Description and validation of the Marine Copernicus Near-Real-Time wave products: derived from altimeter and SAR measurements

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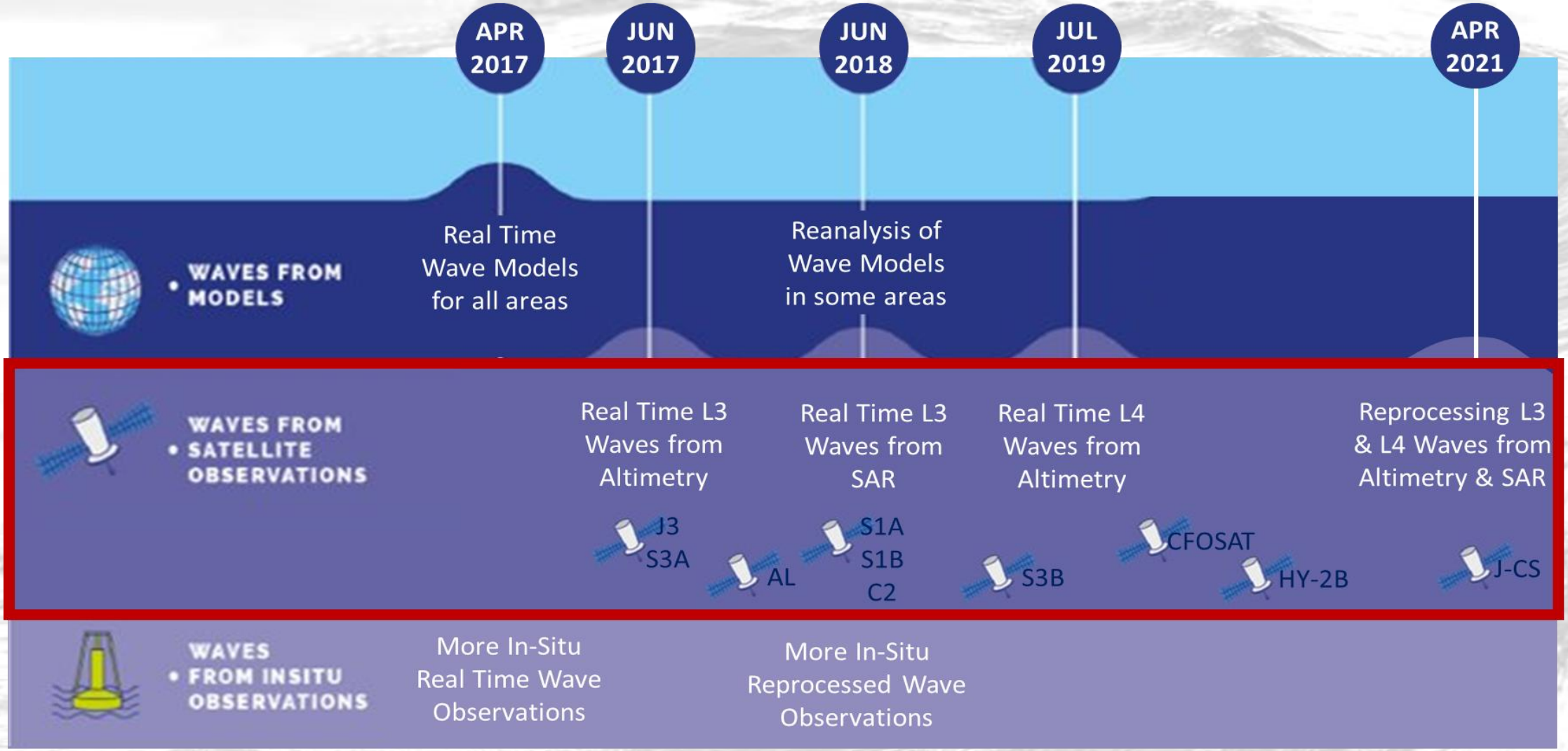
Nicolas Taburet[1], Alexis Mouche[2], He Wang[3]

1-CLS, 2-IFREMER, 3-NOTC

Satellite waves: a recent product in CMEMS

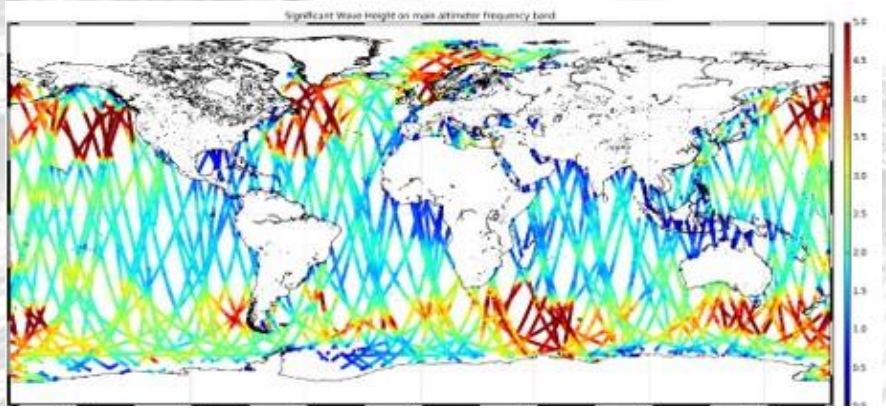


Motivation: Provide users with Real-Time, simplest, best quality, homogeneous and user-friendly formats (netcdf CF convention) and inter-calibrated dataset of satellite wave products

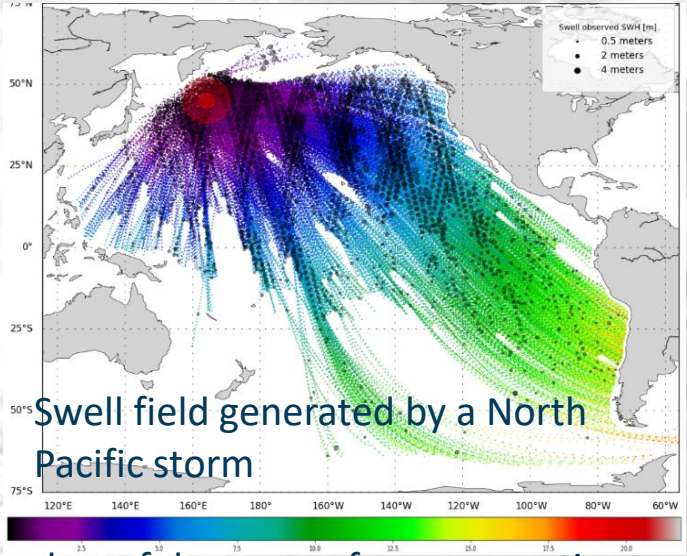
Available products and missions

WAVE_GLO_WAV_L3_SWH_NRT_OBSERVATIONS_014_001:

- Real-Time Level-3 waves from altimetry
- Missions: Jason-3, Sentinel-3A and -3B, Saral/AltiKa, Cryosat-2 and soon CFOSAT
- Significant wave height (SWH) parameter
- Available in 3-hourly files



24 hours of along-track Level 3 SWH measurements

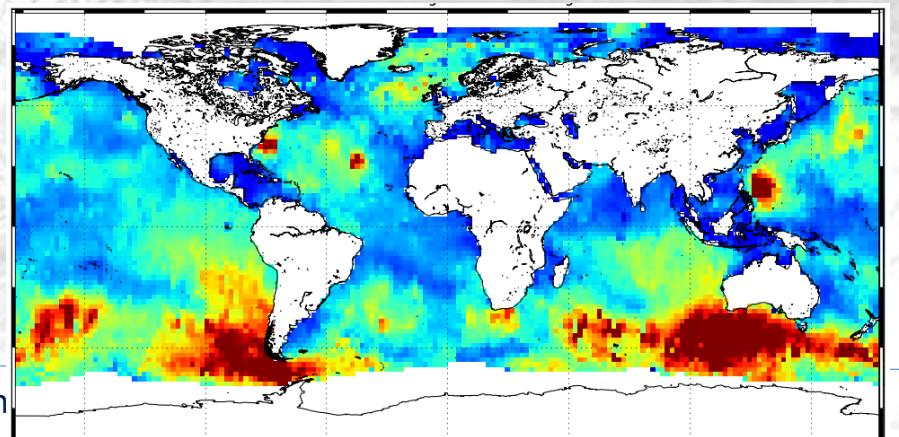


Swell field generated by a North Pacific storm

Number of days away from generation area

WAVE_GLO_WAV_L3_SPC_NRT_OBSERVATIONS_014_002:

- Real-Time Level-3 waves from SAR
- Missions: Sentinel-1A, Sentinel-1B
- Spectral integral parameters (SWH, period, direction, wavelength)
- Backward and forward propagation from the swell observation
- Available in 3-hourly files and in swell system files



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
- *Available from July 2019... More details in the next slides*

Altimeter L3 products

- Distribution via ftp at:

ftp://nrt.cmems-du.eu/WAVE_GLO_WAV_L3_SWH_NRT_OBSERVATIONS_014_001

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

- Content: Along-track Significant Wave Height [meters] @1-Hz (~7km):
  - Unfiltered SWH
  - And Filtered SWH
    - Lanczos (60km cutoff) since June 2019
    - EMD Denoising ready for November 2019

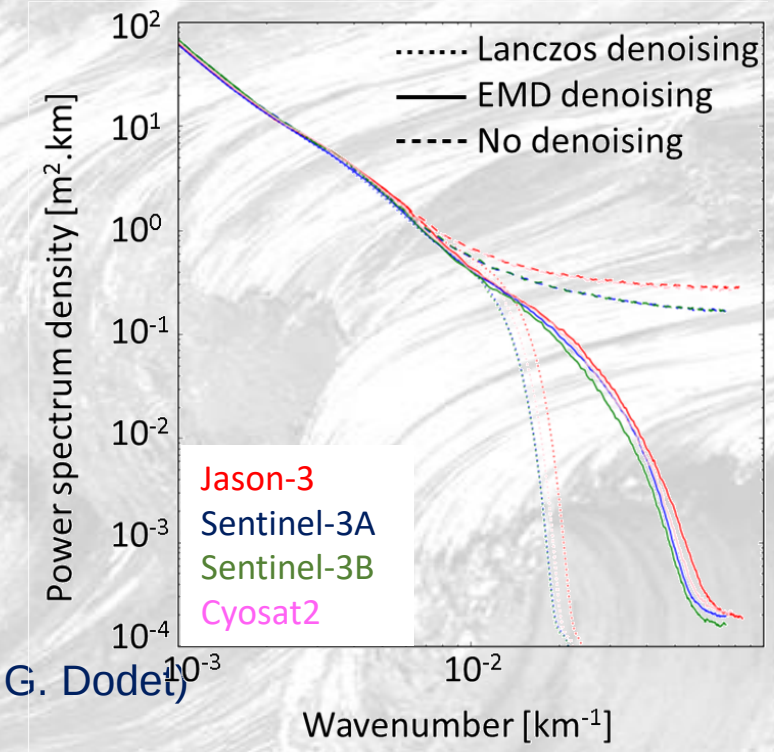
  (following Quilfen and Chapron 2019)
- Delivered in 3-hourly netcdf files

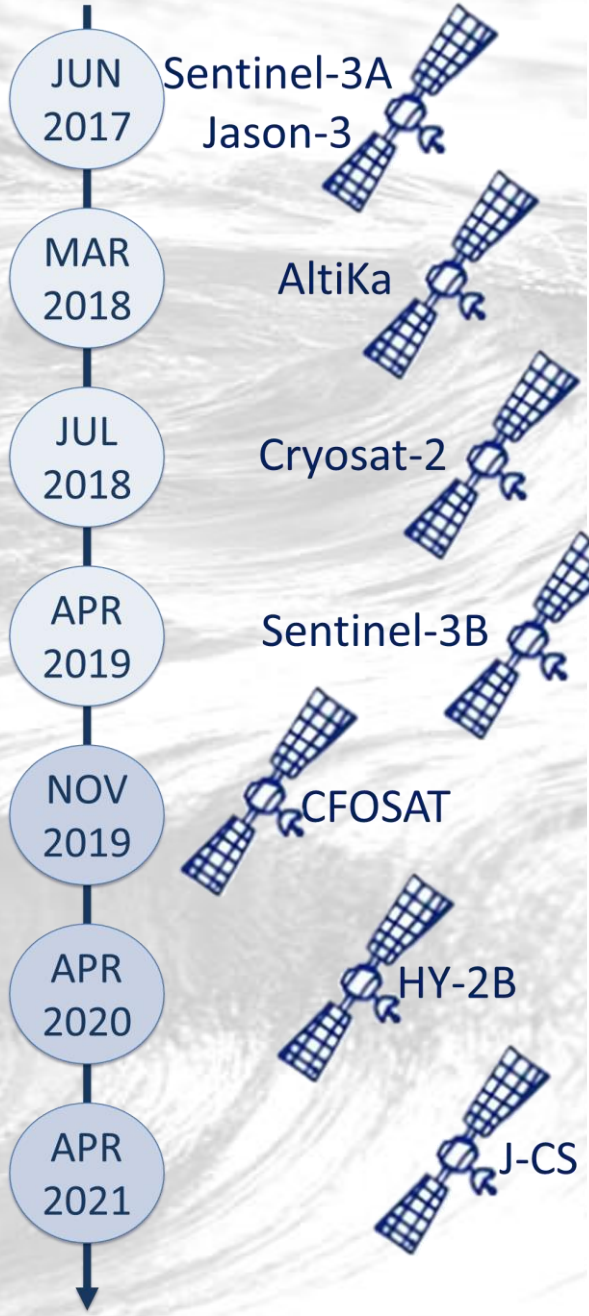
- 1st file production starts 3h after file starting time, then updated every 30min if new L2 data available.

