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TAKING THE PULSE
OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

SWIM ocean surface wave spectra L2S product and application to swell tracking

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CFOSAT mission

- Chinese-French Oceanic SATellite (CFOSAT) is a joint mission of the Chinese (CNSA) and French (CNES) space agencies devoted to the monitoring of the ocean surface wind and waves

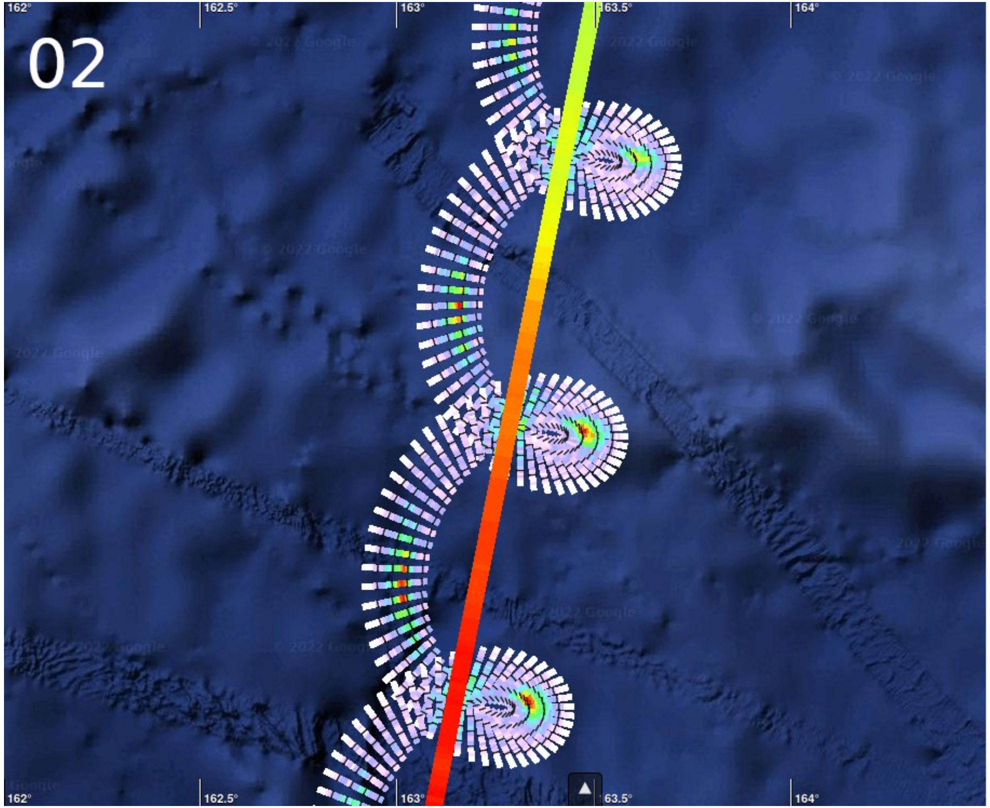
- Launched in October 2018, CFOSAT carries 2 active sensors both in Ku-band:
  - SWIM dedicated to the measurements of directional wave spectra
  - SCAT dedicated to the measurements of ocean surface winds

- On french side, products are available through 2 centers
  - CNES Wind and Wave Instrument Center (CWWIC)
    - NRT L1 and L2 products
    - see https://www.aviso.altimetry.fr/en/data/products/wind/wave-products/wave-wind-cfosat-products.html
  - IFREMER Wind and Wave Operational Center (IWWOC)
    - delayed mode L2S to L3/L4 products
    - motivations: long and consistent time series to complete climate data series, synergy between SCAT/SWIM and alternative processing methods and testing
    - see https://cersat.ifremer.fr/fr/Projects/Recent-and-ongoing-projects/IWWOC

