



CMEMS satellite near-real-time wave products

Recent upgrades and future developments towards delayed-time products

CCI Sea State User Consultation Meeting – 23-25 March 2021

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Outline

1. Status of CMEMS WAVE-TAC available products and missions
2. Focus on SAR spectral wave products
3. Focus on Level-4 gridded SWH product
4. Future developments





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

The Copernicus Marine Environment Monitoring Service

MULTI-YEAR
10 to 45 years

REAL-TIME
Daily, hourly

FORECAST
2 to 10 days

ESSENTIAL MARINE VARIABLES

Blue
(Physics)

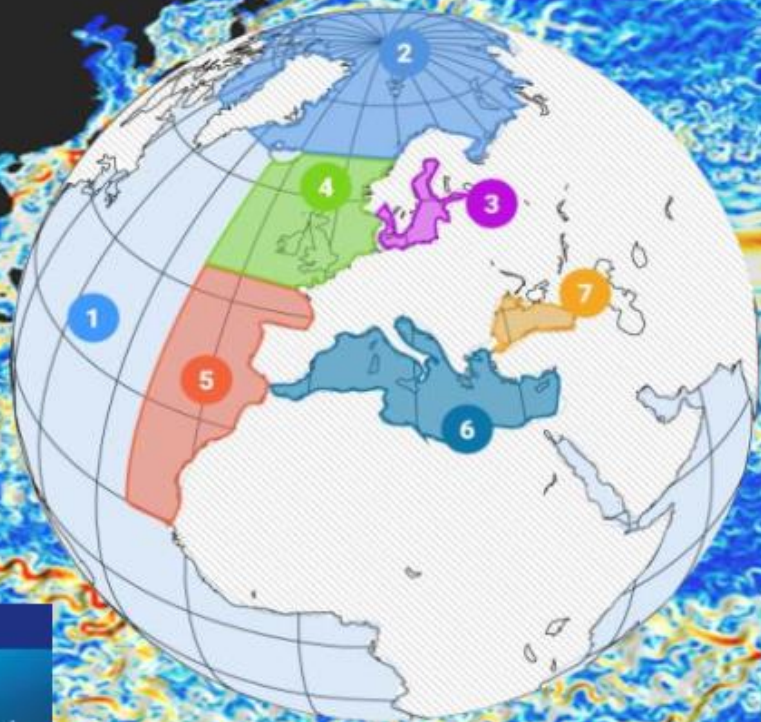
White
(Sea Ice)

Green
(Biogeochemistry)

OBSERVATIONS
In-situ & Satellites

NUMERICAL MODELS & data
assimilation

marine.copernicus.eu



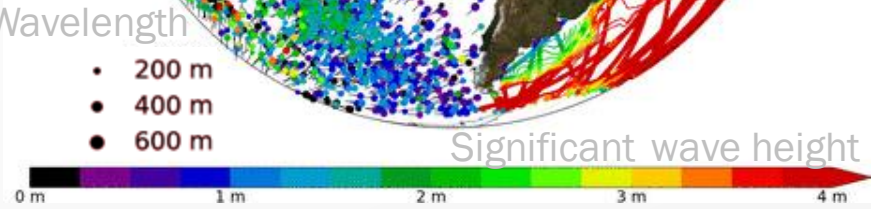
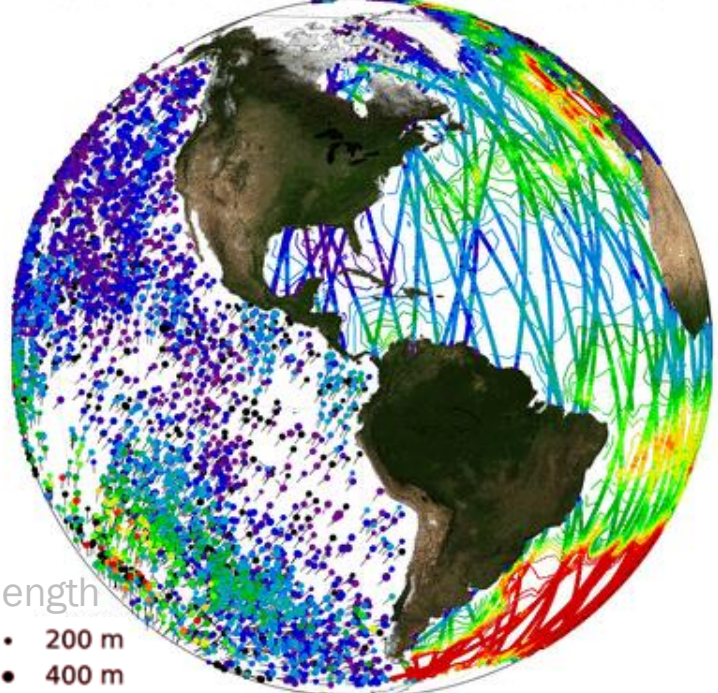
- 1 Global
- 2 Arctic
- 3 Baltic
- 4 NWS
- 5 IBI
- 6 Med Sea
- 7 Black Sea



WAVE-TAC altimetry and SAR products

The WAVE-TAC now distributes 3 near-real-time products derived from the measurements of a constellation composed of 9 satellites:

Satellite wave observations at 2019-08-10T00:00:00



*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:

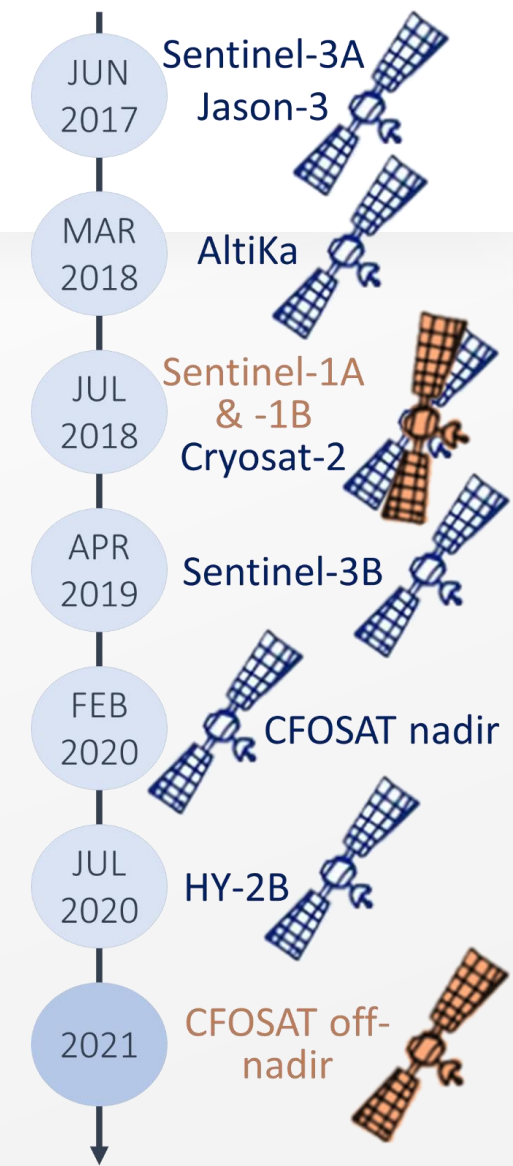
- Real-Time Level-3 waves from altimetry
- Edited, inter-calibrated, noise-filtered significant wave height (SWH) and wind speed (U10)

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 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

Available on <https://marine.copernicus.eu>

Level-4

- L4 SWH**
Sentinel-3A
Sentinel-3B
Jason-3
SARAL/AltiKa
CryoSAT-2
HaiYang-2B
CFOSAT
- Planned for 2021*
L4 SPC
Sentinel-1A
Sentinel-1B

  R&D activities (new retrackings, CCI ...)

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



2 – Focus on SAR spectral wave product

CMEMS L3 SPC along-track product

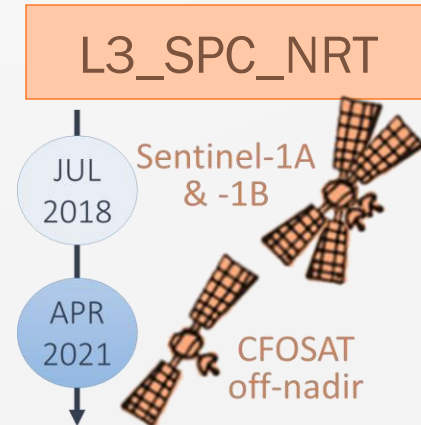
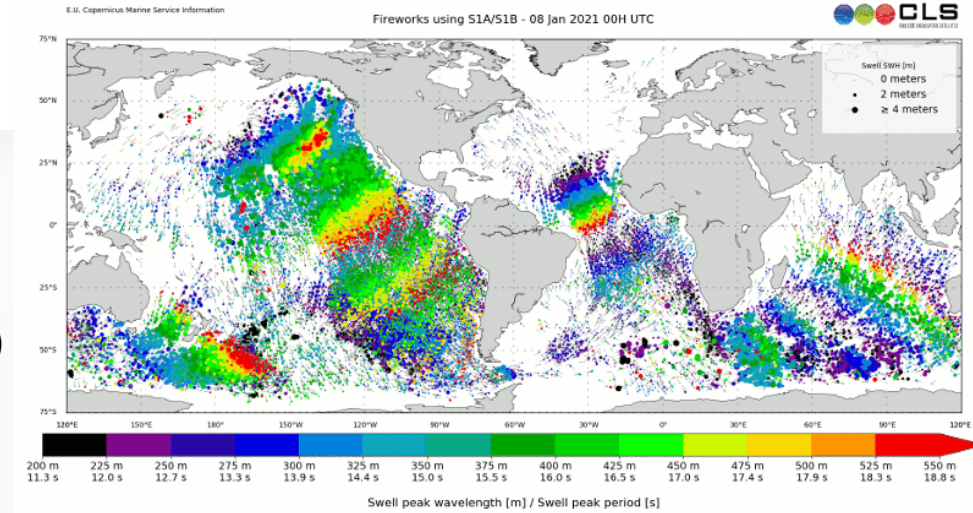
- **Content:**

- 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 + partitions

- **Data Processing**

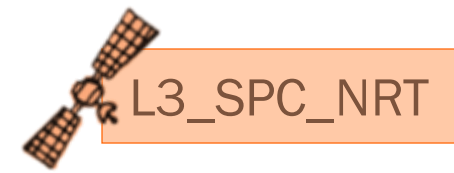
- Acquisition of swell products from Sentinel-1A/B L2 Wave Mode
- Rejection of waves with short wavelength ($wl < 200m$) to keep those who best follow linear propagation theory & small Hs ($< 30cm$) → 60% swell partitions are used
- Backward and forward propagation of partition integral parameters (Hs, Tp, Dp)

- 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



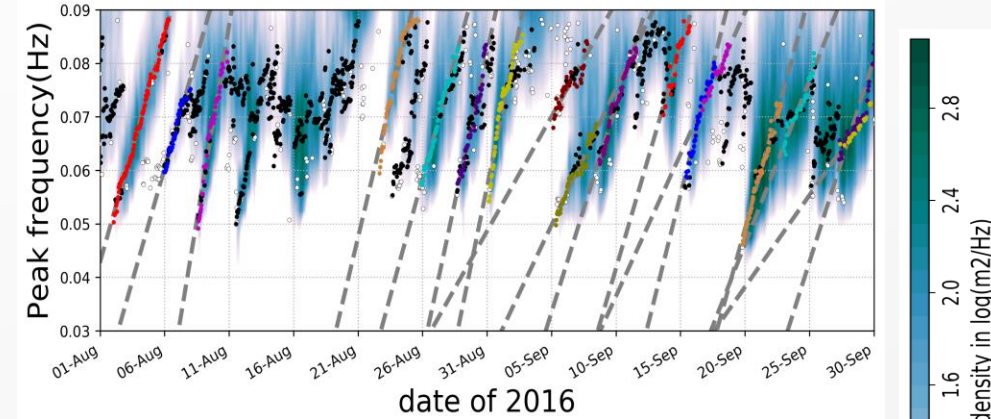
MULTI-YEAR: Distribution of a full L3 reprocessing [May 2016-today] of S1A & B missions for mid-2021.