- Data processing
  - Acquisition of L2 GRD files
  - Editing (thresholds and flags)

  → Harmonized with CCI products (already presented by G. Dodet)
  - Inter- and absolute calibration
  - Filtering

  → Harmonized with CCI products for EMD filtering (already presented by B. Chapron)
  - Quality monitoring: Daily automated controls + Quality controls reports once a week (#edited points + Mean difference at cross-over evolution)





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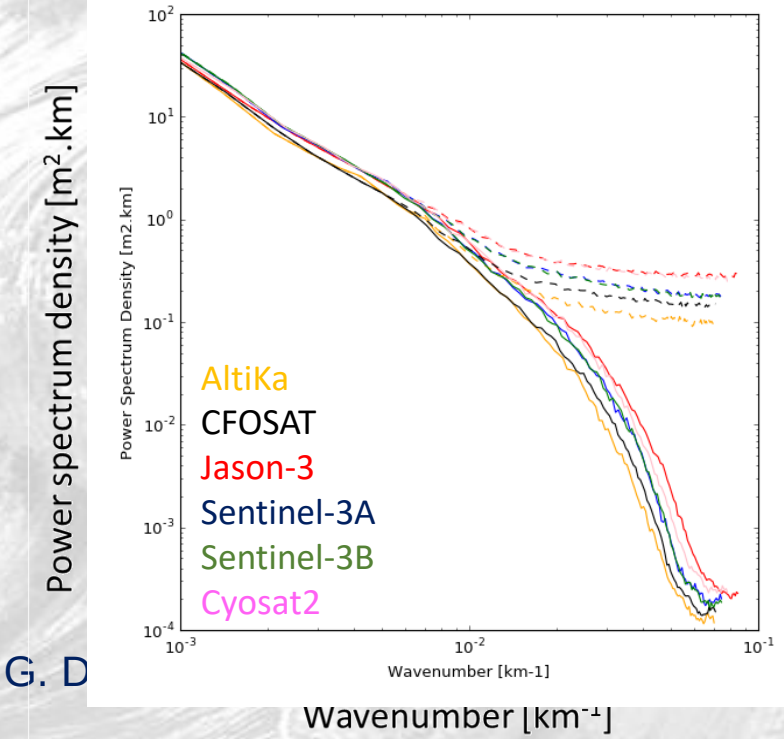
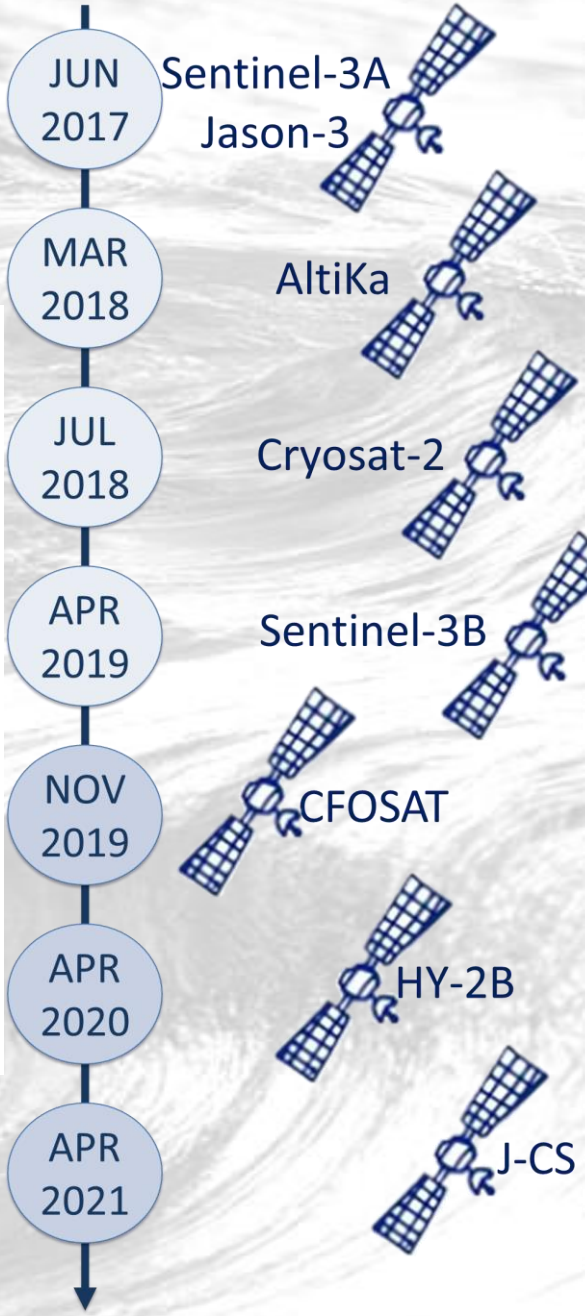
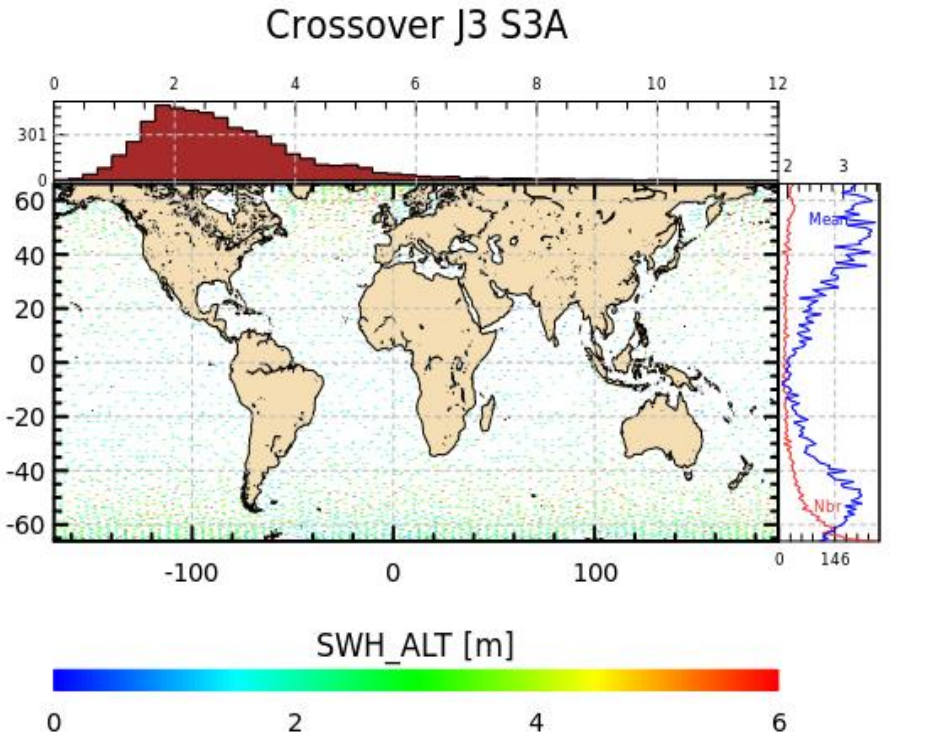
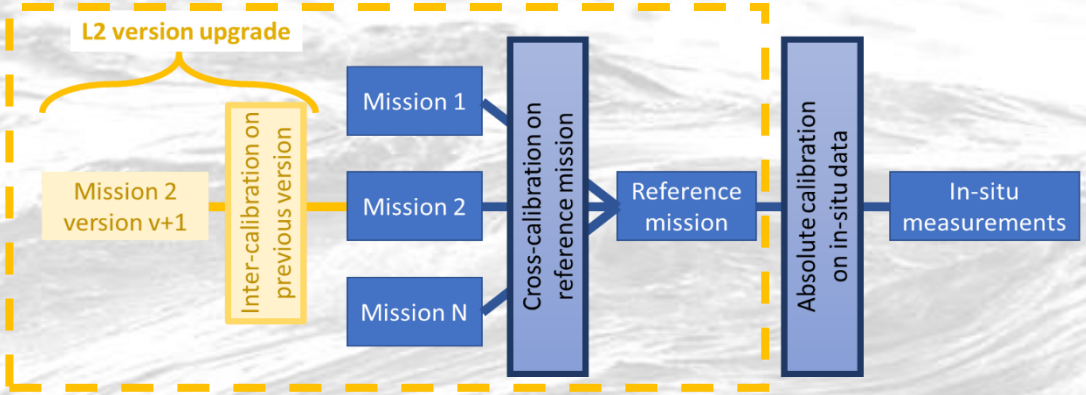


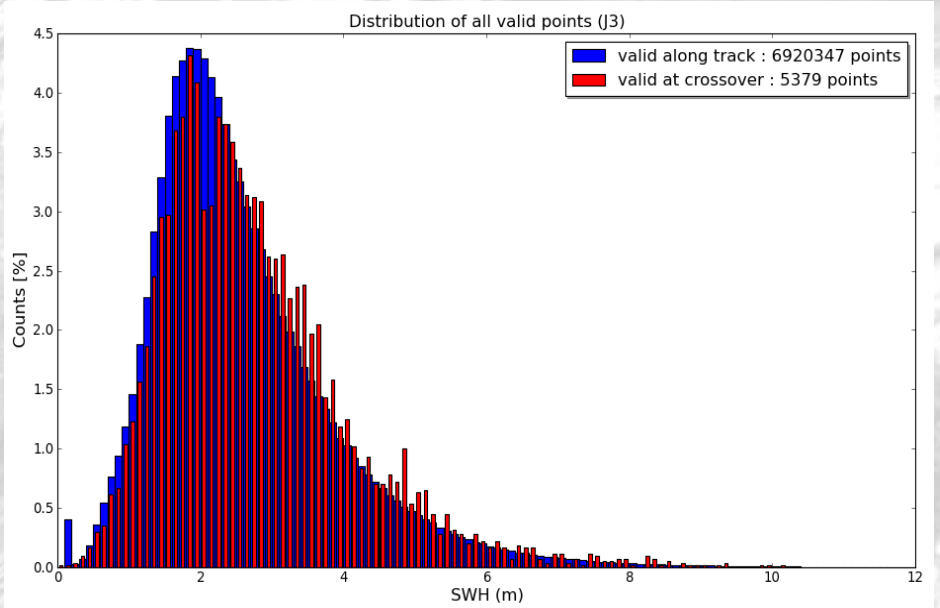


Altimeter L3 products

- Inter-calibration
  - Jason-3 is set as the reference mission
  - Correction estimated independently for each mission and mode (eg: CS2 SAR and LRM mode) through cross-over differences analysis.







