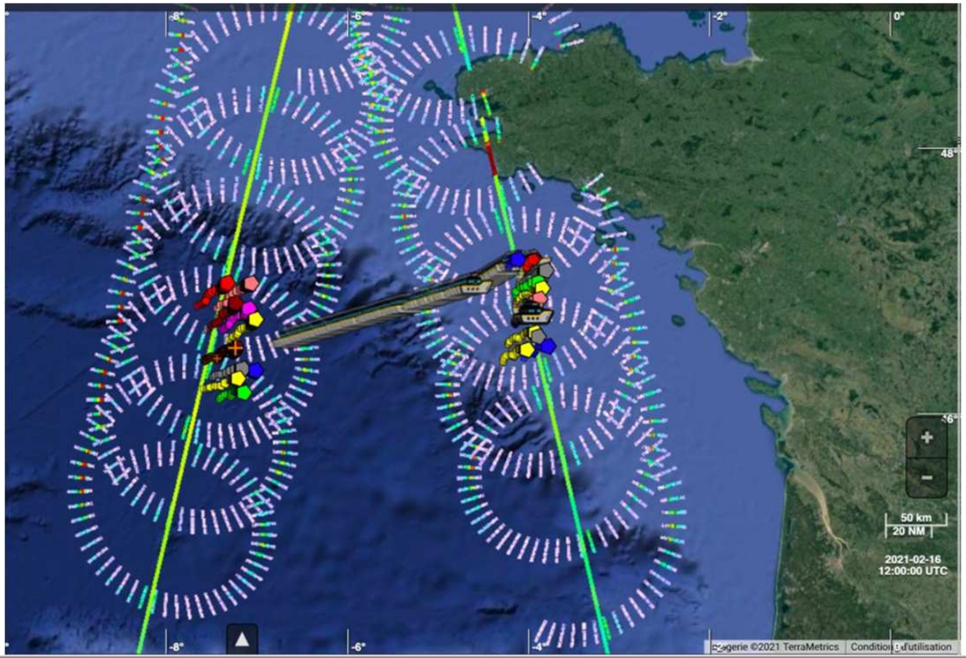
Kuros normalized radar-cross-section



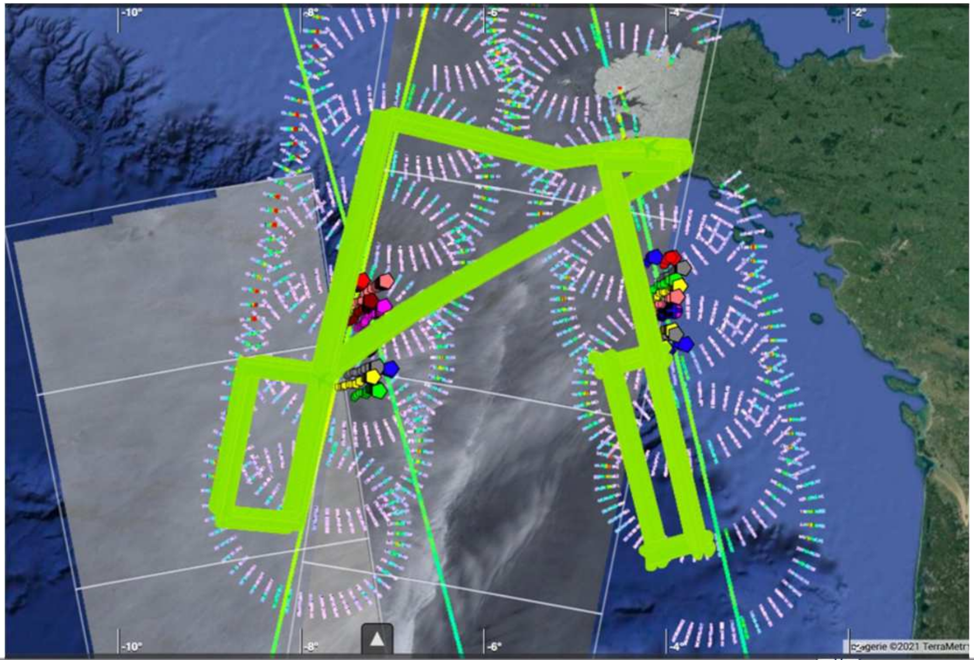
Example of coordinated sampling :

on 16 February 2021 (2 CFOSAT passes at ~08 and ~19 UTC)

CFOSAT nadir, CFOSAT 10°
With RV L'atalante (grey) and drifting wave buoys (diamonds)



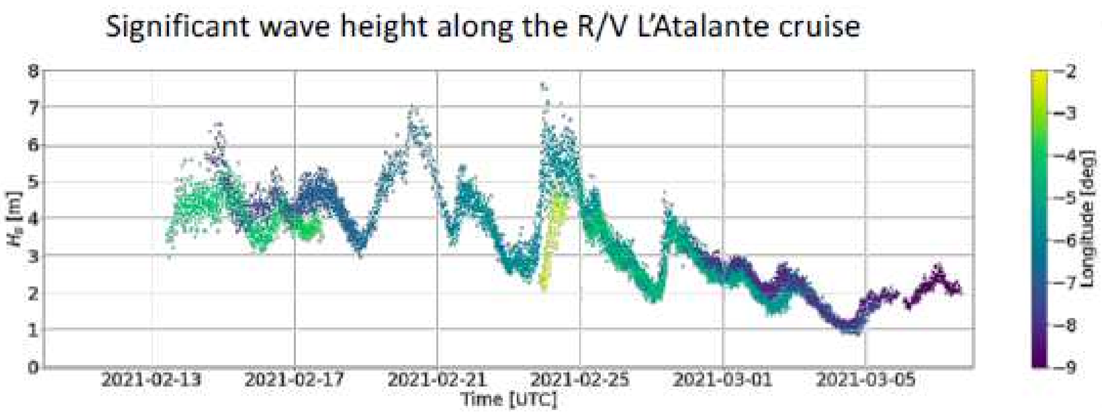
Same, with in addition
aircraft ATR42 (green),
Sentinel1-SAR (grey), Sentinel 3A altimeter track



Data set of high quality

- 14 flybys of SWIM (13 with coordinated KuROS observations)
- 20 Spotter buoys (wave measurements) and 3 Flame buoys (wave and turbulent fluxes) deployed and recovered multiples times
- Large number of acqusitions of ship-borne optical instruments and X-band radar
- 4 KuROS + Karadoc airflights for SKIM-type objectives (Doppler)
- Good meteorological situations (high sea-state, swell, mixed sea)

high significant wave heights, majority of swell or mixed sea conditions



First results on wave spectra intercomparison SWIM/KuROS/buoy/X-band radar

Method

- All 2D spectra (SWIM, KuROS, Spotter buoy, X-Band radar) sampled or re-sampled with the same frequency and direction bins

