climate change initiative

→ SEA STATE

The Sea State CCI project: towards a sea state Climate Data Record based on satellite observations

sea state cci

Sea State CCI Team[1]

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Project Overview

The ESA Sea State CCI+ project

Funded by the European Space Agency Climate Change Initiative program (CCI)

36 months project for Sea State

- Science lead: Fabrice Ardhuin (LOPS/Ifremer)
- Project manager : Ellis Ash (SatOC)
- Large international team

Objectives

- To produce climate-quality satellite products for Essential Climate Variables (ECV) for Sea State
- Consistent approach across ~ 30 projects for other ECVs e.g. Aerosols, Soil moisture, Sea Level, Sea Surface Temperature...

CCI Essential Climate Variables

The Sea State CCI V1 dataset

- Strong heritage from GlobWave project
- Released in July 2019
- New filtered Hs data using EMD-based method (Quilfen and Chapron, 2020)
- Three products available:
  - a multi-mission along-track L2P product
  - a daily merged multi mission along-track L3 product
  - a multi-mission monthly gridded L4 product
- Available on ESA open data portal
  - https://climate.esa.int/en/odp/

Mission	Instrument	Band	Covered period
ERS-1	RA	Ku	1991–2000
TOPEX	NRA	Ku	1992–2006
ERS-2	RA	Ku	1995–2011
GFO	GFO-RA	Ku	1998–2008
JASON-1	Poseidon-2	Ku	2001–2013
ENVISAT	RA-2	Ku	2002–2012
JASON-2	Poseidon-3	Ku	2008–2019
CRYOSAT-2	SIRAL	Ku	2010–Ongoing
SARAL	AltiKa	Ka	2013–Ongoing
JASON-3	Poseidon-3B	Ku	2016–Ongoing

Altimeter missions used for the Sea State CCI dataset v1.

Dodet et al. (2020). The Sea State CCI dataset v1: towards a sea state climate data record based on satellite observations. Earth System Science Data 12, 1929–1951. https://doi.org/10.5194/essd-12-1929-2020

The first version of the Sea State CCI dataset, released in July 2019, covers the period 1991–2018 and includes observations from 10 altimeter missions. The implementation of quality flags and auxiliary parameters in a systematic way, the update of calibration formula for the most recent missions, the development of an EMD-based denoising method, and the validation against an extensive network of in situ data buoy and state-of-the art model results, resulted in a unique dataset designed for the study of wave climate variability.

Quality Assessment of the Sea State CCI V1 dataset

CCI V1 L2P against in situ data and model outputs

In situ data

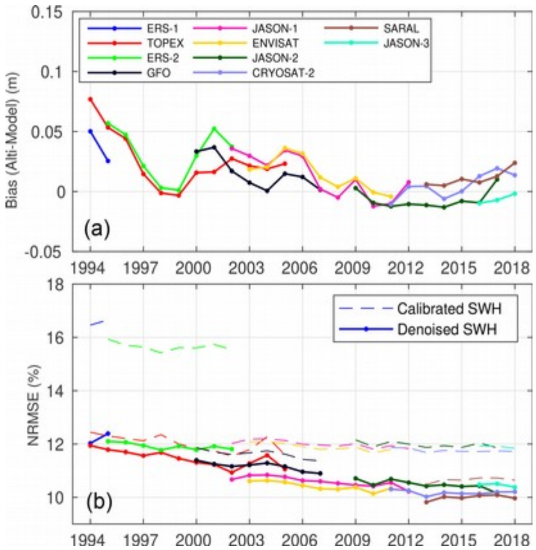
- 73 stations (mooring and platform) from ECMWF operational archive
- > 200 km from the coast
- Quality control to remove outliers
- Match-up criteria : 50km / 30min

Model

- WAVEWATCH3 (T471)
- Global 0.5° resolution
- Winds : ERA-5 reanalysis
- Currents : GlobCurrent
- Ice : SSM/I Sea Ice (CERSAT)

Mission	N years	Match-ups	Bias (m)	RMSE (m)	NRMSE (%)	SI (%)	R^2
ERS-1	3	1018	−0.07	0.26	9.95	8.41	0.97
TOPEX	12	7797	0.01	0.24	9.74	8.39	0.97
ERS-2	17	9207	0.01	0.24	10.41	8.96	0.97
GFO	9	5221	0.03	0.26	10.91	9.46	0.96
JASON-1	12	11 094	0.01	0.22	9.58	8.31	0.97
ENVISAT	11	8286	0.04	0.23	10.05	8.58	0.97
JASON-2	11	14 395	0.07	0.21	9.67	7.86	0.98
CRYOSAT-2	9	7913	0.07	0.20	9.17	7.46	0.98
SARAL	6	7876	0.09	0.21	10.14	7.96	0.98
JASON-3	3	4181	0.10	0.21	9.95	7.48	0.98

Statistical metrics for the validation of denoised SWH in the Sea State CCI dataset v1 against in situ data located > 200 km offshore.