Valid J3 points distribution over the cross-calib period with S3A

Altimeter L3 products

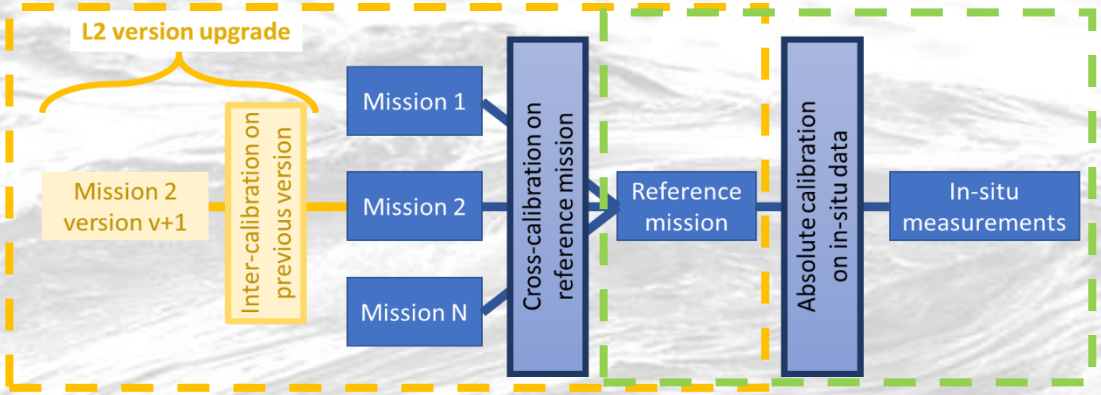
- Inter-calibration
  - Jason-3 is set as the reference mission
  - Correction estimated independently for each mission and mode (eg: CS2 SAR and LRM mode) through cross-over differences analysis.
  - Such correction is expected to remain valid as long as instrumental drifts are not detected or ground segment evolutions does not affect the L2 products in input of the operational system

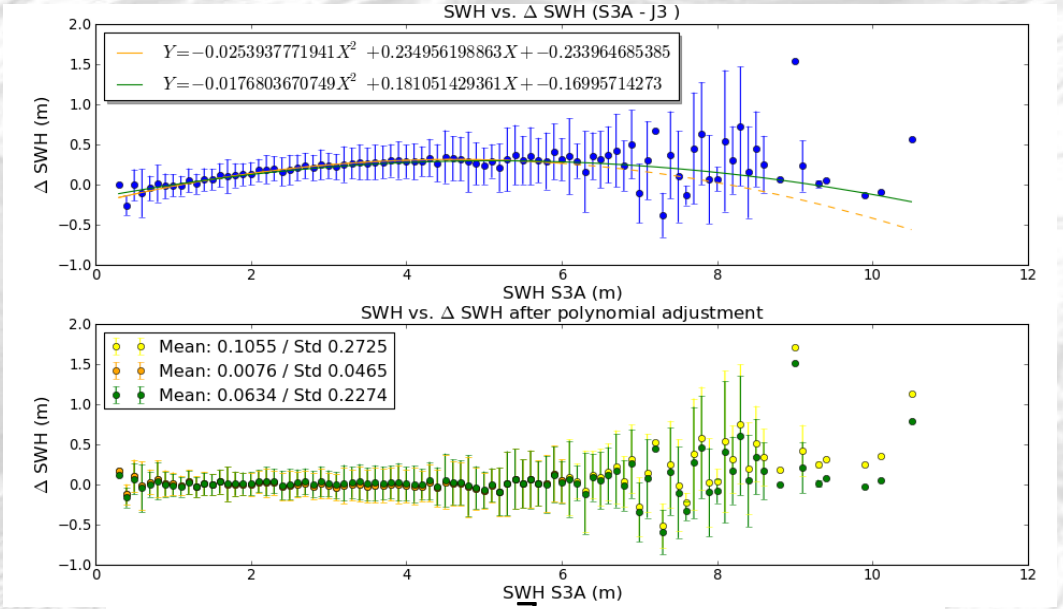
- Absolute Calibration
  - Application of a linear correction to compensate systematic errors

  - *swh_cor = 1.0149 x swh + 0.0277*
    (Queffeulou and Croizé-Fillon 2017)

  - Estimated for Jason-2 against in situ measurements

and applied for Jason-3 (Queffeulou, 2016)

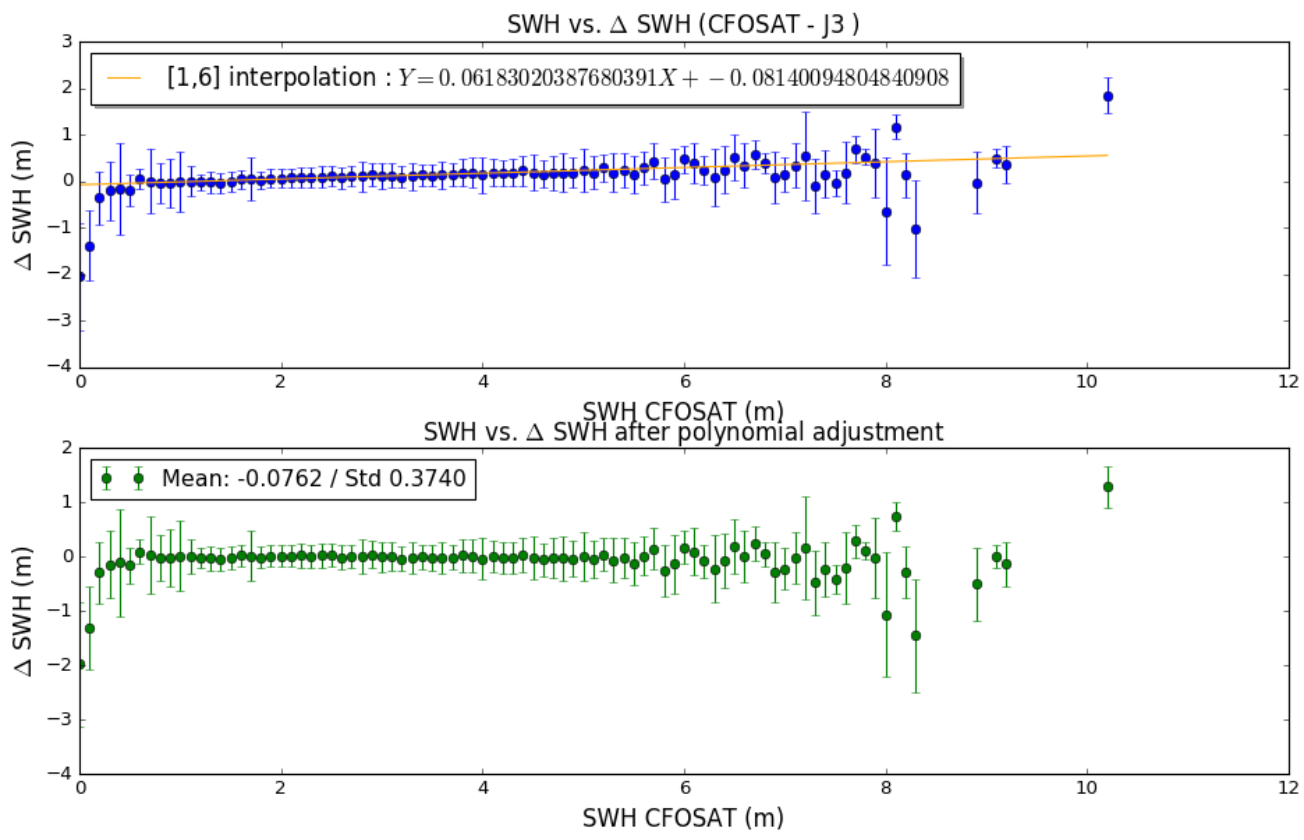




Top: Median of the diff between the S3-A SAR and the J3 value per 10cm bin.
Bottom: Residuals between the median and the fits.

CMEMS version June 2018 (EIS 11/19)

- Integration of CFOSAT mission in L3_SWH product



Top: Median of the difference between CFOSAT and J3 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] meters range. Bottom: Residuals between the median and the fit.

CFOSAT tends to slightly over-estimate large Hs wrt. J3

Altimeter L3 products

- Inter-calibration + Absolute Calibration

Cross-compared missions	Before cross-calibration		After cross-calibration (performed in L2P chain)	
	Bias [cm]	Standard dev. [cm]	Bias [cm]	Standard dev. [cm]
Sentinel-3A / Jason-3	8.2	26.7	-1.1	25.4
Sentinel-3B / Jason-3	7.4	26.2	-2.0	25.0
AltiKa / Jason-3	5.9	22.7	0.7	22.7
Cryosat2 / Jason-3	0.9	24.3	0.3	24.4
CFOSAT / Jason-3	-8	35	TBC	TBC

*Bias and standard deviation between Jason-3 and secondary missions SWH, before and after the **calibration** step (**L2P** on **top**), before and after **filtering** step (**L3 at bottom**). Computation period: February 17th 2019 to July 31st 2019.*

→ Mean bias is reduced after calibration while standard deviation is reduced after filtering.

Cross-compared missions	After cross-calibration (performed in L2P chain)		After Filtering (performed in L3 chain)	
	Bias [cm]	Standard dev. [cm]	Bias [cm]	Standard dev. [cm]
Sentinel-3A / Jason-3	-1.1	25.4	-1.0	21.3
Sentinel-3B / Jason-3	-2.0	25.0	-1.6	21.2
AltiKa / Jason-3	0.7	22.7	0.5	18.8
Cryosat2 / Jason-3	0.3	24.4	0.4	19.6
CFOSAT / Jason-3	TBC	TBC	TBC	TBC

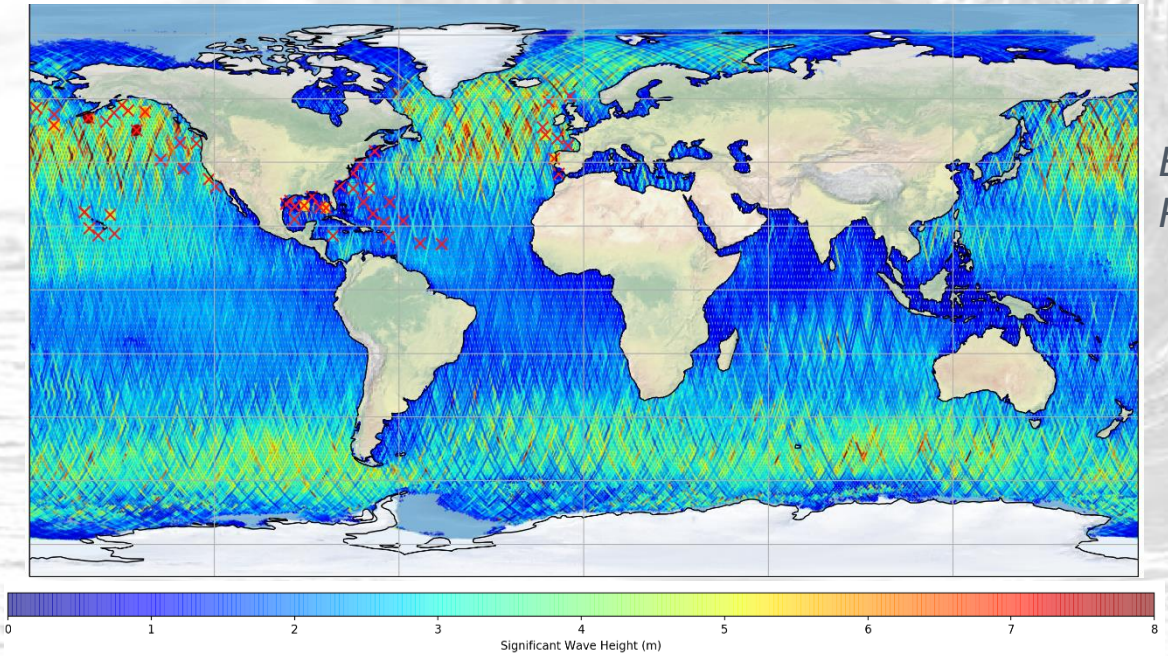
Altimeter L3 products

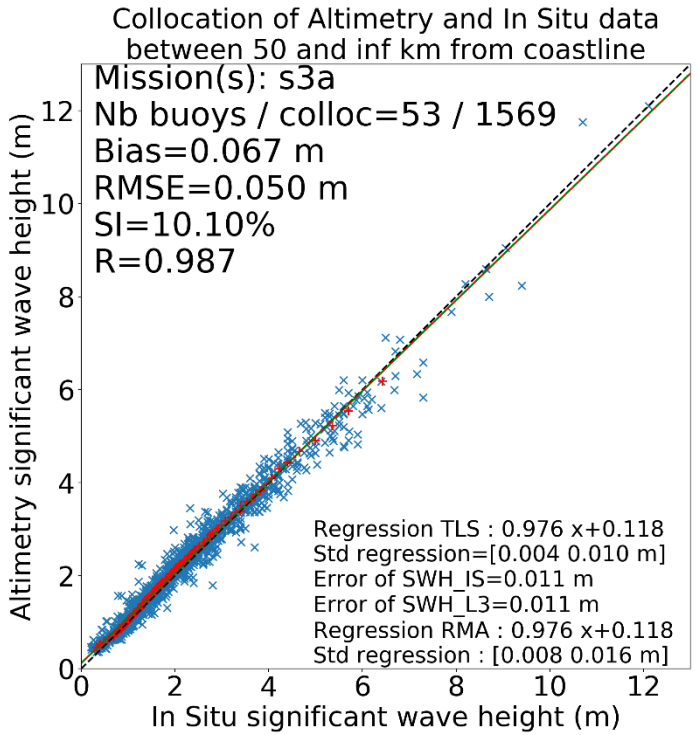
Validation

- Level-3 SWH product compared to a set of 114 offshore buoys (CMEMS in-situ measurements) during the year 2018.
- Buoy SWH measurements compared to the average of L3 SWH data selected within 30 min and 50 km of the buoy record.

