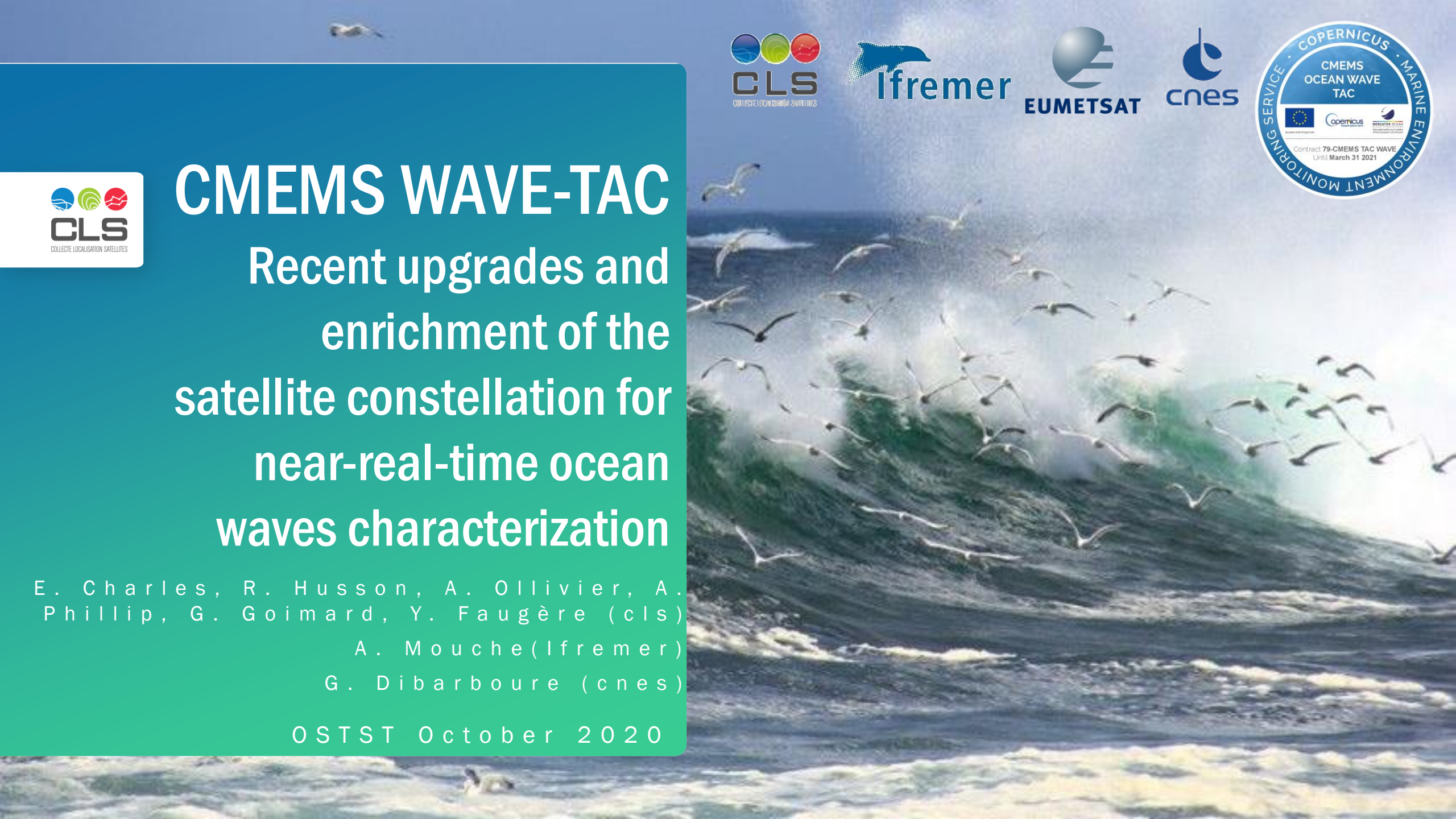


CMEMS WAVE-TAC

Recent upgrades and enrichment of the satellite constellation for near-real-time ocean waves characterization

E. Charles, R. Husson, A. Ollivier, A. Phillip, G. Goimard, Y. Faugère (cls)

A. Mouche(Ifremer)

G. Dibarboure (cnes)

OSTST October 2020

Outline

1. Status of CMEMS WAVE-TAC available products and missions
2. Integration of CFOSAT nadir and HaiYang-2B
3. New altimetry wind speed
4. Upgrade of Level-4 SWH mapping
5. Better characterization of long swells in spectral product
6. Next upgrades: L4 SPC and CFOSAT off-nadir

1 – Status of CMEMS WAVE-TAC available products and missions

CMEMS Wave products result from the contribution of several agencies

Level-2

- Sentinel-3A
- Sentinel-3B
- Jason-3
- Sentinel-1A
- Sentinel-1B
- SARAL/AltiKa
- CryoSAT-2
- HaiYang-2B
- CFOSAT

Level-2P

- Sentinel-3A
- Sentinel-3B
- CFOSAT

Available on www.aviso.altimetry.fr and EUMETCAST (via eoportal.eumetsat.int)

Internal product

Jason-3
Sentinel-1A
Sentinel-1B
SARAL/AltiKa
CryoSAT-2
HaiYang-2B

Level-3

- Sentinel-3A
- Sentinel-3B

- Jason-3
- SARAL/AltiKa
- CryoSAT-2
- HaiYang-2B
- CFOSAT
- Sentinel-1A
- Sentinel-1B

Level-4

L4 SWH

- Sentinel-3A
- Sentinel-3B
- Jason-3
- SARAL/AltiKa
- CryoSAT-2
- HaiYang-2B
- CFOSAT

Planned for DEC-2020
L4 SPC

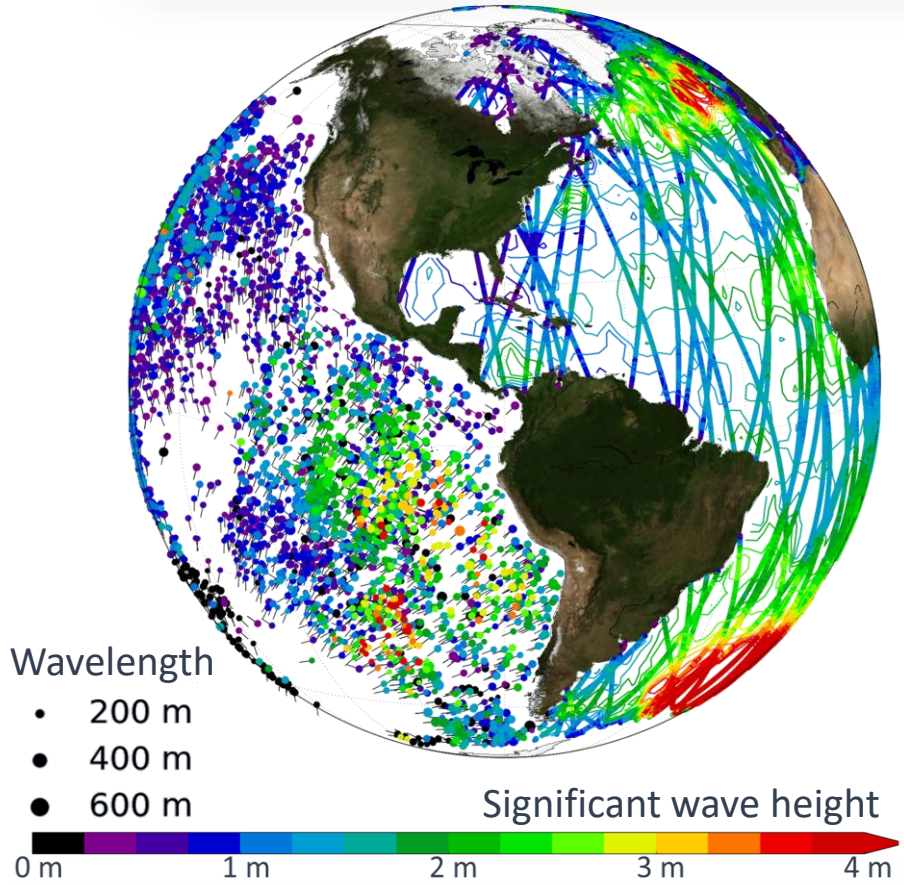
Sentinel-1A
Sentinel-1B

Available on https://marine.copernicus.eu

Thanks to these contributions, R&D and upgrades at each processing level can benefit the CMEMS user community

R&D activities (new retrackings, CCI …)

Status of CMEMS WAVE-TAC available products and missions



Pacific: SAR-derived swell conditions ; Atlantic: Altimetry-derived along-track and gridded (contours) significant wave height

WAVE_GLO_WAV_**L3_SWH_NRT**_OBSERVATIONS_014_001:

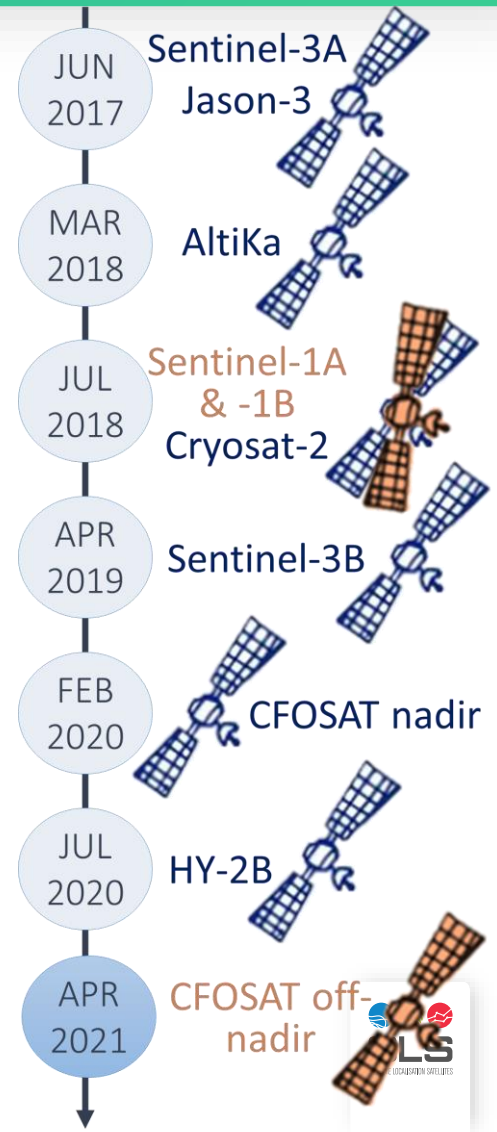
- Real-Time Level-3 waves from altimetry
- Edited, inter-calibrated, noise-filtered significant wave height (SWH) and wind speed