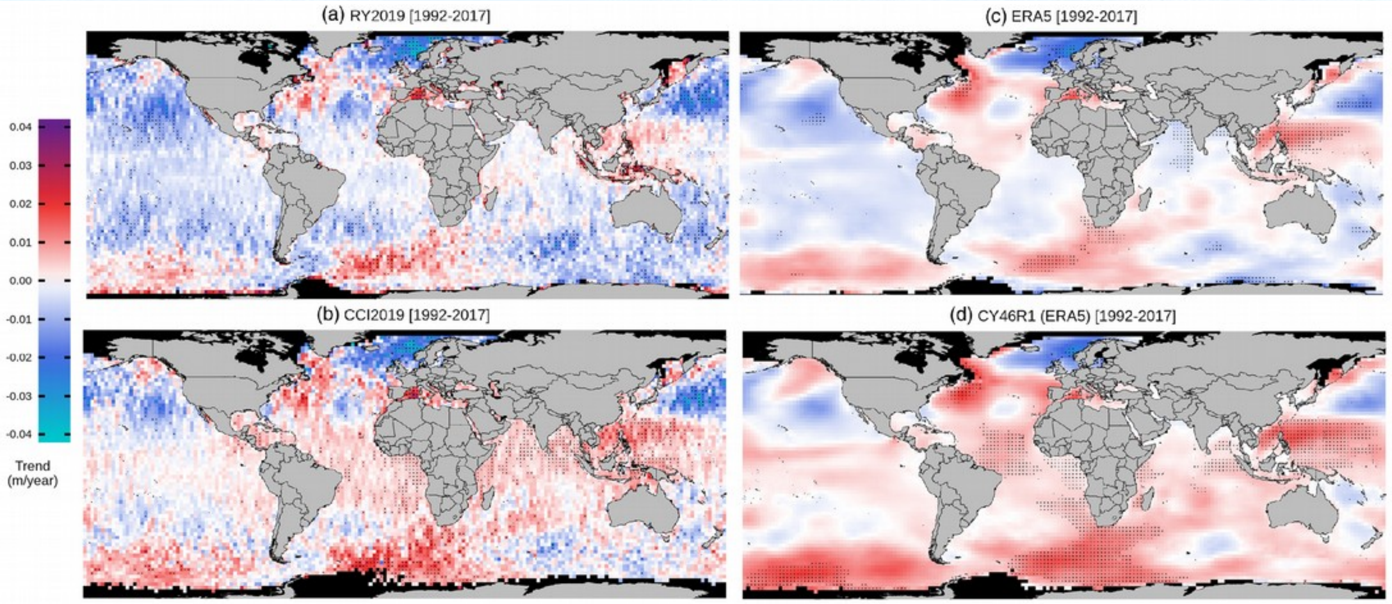


Time series of mean global bias (a) and mean global NRMSE (b) between Sea State CCI dataset v1 and WW3 model outputs forced with ERA5 wind fields. The thin dashed lines in (b) represent the results obtained for the calibrated SWH before denoising was applied (from Dodet et al., 2020).

Statistical metrics (bias, RMSE, NRMSE, SI and R2) between altimeter measurements and in situ data were computed for each mission and each year. The overall scores are provided in the table for the calibrated and denoised altimeter SWH, considering only match-ups that occurred more than 200 km from the coast. Except for ERS-1 for which the bias is negative, all the mission show a positive bias lower than 10 cm.