Validation of Level-3 spectral measurements

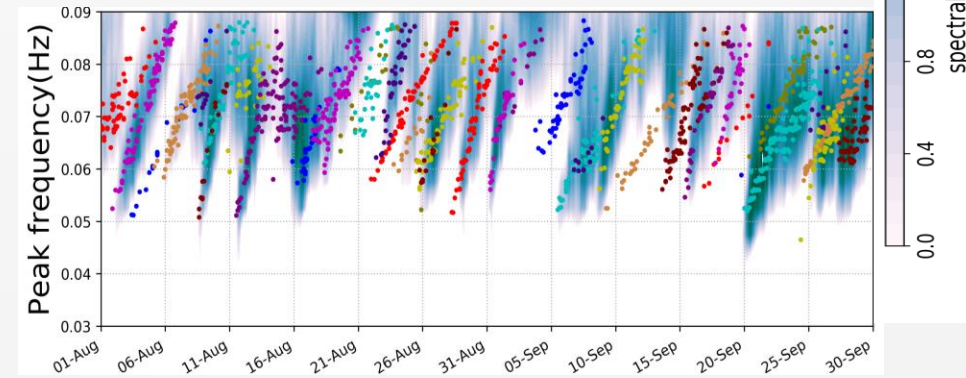


- Time series of wave measurements from L3 Waves product and in-situ buoys have been analyzed by comparing L3 Waves products propagated at buoy location
- Buoy measurements are filtered, gathered by swell event and then associated with corresponding L3 wave product.
- Several events can be identified, Extra-Tropical Cyclones (ETC) and Tropical cyclones (TC).

Real Buoy Analysis



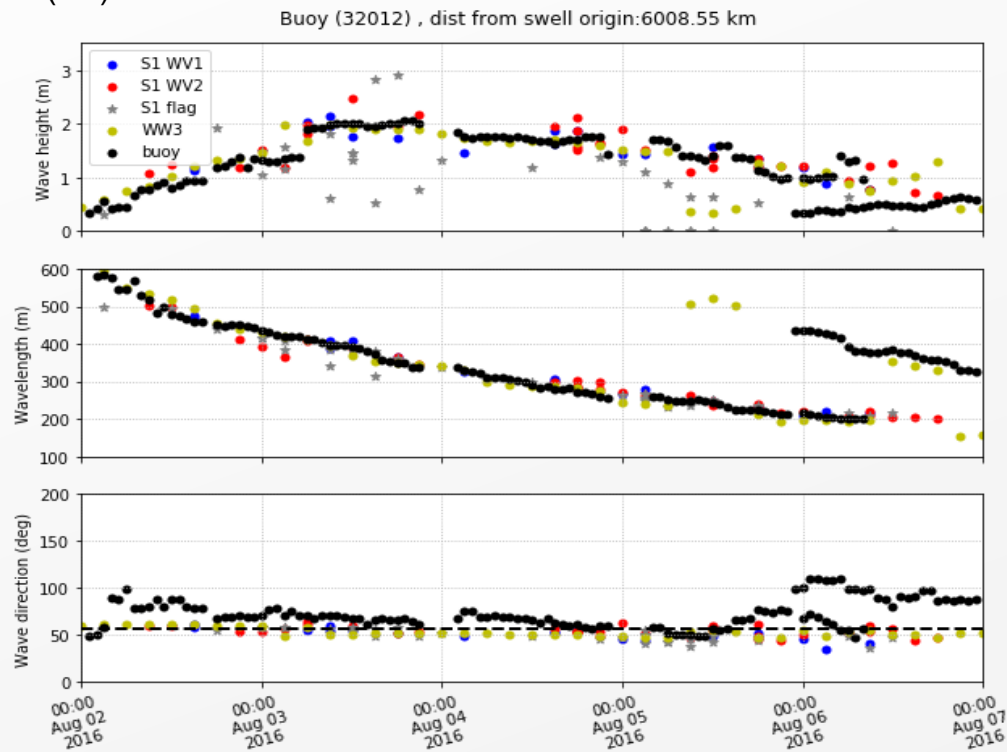
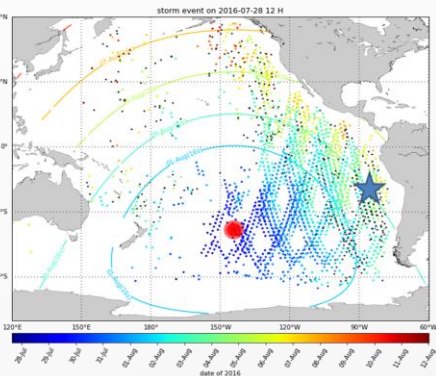
Sentinel-1 Virtual Buoy Analysis



