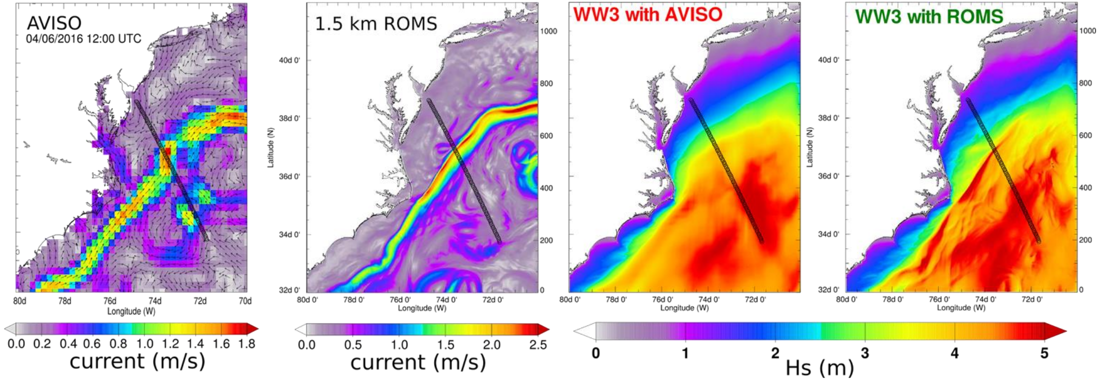
Processing ang wind-waves working group

With contributions from
D. Vandemark, B. Villas Bôas, P. Dubois, F. Nouguier, B. Chapron, L. Lenain, D. Sandwell et al.



Lenain & Pizzo (JPO 2021)

Note : this WG also covers SWOT total error (including roll …) analyses (not presented here).

Reminder: processing … see ATBD or

Dubois et al. (2020): https://tinyurl.com/dubois-WG

Ground processing : L2

	az res.	rg pos.	az pos.

…diate product

	500 m		250 m

…othed data product (Expert)

	500 m		250 m

…diate product

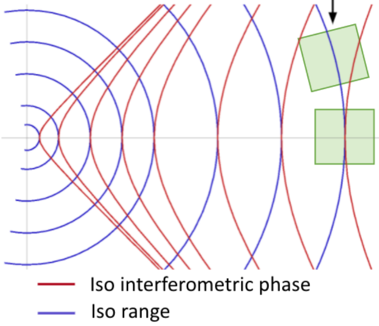
	500 m		250 m

…ata product (distributed)

Slide #10

Ground processing : L1

Within an outer beam IR pixel, the mean of the interferometric phase is not the interferometric phase at the center of the pixel



…tions

Slide #9

On-board (OB) LR processing

In a nutshell, the KaRIN LR OB processing
- is not trivial
- uses approximations because the OB knowledge is not optimal.
- destroys, with no possible step back, the highly resolved (< 500 m) highly sampled (< 250 m) data.

- **Why an OBP ?** The onboard LR processing aims at **reducing the data rate**
  → the data must be **averaged**

- **Why is it not trivial** ? We will later use the interferometric phase to obtain the SSH
  → we ensure that **the interferometric phase information is not destroyed** during the averaging process
  - The channels (master/slave) raw data phases are random → NOT good candidates for averaging.
  - The interferometric data phase (when unwrapped) is very stable → good candidate for averaging.
  - The phase noise of the interferometric data is a function of its coherence: to improve the coherence, the channel data must be prepared consequently *before* the interferogram generation (e.g., compressions).

For these reasons, the raw data channels are
- range compressed → co-registered → azimuth compressed → combined into an interferogram; which is
- unwrapped → averaged

1) Mean Sea Surface (MSS) for SWOT

CLS/CNES
Philippe Schaeffer
Marie Pujol
Yannice Faugere
Gerald Dibarboure
Nicolas Picot

SIO
David Sandwell
Yao Yu
Hugh Harper

DTU
Ole Andersen
Per Knudsen
Adeli Abulaitijiang
Shengjun Zhang

NOAA
Eric Leuliette
Walter Smith

- Need high resolution MSS for CAL/VAL early in the mission.
- MSS should have long wavelength accuracy from multidecadal repeat-track altimetry (ERM) and short wavelength precision from geodetic mission (GM) phases.
- Need uncertainty map as well as error spectrum.
- MSS should have an epoch and a linear variation with time.

1) Mean Sea Surface: Progress and Plans

- Group has generated and compared four models: CNES15 CLS_SIO, DTU18, and a hybrid SIO/CNES_CLS2015/DTU15. [1993-2012]
- Group is developing an uncertainty model.
- Group is adding a long-wavelength time variation.
- Also developing a mean sea surface slope and slope uncertainty model.