Comparison of the altimeter dataset against the WW3 wave model hindcast was performed as a complementary validation with an independent dataset. In order to assess the quality of the dataset over the 1994–2018 time period, mean global bias and NRMSE between the denoised altimeter SWH and the modelled SWH were computed on a yearly basis for each altimeter mission. We can see that the bias is lower than 10 cm and the NRMSE is lower than 13 % over the whole period. The overall trend is a decrease of the error metrics from the oldest missions to the most recent ones that may be attributed to improvements in instrument performance and processing techniques. We also note some inter- and multi-annual variabilities in the metrics that can be associated with changes in missions recording phases and associated orbits. The thin dashed lines show the NRMSE obtained before denoising is applied on the altimeter SWH. Differences in the metrics obtained with the calibrated (not denoised) and denoised SWH illustrate the significant improvements obtained after the small scale (< 100 km) fluctuations in the altimeter measurements are removed, with a NRMSE decrease by up to 20 % and by 10 % on average

Comparisons of long-term wave height trends

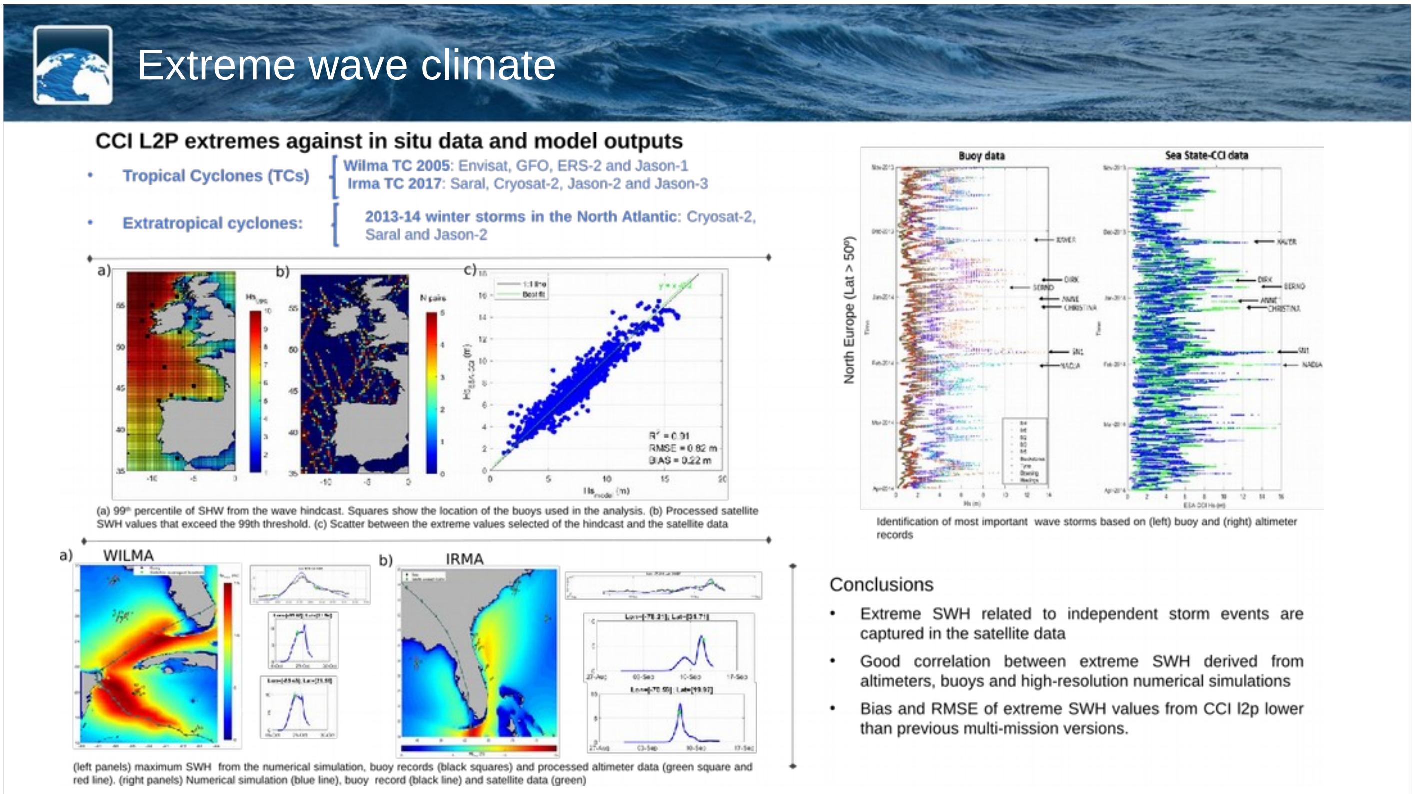


Global distribution of JFM mean Hs trend estimates on a 2 ◦ × 2 ◦ grid over 1992–2017 for (a) Ribal and Young 2019, (b) CCI2019, (c) ERA5, and (d) CY46R1. Dots indicate grid cells where the trend coefficient is significant at the 5% level (from Timmermans et al., 2020. Global Wave Height Trends and Variability from New Multimission Satellite Altimeter Products, Reanalyses, and Wave Buoys. Geophysical Research Letters 47, e2019GL086880. https://doi.org/10.1029/2019GL086880).