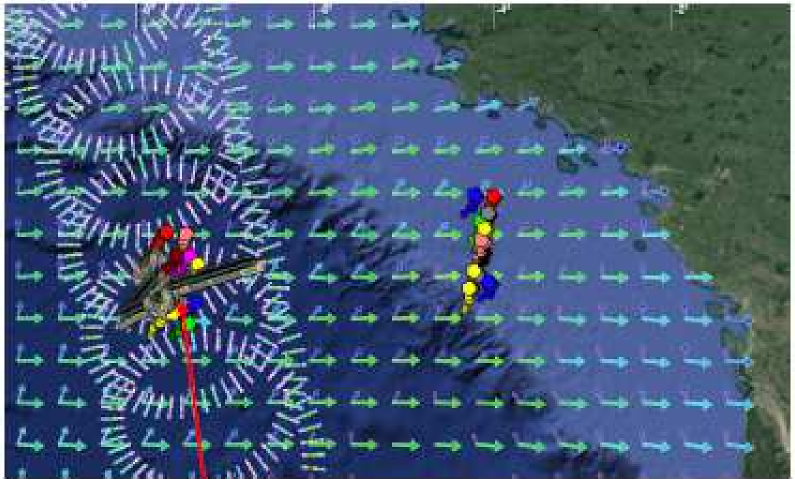
  [kmin-kmax]= [0.01256-0.27895], directions every 15°

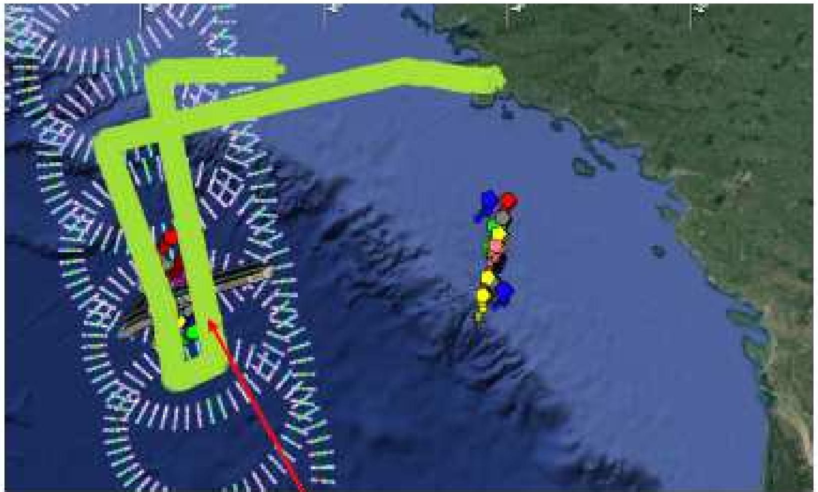
- SWIM, KuROS, X-Band: 2D spectra directly from the sampling
- Spotter buoy: 2D spectra reconstructed using either MLM or MEM methods from the measurements
- Main parameters estimated similarly for all source of data
- SWH estimated over SWIM spectral interval [kmin-kmax]
- dir_{peak} estimated on the 2D slope spectra (weighted average around the energy max)
- l_{peak} estimated on the 2D slope spectra (weighted average around the energy max) or alternatively from the 1D spectra
- Correlation indexes estimated between SWIM spectra and X-band (1D, 2D) and between SWIM and buoy data

15 February 2021, evening (1/4)

SWIM -10° beam : cycloid
Buoy positions: colored diamonds
Ship : grey symbol
Model MFWAM: arrows (fisrt swell and wind sea)

SWIM -10° beam : cycloid,
Buoy positions: colored diamonds
Ship : grey symbol
Aircraft with KuROS: green

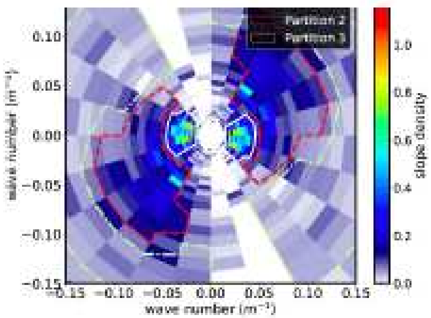
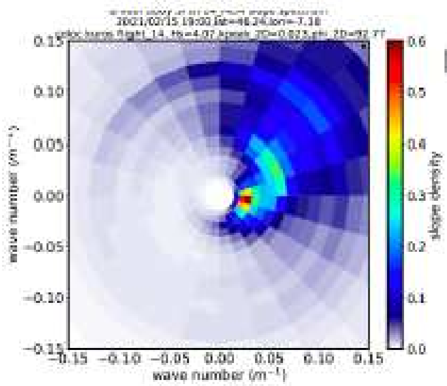
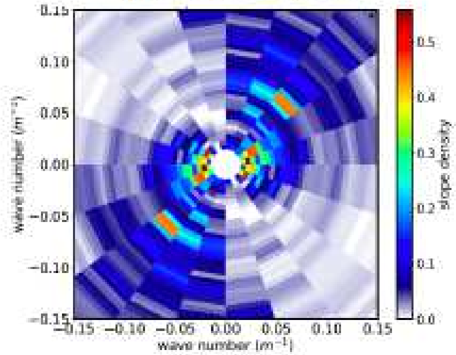
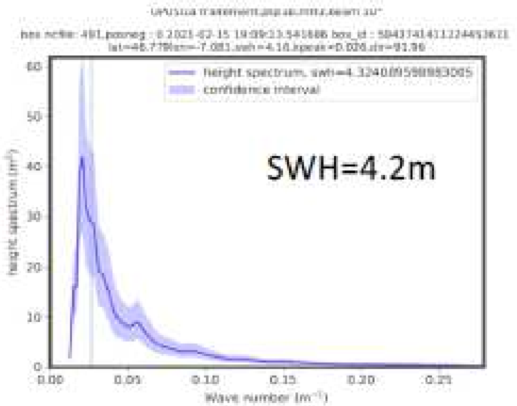
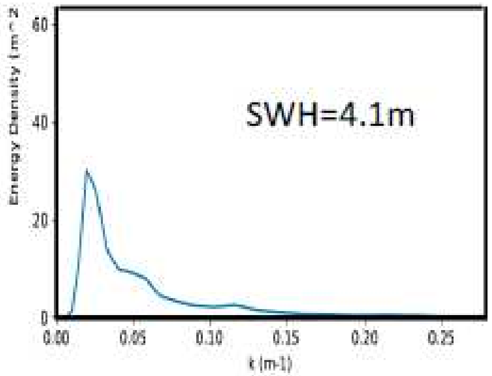
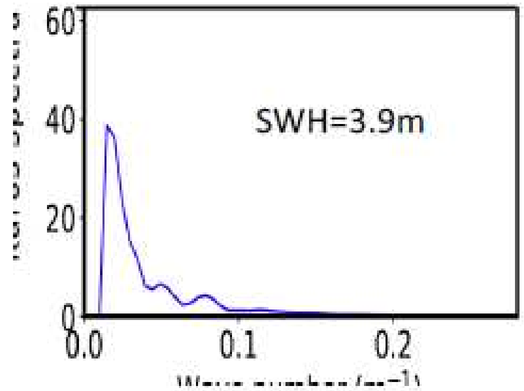