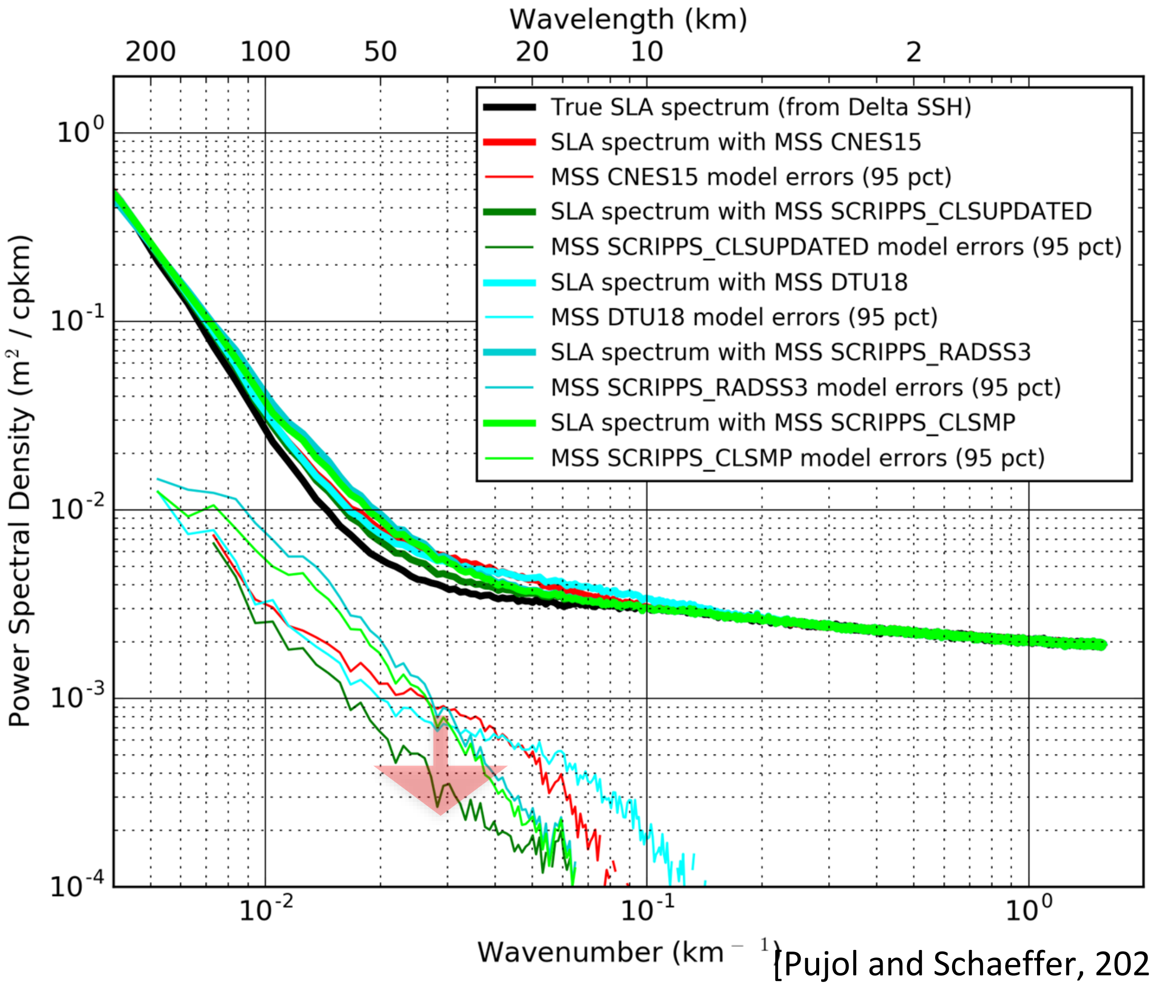
https://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mss/mss-description.html

1) PSD of Errors

Significant improvements in the **10-100 km** wavelength band.

Plan to deliver a combined MSS and error map to GECO in early 2022.

Continue to develop a linear temporal variation correction map.



[Pujol and Schaeffer, 202

2) Why wind waves?