Trends were estimated for four products (CCI Sea State V1, Ribal and Young, 2019, ERA5 and ERA5-CY46R1), for the period 1992–2017 at each grid cell over the full globe using linear regression. The global maps of trends in winter (JFM) mean Hs over 1992–2017 are shown for each product. Black dots indicate statistical significance of the trends in each product.

Overall, the trends in JFM mean Hs over 1992–2017, over most of the globe, lie within ±1cm/year for all products. However, in some regions (northern North Atlantic, north western Pacific, and Southern Ocean) a small number of grid cells exceed this, particularly for RY2019 and CCI2019, with the largest values tending to occur close to land and sea ice margins. Strong negative trends in the North Pacific show up consistently across all products. Other regions of consistency include the Mediterranean and Norwegian seas. Strong positive trends in the Southern Ocean Atlantic sector (southwest of Africa) are also consistent.

The most striking aspect of this intercomparison remains the differences in the magnitudes of the trends between products including a few locations where trends are statistically significant in different products. While the spatial structure appears remarkably consistent across products, qualitatively, the trend magnitude appears to increase steadily between products, from RY2019, showing the most negative trends, to CY46R1, showing the most positive. Strangely, the two altimeter products show some of the largest differences, which can be explained by the different calibration methodology and reference buoy data. Even more strangely, perhaps the best agreement is obtained between CCI2019 and the CY46R1 hindcast, which does not assimilate altimeter data, although we note that during the development of CY46R1 some altimeter data (those received operationally) were used for validation of the tuning.