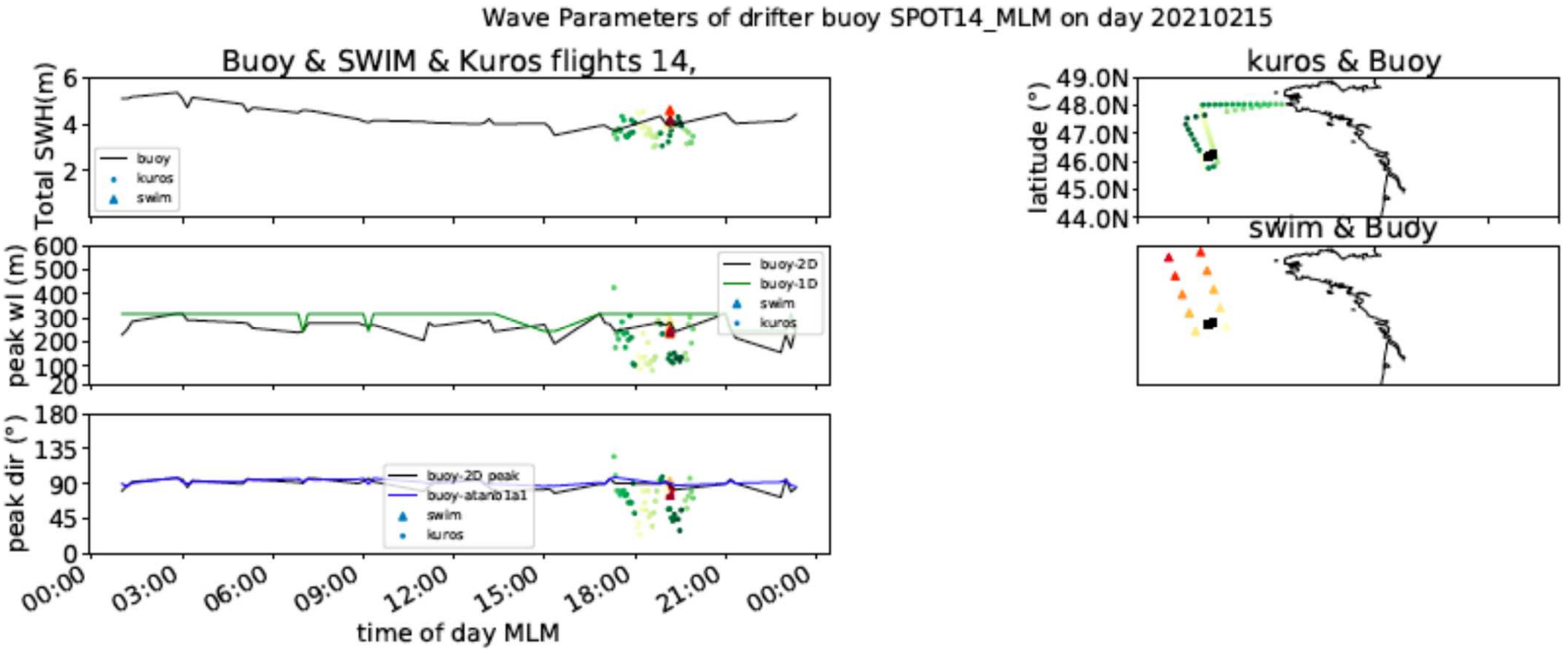
SWIM/X-band/buoy comparison

SWIM/Kuros/buoy comparison

15 February 2021, evening (2/4): comparison SWIM / buoy / airborne KuROS

	SWIM-10°, 19:09 46.78 N, -7.08 W	Spotter Buoy #14, 19:00 46.24N, 7.36W	KUROS, 19:04 46.32N, -7.77W
Wave slope 2D spectra		 MLM	
Wave height spectra (omni)			

15 February 2021, evening (3/4)

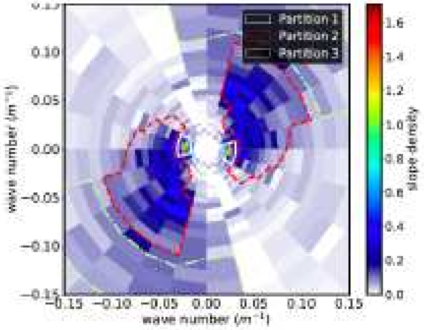


Good agreement between SWIM/buoy (#14 here) and KurOS
Kuros results relatively scattered for peak direction and peak wavelength (found either on wind sea or swell on the 2D slope spectra)

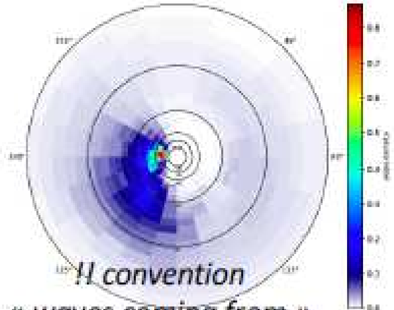
15 February 2021, evening (4/4): comparison SWIM / X-Band radar / buoy