WAVE_GLO_WAV_**L3_SPC_NRT**_OBSERVATIONS_014_002:

- Real-Time Level-3 waves from SAR
- Spectral integral parameters (SWH, period, direction, wavelength) + backward and forward propagation from the swell observation

WAVE_GLO_WAV_**L4_SWH_NRT**_OBSERVATIONS_014_003:

- Real-Time Level-4 waves from altimetry merging all available measurements onto a 2°x2° grid in daily files



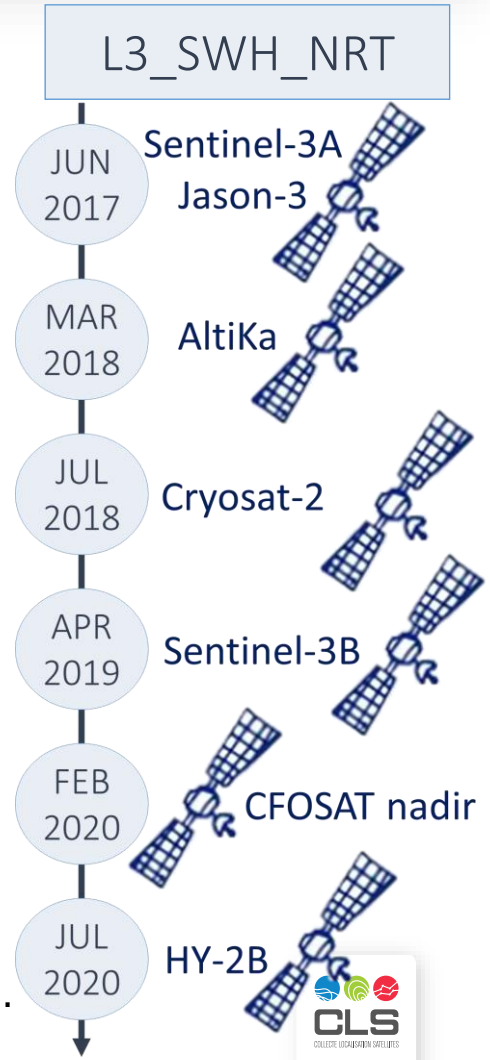
CMEMS L3 SWH along-track product

- Content: Along-track Significant Wave Height [meters] @1-Hz (~7km):
  - Unfiltered SWH
  - Filtered SWH
  - Wind speed

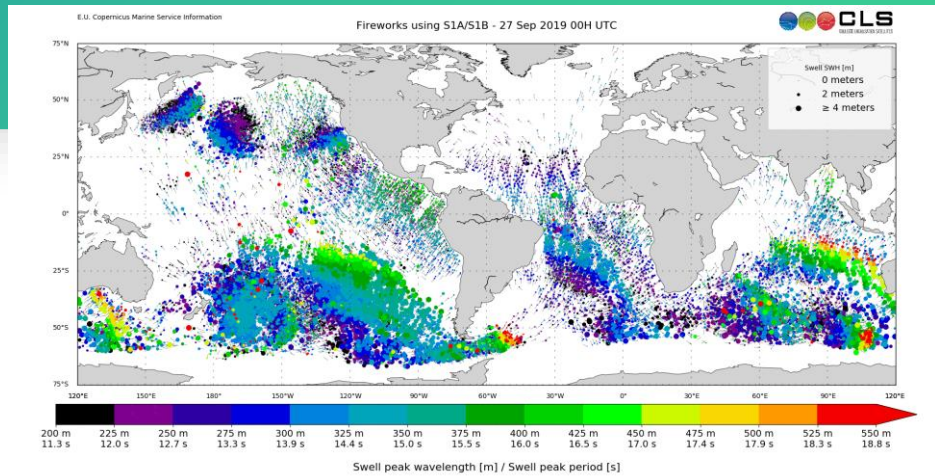
- Data processing
  - Acquisition of L2 NRT files
  - **Editing (thresholds, flags, RMS dispersion)**
  - **Inter- and absolute calibration (wrt Jason3 and in-situ)**
  - Production of intermediate L2P NRT files
  - **Noise-filtering (following EMD denoising method, Quilfen and Chapron 2019)**
  - Quality monitoring: Daily automated controls + Quality controls reports

- Documentation QUID (format, processing, validation): http://marine.copernicus.eu

- Delivered in 3-hourly netcdf files
- 1st file production starts 3h after file starting time, then updated every 30min if new L2 data available.
- Distribution via ftp: ftp://nrt.cmems-du.eu/WAVE_GLO_WAV_L3_SWH_NRT_OBSERVATIONS_014_001

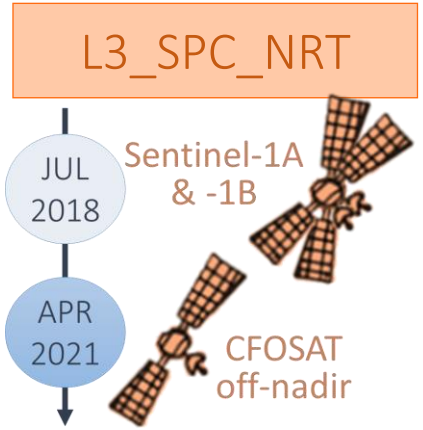


CMEMS L3 SPC along-track product



- **Content**:
  - Propagated partition Hs, peak Period (Tp) and direction (Dp)
  - Observation parameters:
    - Hs, Tp, Dp from L2
    - Quality flag derived from L3 analysis (overall consistency)
    - Overall wave Spectra + partition spectral domain

- **Data Processing**
  - Acquisition of L2 Wave Mode from Sentinel-1A/B wave spectra
  - Editing of waves with short wavelength (wl < 200m) to keep those who best follow linear propagation theory & small Hs (< 30cm) → 60% swell partitions are used
  - Backward and forward propagation of partition (Hs, Tp, Dp) parameters with a 3-hour timestep



- Documentation QUID (format, processing, validation): http://marine.copernicus.eu

- Two available formats: swell observations gathered by swell fields & 3-hourly files
- Daily updated, using all L2 data available at processing time
- Distribution via ftp: ftp://nrt.cmems-du.eu/WAVE_GLO_WAV_L3_SPC_NRT_OBSERVATIONS_014_002

CMEMS L4 SWH gridded product

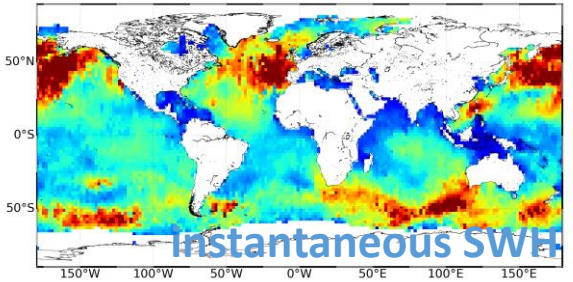
L4_SWH_NRT

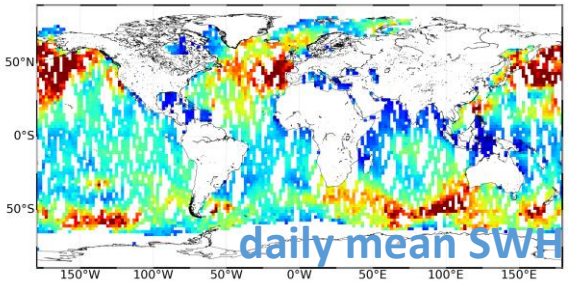
- Content: Gridded Significant Wave Height [meters] @ 2°x2°:
  - Instantaneous estimate of SWH
  - Daily mean SWH
  - Other daily statistics (standard deviation, maximum, number of observations)

- Data processing:
  - Acquisition of available L3 NRT files
  - **Selection of data over 2°x2° box**
  - **Weighted average of SWH measurements in each box**, accounting for the time of measurement and local wave climatology
  - **Dynamic land-sea-ice mask**
  - Quality monitoring: Daily automated controls + Quality controls reports

- Documentation QUID (format, processing, validation): http://marine.copernicus.eu

- Delivered in daily netcdf files
- 1st file is produced 1 day after map time, then updated 2 days and 5 days later.
- Distribution via ftp: ftp://nrt.cmems-du.eu/WAVE_GLO_WAV_L4_SWH_NRT_OBSERVATIONS_014_003