→ Mean positive bias remains for all missions

➔ Absolute calibration to be re-estimated?



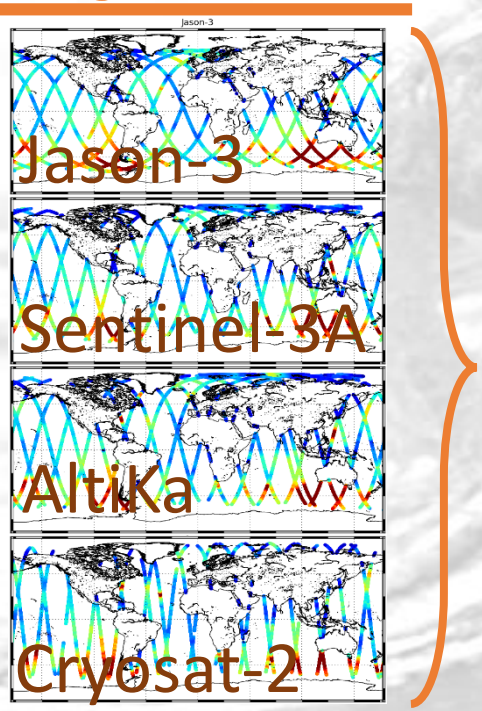


Example of S3A along-track SWH measurements during year 2018. Red crosses indicate match-up with in-situ moorings.

	Nb of match-up	Bias	RMSE	SI	R
L3 Jason-3	1700	8 cm	5 cm	10%	0.99
L3 Sentinel-3A	1569	7 cm	5 cm	10%	0.99
L3 AltiKa	1667	9 cm	6 cm	10%	0.99
L3 CryoSat-2	1488	6 cm	5 cm	10%	0.99

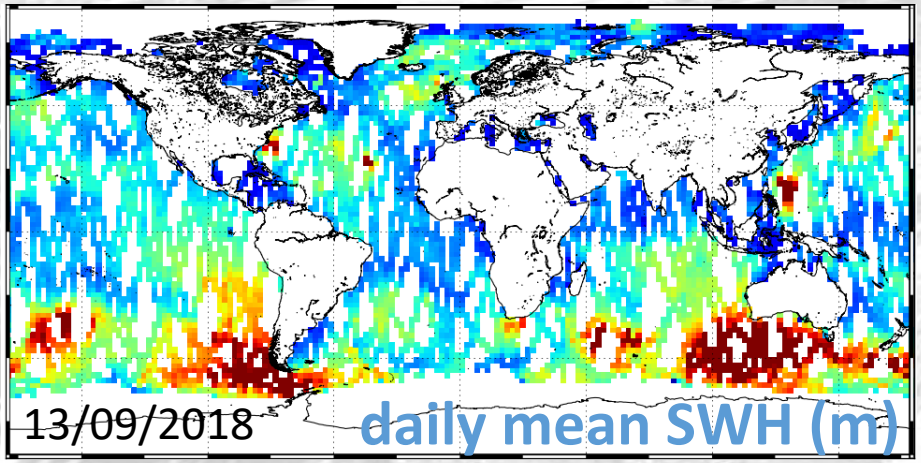
A new NRT Level 4 gridded SWH product

Along-track Level-3

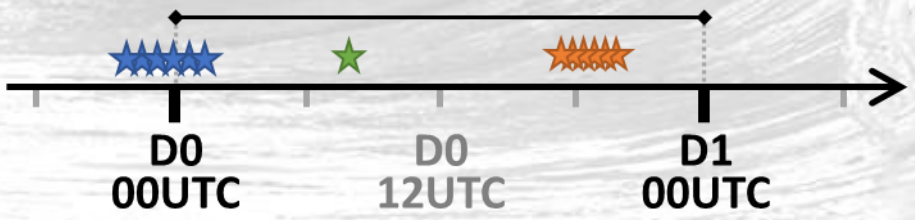


Example of L3 measurements over one grid cell (2°x2°)

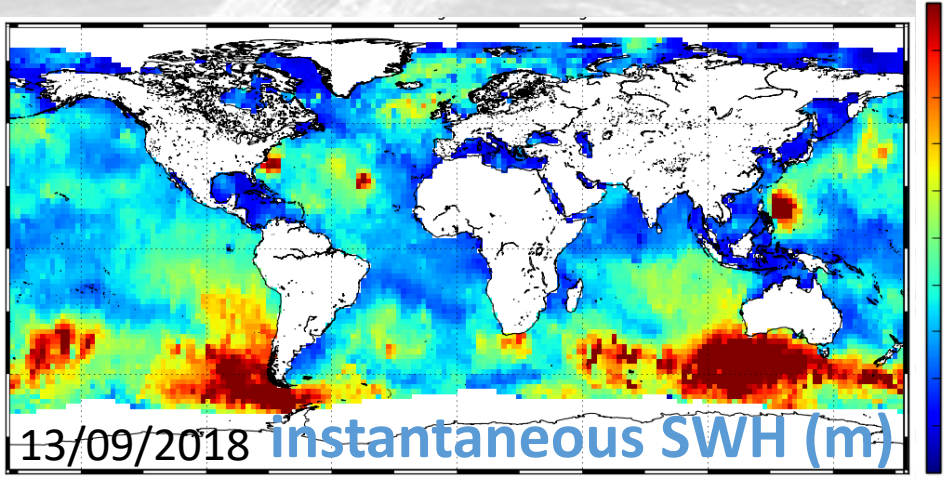
Daily fields



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



Instantaneous fields

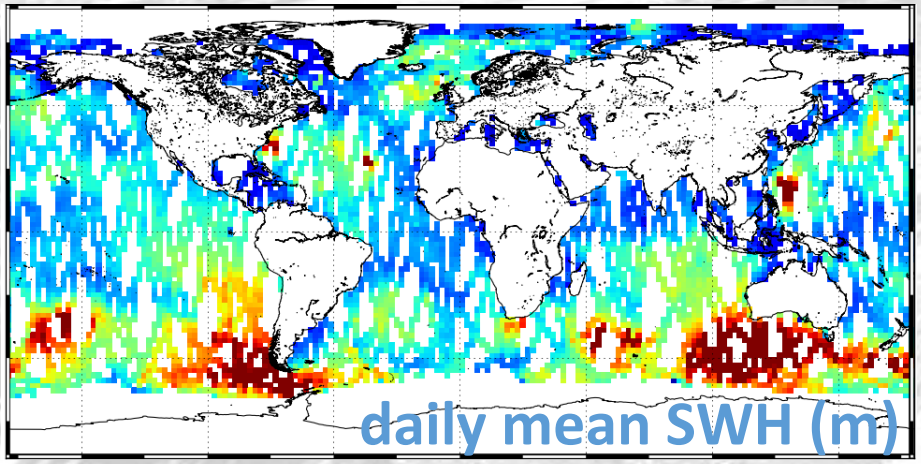


VAVH_INST: weighted average of level-3 available along-track measurements to account for their temporal proximity and spatial interpolation when no measurements

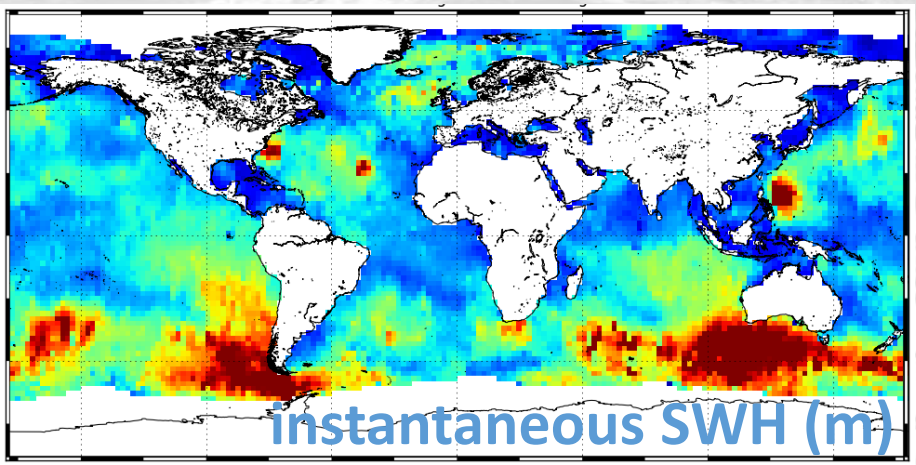
A new NRT Level 4 gridded SWH product

Daily fields

Instantaneous fields

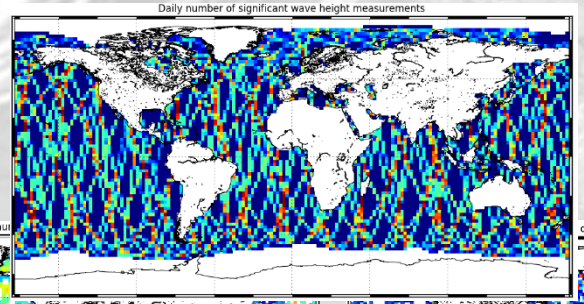


daily mean SWH (m)

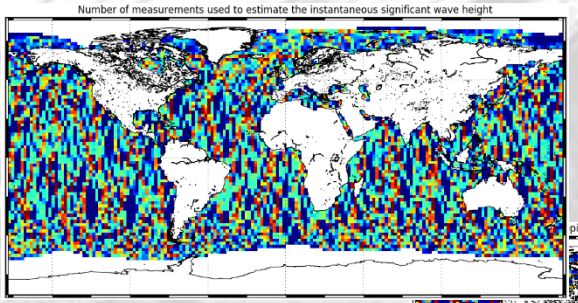


instantaneous SWH (m)

Additionnal parameters



number of daily measurements



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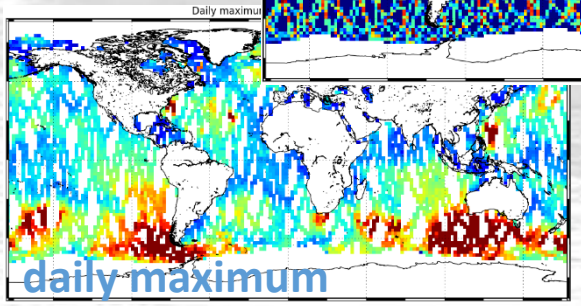
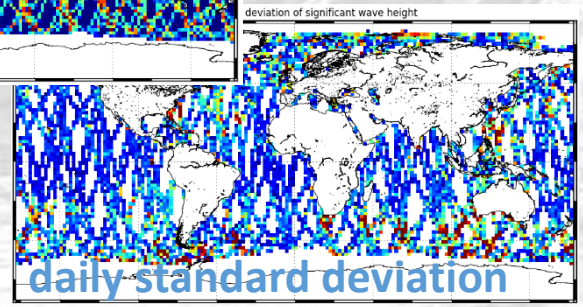
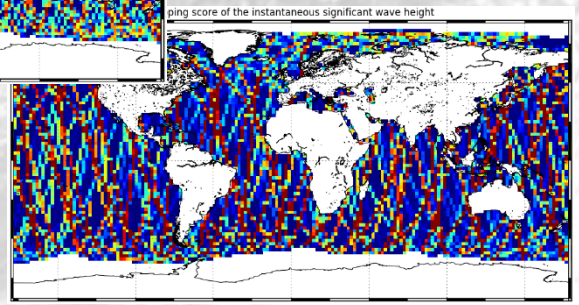