SWIM instrument

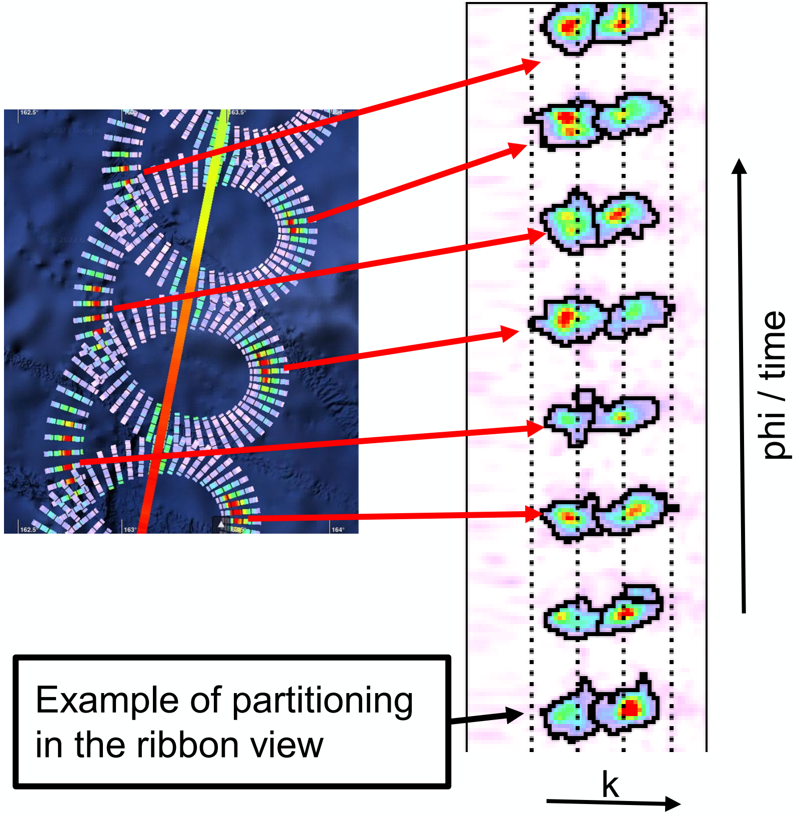
- SWIM (Surface Wave Investigation and Monitoring) measures the ocean surface wave related modulations in Ku band using a rotating instrument
- In nominal macrocycle mode, it provides a directional 1D wave spectra
  - every ~7 degrees
  - for each of its 5 beams at 2, 4, 6, 8, and 10° incidence angle
  - resulting in a very special cycloid ground footprint geometry.

Example of 1D raw spectra projected over range footprint With nadir Hs



IWWOC SWIM L2S product overview

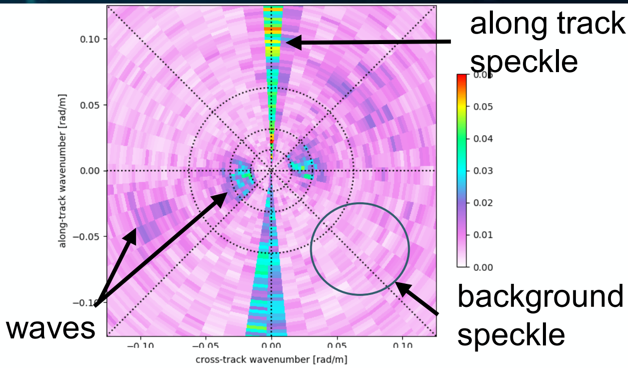
- L2S product is a L2 like product with the following features:
  - wave partitioning along the continuous cycloid ("ribbon view")
  - speckle correction based on a learned look-up table
  - empirical MTF (not yet, work in progress)
  - all beams including 2 et 4 degrees beams (no onboard range migration)
  - includes variables of interest : sigma0, raw spectra, nadir variables, ancillary data
- First public release in early 2022 (version v1.0):
  - HTTP access: https://data-cersat.ifremer.fr/projects/iwwoc/swi_l2s/
  - FTP access: ftp://ftp.ifremer.fr/ifremer/cersat/projects/iwwoc/swi_l2s/



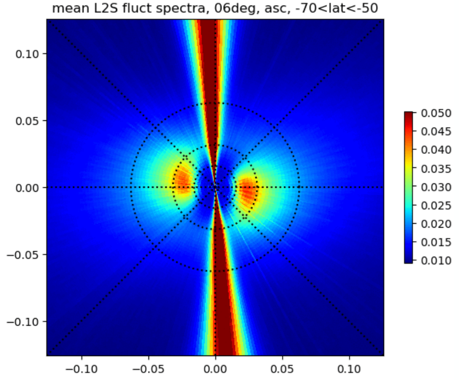
Example of partitioning in the ribbon view