A) Wind-waves are influenced by currents, and SWOT will be unique in mapping smaller scale currents: important for air-sea interactions, coastal applications, navigation safety …

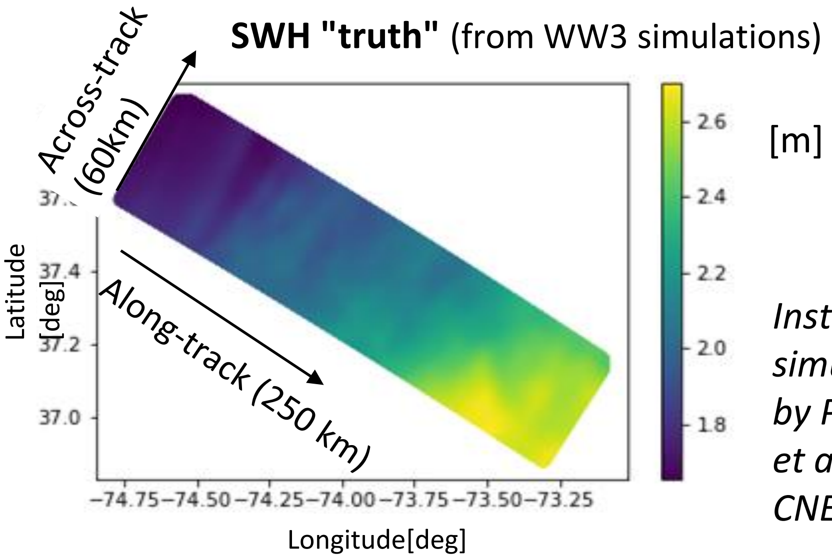
A) Wind waves are an important source of noise for KaRIN (Peral et al. 2015):

- What are the scales impacted by waves?
    - surfboard & other effects (see Peral et al.)
    - Waves vary on all scales (e.g. Ardhuin et al. JGR 2017, Villas Boas & al. 2020, Lenain & Pizzo 2021 …) : what does this do to SSH estimates?

- How can we best estimate sea state parameters to quantify the measurement errors?
- Do we understand everything about the measurement & processing ?
- What are the residual effects on small-scale geoid?
- What kind of information would be useful during CAL-VAL?

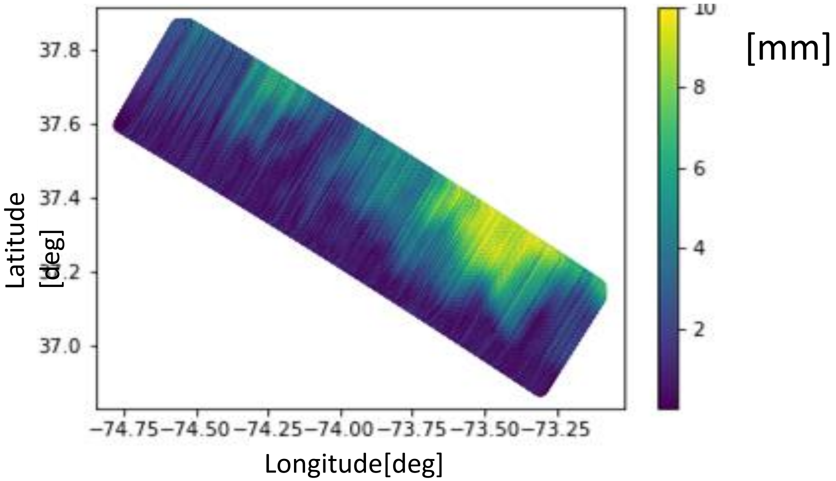
2) Estimation of SWH and impact

SWH "truth" (from WW3 simulations)



Instrument simulations by P. Dubois et al., CLS & CNES

SSB correction error
$$= 3\% \; [\text{SWH(truth)} - \textbf{SWH(estimated)}]$$

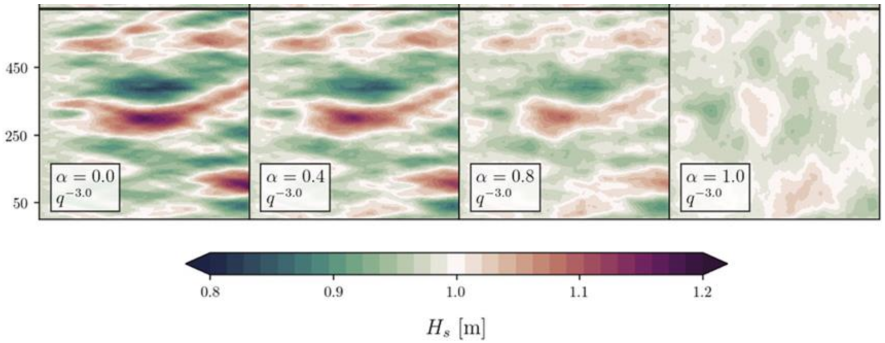


For SWOT, **SWH** is derived from **volumetric decorrelation** between the interferometric channels.
ATBD currently plans 1 SWH estimate in the middle of each swath (+ nadir).
Wave models show small-scale variability. How big is this?
What is the real number (3% is an order of magnitude, WW3 underestimates gradients …)?
If needed, what other wave proxy can we use? (e.g. cross-track grid of Doppler centroid) ?