SWIM-10°

SWIM-10° -19:09
45.93 N, -7.96 W

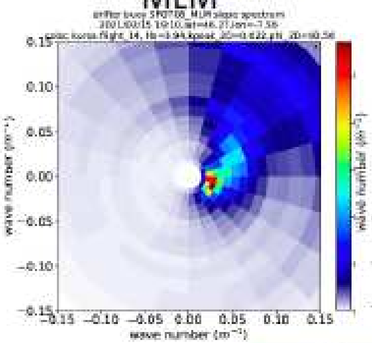


Band-X radar 19:08
46.37, -7.61W

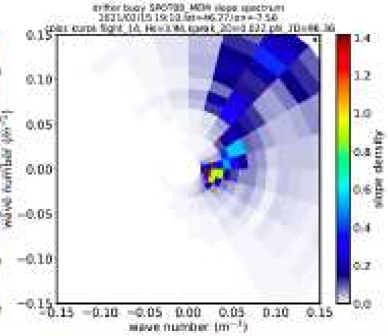


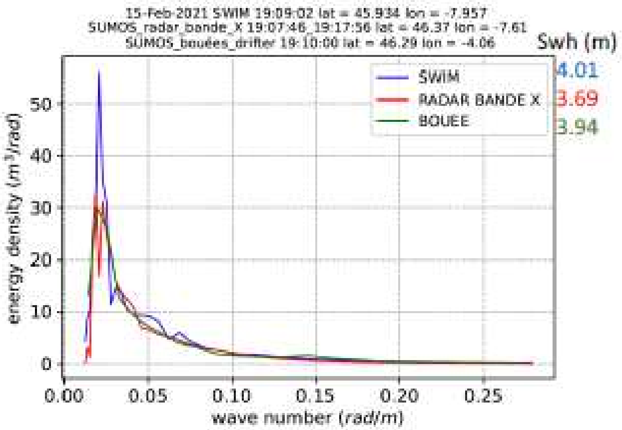
Buoy #08 19:10
46.27N, -7.67W

MLM

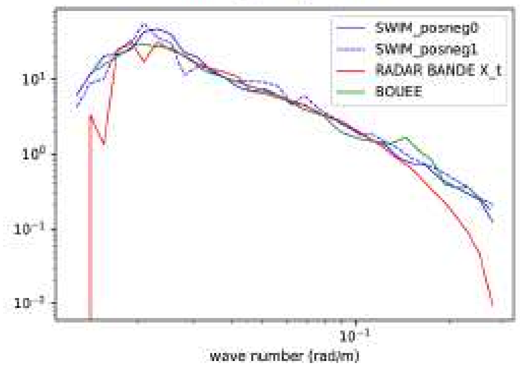


MEM





In log/log scale

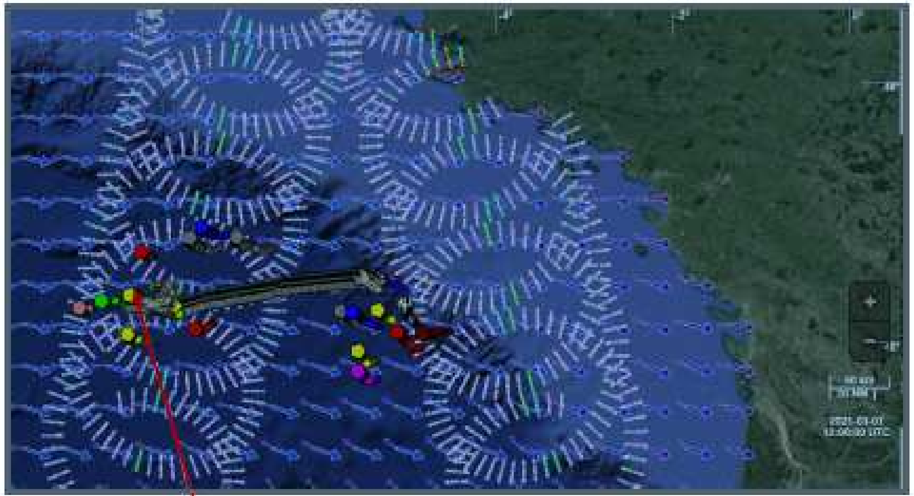


- 2D: good qualitative agreement, but buoy MEM and MLM significantly different. Consistent partitioning on SWIM spectrum

- 1D: Good agreement except for the shortest waves : X-band radar misses some energy- partly because of the normalization approach of X-band radar spectra (buoy reference limited to 70m in wavelength)
- SWIM more sharp near the peak

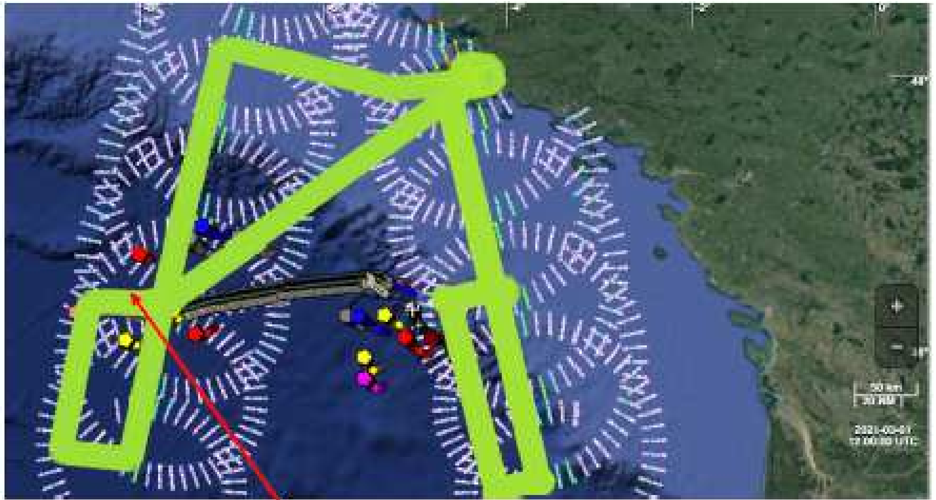
1st March 2021 (1/4)

SWIM -10° beam : cycloid
Buoy positions: colored diamonds
Ship : grey symbol
Model MFWAM: arrows (fisrt swell and wind sea)



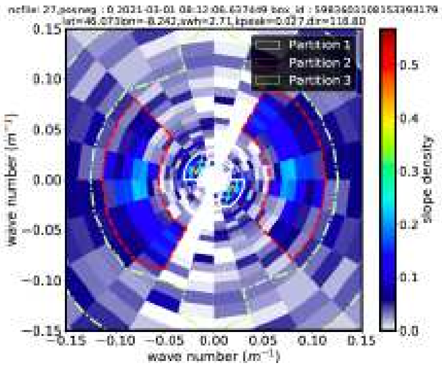
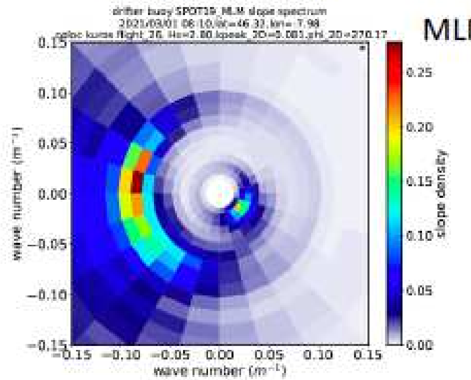
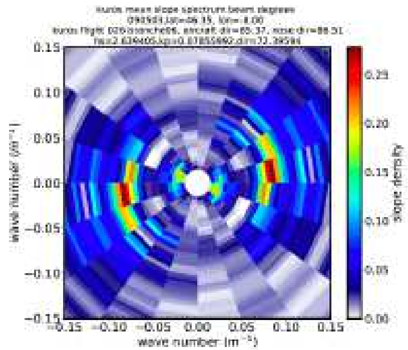
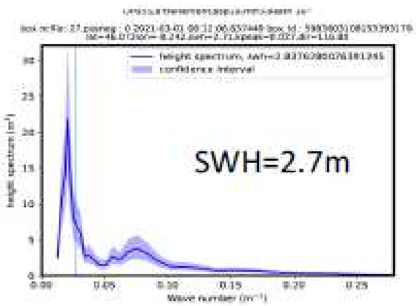
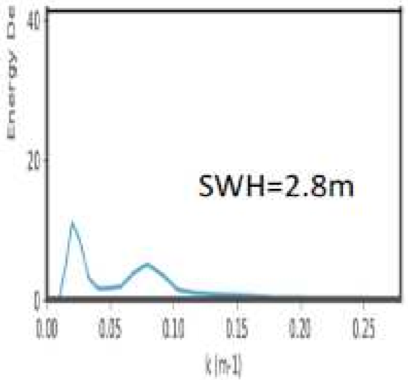
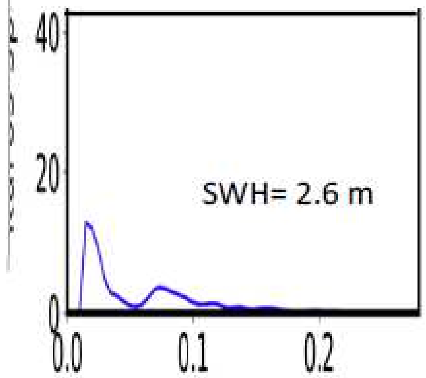
SWIM/X-band/buoy comparison