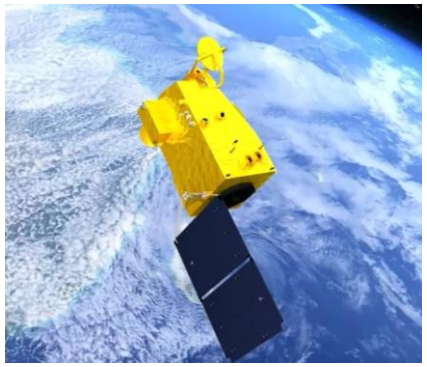


2 – Integration of CFOSAT nadir and HaiYang-2B

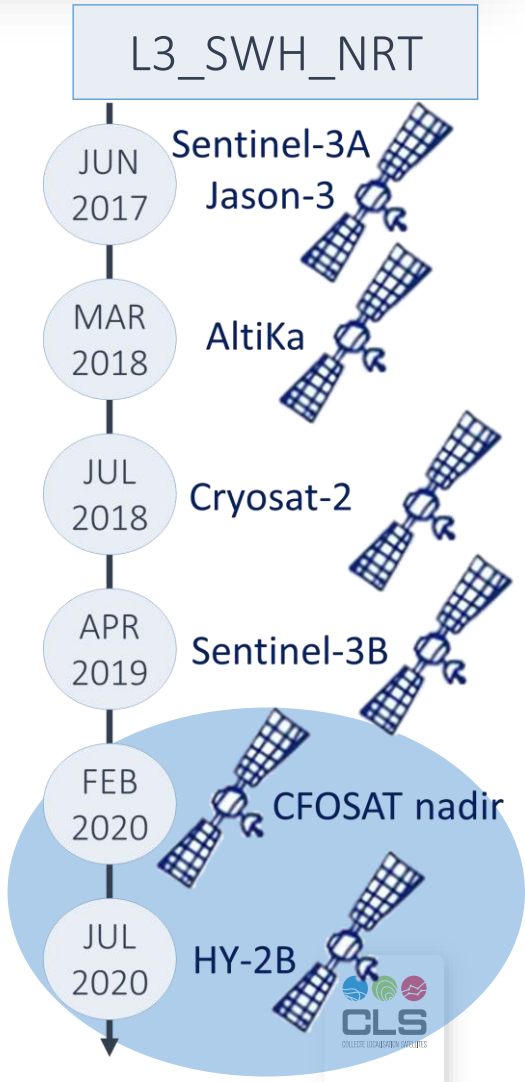
Two new missions

The operational SWH constellation available in CMEMS is now composed of 7 satellites, with the successful integration of:

- CFOSAT nadir in February 2020
  - Exploratory mission with a new type of instrument SWIM
  - CNSA/CNES OGDR data (3-hour delay)
  - CNES intermediate L2P product available on AVISO
  - LRM technology
  - 13-day cycle, +/-83° latitude range



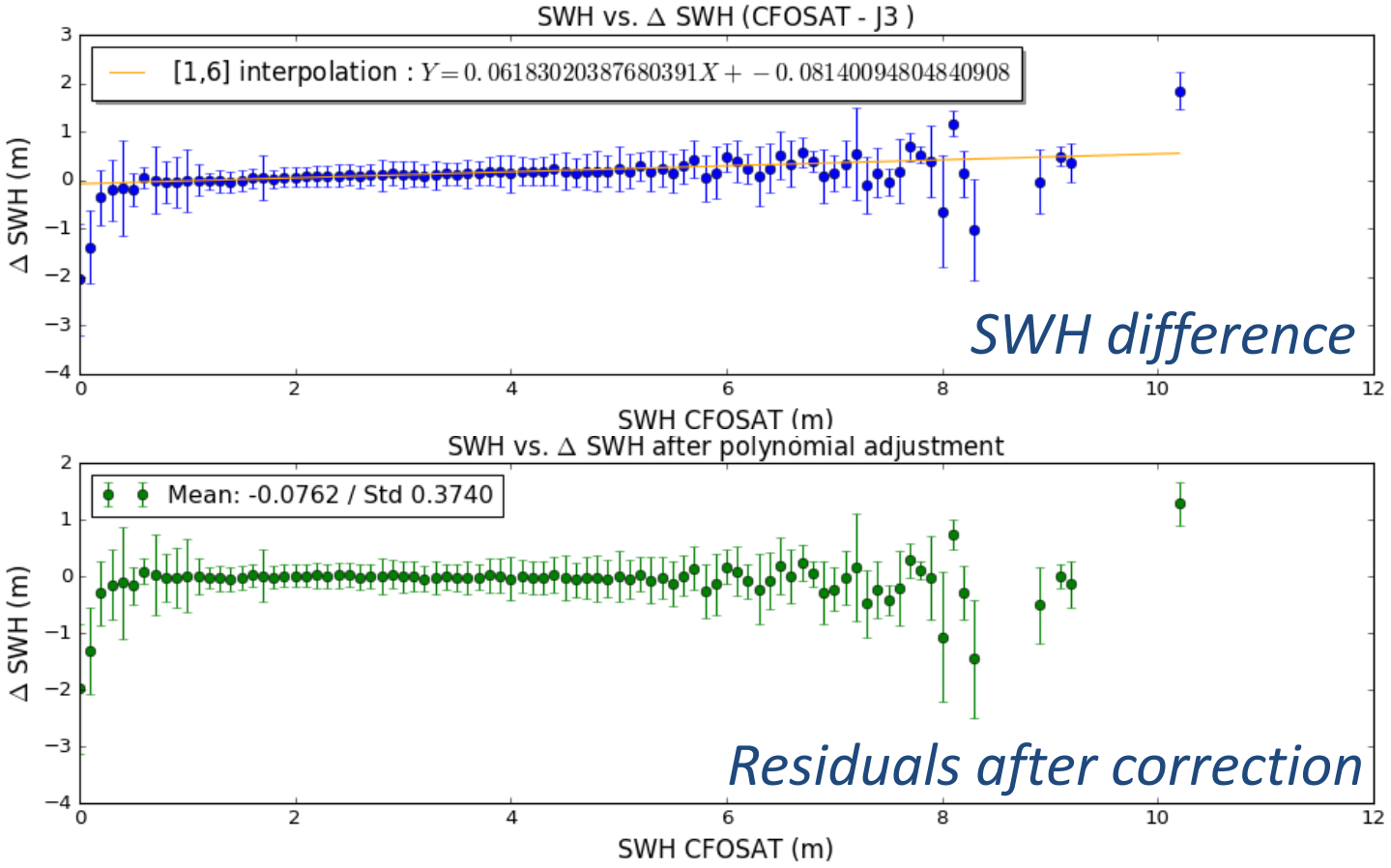
- HaiYang-2B in July 2020
  - NSOAS/CNES IGDR data (2-3 days delay)
  - LRM technology
  - 14-day cycle, +/-81° latitude range



Intercalibration of CFOSAT on Jason-3

L3_SWH_NRT

Cross-calibration of CFOSAT significant wave heights with Jason-3 was performed using the crossover point method with a time difference lower than 3 hours. CFOSAT / Jason-3 values at their 3-hour crossover points were computed over a 117-day period corresponding to CFOSAT cycles 1 to 9. Large biases are noticed for SWH below 1 m, therefore the linear fit was computed over the 1-6 meter range.

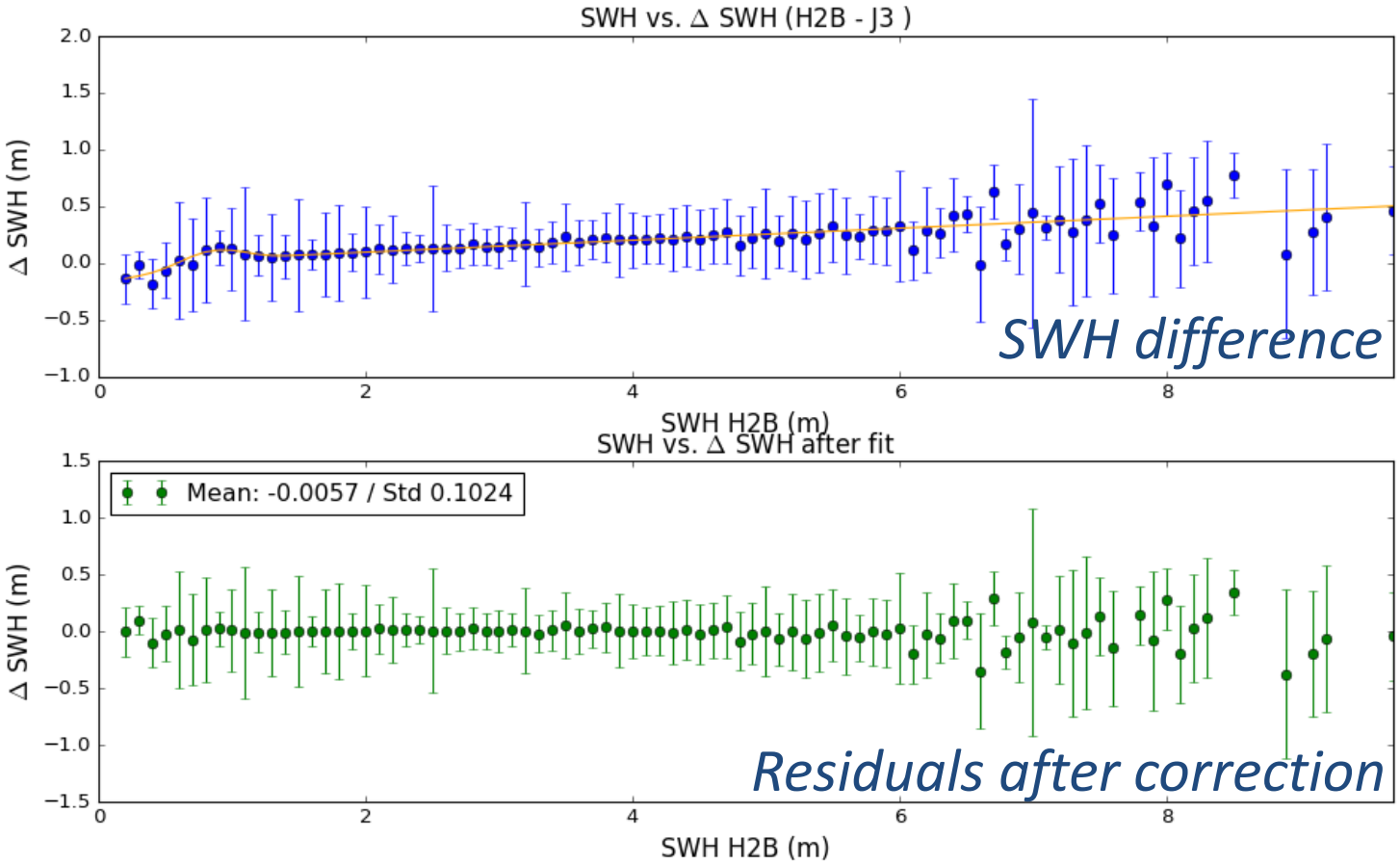


Top: Median of the difference between CFOSAT and Jason-3 SWH values at crossover points per 10-cm bin. Error bars represent the standard deviation of the difference inside each bin. The orange curve represents the linear fit over the [1-6] meter range. Bottom: Residuals between the median and the fit.

