sea state cci

Algorithm Development Plan (ADP)

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Contents

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1.0	8 July 2019	First version for approval by ESA
1.1	25 November 2019	Revised version with corrections following review by ESA
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3.0	11 October 2021	Third version for approval by ESA

List of Acronyms

ACDC	Amplitude Compensation and Dilation Compensation
ADP	Algorithm Development Plan
ALES	Adaptive Leading Edge Subwaveform
ATBD	Algorithm Theoretical Basis Document
DD	Delay-Doppler
EE9	Earth Explorer-9
HF	High Frequency
GDR	Geophysical Data Record
HFA	High Frequency Adjustment
IPF	Instrument Processing Facility
L1A	Level 1A
L1B	Level 1B
L1B-S	Level 1B stack prior to multilooking
LUT	Look-Up Table
LRM	Low Resolution Mode
PM1	Project Meeting 1
PTR	Point Target Response
SAR	Synthetic Aperture Radar
SSH	Sea Surface Height
SWH	Significant Wave Height
UCM	User Consultation Meeting
WHALES	Wave Height Adaptive Leading Edge Subwaveform

1. Introduction

The objective of this document is to define the Algorithm Development Plan (ADP), deliverable 2.4 of the **Sea_State_cci** project. The ADP is to be published on an annual basis, defining the planned algorithm developments to be performed in each year of project activity, together with the algorithm developments achieved in the preceding year (if applicable). This document is version 3 for the third year of the project.

These algorithms include processings for Low Resolution Mode (LRM) Altimetry, Delay-Doppler (DD) Altimetry and Synthetic Aperture Radar (SAR). The following section provides the body of the report and describes the analysis of algorithm shortcomings and their mitigation for altimeter (LRM), altimeter (DD) and synthetic aperture radar (SAR) in turn.

2. Analysis of algorithm shortcomings and their mitigation

2.1 Altimeter (LRM)

ADP-1: WHALES (TUM)

Initial Plan

The development of a new retracker for LRM altimetry has followed the guidelines described in the Technical Proposal. The starting point was the "baseline algorithm" ALES (Passaro et al., 2014), in its latest version written at TUM in November 2015. Using the knowledge acquired with this experience, TUM decided to proceed with the development of a new algorithm to present at the Round Robin, named WHALES (Wave Height Adaptive Leading Edge Subwaveform retracker).

The efficiency of the ALES subwaveform strategy was in fact limited by the fact that the coefficients that determine the width of the subwaveform to be retracked are tuned on a compromise between the theoretical precision of the Epoch estimation compared to the full-waveform case and the need to avoid using the gates in the trailing edge. In the context of this project, new simulations have been performed to obtain a new subwaveform strategy tuned on the Hs and on the sigma0 precision.

Secondly, the application of a weighted least square solution in the Nelder Mead approach was developed. The weights applied on the residual between the fit and the real waveforms are also adaptive and depend on the initial estimation of the Significant Wave Height (SWH). This is an addition compared to the Technical Proposal and is justified by the substantial decrease in high-rate noise.

Shortcoming

No major shortcoming is envisaged for this processor. One shortcoming could be the fact that a specific instrumental correction is necessary to correct for the Gaussian approximation of the Point Target Response (PTR). The latter is nevertheless planned as a sub-WP from PML ("Treatment of Point Target Response" in the Technical Proposal).

Mitigation

To mitigate the current absence of a specific instrumental correction for WHALES, a temporary instrumental correction has been derived by comparing instrumentally corrected official Jason-3 output with uncorrected WHALES output. First tests using this correction show a median bias of 2.5 cm against model and 1.3 cm against buoys, which is considered acceptable.

Updated plan

The development of WHALES was successfully completed as described above and in the ATBD. The mitigation solution explained proved successful, since the algorithm scored overall second in the Round Robin and best concerning most of the analysed parameters in the coastal zone. WHALES code has been already adapted for Jason-1, Jason-2 and Jason-3. The WHALES algorithm developers have assisted the main contractor in obtaining a WHALES version based on the provided documentation. Since WHALES data are being used for production and exploitation, an adaptation of the algorithm for Envisat, AltiKa and Cryosat-2 LRM was also performed .