Timeseries of wave from buoys and L3 SAR Wave products

Case Study over an ETC

Good match between S1, WW3 and the buoy for this extra-tropical storm

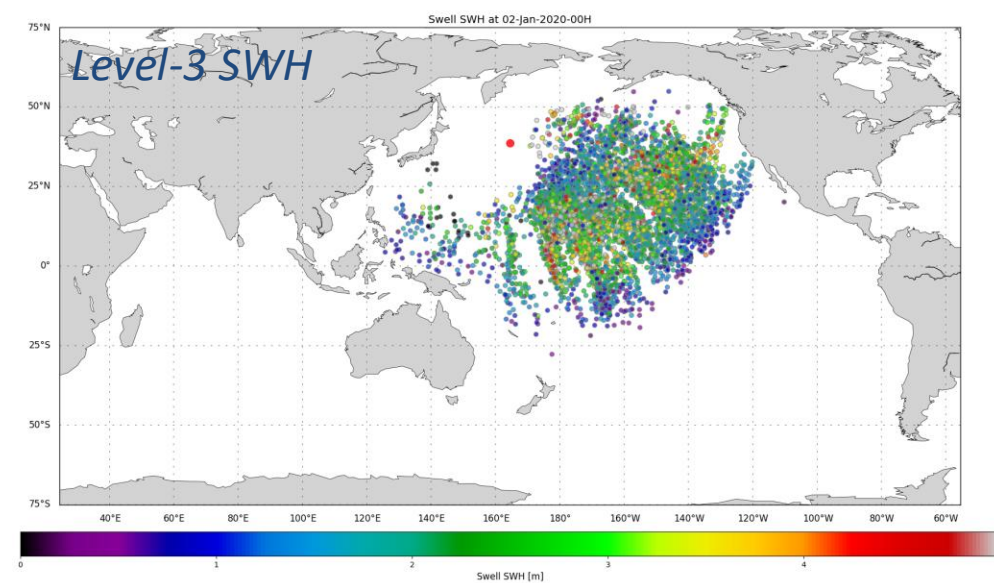
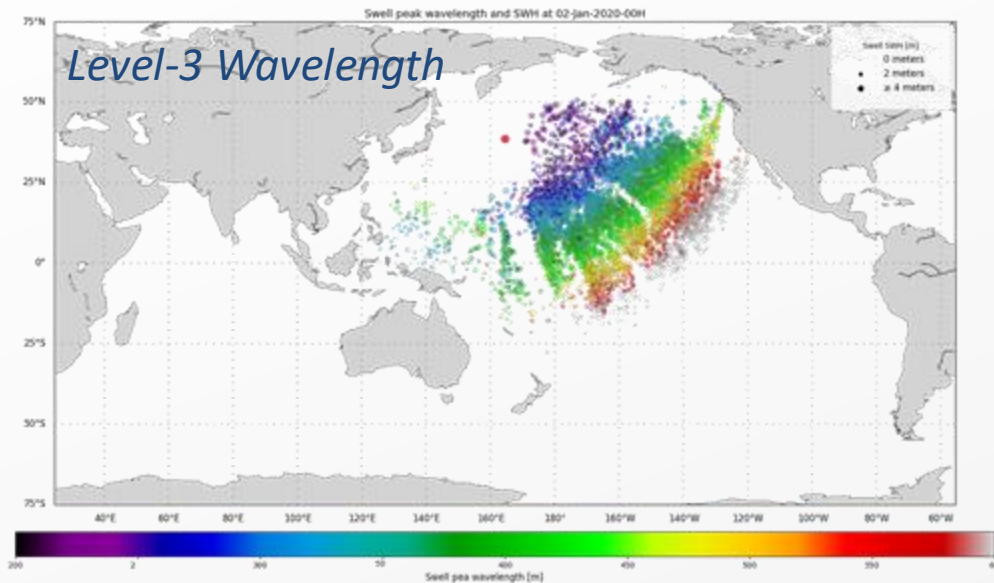


Upcoming launch of Level-4 SPC product



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 in CMEMS catalogue end of 2021



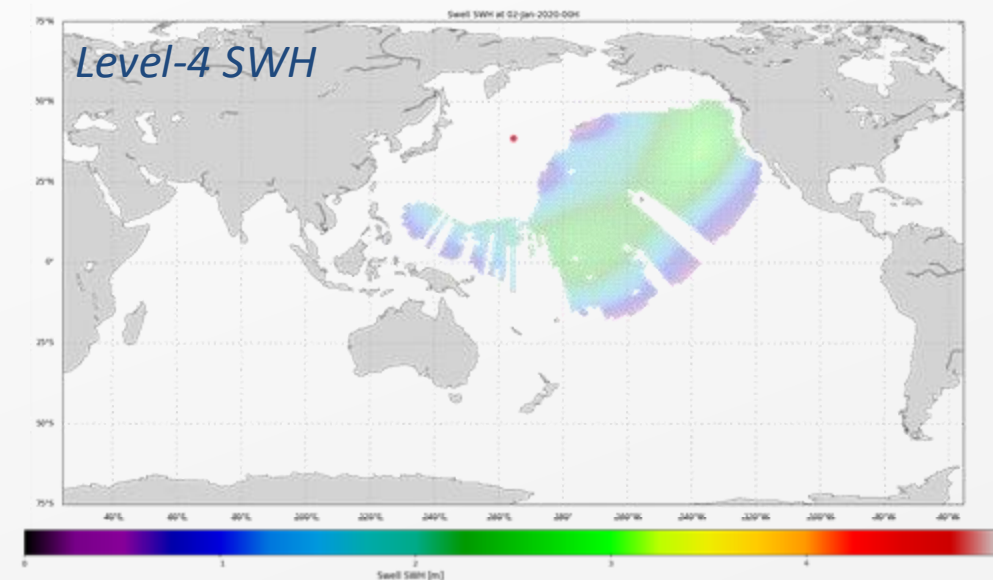
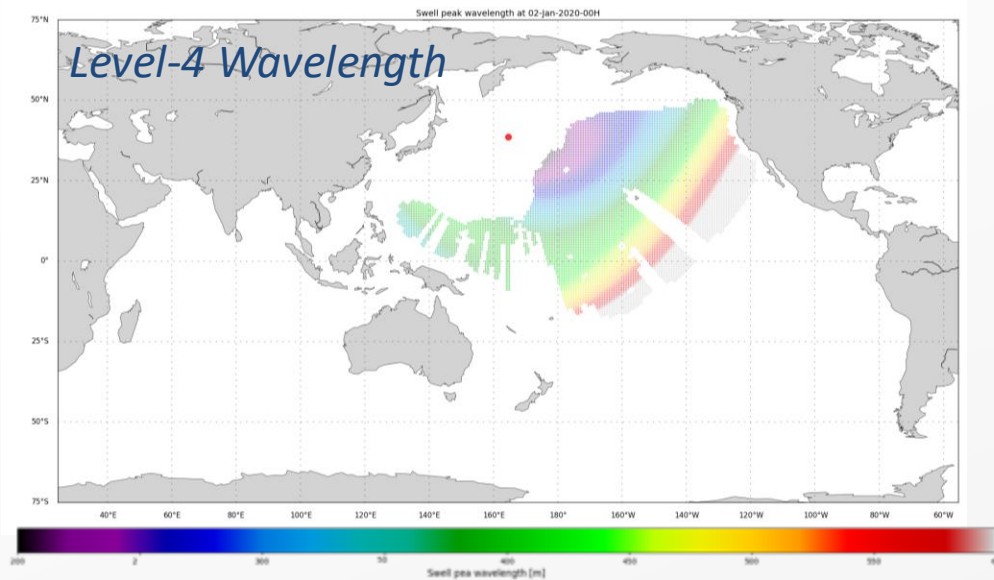
Distribution of peak wavelength (top) and Hs (bottom) extracted from the Level-3 product based on Sentinel-1A and Sentinel-1B on 02/01/2020 - 00h. The Level-3 products are based on several Level-2 measurements. The swell field originates from a storm, whose center is pin-pointed by a red circle.