daily maximum



daily standard deviation

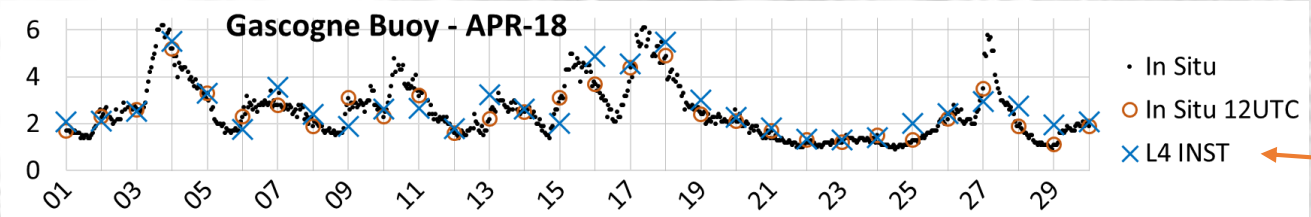
mapping score



Performance to reproduce instantaneous wave field

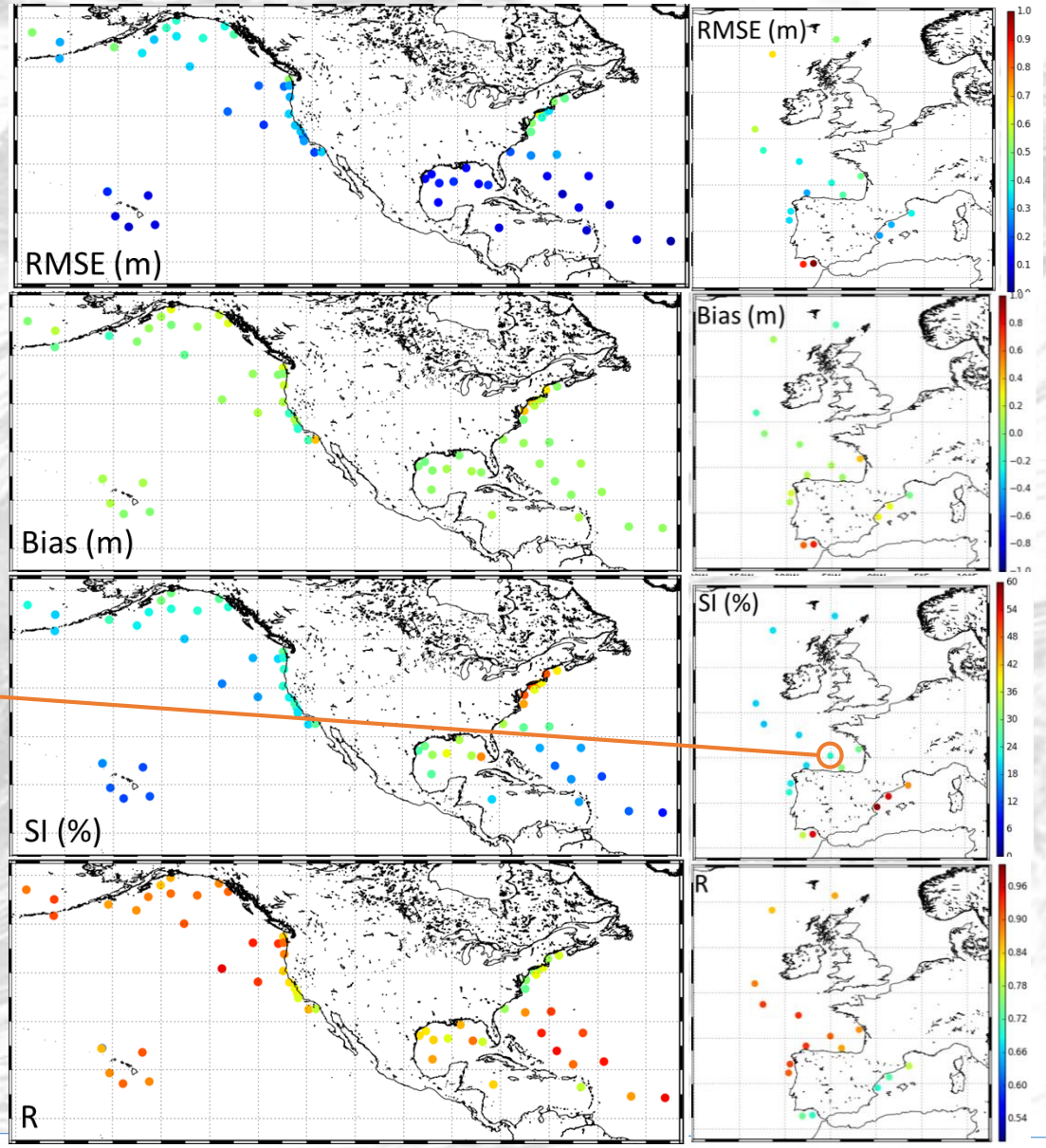
Comparison is performed against a set of 114 buoys (CMEMS InSitu product) during the year 2018.

Level-4 instantatenous SWH are extracted at each buoy location and compared to the buoy measurements at 12UTC every day (see example at Gascogne Buoy below).



Overall statistics, depending on the buoy distance to the shore:

Buoys location	L4 VAVH_INST				
	Nb	Bias (m)	RMSE (m)	SI (%)	R
>30km offshore	23710	0,10	0,31	26	0,86
>100km offshore	12306	0,05	0,26	21	0,89
>400km offshore	3684	0,06	0,21	18	0,92



SAR L3 products

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Input data

- L2 Wave Mode from Sentinel-1A/B wave spectra
- Rejecting waves with short wavelength (wl < 200m) to keep those who best following linear propagation theory
- Rejecting waves with small Hs (< 30cm)

→ 60% swell partitions are used

Content

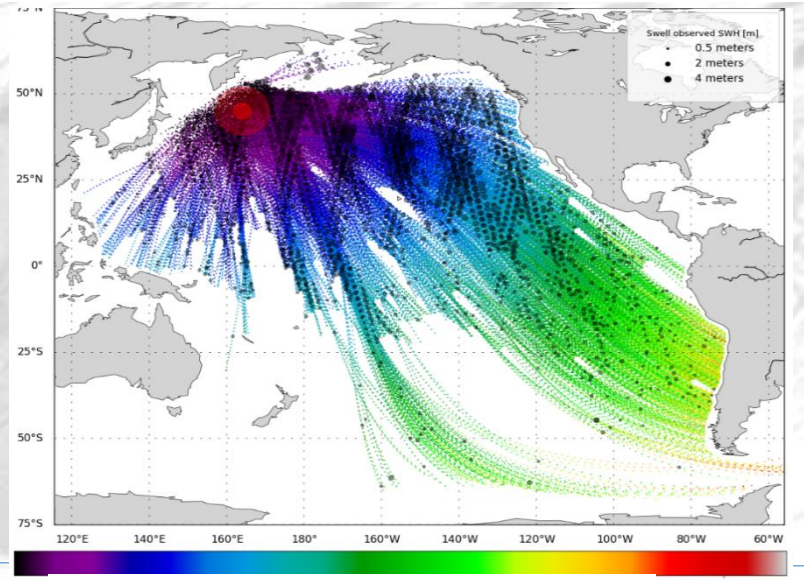
- Partition Hs, peak Period (Tp) and direction (Dp), along swell propagation path form storm to land, a function of time
  - Irregular spatial grid, 3-hour resolution
- Some obs. parameters:
  - Hs, Tp, Dp → from L2
  - Quality flag → derived from L3 analysis (overall consistency)
  - Overall wave Spectra + partition spectral domain

Delivered in two formats

- Swell observations gathered by swell fields (one netcdf by swell field and by sat.)
- 3-hourly netcdf files (all swell observations from different swell fields)

- Daily updated, using all L2 data available at processing time
- Missions: S1A/S1B since July 2018

Swell field generated by a North Pacific storm



SAR L3 products

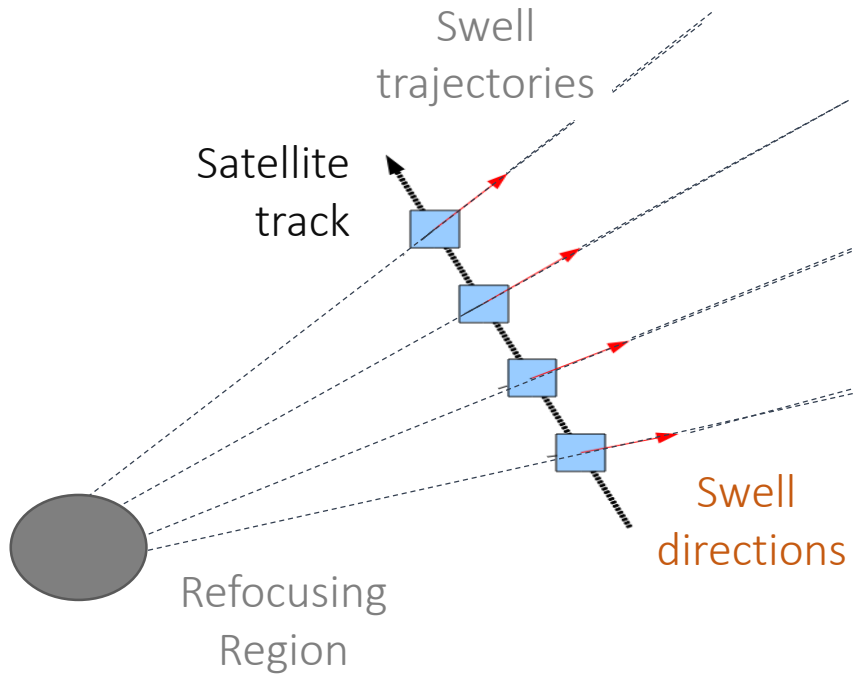
Principle

- From the many available L2 swell observations gather the ones related the same swell system (Heimbach and Hasselmann, 2000; Collard et al., 2009)
  → Refocused observations (first selection – on Tp and Dp): 50% remaining from used
- Swell field space/time evolution described by associated SAR observations propagating from storm to land.
  → Swell observations inconsistent wrt to the neighbors are rejected (second selection – mostly on Hs)
  → 25% remaining from used
- Hs decay with propagation governed by frequency dispersion and angular spreading with additional dissipation: linear decay parameterization proposed:

$$H_s(\alpha) = H_s^{free}(\alpha).\exp\left(-\mu\frac{\alpha-\alpha_0}{2}\right)$$

$$= H_s(\alpha_0)\sqrt{\frac{\alpha_0.sin(\alpha_0)}{\alpha.sin(\alpha)}}exp\left(-\mu\frac{\alpha-\alpha_0}{2}\right)$$

- The decay parameter, μ, is estimated using the swell steepness at 4000km from the storm source (Ardhuin et al. 2009).



Hypothesis

- Linear propagation in open ocean, no current
- Swell energy decay only valid more than 3000km from the storm source

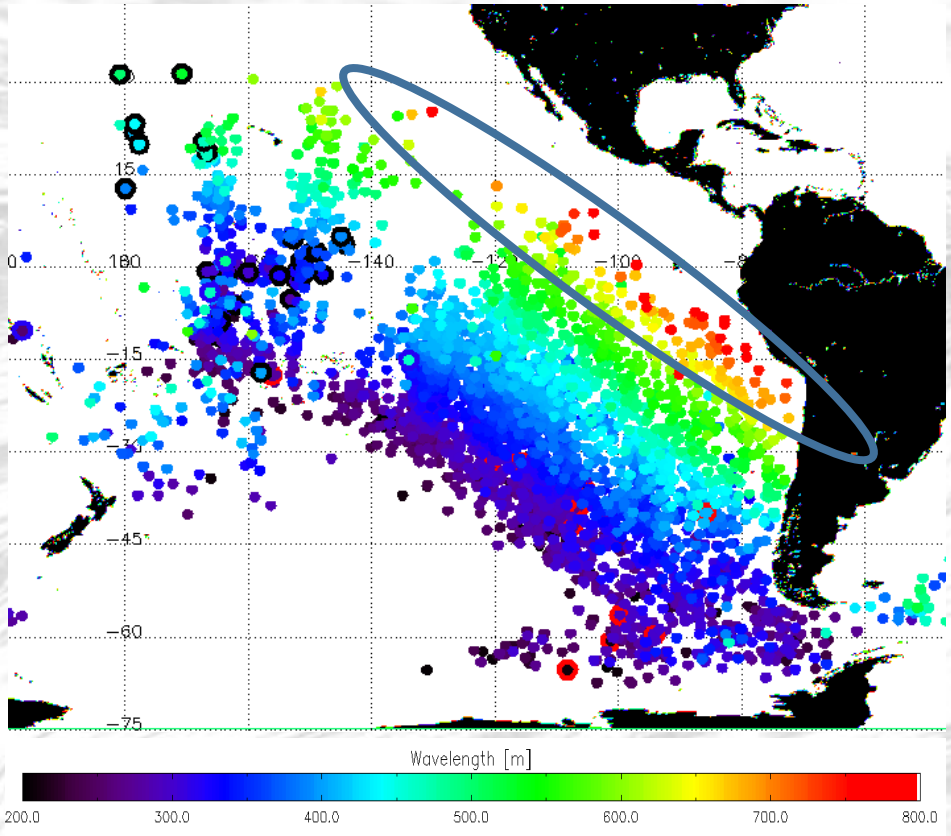
SAR L3 products

Specific processing for long wavelength

- Long swell direction is not well resolved by Sentinel-1 Wave Mode
- It is often indicating opposite direction.