SWIM -10° beam : cycloid,
Buoy positions: colored diamonds
Ship : grey symbol
Aircraft with KuROS: green

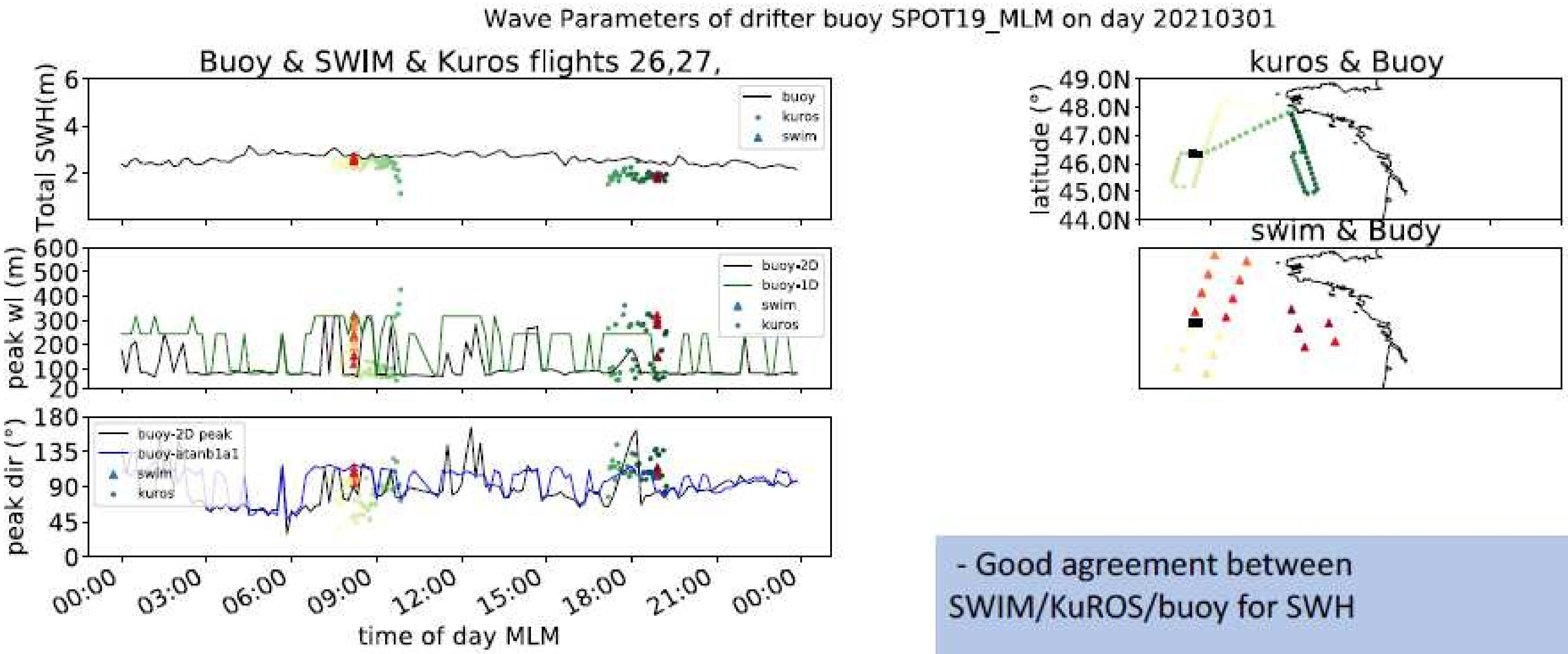


SWIM/Kuros/buoy comparison

1st March 2021 (2/4): comparison SWIM / buoy / airborne KuROS

	SWIM-10° 08:12, 47.07N,-8.24 W	Spotter Buoy #19 08:10 46.32 N, -7.98 W	KUROS, 09:05 46.35N, -8.00W
Wave slope 2D spectra		 MLM	
Wave height spectra (omni)	 SWH=2.7m	 SWH=2.8m	 SWH= 2.6 m

1st March 2021 (3/4)



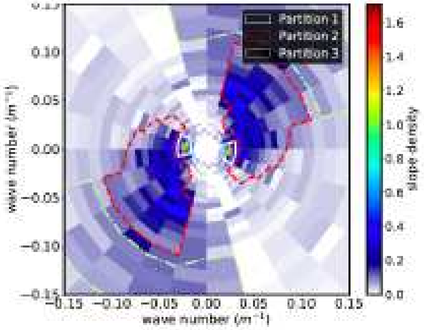
- Good agreement between SWIM/KuROS/buoy for SWH

- Important variations of peak wavelength and direction, (peak found either on wind sea or swell)

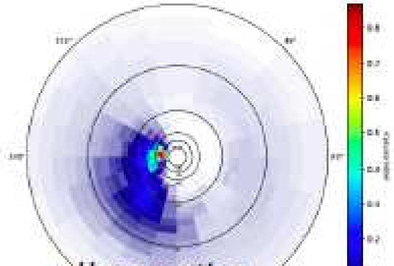
1st March 2021 (4/4): comparison SWIM / X-Band radar / buoy

SWIM-10° -19:09
45.93 N, -7.96 W

SWIM-10°



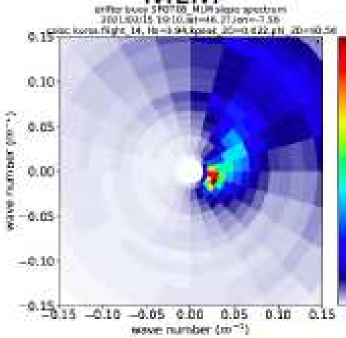
Band-X radar 19:08
46.37, -7.61W



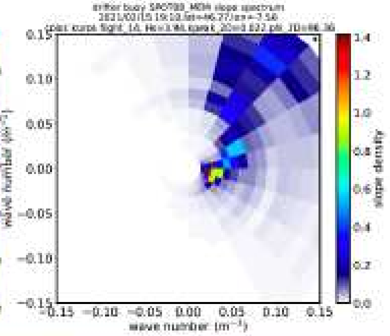
!! convention
« waves coming from »