Upcoming launch of Level-4 SPC product



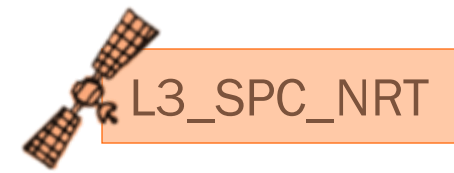
Objective of this new product: merge multi-mission swell observations and provide the swell evolution characteristics on a regular spatio-temporal grid.

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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.

CFOSAT SWIM products for climate studies



L3_SPC_NRT

L2P 2D valid spectra

Last week, CFOSAT Science Team Meeting concluded that the mission has entered its era of scientific exploitation. Its relevance for CCI project is discussed in Daniele Hauser's and Annabelle Ollivier's talks after coffee break today.

Since 2020, L2P and L3 SWH nadir products are provided in the CMEMS.

For climate purpose 2 types of products will be made available on Aviso web site (<https://www.aviso.altimetry.fr/en/missions/current-missions/cfosat/access-to-data.html>):

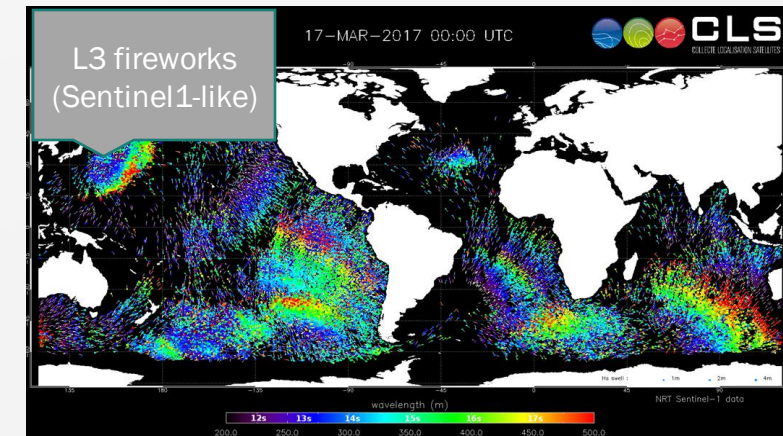
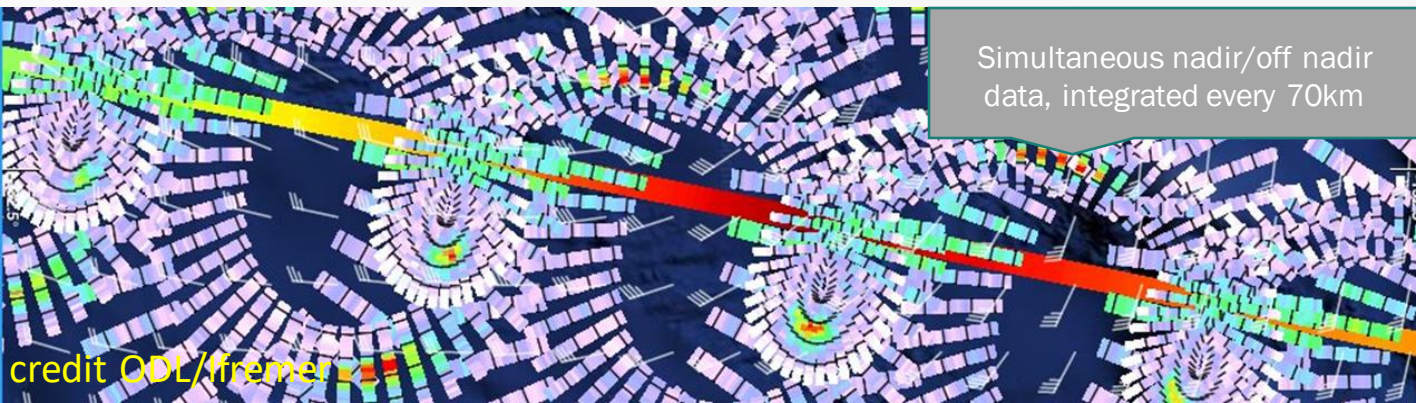
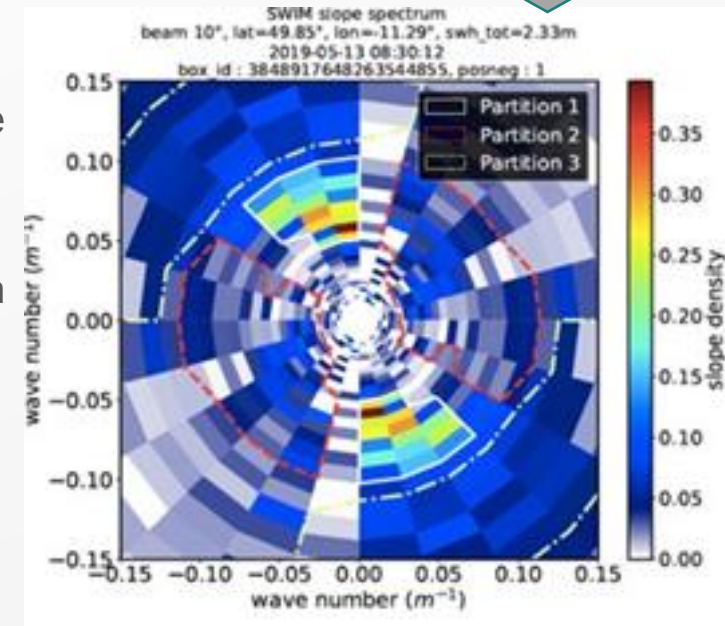
- L2P nadir reprocessed and extended on a long time series (whole mission period)
- L2P off-nadir demo product including recent outputs and improvement from the Calval Team (best spectrum and associated wave parameters, simple quality indicator, improved partitions,..)

And via CMEMS internal catalogue:

- L3 firework demonstration product derived from CFOSAT L2P off-nadir

CCI users are strongly advised to use these products tuned for application (climate) studies.