→ Considering both propagating directions, the most consistent wrt to smaller wavelengths is chosen

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



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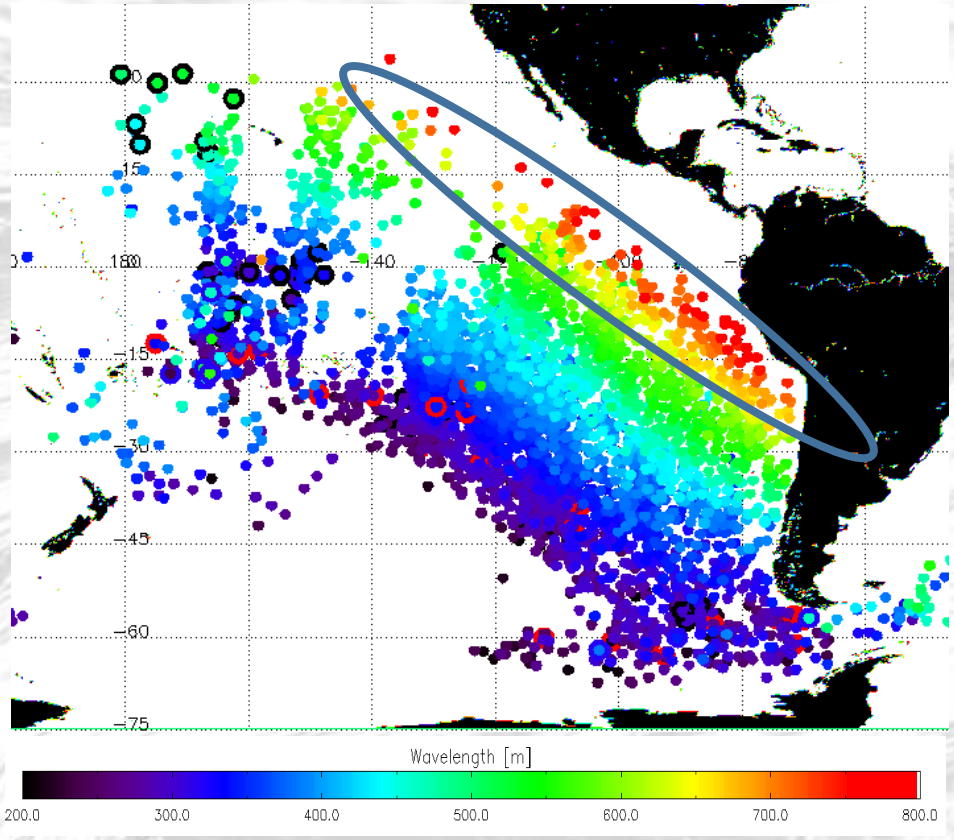
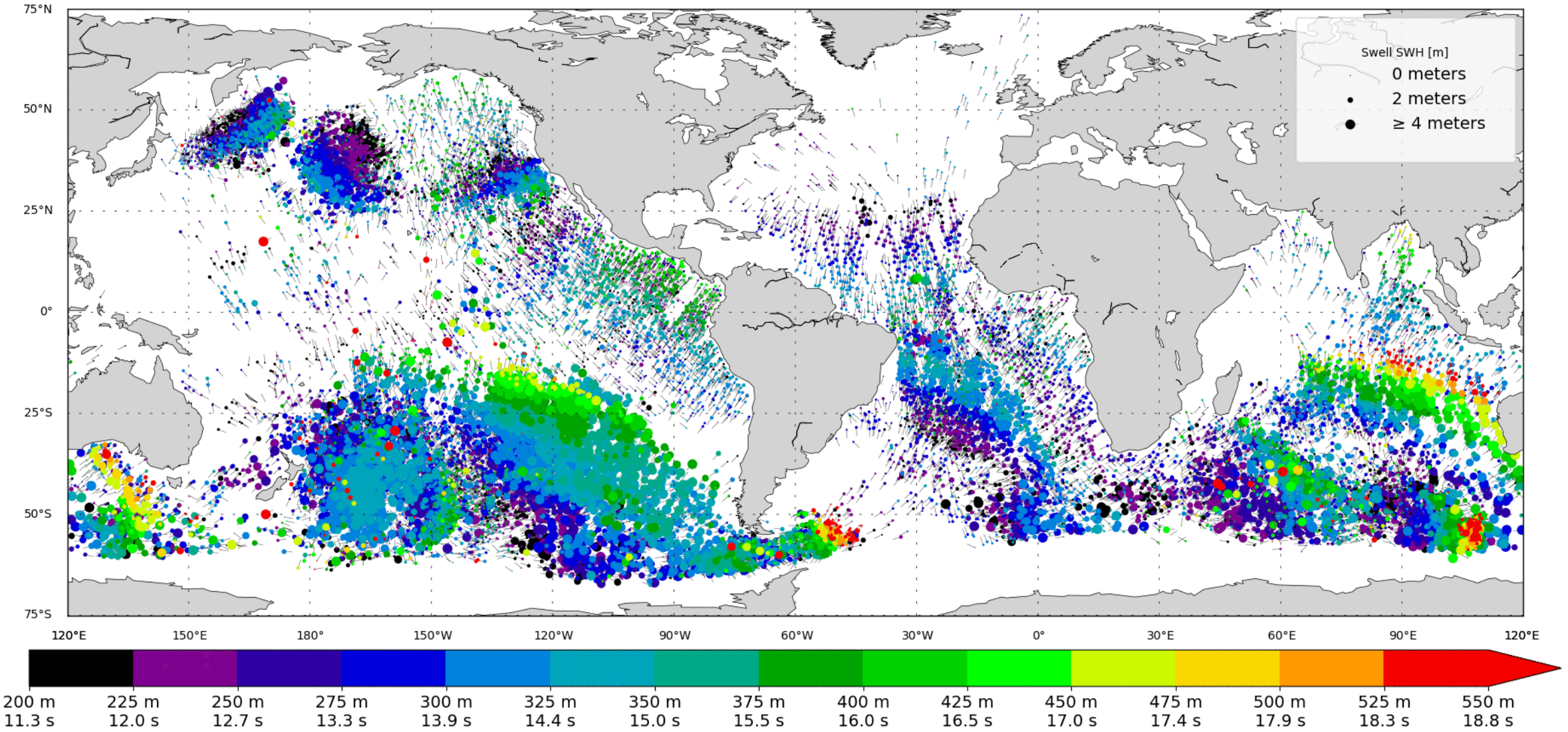


Example of a S1 WV propagated mesurements belonging to a swell field event on 8th May 2018 off NewZealand (strongest Hs ever recorded in South Hemisphere). S1 measured wavelength reach 800m!

E.U. Copernicus Marine Service Information

Fireworks using S1A/S1B - 27 Sep 2019 00H UTC



Swell peak wavelength [m] / Swell peak period [s]

http://satwave-report.cls.fr/

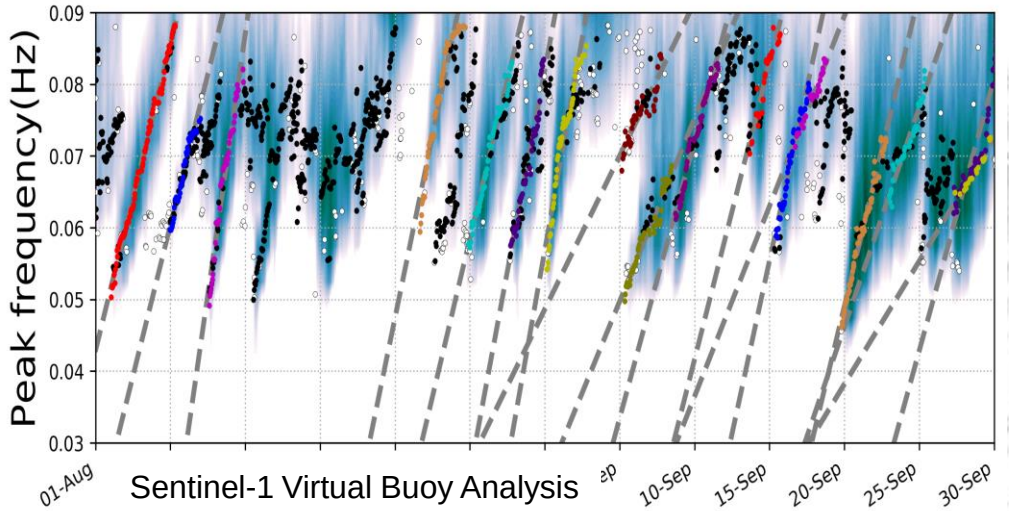
SAR wave products - validation

Validation of L3 measurements

- Time series of wave measurements from L3 Waves product and in-situ buoys have been analyzed.

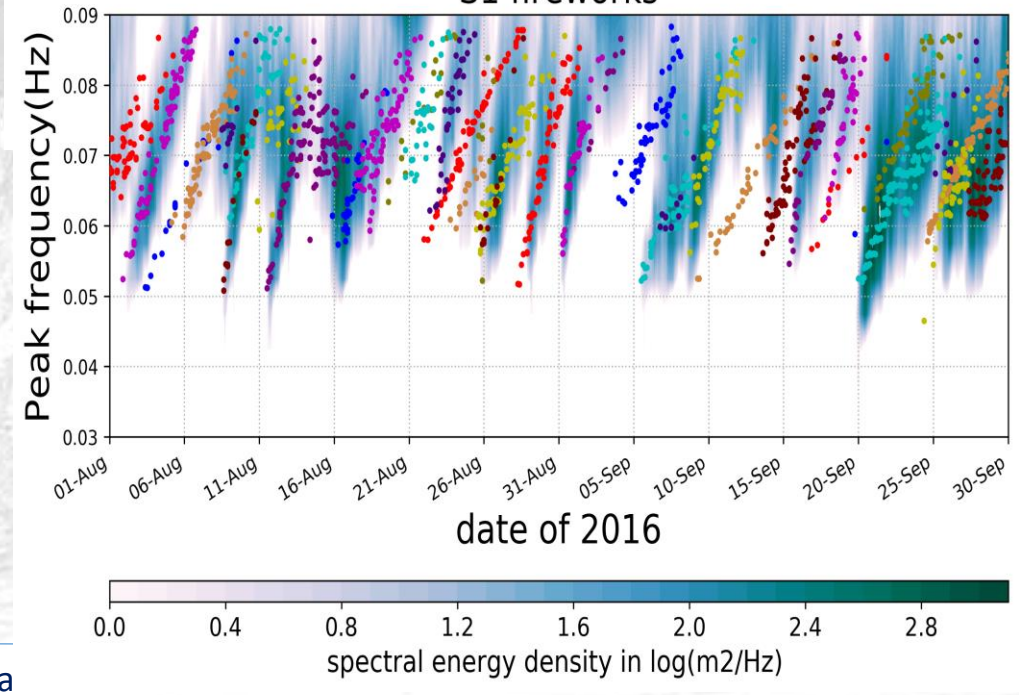
- Several events can be identified:
  - Extra-Tropical Cyclones (ETC)
  - Tropical cyclones (TC)