Speckle noise

- Speckle noise in the SWIM case is reduced by on-board averaging of many pulses
- 2 speckle regimes exist:
  - in the along-track directions, a poor diversity of phase changes between pulses make the speckle noise very correlated and less reduced by averaging
  - outside this along-track domain, the diversity of phase changes is good enough to have a good reduction of speckle level (background speckle)
- Characteristics of the along-track regime:
  - azimuthal position of maximum speckle varies with pass and latitude due to earth velocity
  - azimuthal width decreases as the angle of incidence increases, from ~27.5 degrees at beam 02 to ~10 degrees at beam 10



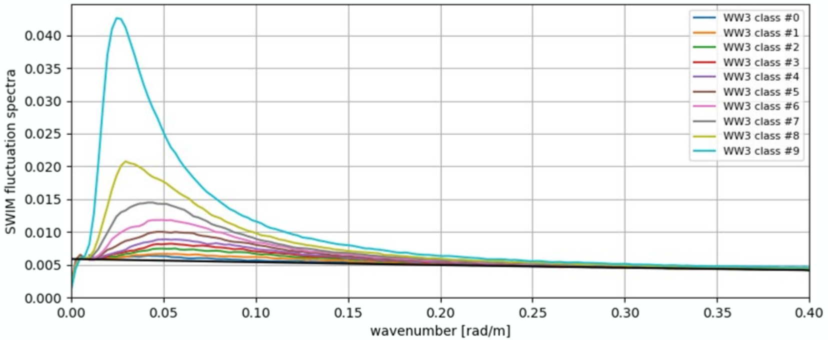
1 rotation (beam 10)

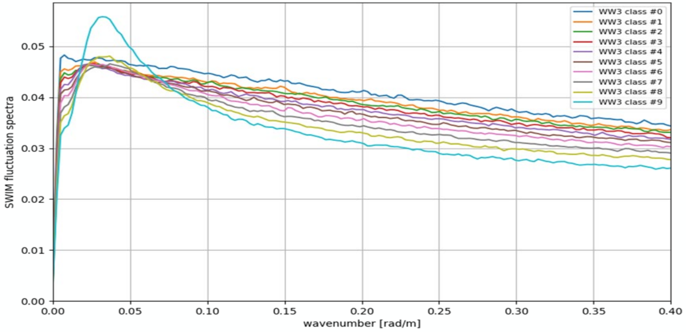


Average according to pass and latitude (beam 6)

Speckle noise

- Investigations on speckle also revealed that in the along-track regime, speckle noise varies with sea state





Averaged SWIM spectra according to WW3 energy in cross-track (left) and along-track (right)

→**L2S strategy for speckle correction** is to use a look-up table empirically learned according to the beam, the azimuth, the pass, the latitude and the wind (as a proxy of sea state)

Modulation transfer function (MTF)