These added value products will be available during year 2021





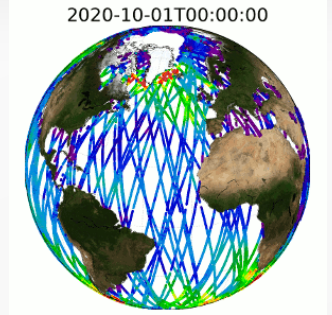
3 – Focus on Level-4 gridded SWH product

CMEMS L4 SWH gridded product

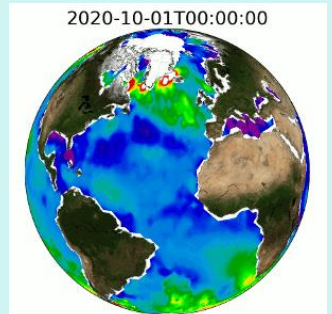


- Content: Gridded Significant Wave Height [meters] @ 2°x2°:
 - Daily mean SWH and other statistics (std deviation, max, nb of obs)
 - Instantaneous estimate of SWH
- Data processing:
 - Acquisition of available L3 NRT files
 - **Selection of data over 2°x2° box**
 - **Weighted average of SWH measurements in each box**, accounting for the time of measurement and local wave climatology
 - **Dynamic land-sea-ice mask**
 - Quality monitoring: Daily automated controls + Quality control 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

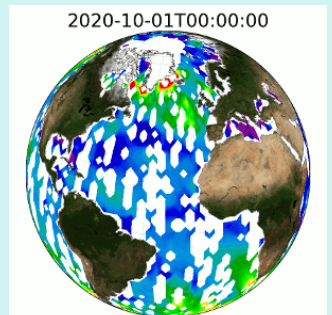
MULTI-YEAR: Distribution of a multi-year L4 SWH based on CCI L3 dataset + CFOSAT nadir reprocessing by mid-2021.



Level-3 SWH



Instantaneous SWH



Daily mean SWH

CMEMS L4 SWH gridded product



Along-track Level-3

Daily fields

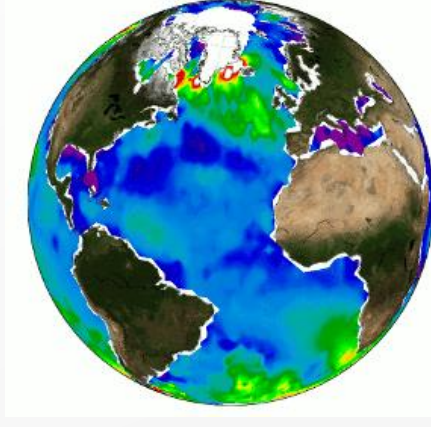
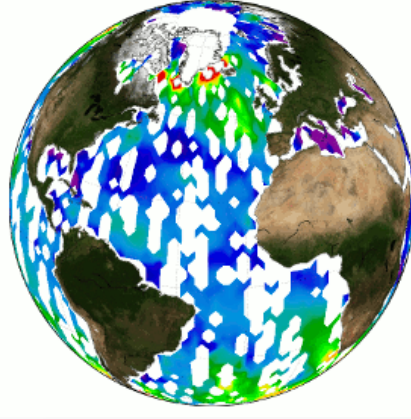
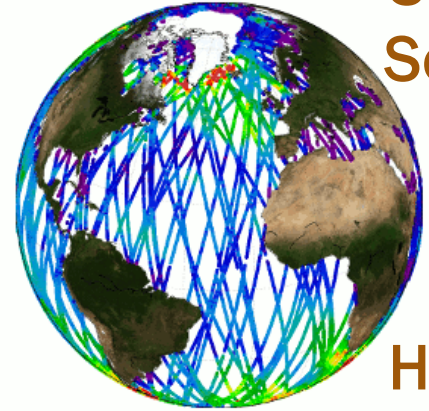
Instantaneous fields

2020-10-01T00:00:00

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

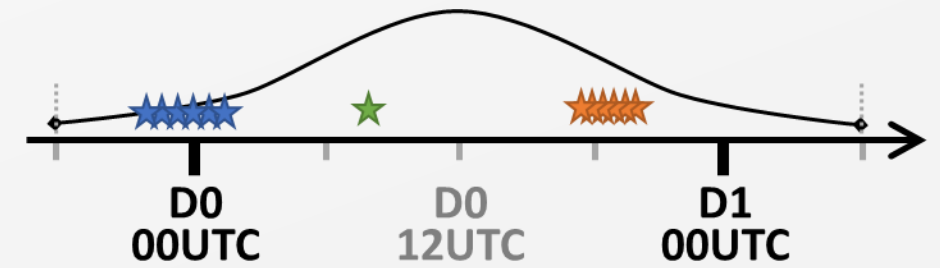
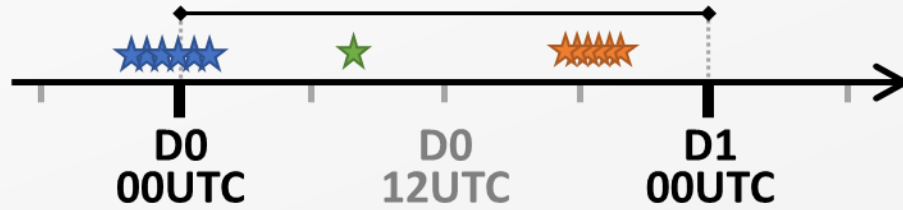
2020-10-01T00:00:00

2020-10-01T00:00:00



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

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°)