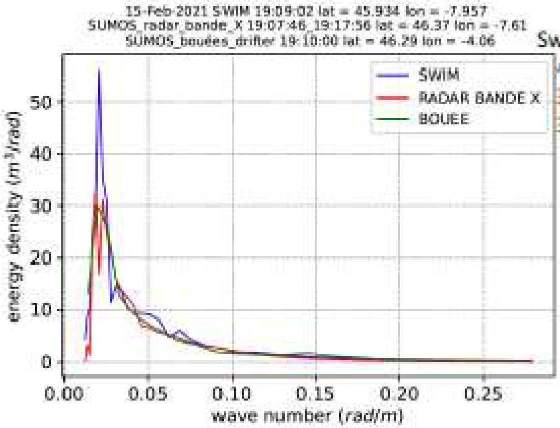
Buoy #08 19:10
46.27N, -7.67W

MLM



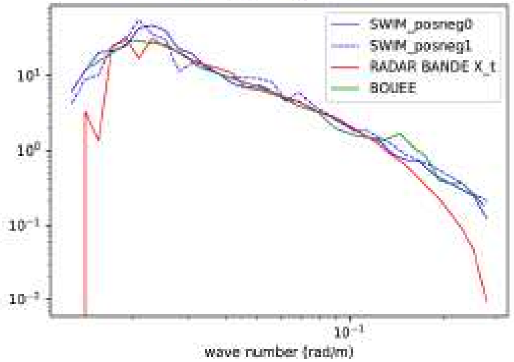
MEM





Swh (m)
4.01
3.69
3.94

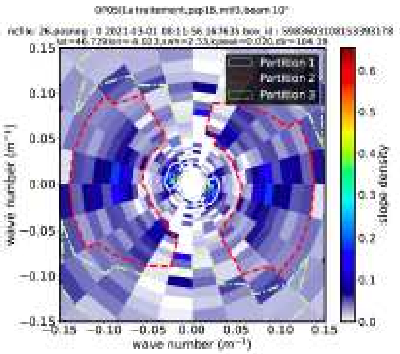
In log/log scale



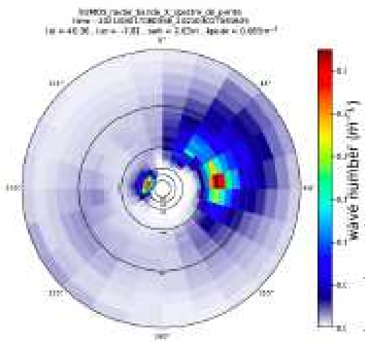
- 2D: good qualitative agreement, but buoy MEM and MLM significantly different. Consistent partitioning on SWIM spectrum
- 1D: Good agreement except for the shortest waves : X-band radar misses some energy- partly because of the normalization approach of X-band radar spectra (buoy reference limited to 70m in wavelength)
- SWIM more sharp near the peak

1st March 2021 (4/4): comparison SWIM / X-Band radar / buoy

SWIM-10°, 08:11
46.73N, -8.02W

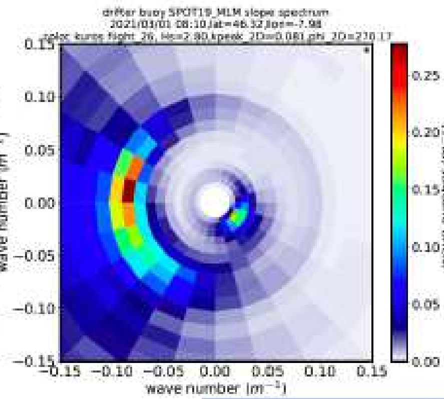


Band-X radar, 08:16
46.36, -7.81N

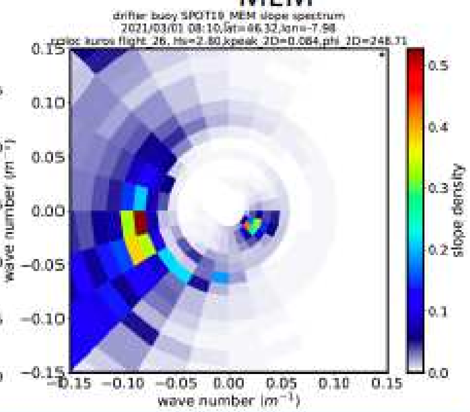


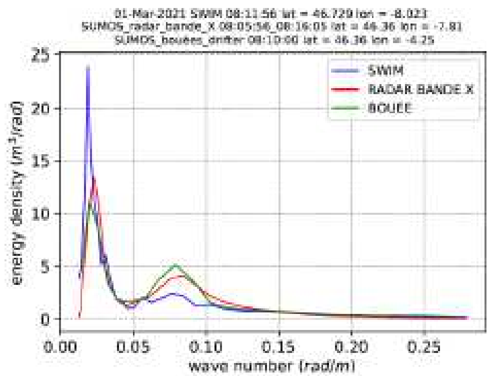
Buoy #19 01 March 08:10 UTC
46.32N -7.98 W

MLM



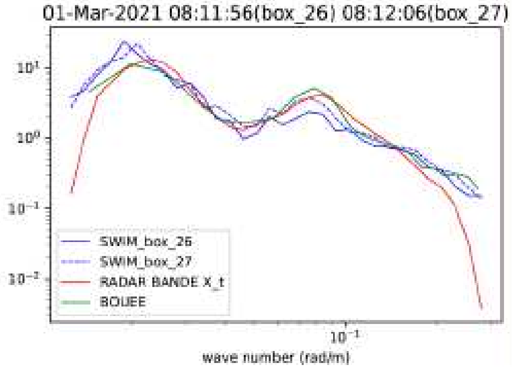
MEM





log/log scale

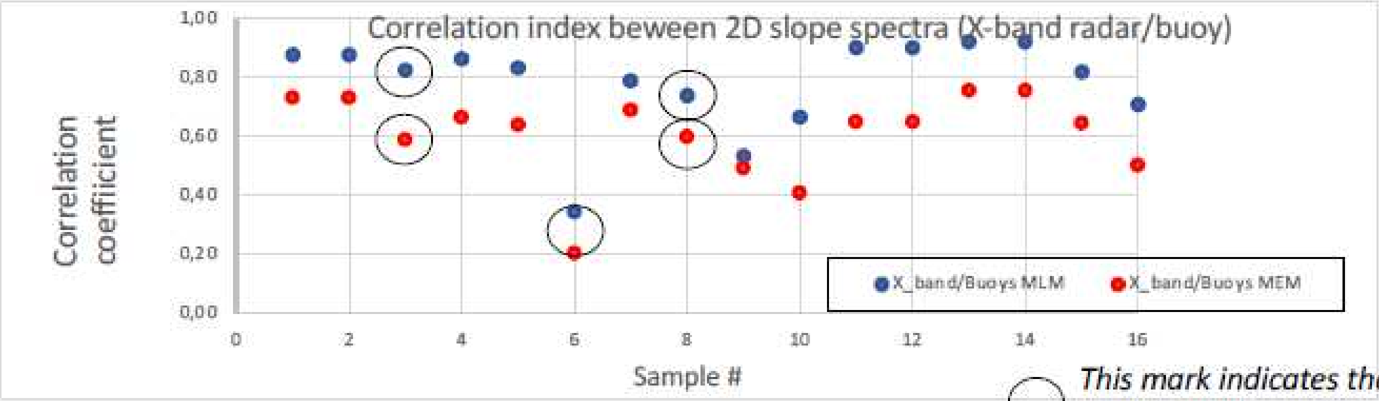
01-Mar-2021 08:11:56(box_26) 08:12:06(box_27)