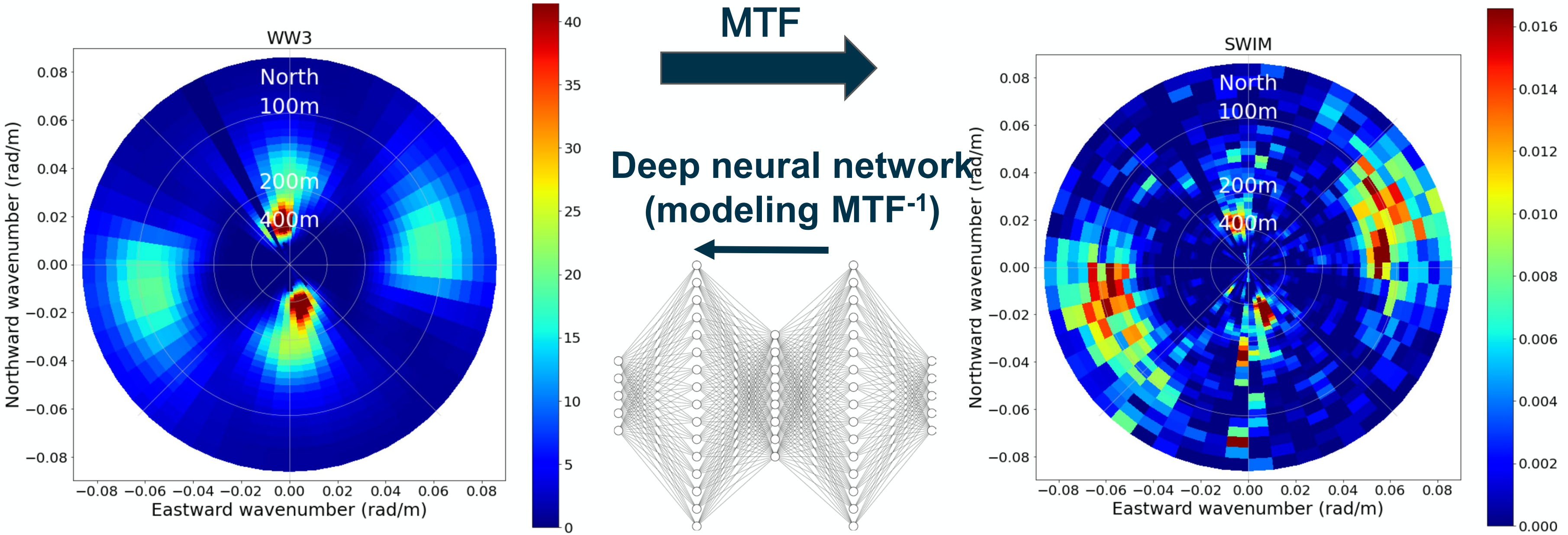
- **Current L2S strategy:** MTF is theoretical (tilt effect, Jackson 1981) and parameterized with ancillary wind
  - Still some questions:
    - impact of wave directional spread on MTF
    - impact of range bunching especially at low incidence beams

- **(work in progress) Data-driven MTF inversion:** Learn MTF directly from SWIM data, coupled with model and/or in situ data (WaveWatch3, buoy data)
  - classical statistical approach: understand the link between SWIM and “ground truth” according to beam, azimuth, wind, wave directional spread