Intercalibration of HaiYang-2B on Jason-3

L3_SWH_NRT

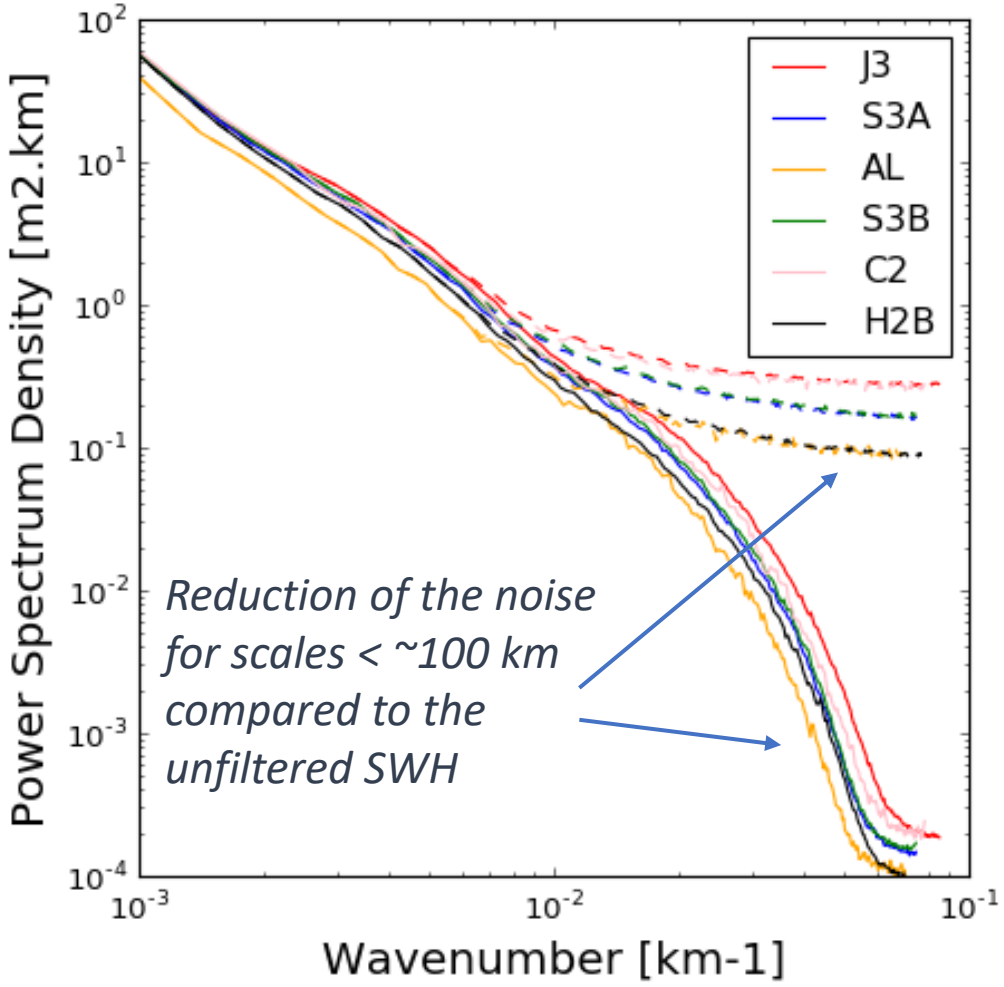
Cross-calibration of HaiYang-2B significant wave heights with Jason-3 was performed using the crossover point method with a time difference lower than 3 hours. HaiYang-2B / Jason-3 values at their 3-hour crossover points were computed over the period 11/12/2019 until 30/03/2020.



Top: Median of the difference between HaiYang-2B and Jason-3 SWH values at crossover points per 10-cm bin. Error bars represent the standard deviation of the difference inside each bin. The orange curve represents the correction applied. Bottom: Residuals between the median and the fit.

Spectral analysis of CMEMS Level-3 products

L3_SWH_NRT



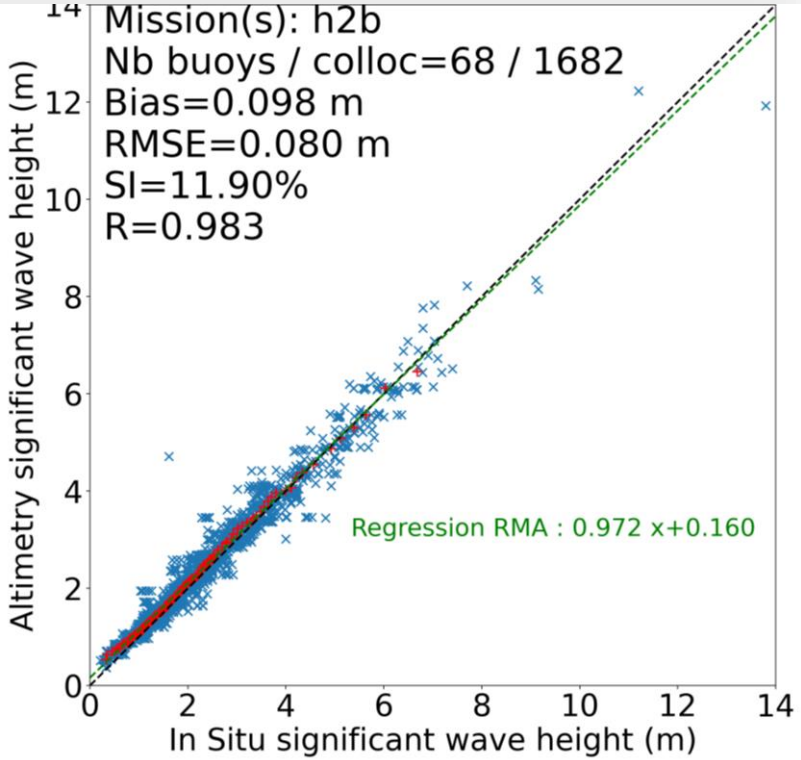
- Along-track Significant Wave Height is noise filtered using Empirical Mode Decomposition denoising method (following Quilfen and Chapron 2019)
- This graph shows the comparison of along-track altimeter wavenumber spectrum for global ocean filtered (continuous line) and unfiltered (dashed line) significant wave height [period June – October 2020].
- It highlights the performance of the denoising method and also the differences between the missions.
- SARAL/AltiKa and HaiYang-2B exhibit a noise plateau significantly reduced compared to Jason-3 and Cryosat-2 missions

CMEMS L3 SWH product: Comparison with in-situ

L3_SWH_NRT

- Level-3 SWH product is compared to a set of ~100 offshore wave buoys (CMEMS in-situ TAC) during the 6-month period January–June 2020
- Buoy SWH measurements are compared to the average of Level-3 SWH data selected within 30 min and 50 km of the buoy record

	Nb of match-up	Bias	RMSD	SI	R
L3 Jason-3	2276	8.6 cm	7.8 cm	13%	0.98
L3 Sentinel-3A	2303	10 cm	7.4 cm	12%	0.98
L3 Sentinel-3B	2079	8.4 cm	9.4 cm	14%	0.98
L3 AltiKa	1247	7.8 cm	4.2 cm	12%	0.98
L3 CryoSat-2	1935	8 cm	6.2 cm	11%	0.98
L3 CFOSAT	1893	11.8 cm	6.2 cm	11%	0.99
L3 HaiYang-2B	1682	9.8 cm	8 cm	12%	0.98



Scatter (blue crosses) and quantile-quantile (red crosses) plot of HaiYang-2B comparison with in-situ measurements [January-June 2020]

- L3 SWH were calibrated on NDBC buoy network. The comparison is performed on several buoy networks, mainly located around US and European coasts.

3 – New altimetry wind speed

Addition of altimetry wind speed

L3_SWH_NRT

In support to the significant wave height data, the collocated wind speed, measured by altimeters, was integrated as an additional field in the existing L3 SWH files.

Altimetry wind speed is taken from Level-2 products and is intercalibrated on the reference mission Jason-3.

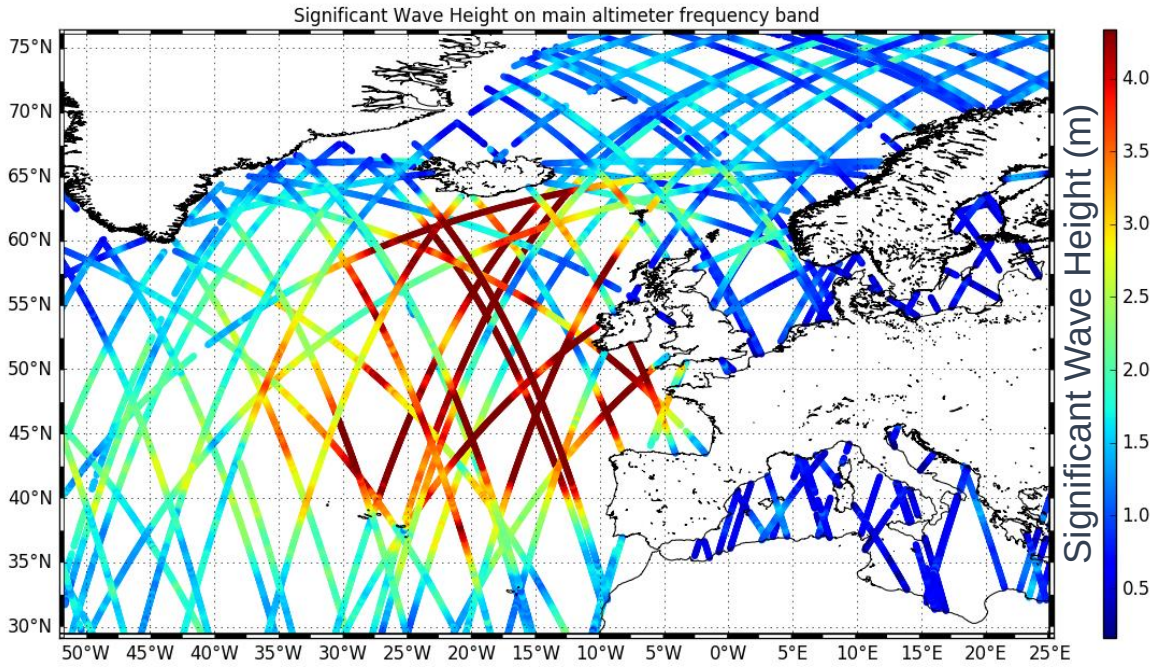
The table below lists the wind algorithms used in upstream Level-2 NRT products.