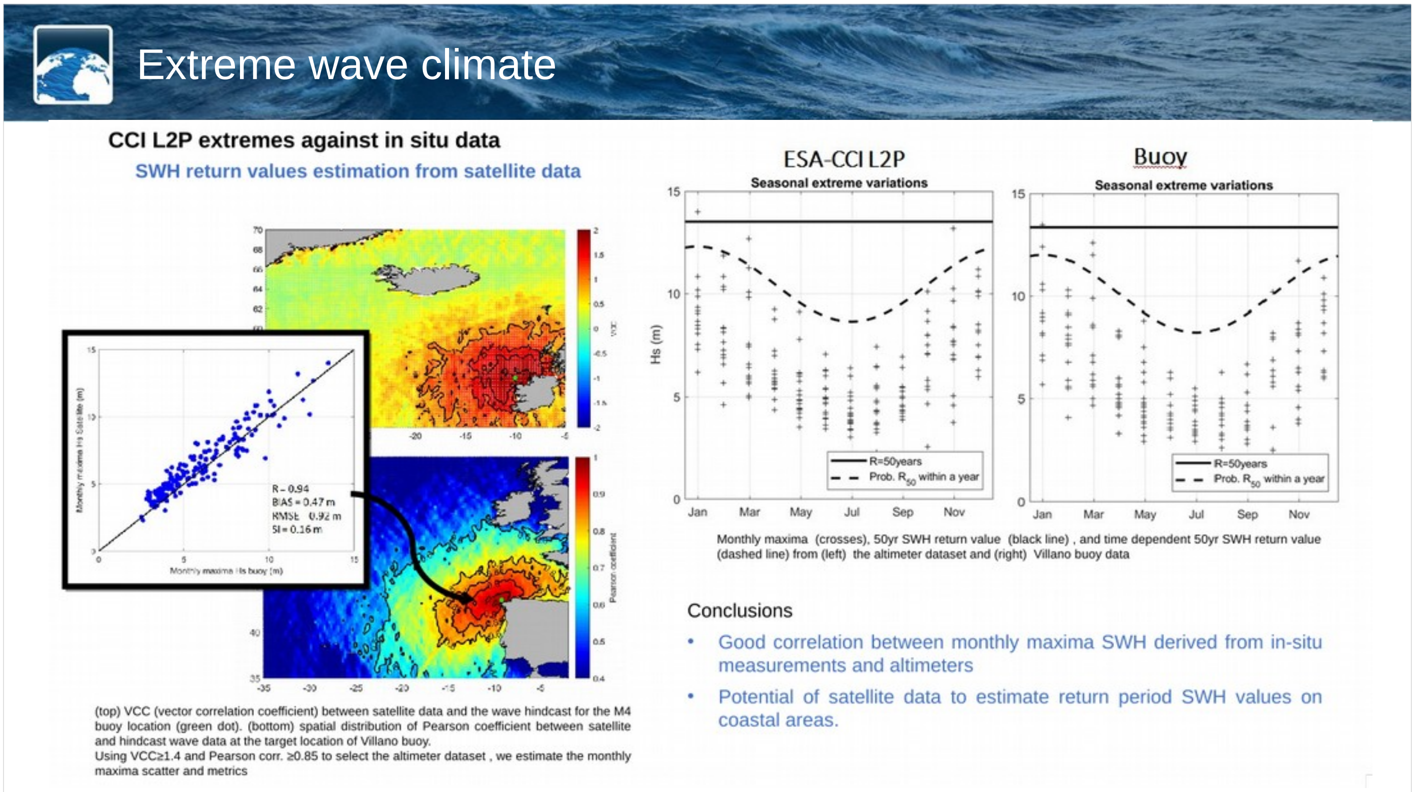


We evaluate the capability of the Sea Sate CCI v1 dataset to provide climate information of extreme SWH events.

Two tropical cyclones in the Caribbean (hurricanes Wilma in October-2005 and Irma in September-2017 affecting the Caribbean Islands and Florida Peninsula) and the storms during 2013/14 winter over Europe are selected due to their strong wave impacts on the coast (flooding, damages..)

The SWH extreme analysis uses the altimeter data equal or higher than the 99th percentile of SWH estimated from 0.25º x 0.25º grid cells. This threshold is determined based on hourly historical information from the GOW2 wave hindcast.

Comparison between these selected extreme values from satellite data and numerical model / buoys are analyzed. Extreme data pairs available from buoys and altimetry are however too few values. Hindcast vs. satellite extreme data pairs allow a more robust comparison. Results show very good correlation between altimeter and, both modeled data (R2= 0.76 and 0.91 for the tropical and extratropical cyclones, respectively) and in-situ measurements (R2= 0.92 and 0.97 for the tropical and extratropical cyclones, respectively). Furthermore, the similar extreme SWH analysis performed using the previous version of altimeter dataset (Ifremer-CERSAT, 2016, not shown in the slide) demonstrates the added value of the Sea State-CCI dataset. The Bias and the RMSE improve from 0.44 to 0.22 m and from 0.8.2 to 0.9 m, respectively.



With the aim of assessing the extreme wave climate variations, a new approach based on a non-stationary statistical extreme model, based on GEV distribution, is applied to the altimeter-derived and buoy record SWH monthly maxima.

The approach has the following steps:

- Identify the buoy stations around the world (offshore 5km) with enough quality and length of historical information to estimate extreme return levels.
- Analyze the regional area of the satellite data into 0.25 x0.25º grid cells with similar wave climate behavior to the target location at the buoy (using wave hindcast data), and take into account the time-dependence of the spatial area at monthly scale.
- Calculate the monthly maxima from satellite into the selected areas
- Apply a non-stationary extreme statistical model to estimate SWH return values and compare against extreme analysis from the buoy record.
- Calibrate the required parameters, thresholds, etc of the approach to apply at any coastal location worldwide.