  - deep neural networks approach
    - Preliminary results show good mean performance, but more work is still needed
    - Multiple improvements to be explored (different network architectures, network pre-training on synthetic datasets, data augmentation, transfer learning, etc)

Data-driven inversion of the MTF

Objective: Learning the (inverse) MTF directly from data

$P_m = MTF(F_m, k, ?)$



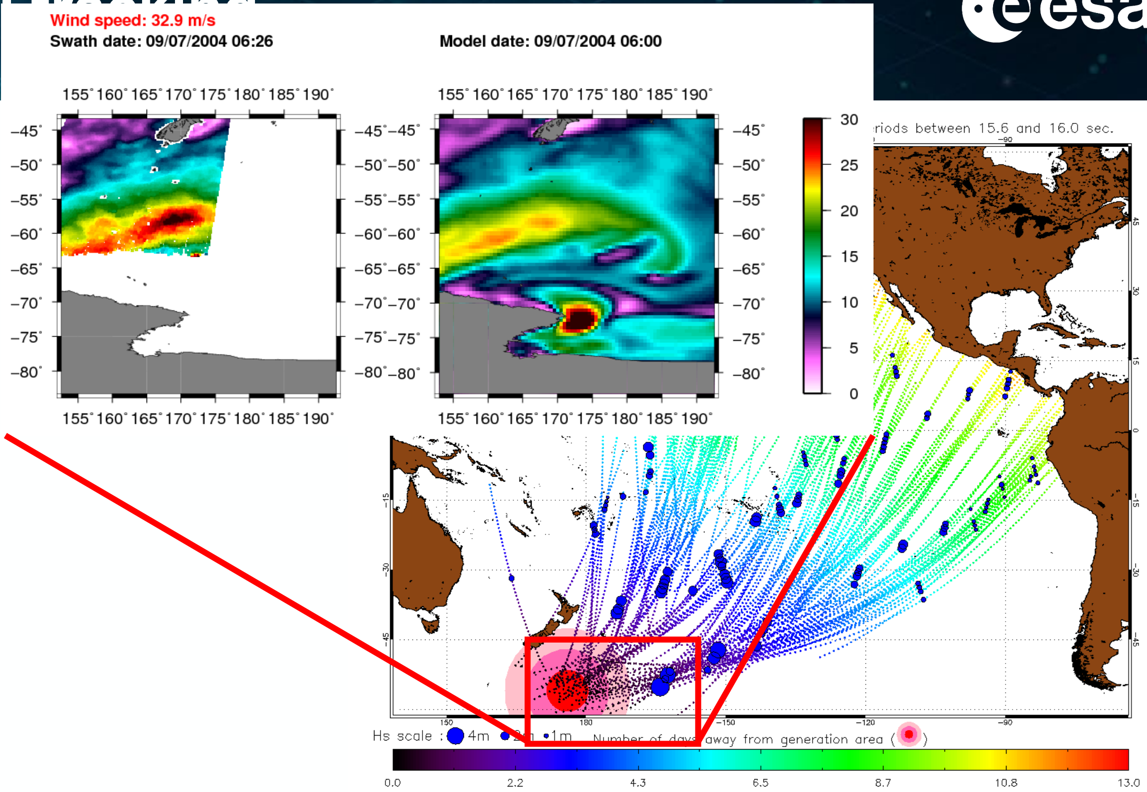
Wave directional spectra $F_m(k,\theta)$
(model with 180° ambiguity added)