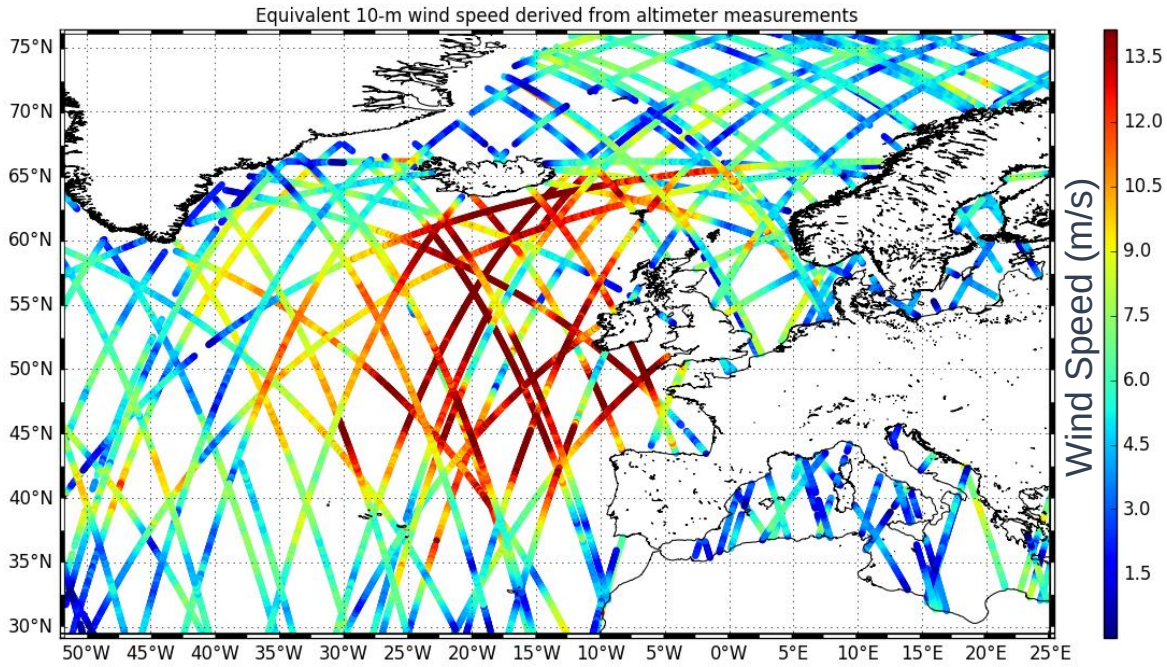
Mission	Wind algorithm	Type
Jason-3	Collard 2005	2-parameter (sig0 and SWH)
Sentinel-3A	Abdalla 2007	1-parameter (sig0)
Sentinel-3B	Abdalla 2007	1-parameter (sig0)
SARAL/AltiKa	Tran 2014	2-parameter (sig0 and SWH)
CryoSAT-2	Abdalla 2007	1-parameter (sig0)
HaiYang-2B	Gourrion 2002	2-parameter (sig0 and SWH)

Addition of altimetry wind speed

L3_SWH_NRT

Example of collocated Significant Wave Height and Wind Speed during Ellen Storm (19-20 August 2020), as seen by the NRT satellite constellation.



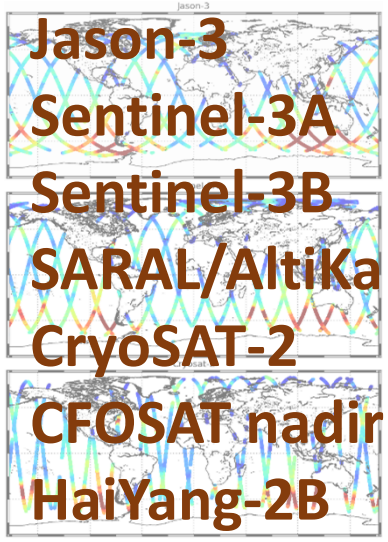


4 – Upgrade of Level-4 SWH mapping

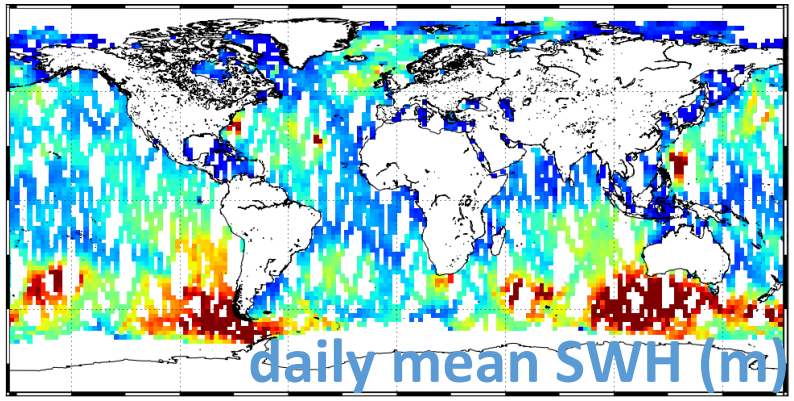
CMEMS L4 SWH gridded product

L4_SWH_NRT

Along-track Level-3

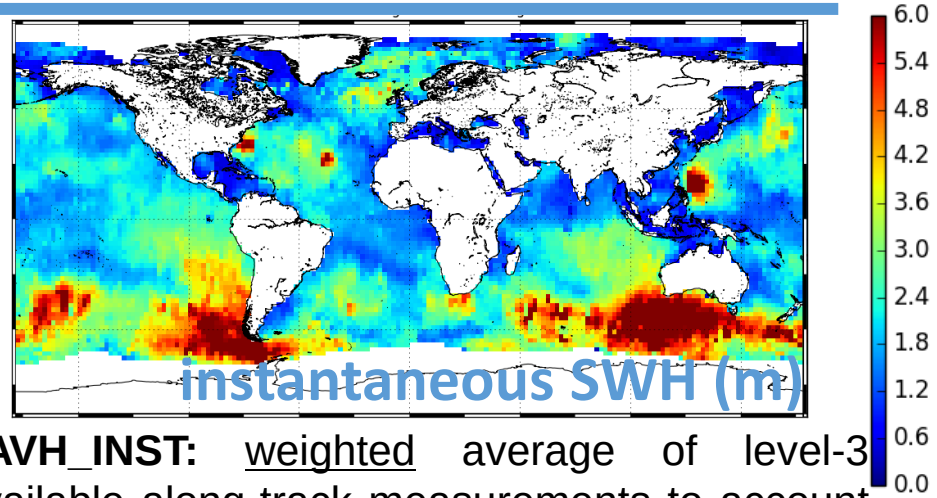


Daily fields



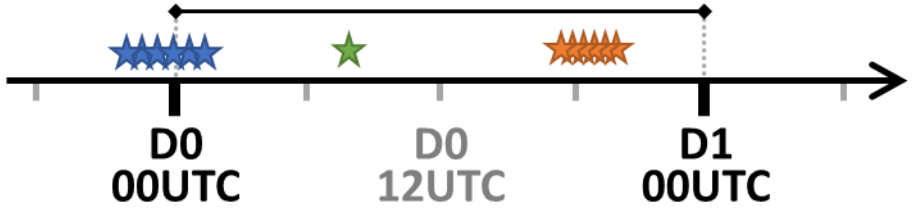
VAVH_DAILY_MEAN: average of available Level-3 along-track measurements from 00 UTC until 23:59 UTC

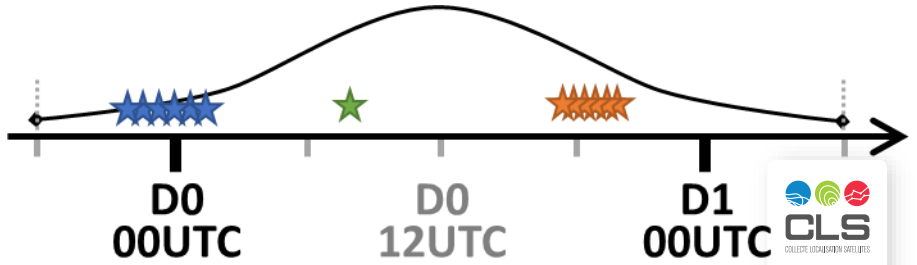
Instantaneous fields



VAVH_INST: weighted average of level-3 available along-track measurements to account for their temporal proximity and spatial interpolation when no measurements