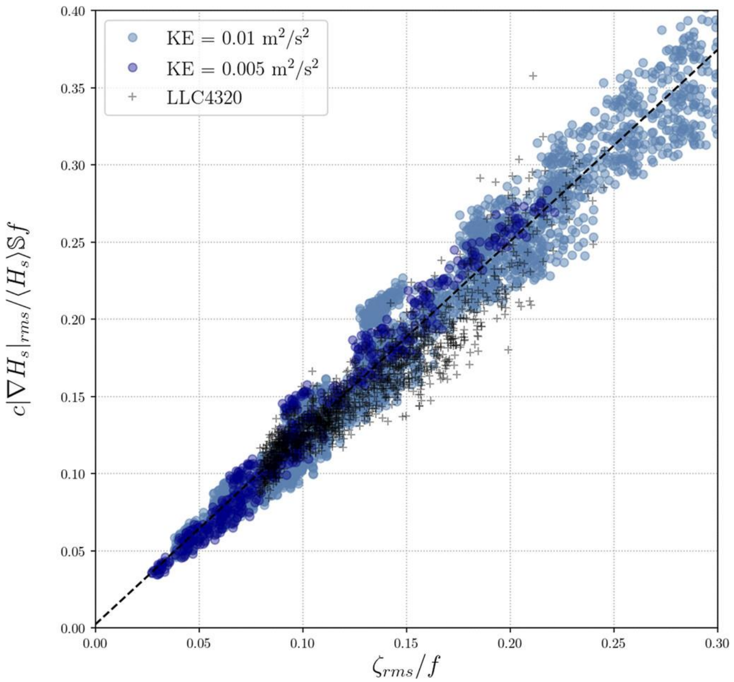
Related activities: Cal-Val with wave measurements (e.g. airborne “MASS”, Lenain et al., SIO), coupled numerical modelling with assimilation (SIO + JPL), interpretation of Doppler centroid & NRCS gradients (LOPS) …

2) Spatial variability of SWH

- We now understand that scales < 100 km are dominated by currents or coastal effects
- Empirical relation between SWH spectrum and surface current spectrum (e.g. Villas Boas & al. 2020)
- More theoretical work underway
- Processing of nadir altimeters with denoising (Quilfen & Chapron 2019): done as part of ESA SeaState CCI (Dodet et al. 2020, 2021). Analysis is coming.