ADP-1.1: Correction for PTR (PML)

Initial Plan

An altimeter waveform simulator was developed that mimicked the signals that should be returned by a uniform rough surface, with given wave height distribution. The simulator allowed the use of an idealised waveform (Gaussian), a simplified version (sinc2) or the real digitised PTR. Fading noise could then be applied at the correct level. The chosen retracker could then be applied, and the bias (relative to the simulated scenario) be characterised as a function of SWH and position of waveform within the window.

This methodology was tested on the WHALES retracker, showing that the inferred correction only varied at low wave height; thereafter it was close to a constant offset. It was also shown to vary with position of the waveform within the window, giving a bimodal distribution for the corrections at a given Hs.

Shortcoming

The simulations failed to cover all parameter space for the output, and thus the developed correction required some interpolation across gaps. The correction was moderately effective, but did not surpass the performance of a LUT constructed from corrections supplied on the Jason-3 GDRs.

Mitigation

For WHALES with Jason-3 the use of a GDR-derived LUT seems more effective; however, the method showed enough success that it could be amended and applied to altimeter data streams that do not provide such a correction. This could be implemented in Phase II of the project.

ADP-1.2: Removal of Correlated Errors (PML)

Initial Plan

Work a decade ago had shown that the errors in the two parameters derived from the waveform trailing edge (namely sigma0 and mispointing) showed a strong covariance, and that assuming that one of these (mispointing) should only be slowly-varying led to an empirical correction for the other. This greatly reduced the high-frequency variability in sigma0, giving more realistic along-track profiles and a significantly improved correspondence between the Jason-1 and Jason-2 data when in the tandem mission scenario. This idea was extended to the two parameters from the leading edge (wave height and range) by Zaron and deCarvalho (2016) and Quartly et al. (2019) using anomalies in SWH to improve the quality of range information.

Within the Sea State CCI project, we evaluated the reverse operation i.e. using anomalies in the range data to improve the consistency of SWH. An initial investigation was carried out by PM1 (Sept. 2018), which showed that one needed to use the variation in the immediate SSH relative to some moving average value. (Theoretically an approach should be more valid implemented in terms of the composite sigma rather than Hs.) This adjustment removes the high-frequency variability in the signal, whilst leaving the larger scale variations unchanged. The methodology has been implemented and tested on Jason-2, Jason-3 and AltiKa, with reductions in sigmaHs of 22%, 22% and 18% respectively. This work has now been published (Quartly, 2019).

Shortcoming

In the Round Robin evaluation, this adjusted algorithm did far better than the original WHALES in terms of noise and small-scale variability, but appeared to be slightly worse at the larger scales for comparison with buoys.
The implementation to-date has used anomalies in (altitude minus range) relative to a 21-point running median. CLS has implemented something similar for “adaptive” with a much larger window, which appears to be more effective.

Mitigation

We could implement the smoothing on a much larger scale or use SSH rather than (altitude minus range) and see whether it then agrees better with the CLS implementation. This will need use of a much higher resolution Mean Sea Surface, and possibly for all the other corrections.

ADP-2: ADAPTIVE NUMERICAL RETRACKER (CLS)

Initial Plan

The basis of this ocean LRM mode is the in-house CLS implementation of the Adaptive LRM ocean model that has been developed during the recent years and fully validated with Jason dataset. It has been also fully validated with CFOSAT nadir data (we recall here that the Adaptive Numerical retracker is implemented in the CFOSAT ground segment and that the products providing SWH and distributed to the users are computed with this algorithm). A paper has been submitted (Tourain & al, 2020) fully describing the algorithm and the results that have been obtained.
After the retracking algorithm, a High Frequency Adjustment is then applied to account for the correlation between range and Hs noises. As well, a paper (Tran et al, 2019) has been published in ASR.
Hence, the development plan for this algorithm mainly focuses on the determination of an optimal HF adjustment correction and on the generation of the dataset for its evaluation in the Round Robin.