Measured modulation spectra $P_m(k,\theta)$

First use of L2S for swell tracking

<u>Firework analysis : Principle</u>

- Extraction of swell systems parameters from wave spectra level2 products.
- Backward propagation to identify the swell origin (Storm source).
- Identification of all swell observations relative to a given Storm source.
- Determination of the propagation path by forward and backward propagation between observations (using deep water waves dispersion relation).

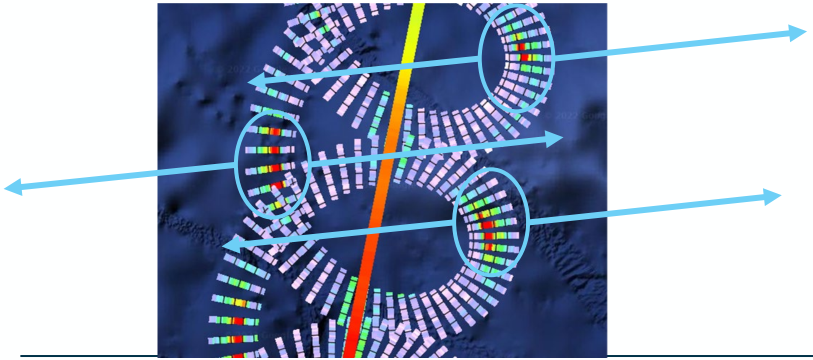


Propagation of 15-16s swell from July 8 to July 20, 2004, Envisat

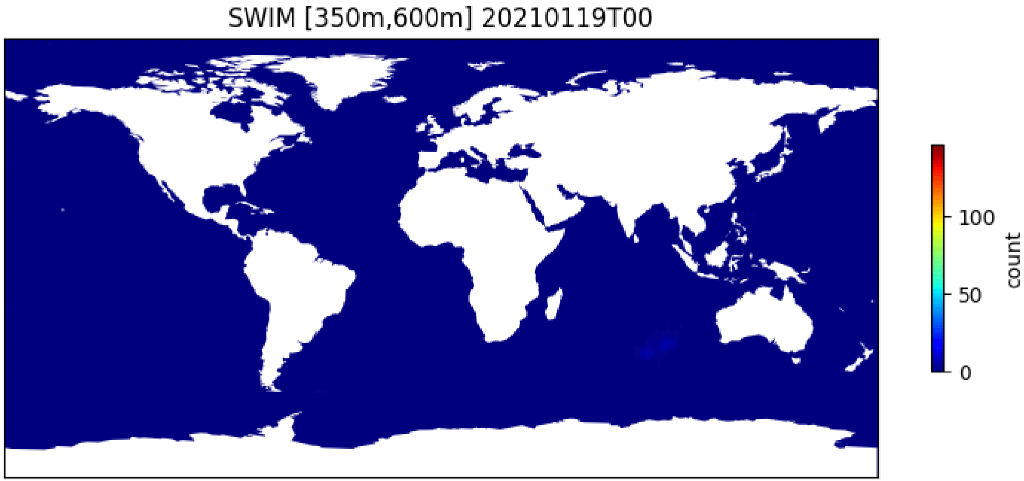
First use of L2S for swell tracking

L2S inputs

- L2S partitions from 2021-02-01 to 2021-02-14
- use of all 5 beams 2/4/6/8/10° (only wavelengths longer than 350m for beams 2 and 4 degrees)
- observations are back propagated in two opposite directions because of SWIM propagation 180° ambiguity



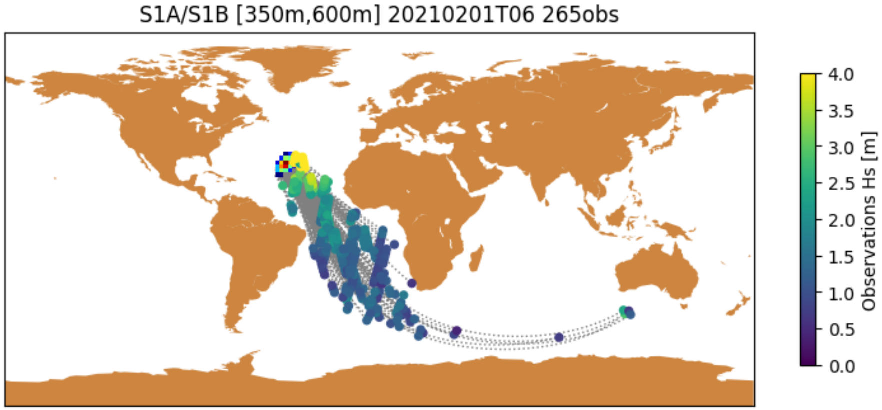
One month of SWIM back-propagation rays density

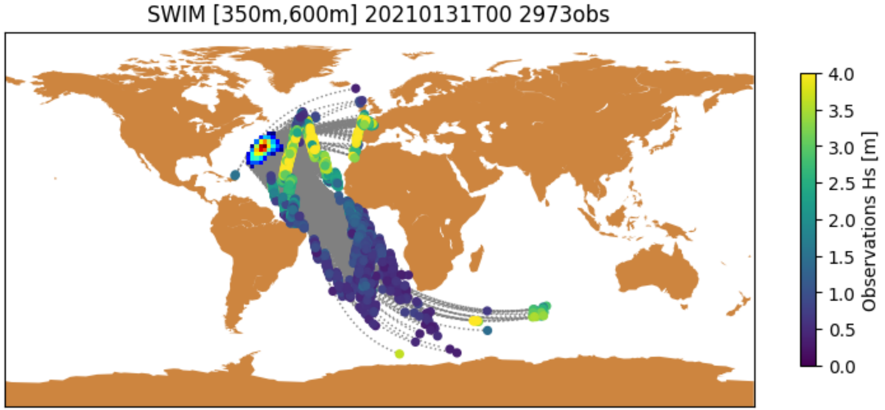


First use of L2S for swell tracking

Storm source seen by S1A/S1B WV (top) and SWIM (bottom) - refocusing

- higher density of observations with SWIM (factor 10)
- SWIM brings observations in North Atlantic where S1 WV mode is not acquired
- different overall sampling of SWIM (orbit daily drift about 380km to East) and S1 (1000km to West)