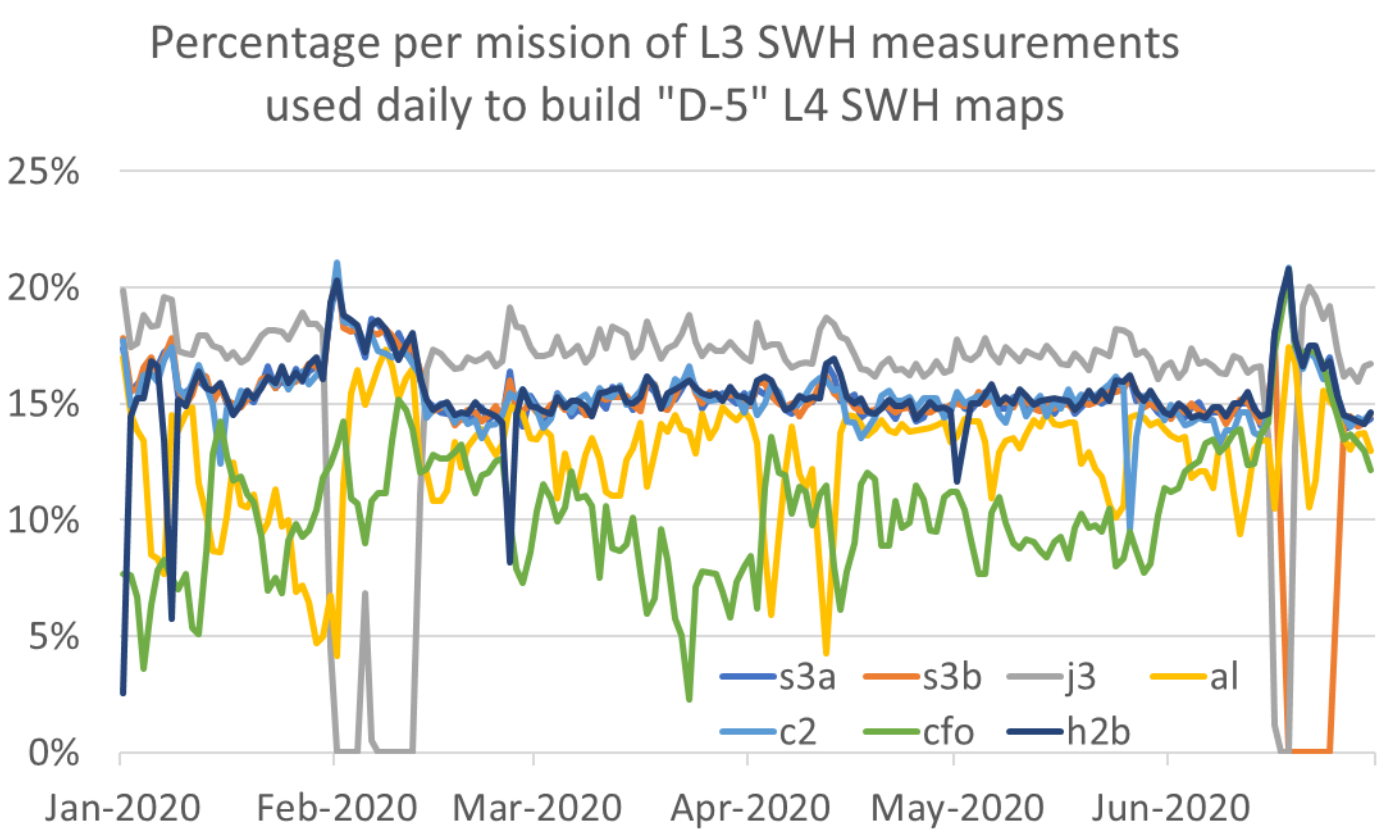
Example of L3 measurements over one grid cell (2°x2°)





Contribution of the different missions to L4 SWH product

L4_SWH_NRT



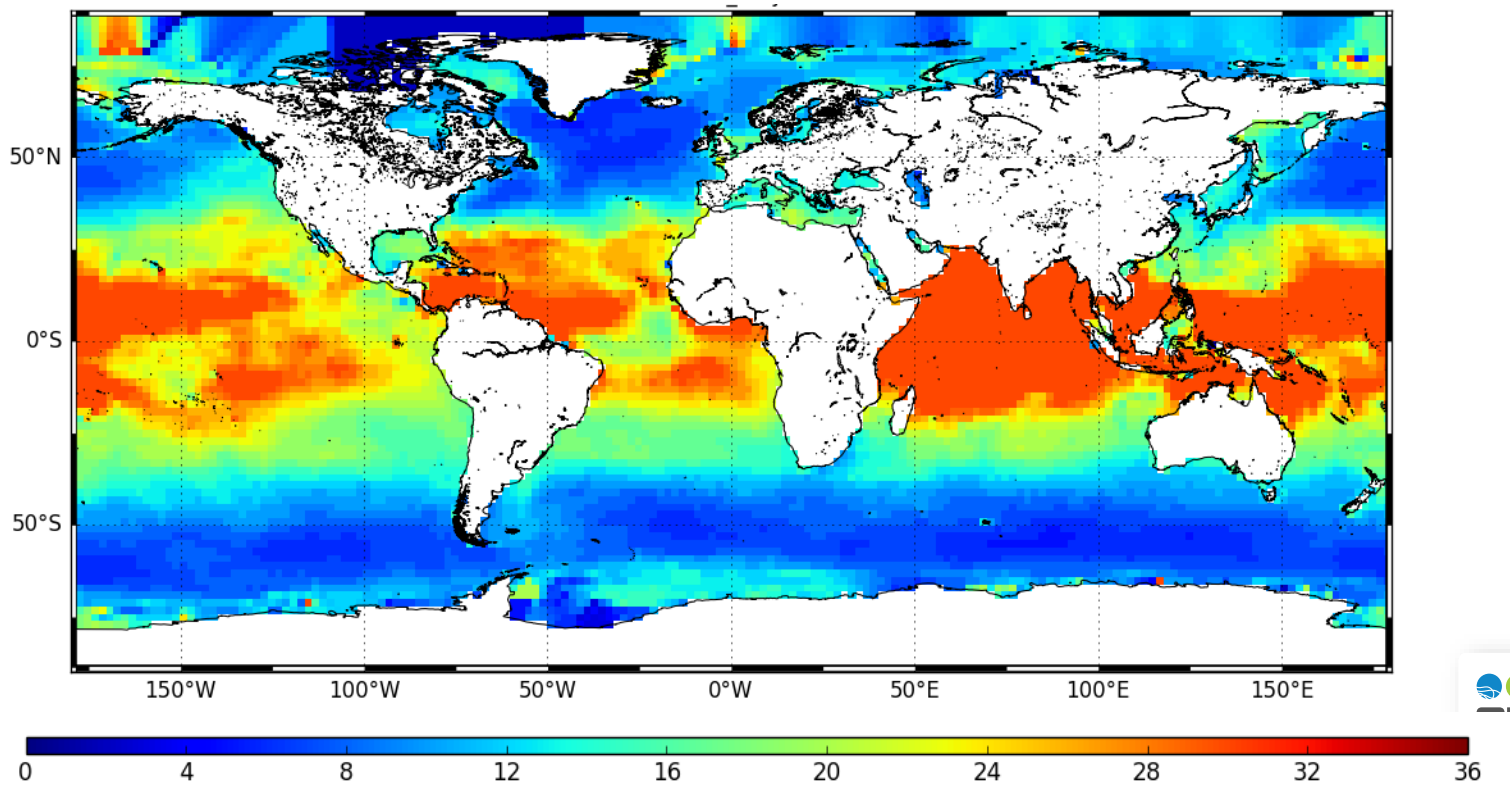
- The daily gridded Level-4 SWH product is now merging wave heights derived from 7 different missions: Jason-3, Sentinel-3A, Sentinel-3B, SARAL/AltiKa, CryoSAT-2, CFOSAT, and HaiYang-2B.
- The increased spatial and temporal density of measurements allows a better mapping of the wave heights.
- This graph shows the percentage per mission of L3 SWH measurements used daily to build L4 SWH maps reprocessed over the January-June 2020 period

Evolution of the mapping method

L4_SWH_NRT

- The gridded VAVH_INST field aims at estimating the instantaneous wave field at 12UTC with no empty cells
- Measurements available over a 36-hour time window centred on 12UTC are projected on the grid
- This temporal window used to be constant across all oceanic basins. From December 2020 version, it will vary spatially to account for different wave conditions. It is smaller in regions where wave conditions can change rapidly (e.g. storm affected areas) and larger in regions where wave conditions are steadier (e.g. sheltered regions)

Spatial variability of the temporal window (in hours) used to select observations. It accounts for the temporal correlation and difference modelled at each grid point in CMEMS WAVERYS dataset.



Evolution of the mapping method

L4_SWH_NRT

- The new mapping method presents a reduced RMSD of 22 cm, a reduced scatter index of 23% and an increased correlation of 0.895 (comparison with moorings located at more than 40 km from the coast)

Mapping method	VAVH_INST				
	N	Bias (m)	RMSD (m)	SI (%)	R
Fixed temporal window (36h)	30551	0.058	0.251	24.3	0.887
Variable temporal window (<36h)	30545	0.059	0.221	23.3	0.895

Performance of the Level 4 product with different mapping methods. SWH maps are compared with in-situ data at selected buoys during the period July 2019 – June 2020