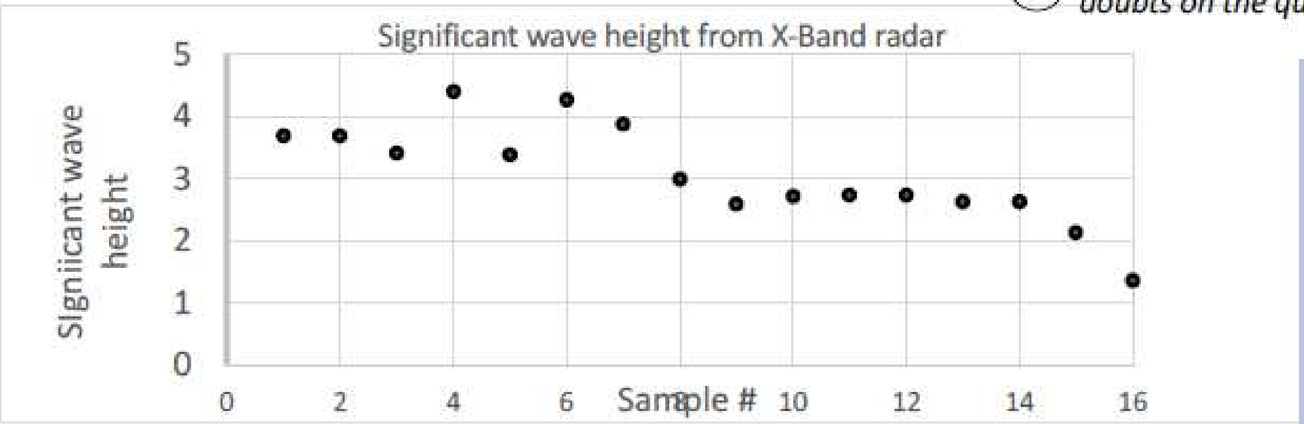
- 2D: good qualitative agreement, but buoy MEM and MLM significantly different. Consistent partitioning on SWIM spectrum
- 1D: Good agreement but wind sea (swell) under (over)-estimated from SWIM
- Swell-peak from SWIM more sharp
- Underestimation of shortest waves by X-band, maybe due to the normalization approach of X-band radar spectra (buoy reference limited to 70m in wavelength)

Correlation index between 2D slope spectra (Hasselmann et al, 1996)

$$C = \frac{\iint S_{p\_SWIM}(k,\Phi) S_{p\_bandeX}(k,\emptyset) k dk d\Phi}{\left[\iint S^2_{p\text{-}SWIM}(k,\Phi) \mathrm{k dk d\Phi} \iint S^2_{p\_bandeX}(k,\Phi) \mathrm{k dk d\Phi}\right]^{1/2}}$$



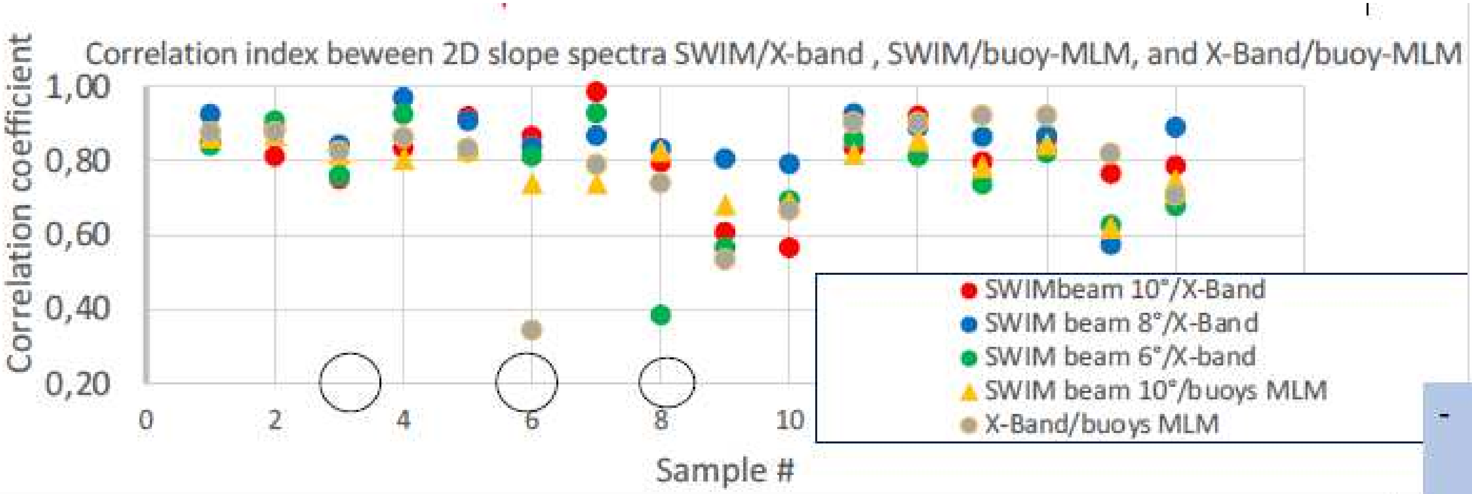
This mark indicates the samples where there are doubts on the quality of X-band radar data

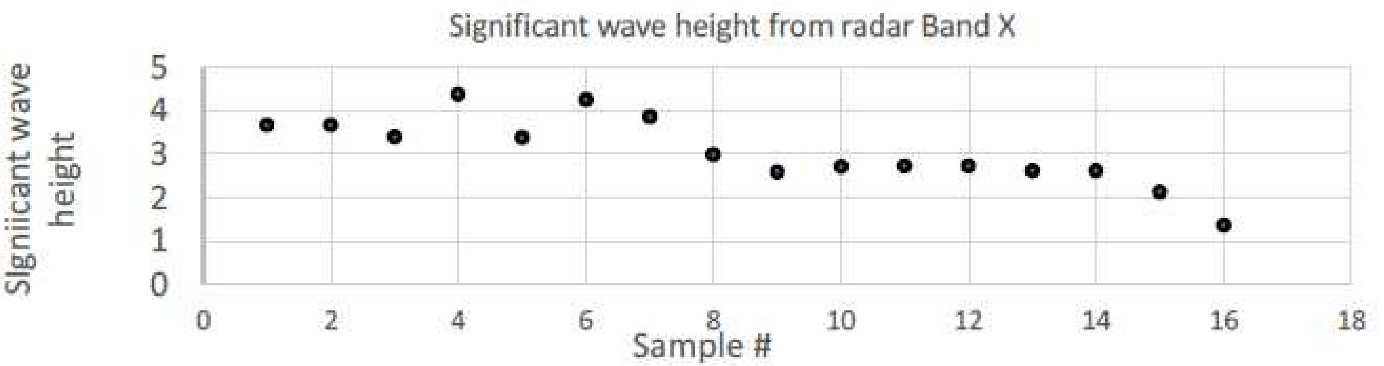


- Higher correlation of buoy_MLM/X-band than buoy_MEM/X-band

=> Recommendation to use MLM rather than MEM spectra from buoys for directional analysis (or maybe test EMEM)