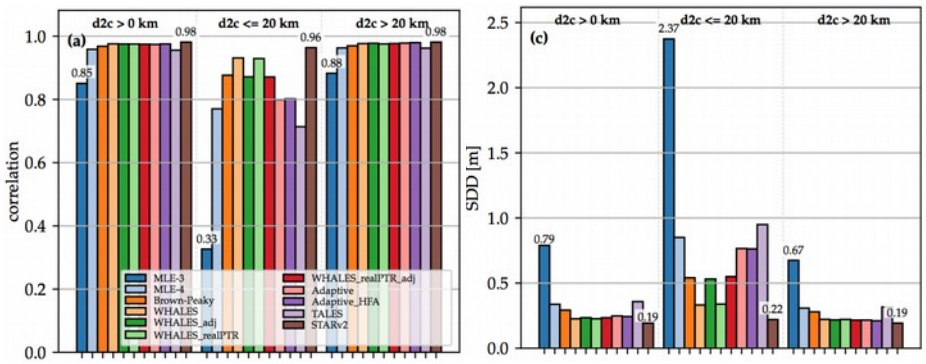
Results show a similar behavior of seasonal SWH extreme variations between both datasets.

The difference in the 50-years return value of the SWH between satellite and the villlano buoy is lower than 2%.

Assessment of retracking algorithms for SWH

- Both LRM and SAR algorithms evaluated
- Comparisons with both models and buoys
- Assessment in ocean ocean and coastal zone

Correlation and S.D. for 11 retrackers applied to Jason-3



Comparison of the (left) correlation coefficient, and (c,f) standard deviation of differences (SDD) against ERA5-h model (ERA5-forcing and CY46R1 version of the ECMWF wave model, with no altimeter wave data assimilation) of the individual J3 retrackers as a function of distance to coast.

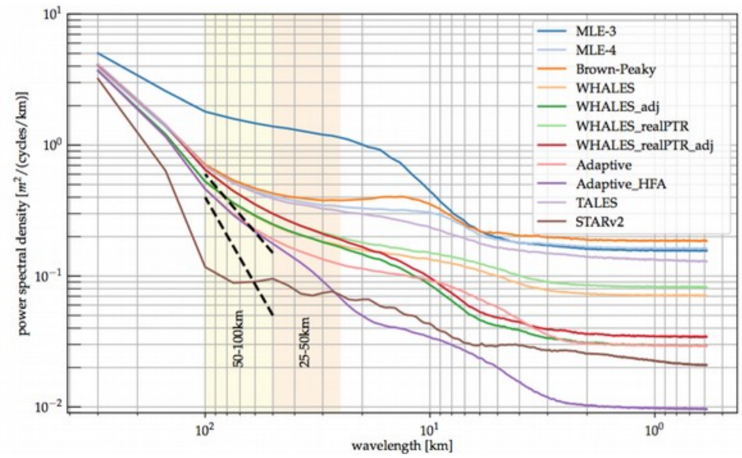
Schlembach et al. 2020. Round Robin Assessment of Radar Altimeter Low Resolution Mode and Delay-Doppler Retracking Algorithms for Significant Wave Height. Remote Sensing 12, 1254.

In order to determine the best performing retracking algorithm for both Low Resolution Mode and Delay-Doppler altimetry, an objective assessment is conducted in the framework of the Sea State Climate Change Initiative project. All algorithms process the same Level-1 input dataset covering a time-period of up to two years. As a reference for validation, an ERA5-based hindcast wave model as well as an in-situ buoy dataset from the Copernicus Marine Environment Monitoring Service In Situ Thematic Centre database are used. Five different metrics are evaluated: percentage and types of outliers, level of measurement noise, wave spectral variability, comparison against wave models, and comparison against in-situ data. The metrics are evaluated as a function of the distance to the nearest coast and the sea state. The results of the assessment show that all novel retracking algorithms perform better in the majority of the metrics than the baseline algorithms currently used for operational generation of the products. Nevertheless, the performance of the retrackers strongly differ depending on the coastal proximity and the sea state. Some retrackers show high correlations with the wave models and in-situ data but significantly under- or overestimate large-scale spectral variability.

Assessment of retracking algorithms for SWH

Choice of retracker gives very different wavenumber spectra

- Wavenumber spectra of SWH were computed over Jason-3 along-track segments for each retracking algorithm
- Some algorithms include a "High-Frequency Adjustment" to minimize effect of fading noise on short-scale variability