Real Buoy Analysis



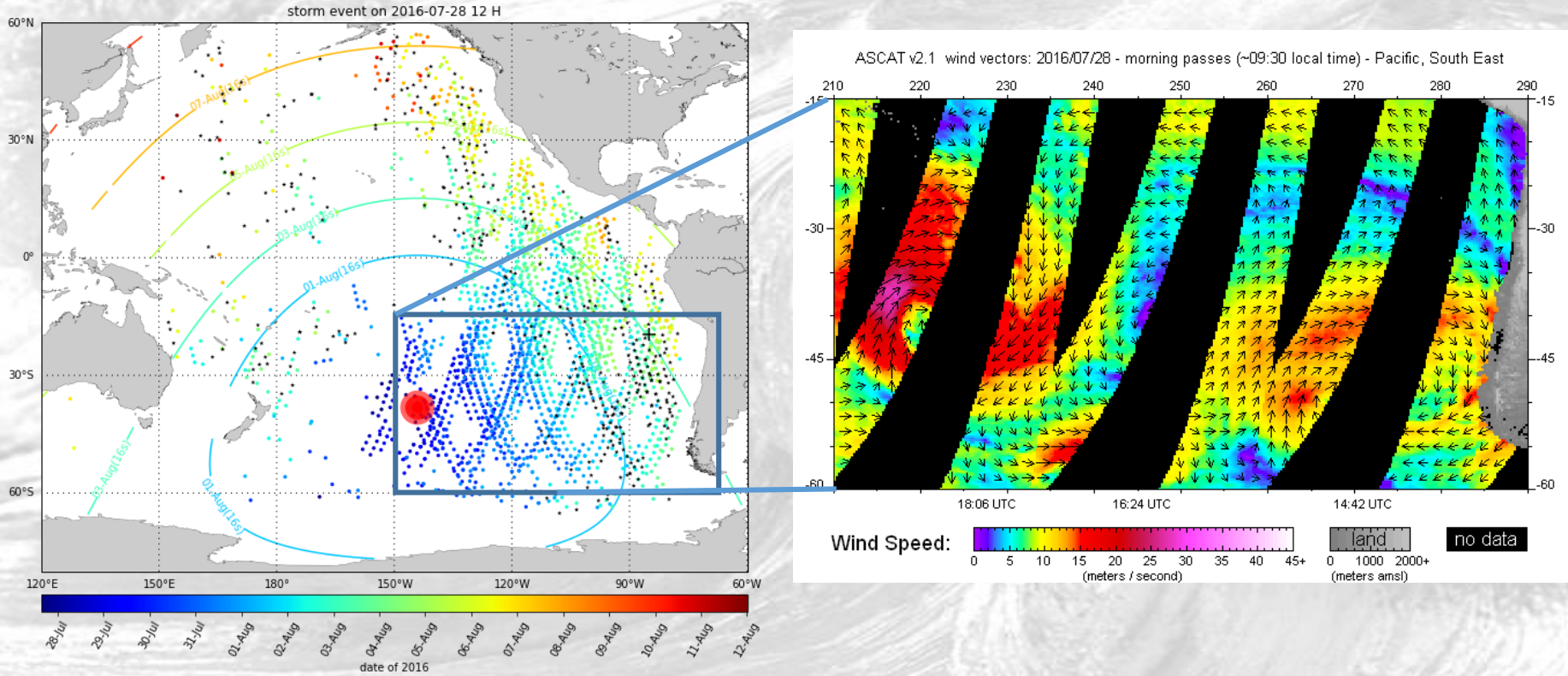
Sentinel-1 Virtual Buoy Analysis

S1 fireworks



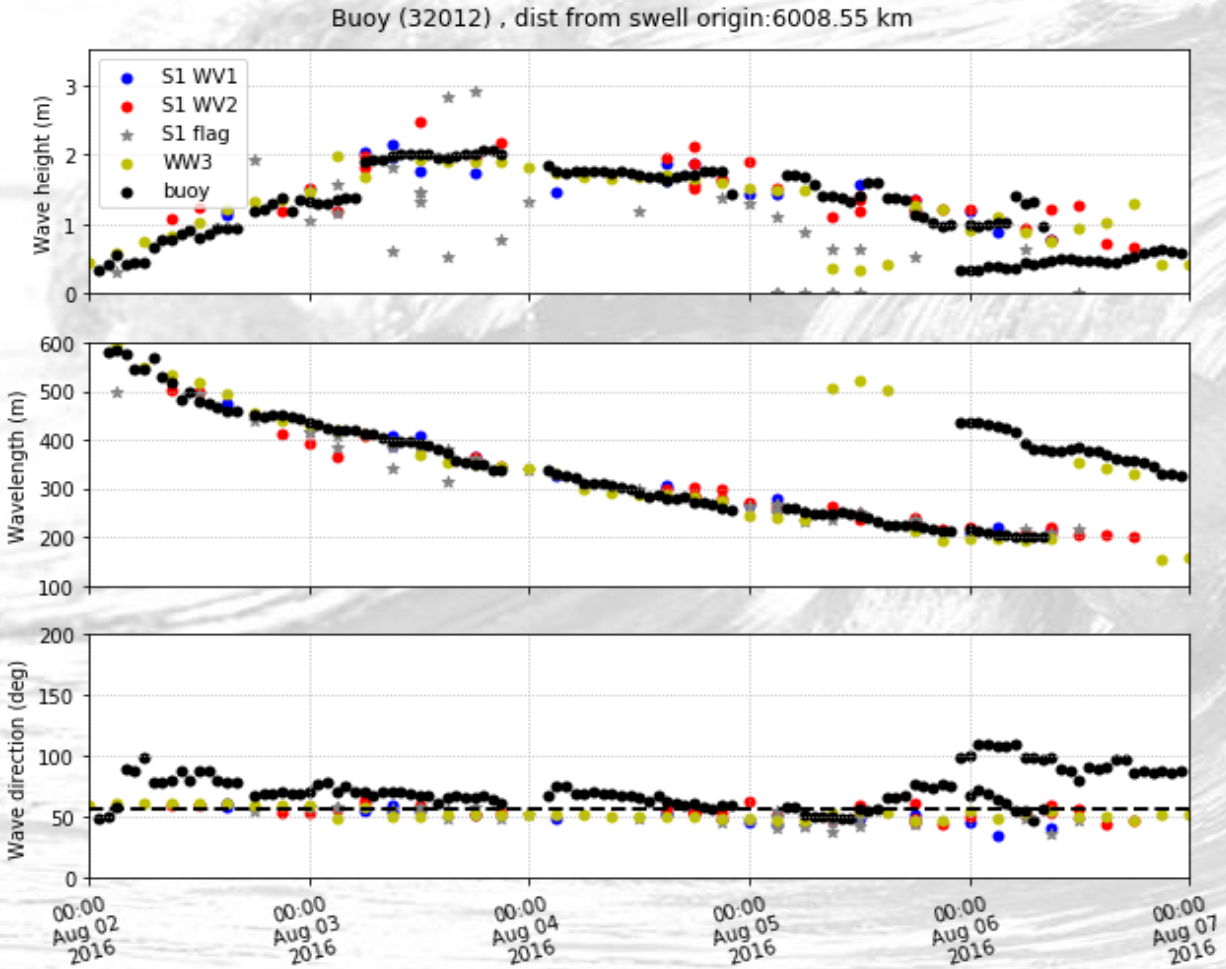
SAR wave products - validation

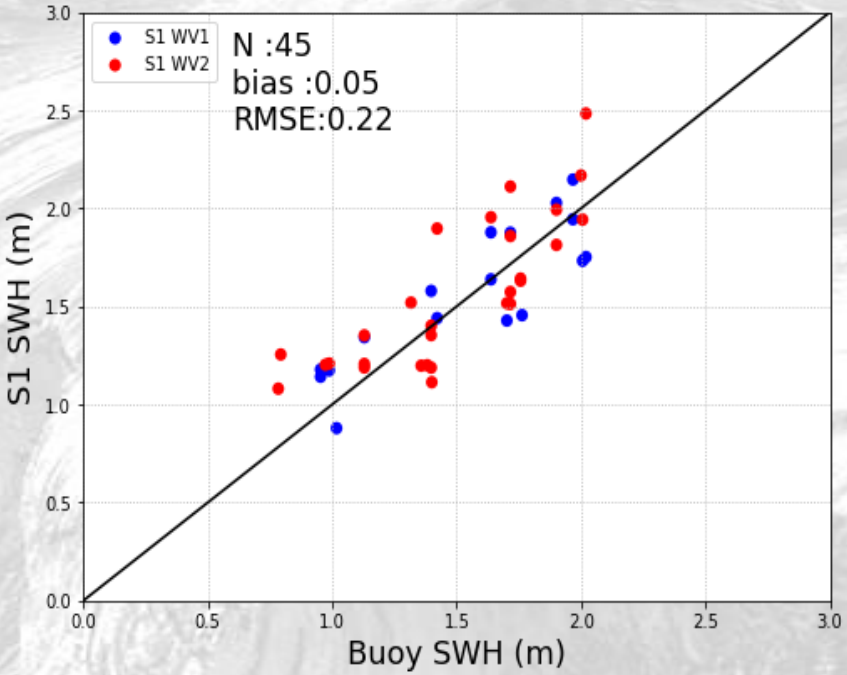
Validation of L3 measurements – Case Study: ETC 1