5 - Better characterization of long swells in spectral product

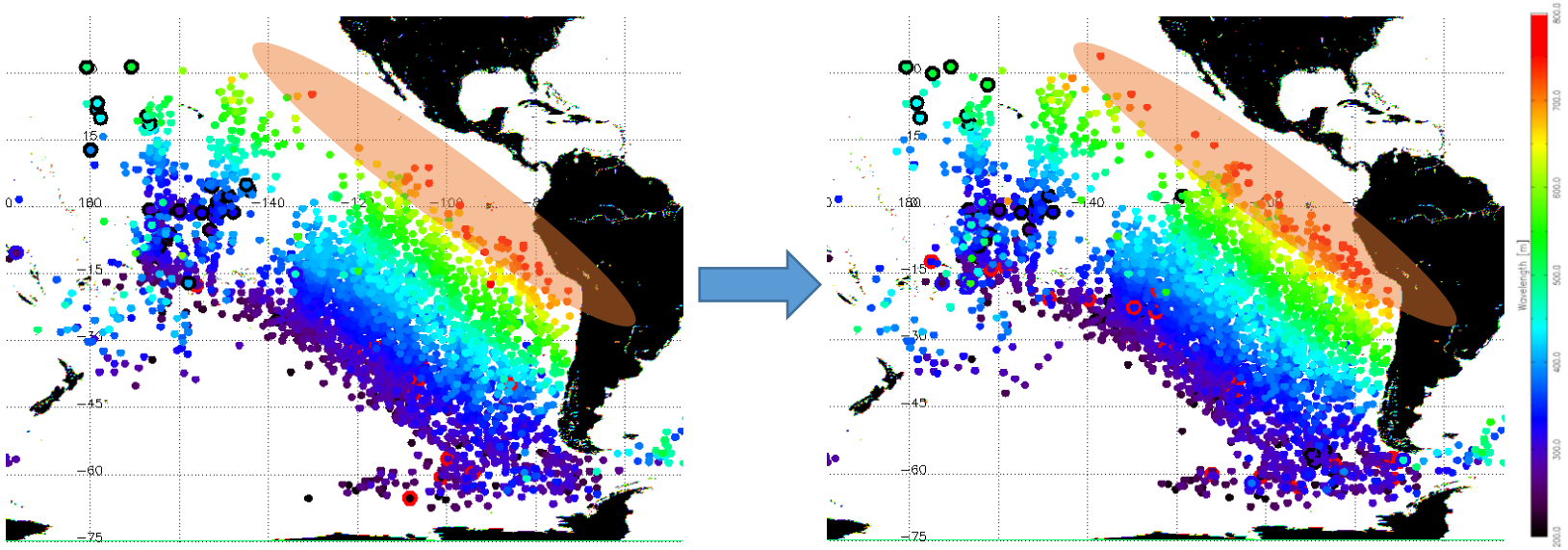
Improvement for long swells in L3 SPC

L3_SPC_NRT

Quality improvement and increase of valid observations: specific processing for long wavelength since July-2019

- Long swell direction is not well resolved by Sentinel-1 Wave Mode, often indicating the opposite direction
- Considering both propagating directions, the most consistent wrt to smaller wavelengths is chosen

→ +100% more swell with wavelength > 600m are refocused



Example of a S1 WV propagated mesurements belonging to a swell field event on 8th May 2018 off New Zealand (strongest Hs ever recorded in South Hemisphere). S1 measured wavelength reaches 800 m!

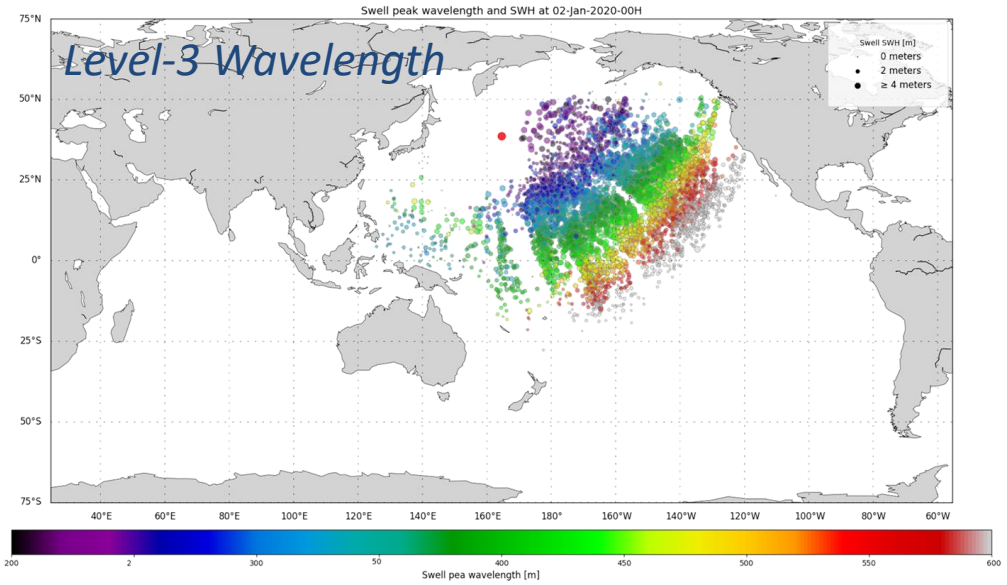
6 - Next upgrades: L4 SPC and CFOSAT off-nadir

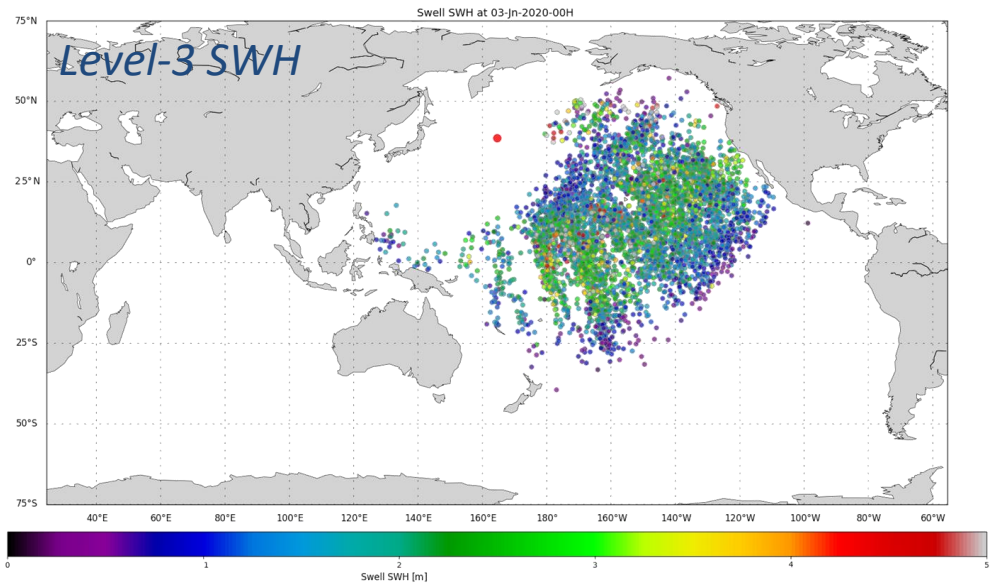
Upcoming launch of Level-4 SPC product

L4_SPC_NRT

Objective of this new product: merge multi-mission swell observations and provide the swell evolution characteristics on a regular spatio-temporal grid

It will be launched on CMEMS catalogue in December 2020





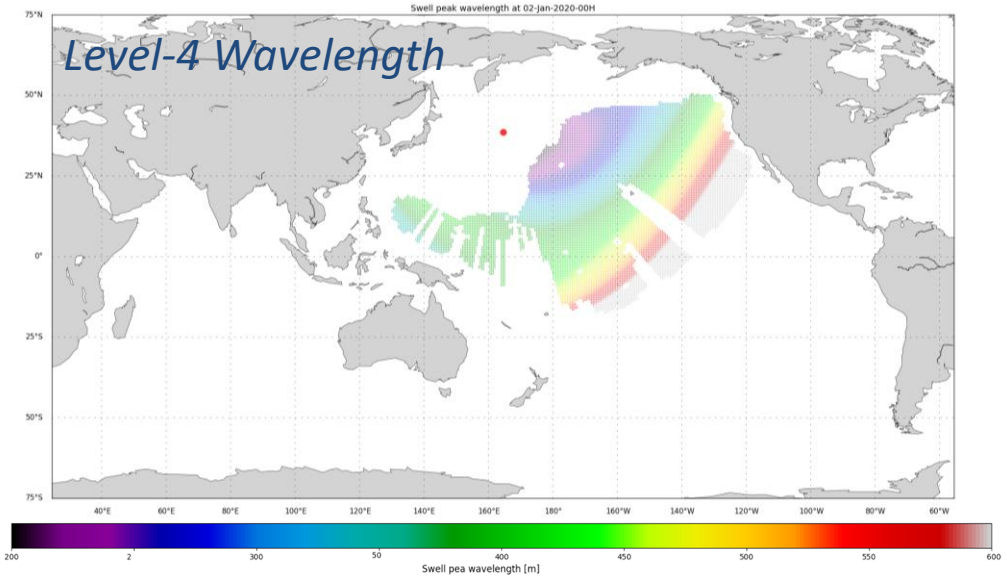
Distribution of peak wavelength (top) and Hs (bottom) extracted from the Level-3 product based on Sentinel-1A and Sentinel-1B on 02/01/2020 - 00h. The Level-3 products are based on several Level-2 measurements. The swell field originates from a storm, whose center is pin-pointed by a red circle.

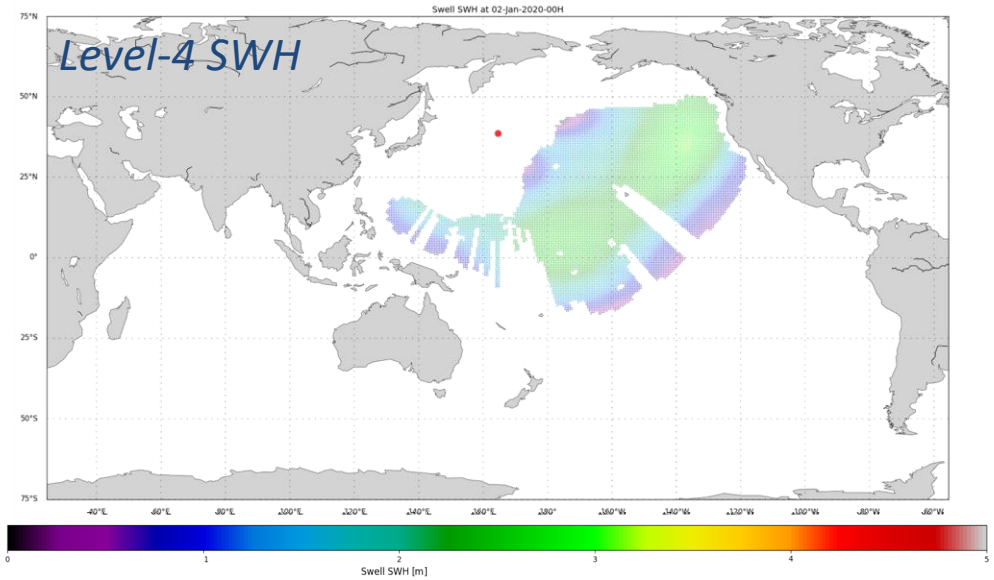
Upcoming launch of Level-4 SPC product

L4_SPC_NRT

Objective of this new product: merge multi-mission swell observations and provide the swell evolution characteristics on a regular spatio-temporal grid

It will be launched on CMEMS catalogue in December 2020





Distribution of peak wavelength (top) and Hs (bottom) extract from a Level-4 product derived from Sentinel-1 constellation on 02/01/2020 - 00h. The Level-4 product is based several S1-A and S1-B Level-3 products illustrated in the previous figure. The swell field originates from a storm pin-pointed by a red circle.