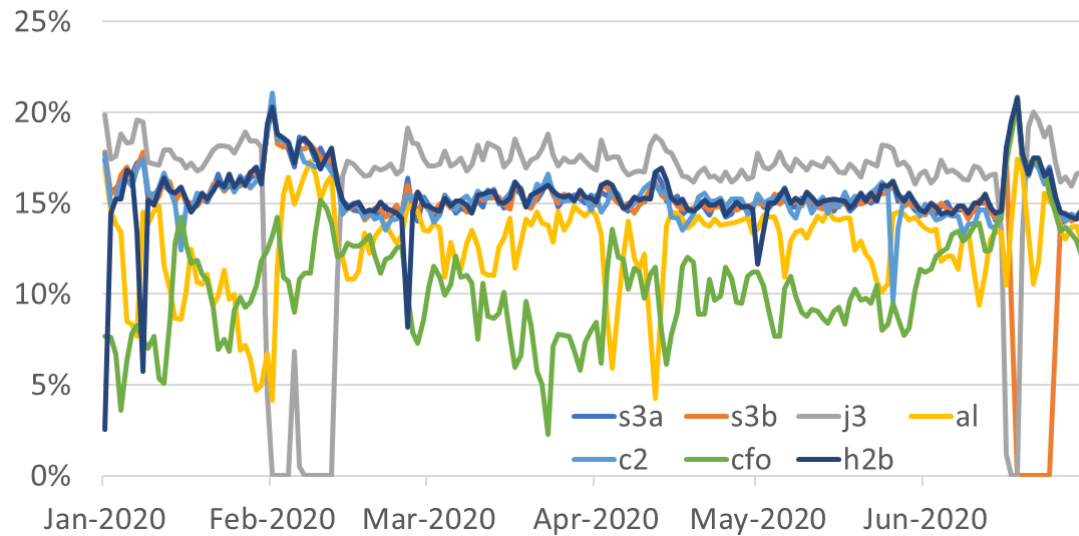
Time window = 24 hours

Size of the time window varies according to the local wave climatology

Contribution of each mission to the L4 SWH product



Percentage per mission of L3 SWH measurements used daily to build "D-5" L4 SWH maps



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

| Constellation used for the mapping | VAVH_INST | | | | | VAVH_DAILY_MEAN | | | | |
|------------------------------------|-----------|----------|----------|--------|-------|-----------------|----------|----------|--------|-------|
| | N | Bias (m) | RMSD (m) | SI (%) | R | N | Bias (m) | RMSD (m) | SI (%) | R |
| 5SAT (without S3) | 30519 | 0.065 | 0.282 | 26.1 | 0.868 | 24584 | 0.070 | 0.183 | 20.4 | 0.909 |
| 7SAT (with S3) | 30545 | 0.059 | 0.221 | 23.3 | 0.895 | 27897 | 0.066 | 0.156 | 18.9 | 0.922 |

Comparison of SWH maps with in-situ data at selected buoys during the 1-year period July 2019 – June 2020



4 – Future developments

Year 2021 and beyond



WAVE-TAC roadmap: Main drivers and user needs



Robust and stable near-real-time L3/L4 wave products with reliable intercalibration and in-situ calibration



Access to spectral wave parameters derived from Sentinel-1 SAR wide swath mode and CFOSAT/SWIM



Increased sampling and accuracy of altimetry along-track measurements to support regional and coastal wave modelling



Access to wind speed collocated with waves (altimetry and SAR)



Improved description of uncertainties related to the different instruments and datasets



Access to homogeneous long-term wave measurements for climate applications



Conclusions

Conclusions

CMEMS NRT L3 SWH products

- A Near-Real Time constellation of 7 satellites, providing Significant Wave Height :
Quality controlled / Inter-calibrated / Noise-Filtered / Monitored / With collocated wind speed

CMEMS NRT L4 SWH products

- A Near-Real Time multi-mission gridded Significant Wave Height: daily statistics, estimate of instantaneous wave field

CMEMS NRT L3 SPC products

- Reduced but more consistent set of swell observations compared to Level-2
- Offer the possibility to deploy virtual-buoy observer

Upcoming launch of MULTI-YEAR products [mid-2021]

- Level-3 SWH reformatted from CCI Sea State dataset + CFOSAT nadir reprocessing
- Level-4 SWH (daily fields) computed from L3 CCI dataset
- Level-3 SPC reprocessed over the full period of S1-A and -B missions (since May 2016)

Continuous collaboration between spatial agencies, CMEMS, R&D projects 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



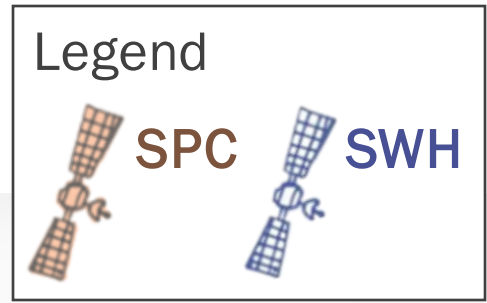
Thank you

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

WAVE-TAC 2018-2020 main evolutions



2018 Launch of the WAVE-TAC

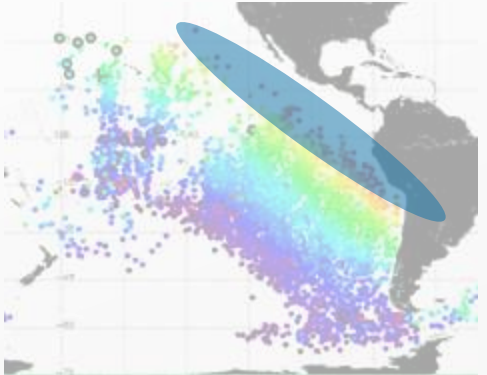


New Level-3 spectral product derived from S1-A/B

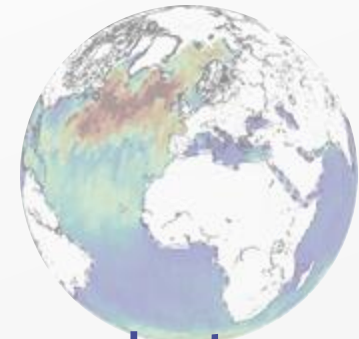
2019

Level-3 Lanczos noise-filtering

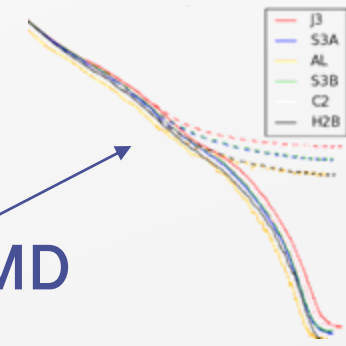
Better characterization of long swell measurements