SAR wave products - validation

Validation of L3 measurements – Case Study: ETC 1

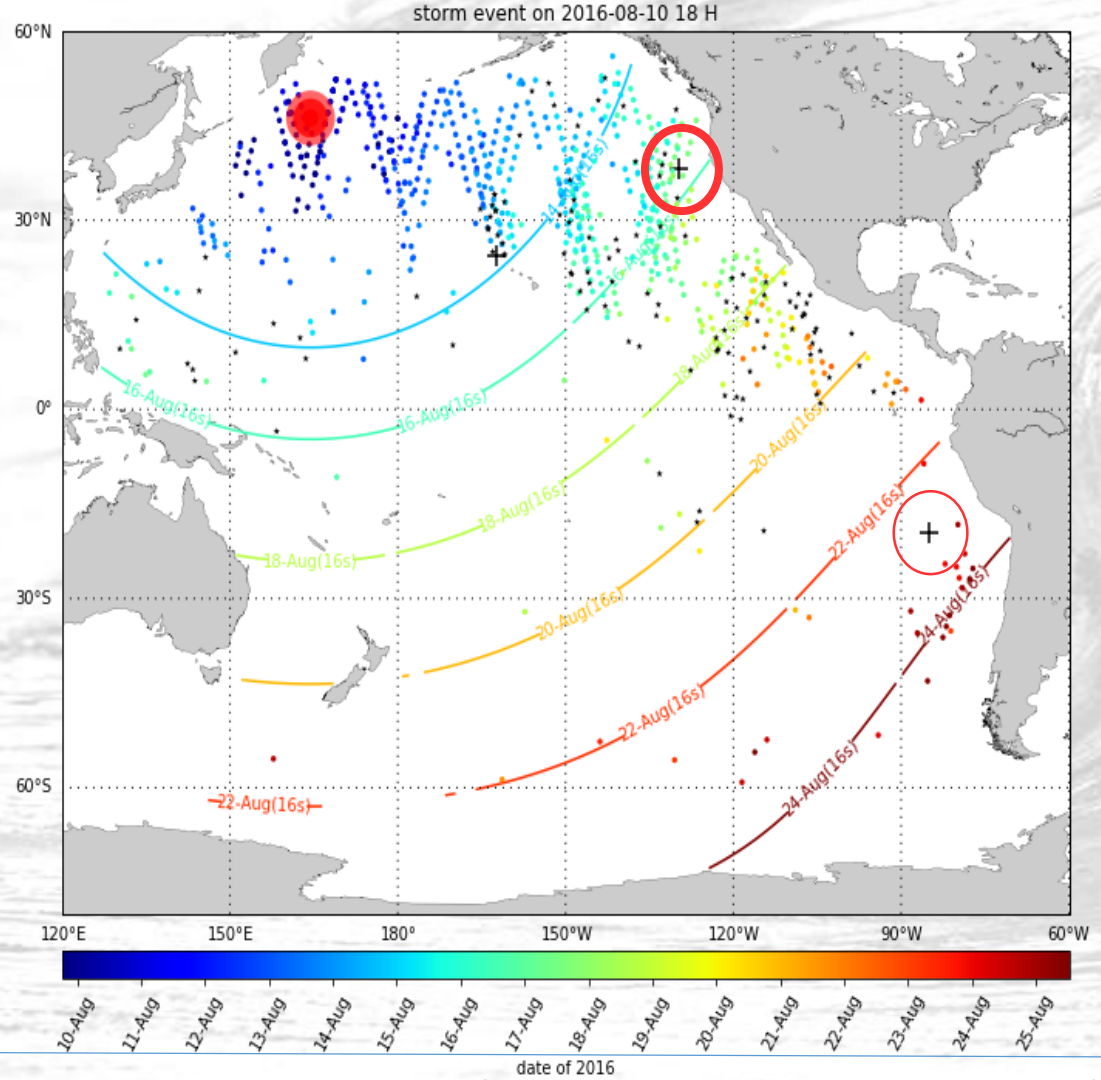


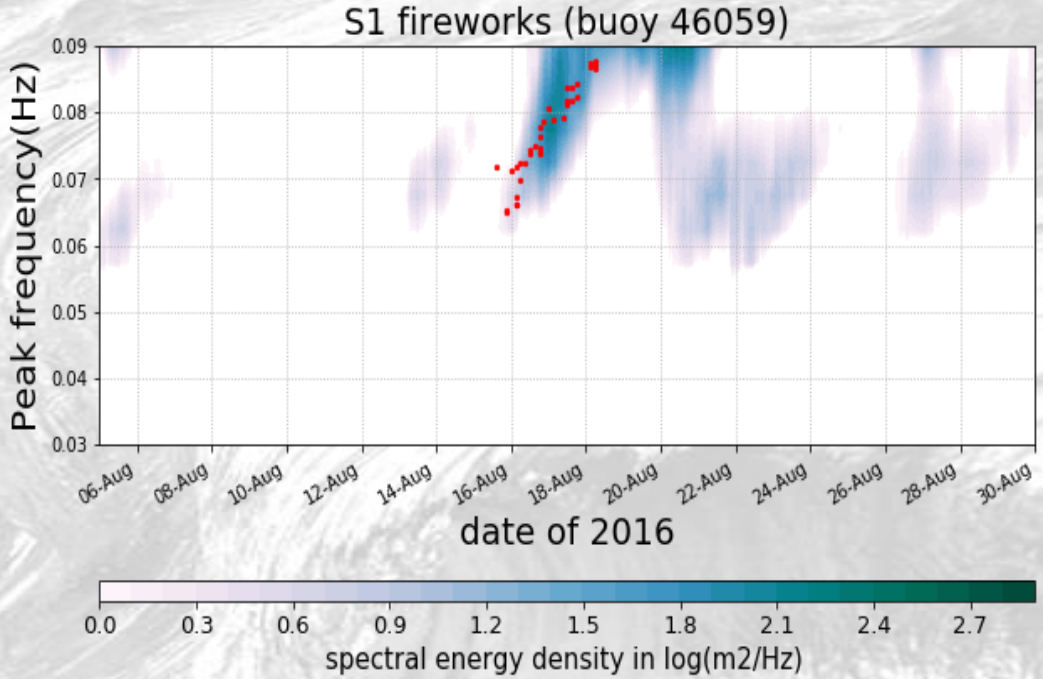


Good match between Sentinel-1 propagated waves and WW3 and the buoy

SAR wave products - validation

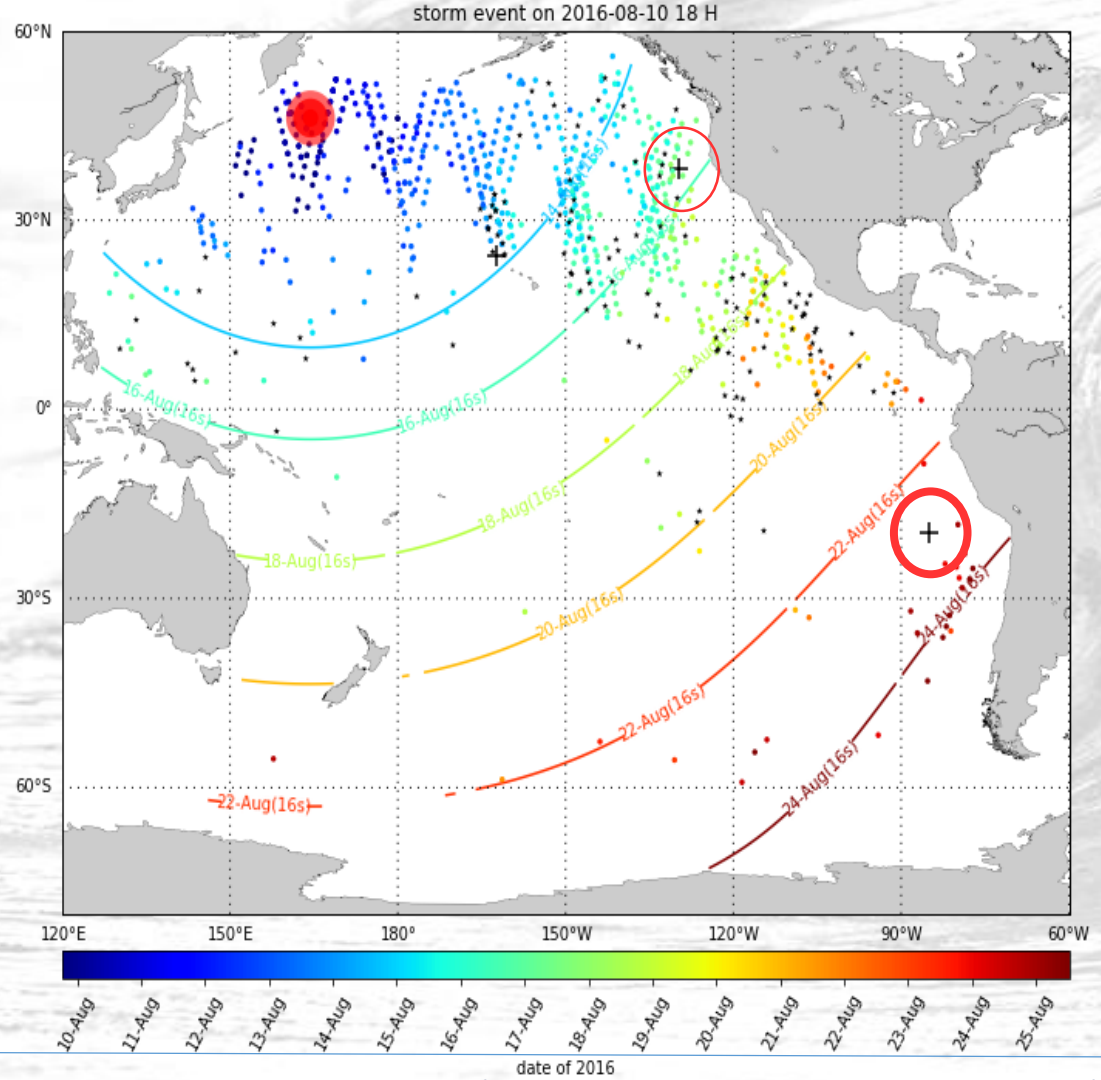
Validation of L3 measurements – Case Study: ETC 2

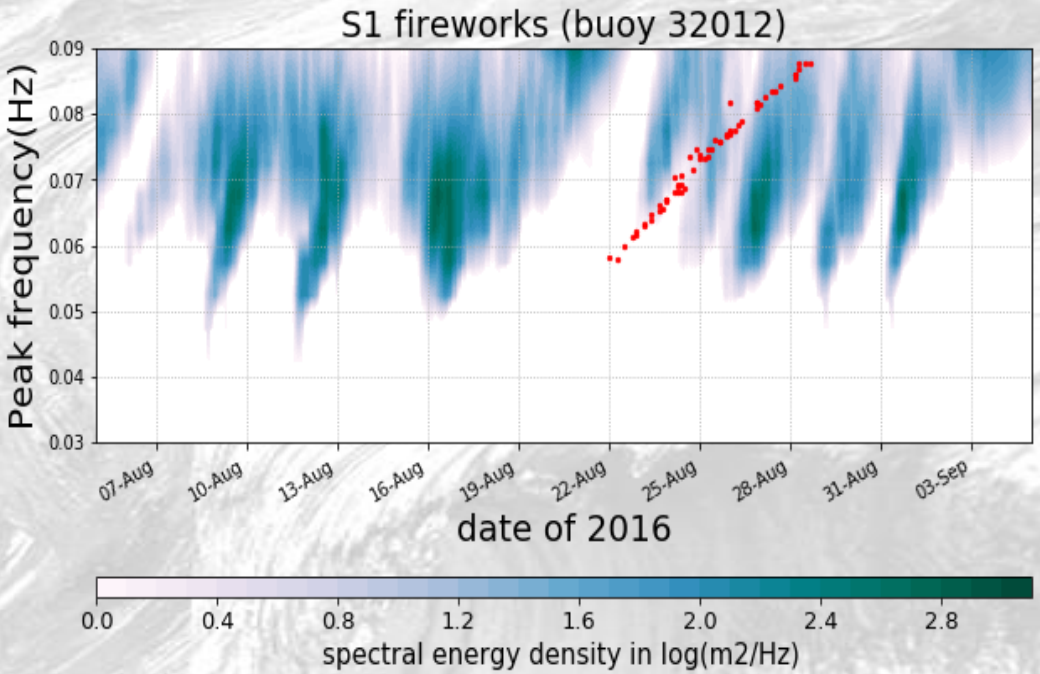




SAR wave products - validation

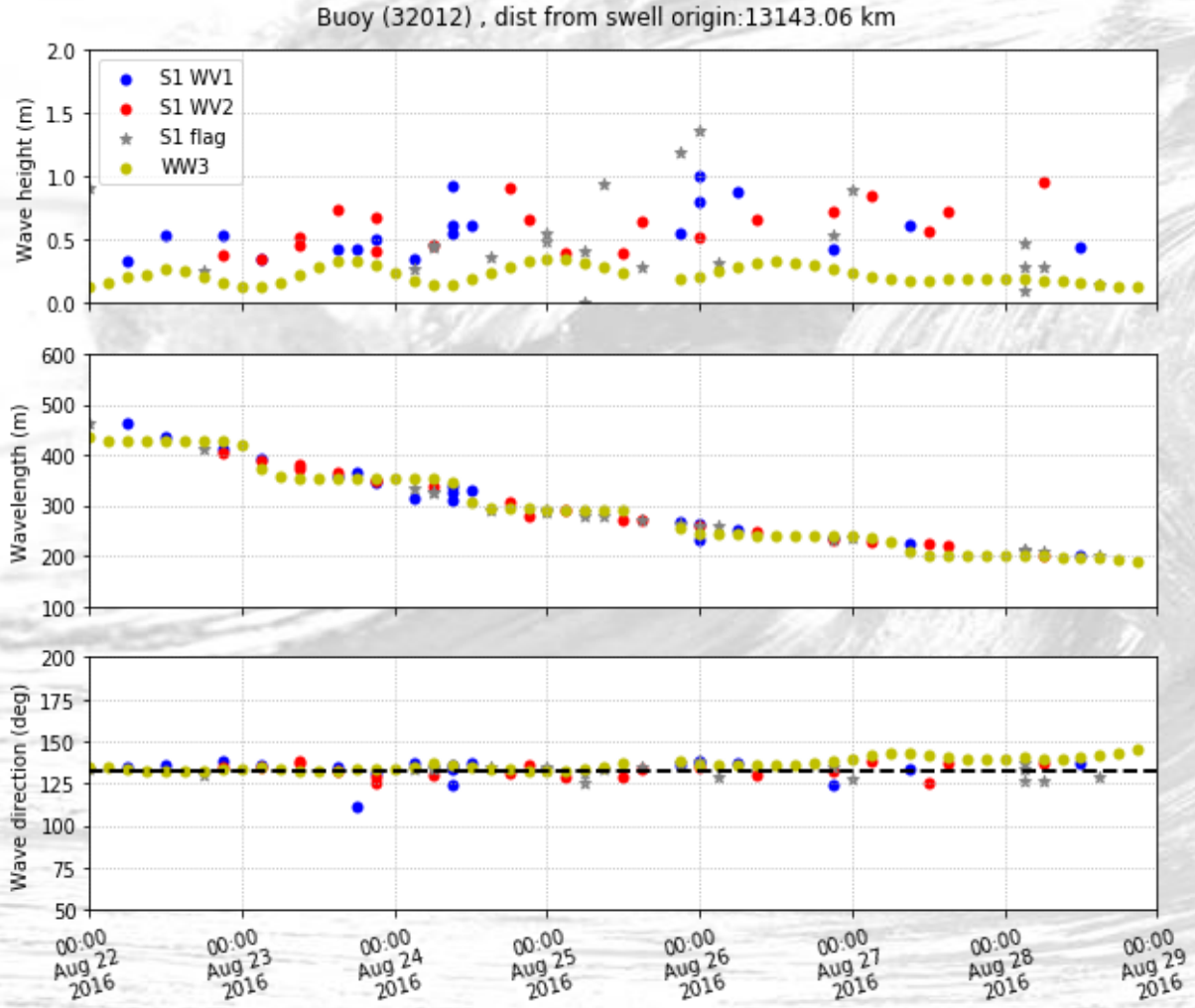
Validation of L3 measurements – Case Study: ETC 2





SAR wave products - validation

Validation of L3 measurements – Case Study: ETC 2



- No signal in the buoy !
- Swell wavelength and direction between SAR & WW3 are consistent
- Weaker signal in WW3 than in SAR.

Are they issues ?

- In the dissipation law applied to SAR observations ?
- Difficulty to validate Hs at low sea states, but how critical is it?

Conclusion

CMEMS L3 Altimeter products

- A Near-Real Time dataset of altimetry Significant Wave Height with quality controlled, monitored, inter-calibrated, user-friendly format and filtered for noise.

- Today, 5 satellites: J3, AL, S3A, S3B, CS-2 and soon CFOSAT

- Will be completed with Sentinel-1A/B Total Hs

CMEMS L3 SAR products

- Level-2 Wave mode measurements can be complex to use. Their data quality is quite sparse. Yet, a quality flag is delivered since June 2019.

- Level-3 SAR wave measurements offer a reduced but more consistent set of swell observations compared to L2, 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).

Thank you for your attention