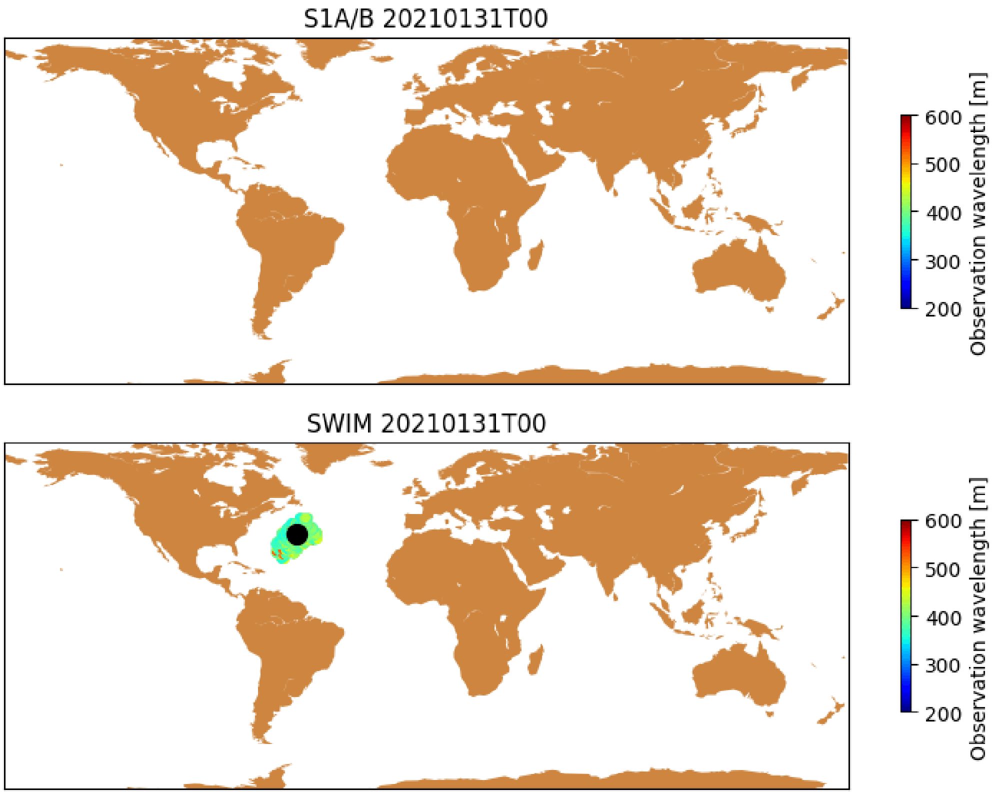




First use of L2S for swell tracking

One storm source seen by S1A/S1B WV (top) and SWIM (bottom)

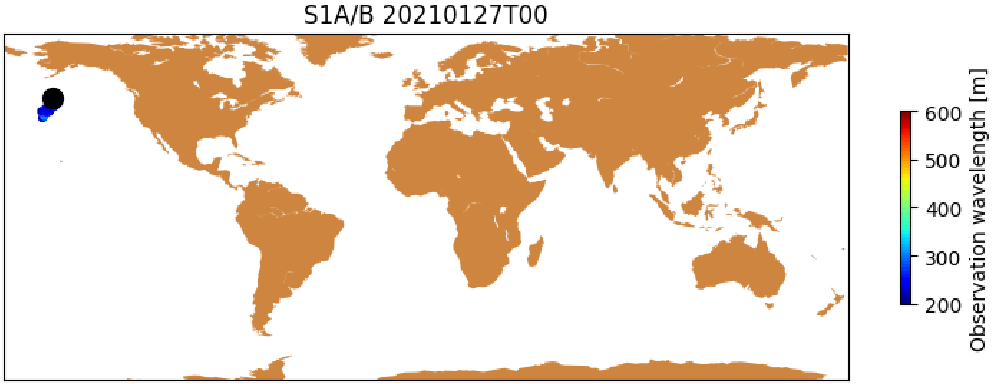
- animation including forward propagation