New Level-4 gridded SWH product

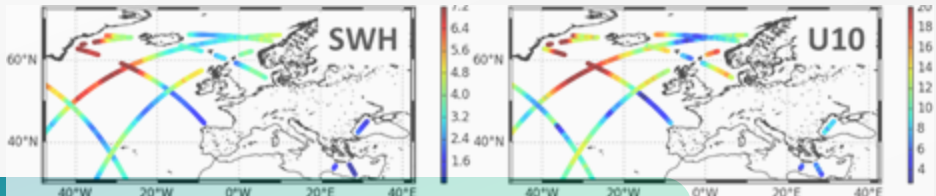


Improved noise filtering based on EMD

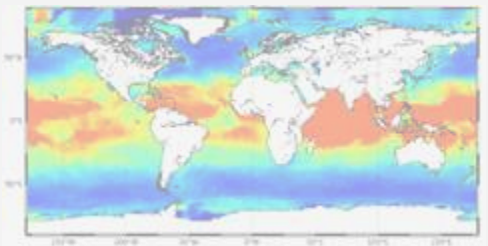


2020

Addition of collocated wind speed



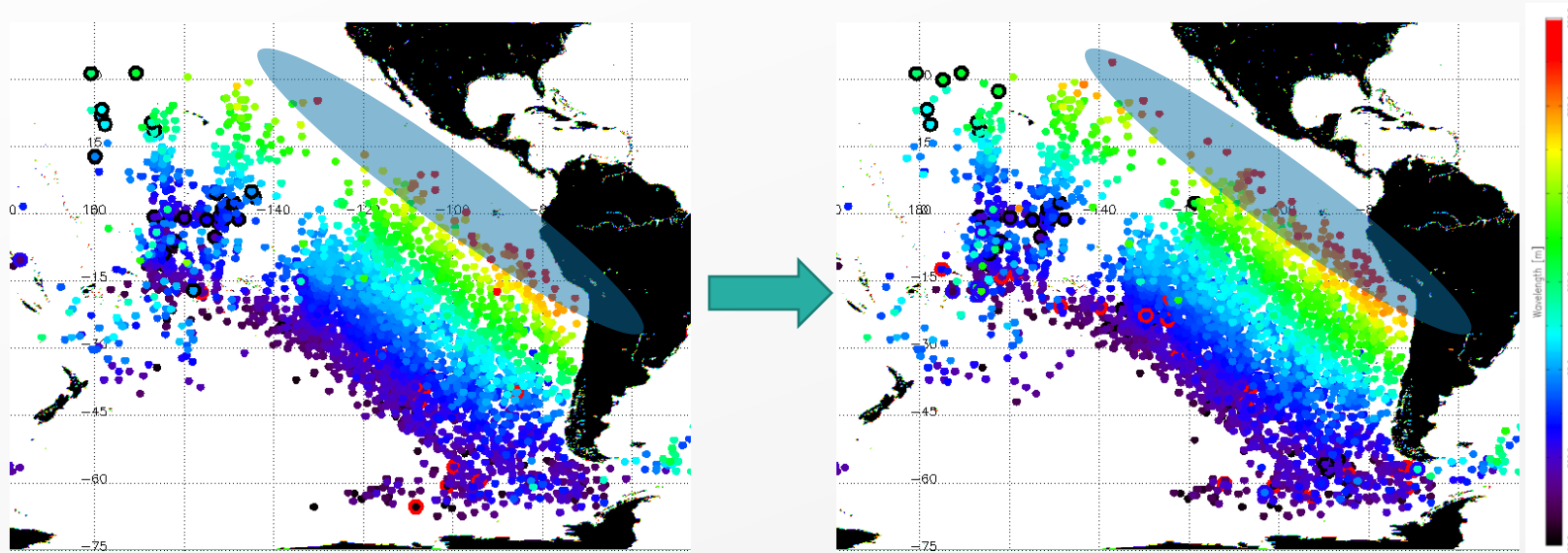
Improved L4 mapping method



Improvement for long swells

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 identified

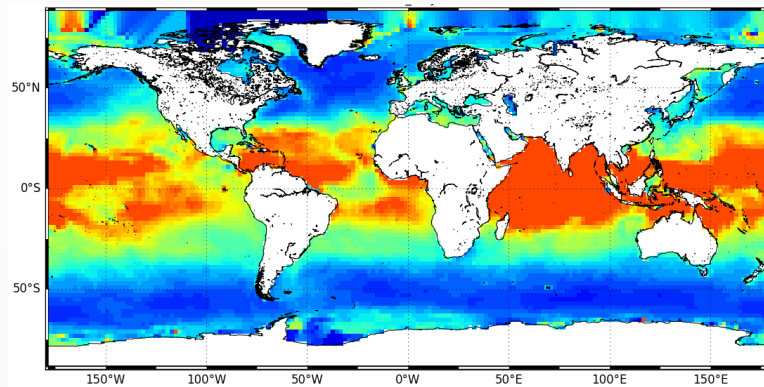
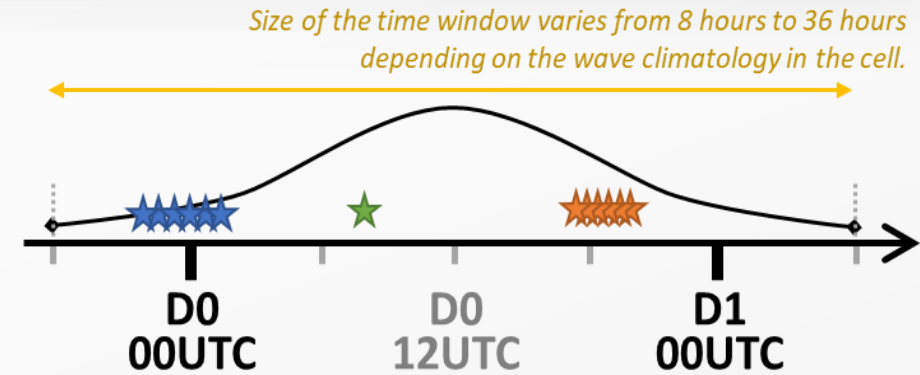


Example of a S1 WV propagated measurements belonging to a swell field event on 8th May 2018 off New Zealand (strongest Hs ever recorded in South Hemisphere). S1 measured wavelength reaches 800 m!

Evolution of the SWH mapping method



- Since December 2020 version, the temporal window used to select observations projected in each grid cell varies 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, equator).



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 WAVERY5 dataset.

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

| Mapping method | VAVH_INST | | | | |
|---------------------------------|-----------|----------|----------|--------|------|
| | N | Bias (m) | RMSD (m) | SI (%) | R |
| Fixed temporal window (36h) | 30551 | 0.058 | 0.25 | 24 | 0.89 |
| Variable temporal window (<36h) | 30545 | 0.059 | 0.22 | 23 | 0.90 |