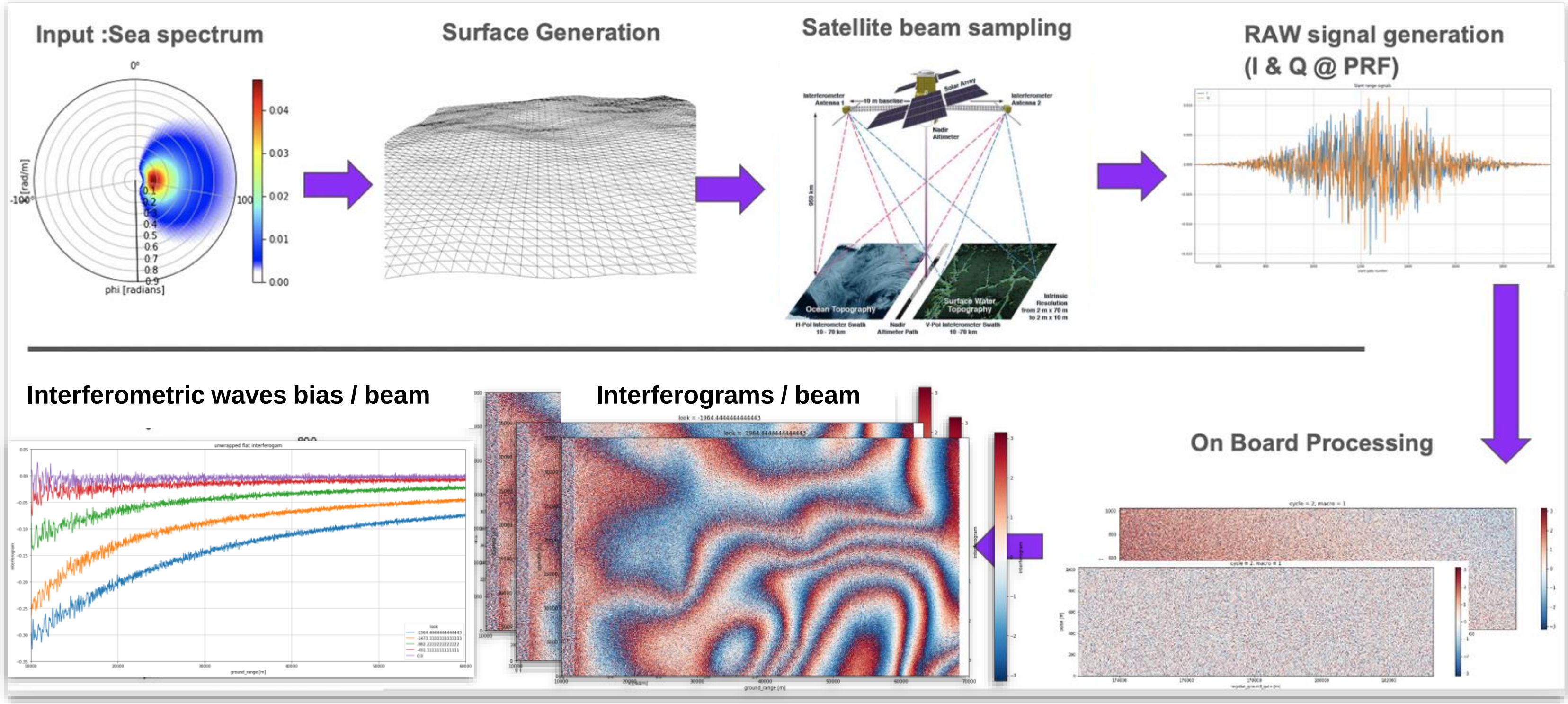


(Villas Bôas & al., J. Phys. Oceanogr. 2020)



3) Are we missing small-scale correlation effects?
Development of end-to-end simulator (F. Nouguier)

Adaptation to SWOT was completed 10 days ago: very preliminary simulations

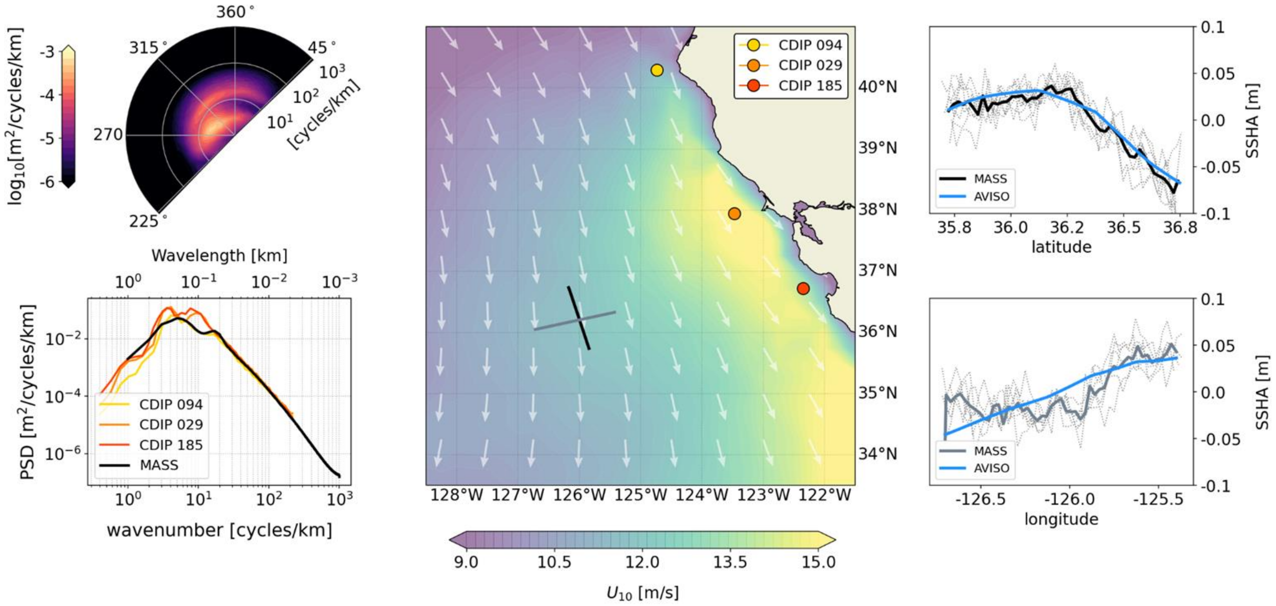


4) Wave analysis during CAL-VAL

- End-to-end simulator to be applied to Southern Ocean (using remote sensing, e.g. SWIM on CFOSAT as input)

- Wave measurements possible during in situ experiments:
    - Basic wave data from drifting wave buoys at adopt-a-X-over sites
    - Detailed spatial observations of directional and spectral properties of surface waves & slopes data from airborne MASS (SIO)

4) Example of wave aliasing in MASS lidar data: April 9 flights: one swell and one sea



- Strong winds 11-15 m/s
- Swath width: ~500 m

Sea:

H_s = 3 m

T_p = 6 s

λ_p = 60 m

θ_p = 321°

Swell:

T_p = 11 s

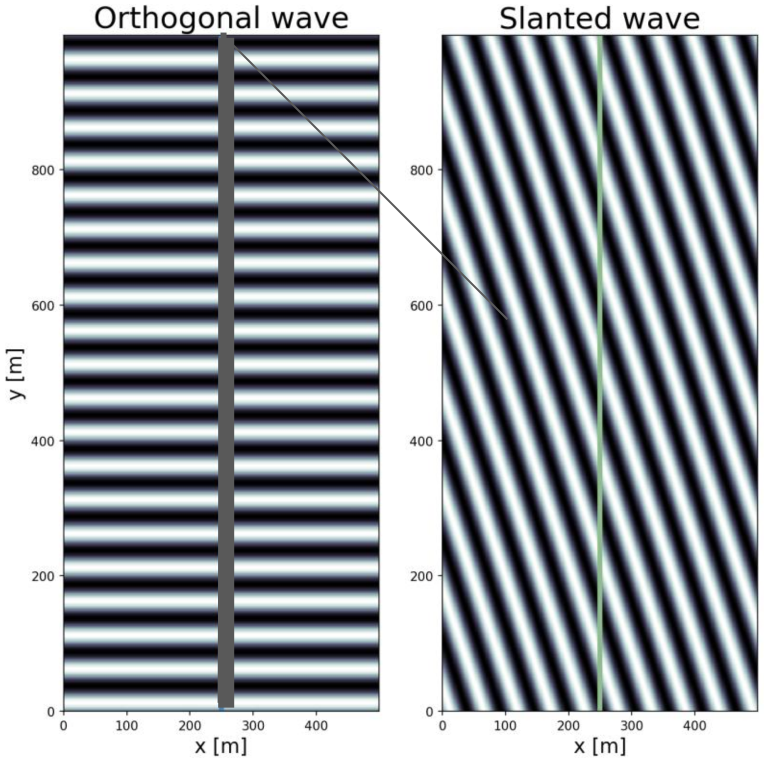
λ_p = 200 m

θ_p = 308°

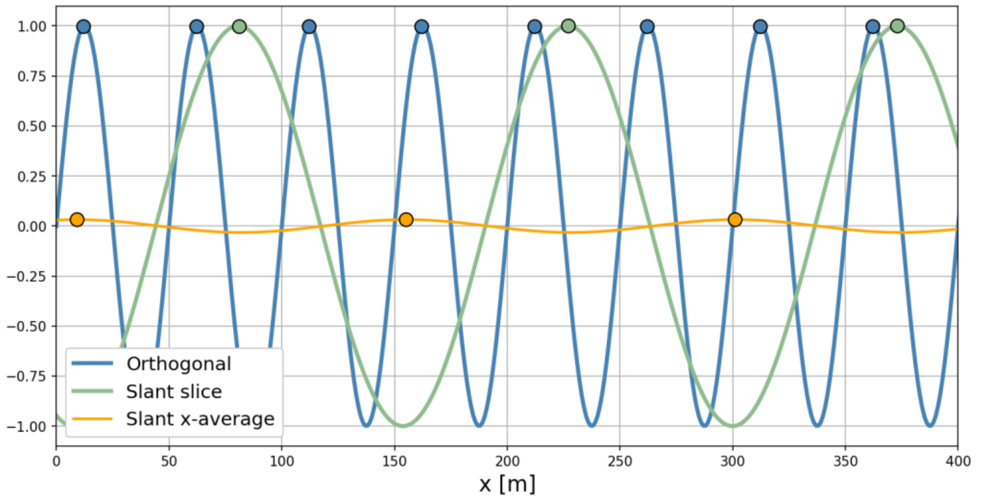
Aircraft heading: 341

B. Villas Bôas, L. Lenain, B. Cornuelle, S. Gille, and M. Mazloff

4) Example of wave aliasing in MASS lidar data: why wave directions matter:

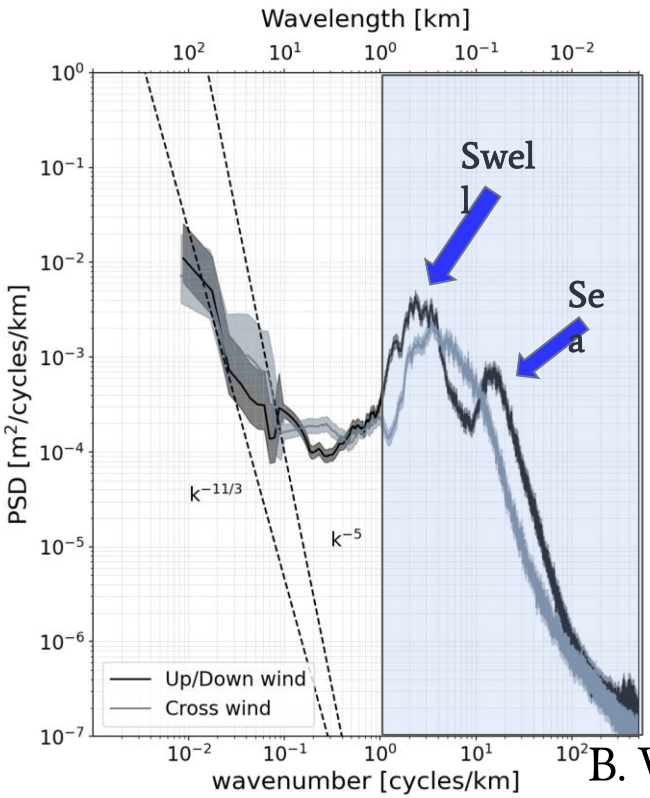


- Across-track averaging lowers the wavenumber and attenuates the amplitude of oblique waves



*Similar to Ray and Zaron (2015) for internal tides

4) Example of wave aliasing in MASS lidar data: Across-track averaged spectrum

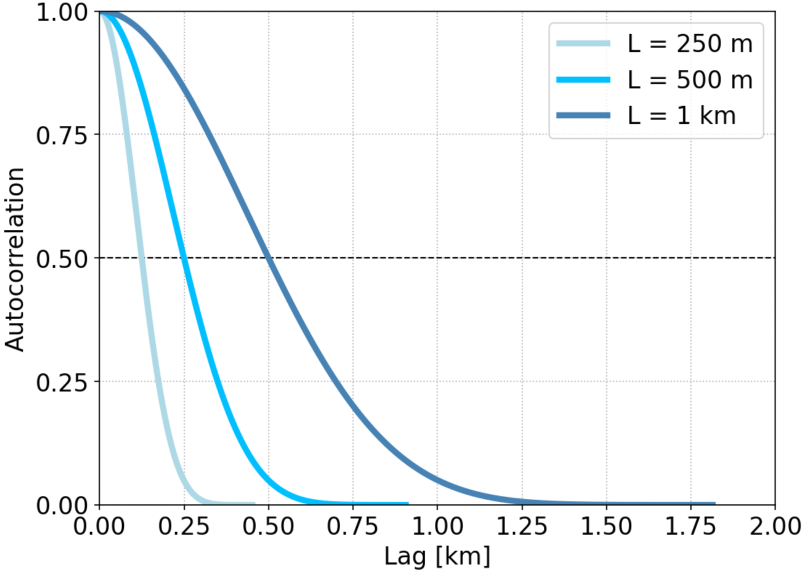


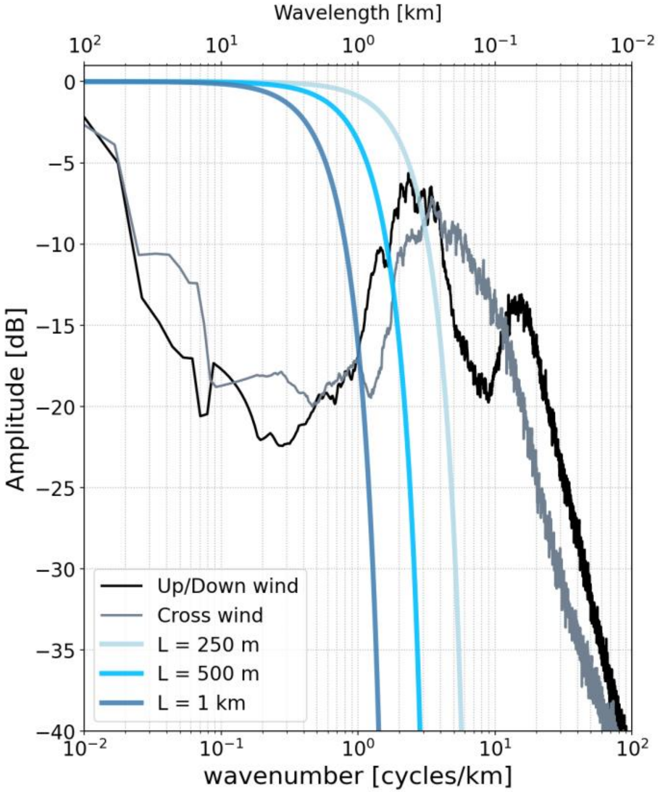
- The blue zone (k > 1 cycles/km)
  - At high wavenumbers the spectrum is blue and dominated by surface waves
  - We see both the swell and sea peaks
  - Up/down-wind and cross-wind are remarkably different
    - Across-track average depends on relative direction between waves and the aircraft heading.