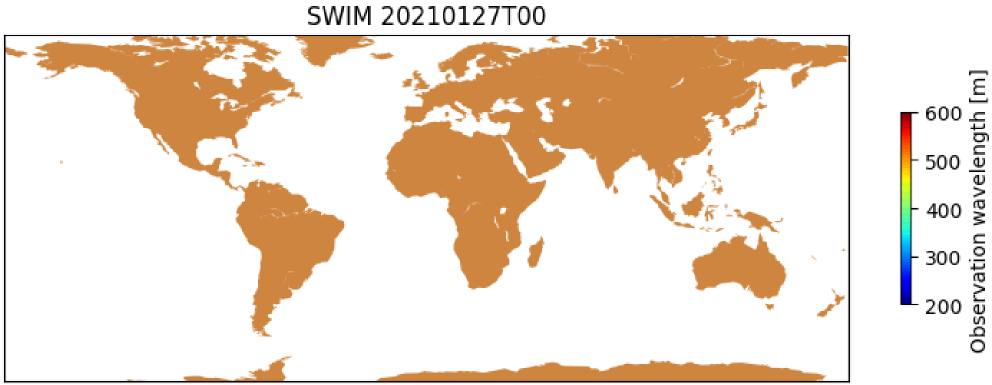


First use of L2S for swell tracking

All storm sources seen by S1A/S1B WV (top) and SWIM (bottom) - propagation

- One month animation including forward propagation





L2S limitations and evolutions

- L2S is still a young product (freshly released). To be used with caution for climatological studies because of:
  - MTF not yet learned making Hs questionable
  - False detection of wave partitions

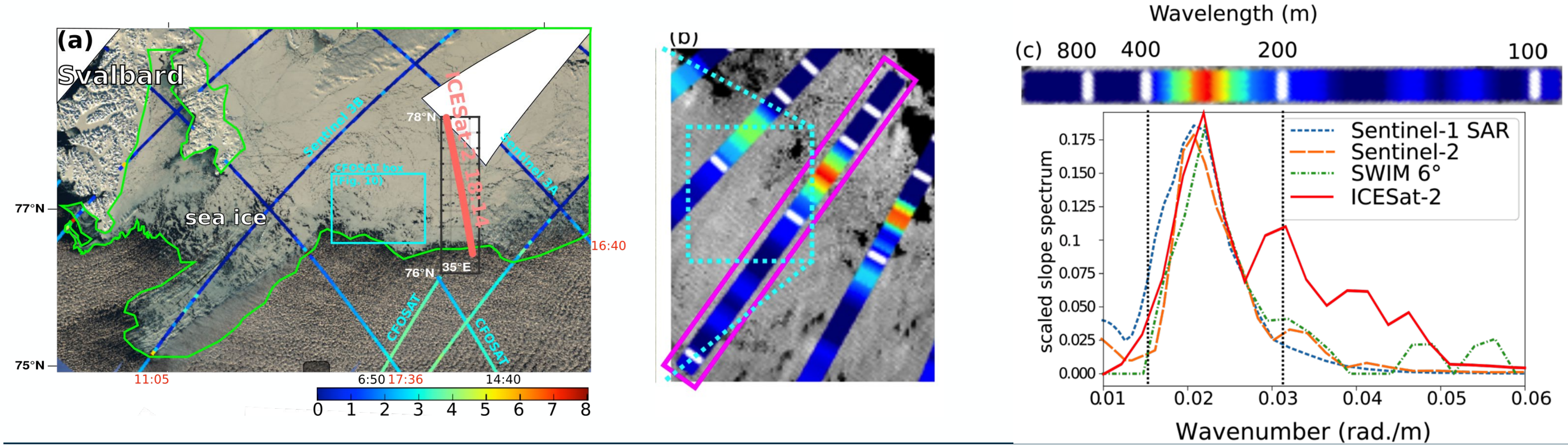
    –> Feedbacks are welcome !

- Short-term evolutions : planned for 2022
  - MTF learning from observations
  - partitioning improvement
    - reduce number of false partitions (beam synergy)
    - propagation ambiguity removal (model a priori, fireworks feedback, …)
  - systematic production of L3 products (gridded partition parameters statistics) and L4 products (fireworks).

Applications

- wave attenuation under Sea ice
- wave coupling with ocean circulation models
- air sea interaction analysis

Talk (16h55, H2-17): Wave attenuation under sea ice in the Arctic: : a review of remote sensing capabilities



Thank you !

- L2S free data access:
  - short delayed time: <7 days
  - HTTP access: https://data-cersat.ifremer.fr/projects/iwwoc/swi_l2s/
  - FTP access: ftp://ftp.ifremer.fr/ifremer/cersat/projects/iwwoc/swi_l2s/

- A few L2S samples (raw spectra) as well as CWWIC L2 samples are visible at https://cfosat.oceandatalab.com