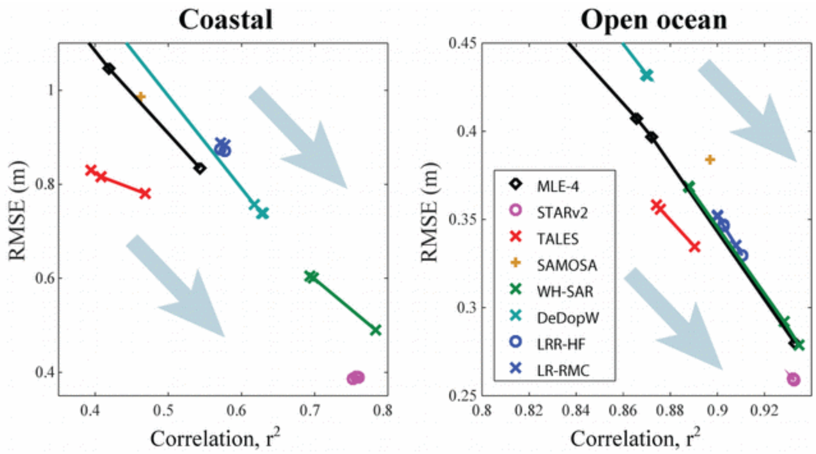


Mean wavenumber spectra of SWH from the various LRM retrackers applied on Jason-3 and calculated from 1024-point segments using the Welch periodogram method. The dashed lines indicate k^{-2} or k^{-3} spectral slope

Wavenumber spectra of J3 LRM data were determined for around 62,000 segments, except for TALES for which there were only ~ 50,000 segments because of the greater occurrence of flagged data for that retracker. One notes that the de facto reference provided by MLE-4 exhibits a “spectral hump” between 8 and 50 km. Most of the newer algorithms have lower spectra levels than that within this band, whereas the simpler algorithm MLE-3 has higher noise levels for wavelengths of 8 km and upwards. This may indicate that the actual waveform shapes are responding to other factors, for example, slight variations in sea surface skewness or in the angle between the surface perpendicular and the antenna boresight that are better represented by the MLE-4 algorithm. In the absence of any waveform bins being deemed to contain anomalous peaks, the Brown-Peaky algorithm effectively reverts to MLE-4; thus, its mean/median spectrum is similar to that of MLE-4, although it does exhibit extra variability in the 8-25 km band. TALES shows slightly lower noise levels than MLE-4 for all scales below 25 km, but the difference is always less than 10%. The four flavours of WHALES have almost identical behaviour at large wavelengths, with their associated power levels below 50 km being at least 45% lower than for MLE-4, with those having a correction for covariant errors being significantly lower again for scales under 15 km. Those versions of WHALES incorporating a bespoke PTR correction show slightly greater noise levels than those corrected using an empirical LUT. For the Adaptive algorithm, which already has one of the lowest noise levels, the version with the HFA again reduces the noise level at scales below ~ 50 km. This latter adjustment is effective over a longer span of scales (i.e., all those below 50 km) than the WHALES version (<15 km) partially because it calculates height anomalies relative to a longer along-track scale. Finally, the performance of STARv2 is noteworthy, in that it achieves the lowest spectral levels in the 25–100 km range of wavelengths but has produced an unexpected spectral shape. The procedure it uses for fitting a SWH profile through the cloud of solution space certainly amounts to significant filtering, reducing the noise levels. According to the developer of STARv2, a more recent version of the algorithm shows a spectral slope more similar to other retracker (personal communication)

Assessment of retracking algorithms for SWH

Revisit of Assessment: performances improve with data selection



Generally improved performance as minimum no. of valid measurements is increased from 1 to 5 to 10 to 20. The results are displayed for the various different Sentinel-3A algorithms for (a) Coastal zone (buoy within 15 km of coastline), (b) Open ocean. For many algorithms, their performance with a minimum of one point led to such RMSE as to be plotted off the axes; in nearly all cases, more observations leads to higher r2 and lower RMSE. Due to the limited flagging on SAMOSA, all its points coincide.

Quartly, G.D and A.A. Kurekin (2020). Sensitivity of Altimeter Wave Height Assessment to Data Selection. Remote Sens. 2020, 12, 2608

Further work using the Sentinel-3A buoy match-up dataset showed how the evaluations of the various retracker algorithms could be sensitive to choices of the minimum number of valid altimeter points for a comparison, and also the selection of which buoys to be used.

Future developments

Full reprocessing of S-GDR data from 2002 to 2020

- Waveform retracker with enhanced performance for SWH
- Improved data editing and filtering method
- Cross-mission inter-calibration
- Integration of SAR data (Sentinel 1-A)

Upcoming events:

- Version 2 to be released in early 2021
- Virtual User Consultation Meeting on 23-25 March 2021