Upcoming launch of Level-4 SPC product

The overall methodology can be split in five steps:

1. Validity mask: A validity mask is estimated, corresponding to the region where swell can propagate freely, starting from the original re-focusing region, away from land and island shadow.

2. Reference system: An intermediate output grid is estimated using a spherical coordinate system (r, theta) grid centred on the storm source whose North Pole would correspond to the storm source. Two main directions are defined: (theta) for transverse (equal distance to the storm source) and (r) for longitudinal (constant propagating direction from the storm source)

3. Data weighting: For each valid propagated swell observation, as provided in the L3 products quality flag, an associated weight is attributed according to the measured statistical error with respect to the partition energy ratio, azimuth cut-off and wave azimuthal wavelength at observation time, propagation time since observation, partition ambiguity factor for estimating the direction on the observed swell spectrum, wind speed at observation time.

4. Interpolation and rejection: For each time step and for the three integral parameters, the valid propagated observations are interpolated onto the reference system grid using a polynomial regression in transverse and longitudinal coordinates. In addition to the mean integral parameter value, the standard deviation and the number of propagated observations are also retrieved.

5. Projection on the final regular lon/lat grid: The previous parameters are projected on a regular lon/lat grid with a 1x1° resolution.

Arrival of CFOSAT SWIM off-nadir spectral wave parameters

L3_SPC_NRT

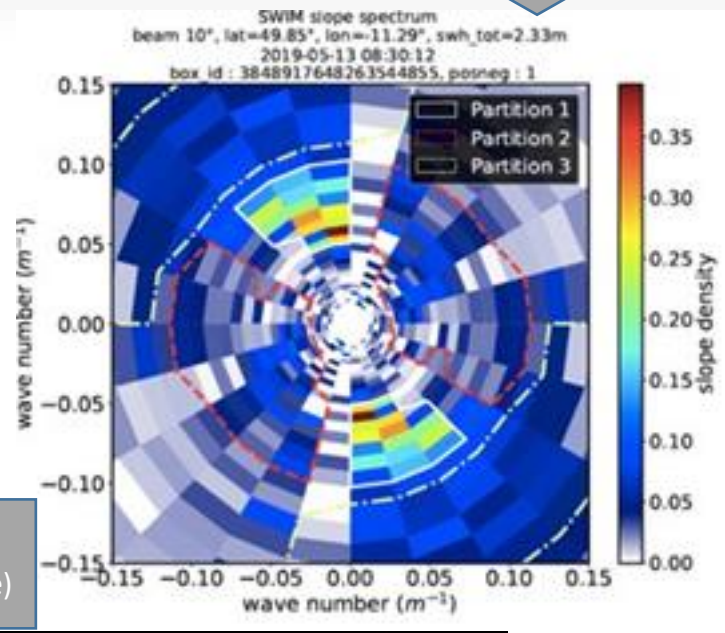
Since June 2020, CFOSAT ground segment could provide the improvements proposed by the calval group during the calval phase. Even though this mission is very innovative, and will still improve in a near future, the wave spectra is now clean and relevant: see *C. Tourain et al., CFOSAT SWIM latest products* in CFOSAT session: new speckle managing, new MTF…

Through CMEMS diffusion canal, the project will also provide to the scientific community **L2P and L3** products, including :

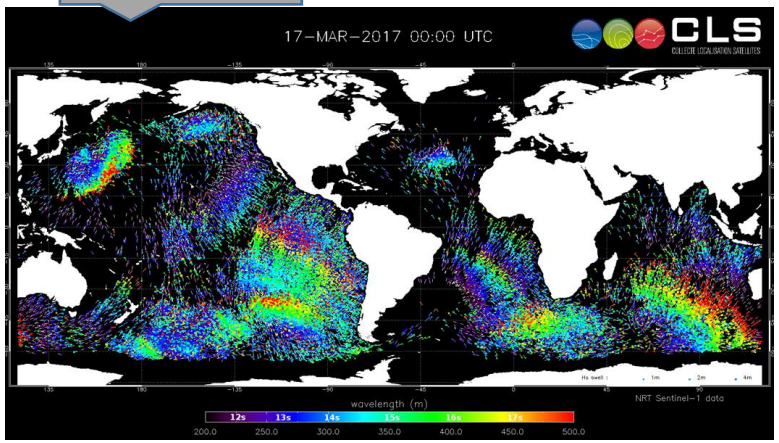
- ✓ its **best spectra selection (simple and easy to use)**
- ✓ its **best data selection** complete algorithm
- ✓ dedicated improved **partitionning**
- ✓ **homogeneous to S1** formats fireworks

These added value products will be available by end 2020 (internal product) and march 2021 (official products).

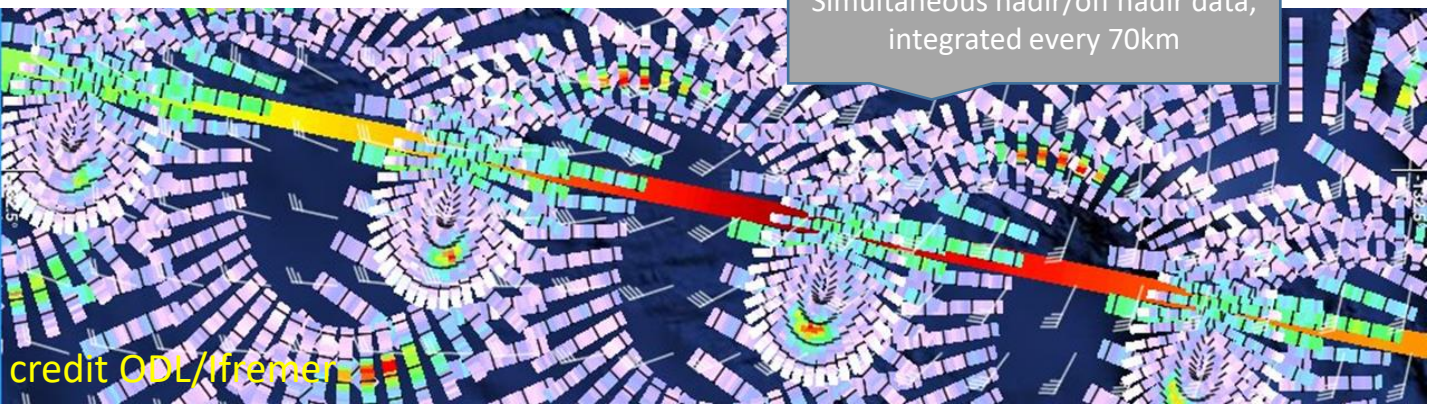
L2P 2D valid spectra



L3 fireworks (Sentinel1-like)



Simultaneous nadir/off nadir data, integrated every 70km



credit CDL/Ifremer

Conclusions

CMEMS L3 SWH products

- A Near-Real Time dataset of altimetry Significant Wave Height
  - Quality controlled / Inter-calibrated / Monitored / Noise-Filtered
- Today, 7 satellites: J3, AL, S3A, S3B, C2, CFO and H2B

CMEMS L4 SWH products

- A Near-Real Time dataset of multi-mission gridded Significant Wave Height
  - Daily statistics
  - Estimate of instantaneous wave field

CMEMS L3 SPC products

- Level-3 SAR wave measurements offer a reduced but more consistent set of swell observations compared to Level-2, based on overall consistency of these observations.
- Offer the possibility to deploy virtual-buoy observer
  → where there is no buoy
  → or to compare with actual buoy or other instruments (seismic noise, SWIM, or Sentinel-1 itself).

Perspectives, Future work

- End 2020, new **Level-4 SPC** product will provide for the first time gridded spectral parameters derived from Sentinel-1 actual and propagated measurements
- Early 2021, Level-3 SPC product derived from **CFOSAT SWIM off-nadir** will provide spectral parameters over all the oceans, including the North Atlantic Ocean
- Mid-2021, new **Multi-Year reprocessing** of Level-3 and Level-4 altimetry SWH, derived from the reformatting of ESA CCI Sea State Level-3 dataset (v2 covering 2002-2020)
- Preparation of **CMEMS Wave Working Group / TWAPAS** meeting next year to collect user feedbacks and identify their needs regarding:
  - Adequacy of the operational wave service with NRT constraints
  - Access to spectral wave parameters
  - Relevance of the along-track sampling with wave models resolution
  - Pertinence of the products (accuracy, resolution, …) in complex areas
  - Access to collocated wind speed
  - Description of uncertainties
  - Long-term measurements for climate applications
- **Continuous collaboration** between spatial agencies, CMEMS and users is essential to sustain a performing satellite constellation for the monitoring of wave conditions and state-of-the-art data processing from Level 0 to Level 4.
- Currently, Sentinel-3 and CFOSAT **Level-2P operations and evolutions** are supported, respectively, by EUMETSAT and CNES. What about the other collaborative missions? This lack should be discussed with agencies and reinforced in the future.

Thank you!

Data Access and Documentation, visit:
http://marine.copernicus.eu

Specific questions on SAR and altimeter wave products, contact:
servicedesk.cmems@mercator-ocean.eu

Feedback on products, contact us:
echarles@groupcls.com
rhusson@groupcls.com