Comparison of correlation indexes for the 3 beams of CFOSAT

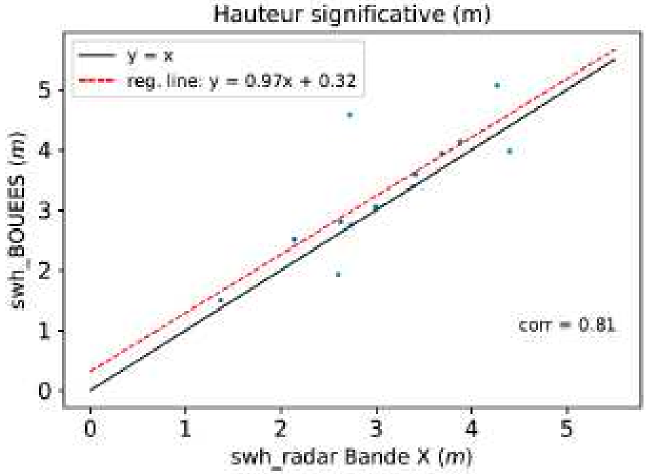




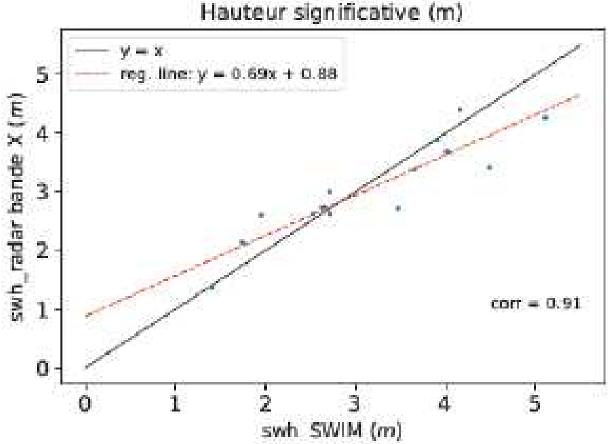
- compared to X-Band, SWIM-beam 10° and 8° have generally higher correlation compared to X-band vs SWIM-beam 6° (but not systematic)
- Correlation SWIM/buoy MLM generally less than SWIM/X-band

Comparaison of wave parameters X-Band/SWIM_beam 10°

SWH- Buoy/X-Band



SWH- X-Band/SWIM

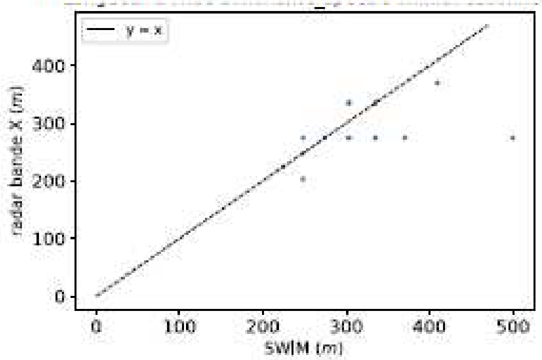


Bias between buoy and X-Band on the left plot in spite of the use of buoy to normalize the X-band spectra => probably du to the different limits for SWH calculation (reduced to SWIM range for X-band, but not for buoy in this plot)

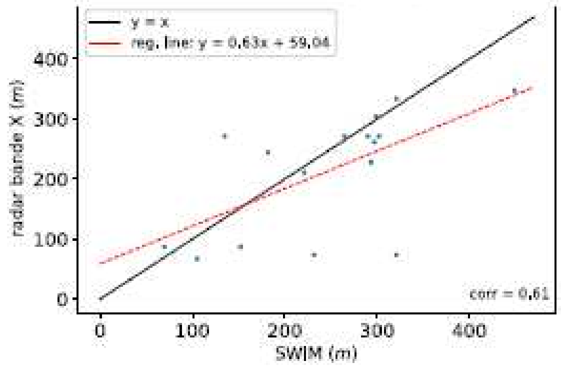
Tendency of SWIM to slightly over-estimate large SWH (but small number of cases)

Comparaison of wave parameters X-Band/SWIM_beam 10°

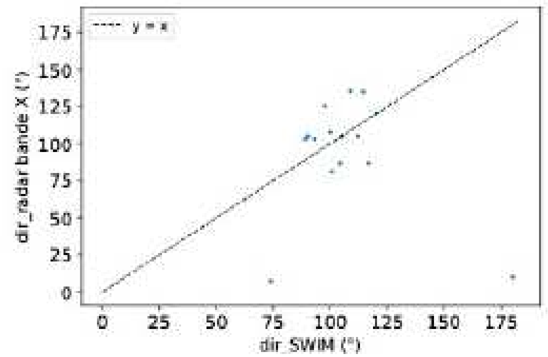
Dominant wavelength from **omni-directional** wave height spectrum



Dominant wavelength from **2D directional** wave slope spectra



Dominant direction from 2D directional wave slope spectra



Better agreement if we consider the peak wavelength form the 1D omni-directional spectrum than if we consider the peak wavelength from the 2D slope spectra => due to occurrence of mixed sea systems (peak not found on the same system on buoy and SWIM)

Summary

- Preliminary analysis shows qualitative consistent results
  - SWH globally consistent
  - Shape of 1D spectrum => seems more peaked on SWIM spectra than on buoy or X-band spectra, specially for the swell component
  - Comparisons of dominant wavelength is sensitive to the wayit is estimated (2D slope spectra, 1D height spectra). Probably due to the specific conditions encountered during SUMOS (mixed seas). Dominant direction from 2D spectra not very stable also die to the presence of mixed sea
  - Correlation between 2D slope spectra: high correlations obtained, and MLM for buoy spectra reconstruction is better appropriate
  - For directional analysis, X-band radar and KuROS seem more apropriate than buoy

To be further explored

- Due to mixed sea conditions, consolidate the method to estimate dominant wavelength/direction
- Estimate systematically correlation indexes between 1D and 2D spectra for SWIM/KuROs, KurOS/buoy, KuROS/X-band
- Extend comparison between mean parameters
- Spectral shape parameters (frequency spread, Qp and directional spread): first results obtained (not shown)=> to be continued
- Data set probably better appropriate to analyze details of spectra (directional spread, shape in frequency,..), which may help to analyze the SWIM MTF
- SUMoS observations used for testing impact of assimimation in models (L. Aouf)

Campaign data availability

SUMOS data set available on ODATIS:

https://www.odatis-ocean.fr/donnees-et-services/acces-aux-donnees/catalogue-complet#/metadata/b4061746-90af-4844-8d07-9a1f06a23925

- Airborne data coming from KuROS
  - L1: sigma0 at radar resolution
  - L2: wave spectra and associated parameters
- Wave drifting buoys (SPOTTER):
  - wave spectra measurement using GPS velocity measurements

Campaign data availability

SUMOS data set available on IFREMER site (soon on ODATIS):

- Access request form : https://forms.ifremer.fr/lops-siam/access-to-esa-skim-iasco-data/
- Data acces : https://data-skim-iasco.ifremer.fr/
- X Band radar
  - directional wave spectra measurements over scales of 20m to 50
- FLAME (Flux Air-MEr) buoy data
  - atmospheric parameters measurements as fluxes of momentum, heat, and CO_2 across the air-sea interface
- Wave drifting buoys (SPOTTER):
  - wave spectra measurement using GPS velocity measurements

Thank you for your attention!

BACKUP