B. Villas Bôas, L. Lenain, B. Cornuelle, S. Gille, and M. Mazloff

Filtering the surface wave signal

- Hanning window in the azimuth direction



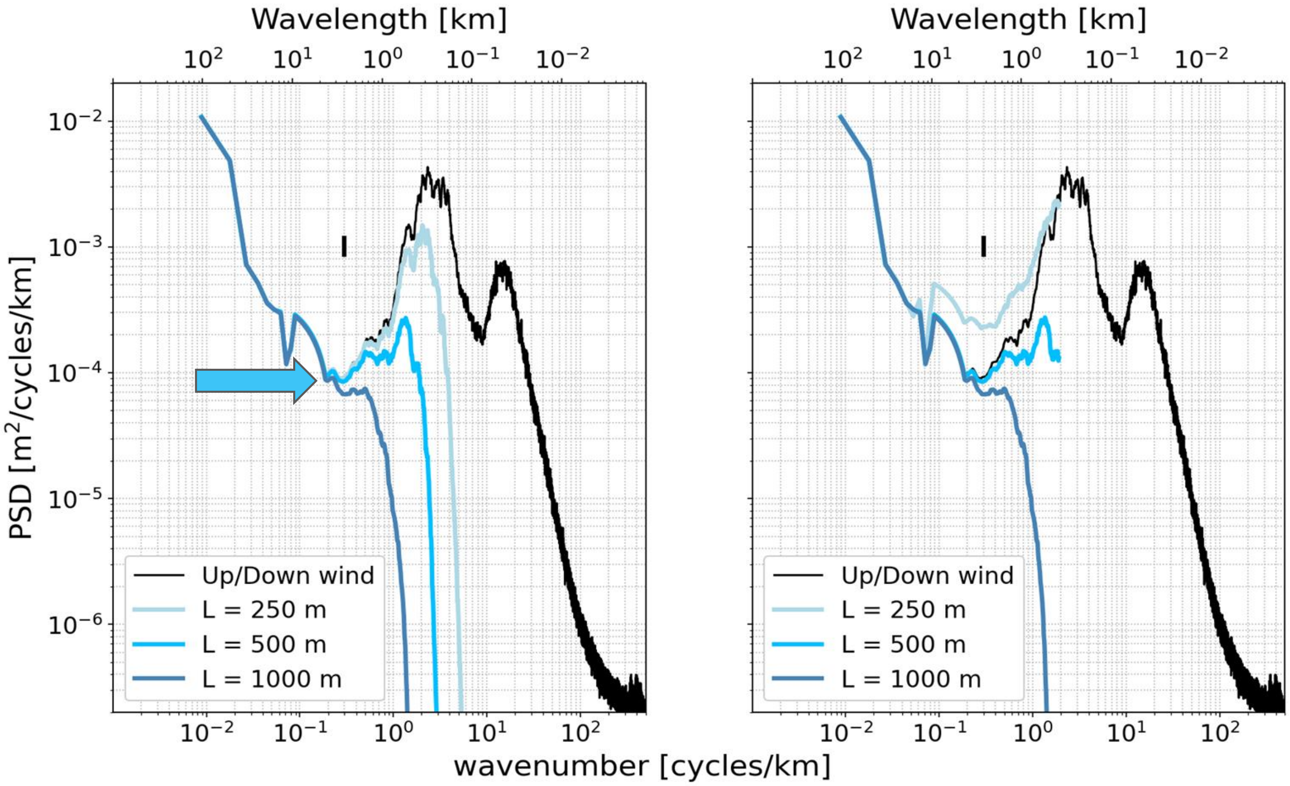


B. Villas Bôas, L. Lenain, B. Cornuelle, S. Gille, and M. Mazloff

Posting at 250 m

OBP choice:

Good for alias minimization



B. Villas Bôas, L. Lenain, B. Cornuelle, S. Gille, and M. Mazloff

Summary

- Mean Sea Surface work progressing: new MSS will be available for CAL/VAL

- We now know better the expected SWH variability at scales 10 to 100 km, more to come with nadir altimeters… but 1D only.

- End to end simulations can test hypotheses on correlations (or lack thereof) at sub-500 m scales: are there some unknown residual errors caused by wave spatial variability? Wave-induced Doppler?

Directional wave measurements during CAL-VAL can be useful to verify the known wave aliasing effects (see example by Villas Bôas et al. using MASS during SWOT pre-launch experiment and also Yu et. al., 2021 using ICESat-2)

Directional wave spectra from CFOSAT (extension of mission after 2022 under discussion) can be used to look at wave impacts, globally (in particular in southern ocean).