Shortcoming

No major shortcoming is envisaged for this processor except the fact that the retracker being numerical and including the real value of the Point Target Response without approximation (and thus no Look Up Tables), it requires more CPU time that a classical MLE3 or MLE4 retracker. Particular studies must however be conducted to account for specific characteristics of the different missions (weighing function for RA-2, mispointing for Saral, elliptical antenna gain pattern for CryoSat-2, small antenna aperture for saral which prevents from using a gaussian approximation, …) and to guarantee that the performances that have been observed for Jason-3 will be observed as well for the other missions.

Mitigation

For Jason-3, we do not anticipate the need of any mitigation plan considering the fact that the study and the generation of the dataset should not encounter any issues.
For the other altimeters, the situation is a bit different and requires some attention in particular due to the fact that for being efficient, a quite perfect modelling of the waveform has to be considered. This is why we introduced the real PTR for Jason-3. It will be the same for Jason-2 and Jason-1 (after some minor adaptations as the antenna gain pattern, etc.). The table below lists all the missions (conventional ones) and potential adaptations that have to be done to overcome particular characteristics of each mission. In the frame of the Sea State CCI, it has not been decided yet which of these studies and developments will be carried out. It will mainly depend on priorities and funding. Note that in this table, we propose alternatives to the reprocessing of the whole missions by IFREMER accounting for the other current projects undertaken by CLS for ESA or for CNES.

Low Resolu[…]n Mode ==> Adaptive retracker			
Missions	Status of the current developments	Shortcoming	Study to be done
GFO	Nothing has been done yet on this mission.	Not applicable because the PTR are not available	None
ERS-1	The generation of a SWH dataset for the whole mission could be undertaken in the frame of the Fundamental Data Record For Altimetry Project (FDR4ALT). This study has been proposed as an option of the main contract funded by ESRIN and managed by CLS.	Potential issue due to the fact that blurring effects are affecting the waveform (this is a issue that has been identified on ERS-1 and that is caused by the on-board tracker). if the option is accepted, the FDR4ALT project will have to check the applicability of such an algorithm even in case of blurring. The study phase should last till end of 2020 and the generation of a complete dataset will be done during 2021; Once done, the dataset could be transfered to Sea State CC project.	None. Sea State CCI could directly use the FDR4ALT L2+ Thematic Data products
ERS-2	idem ERS-1	idem ERS-1. To be checked if the bluring issue is similar for ERS-1 and ERS-2. Not sure.	None. Sea State CCI could directly use the FDR4ALT L2+ Thematic Data products
Topex	Nothing has been done right now on CNES/CLS side. JPL (Jean Damien Desjonqueres) is conducting an activity to reprocess the whole dataset with a **numerical retracker** (not an adaptive one). We have not yet a clear planning saying when the dataset will be available. The performances of the numerical retracker are not as good as the Adaptive one but should clearly bring improvements wrt to the current Topex products (in particular for the SWH issue seen on Topex-A)	Adaptive not applicable because PTR are not available on Europe side (data protected by the US right now)	None
Jason-1	See Jason-3 below on which the demonstration of the potential of the Adaptive has been done in the frame of the Seat State CCI Round Robin. Nothing has been done yet on this mission. Jason-1 dataset has not been included in CNES databases right now.	Except a small study dealing with the impact of waveform compression (see D8), we do not anticipate any issue to reprocess the whole dataset (with CNES facilities) but it is a huge work to be done in terms of acquisition of the databases, tunning of the algorithms, run, production and delivery of the data.	Study to be done on the impact of range gates avaraging on the waveform trailing edge. We anticipate that the impact should be weak.

			Acquisition of the complete SGDR dataset in our databases (on CNES facilities), run of the Adaptive retracker on the whole dataset and verification that the results are correct and in line with Jason-3 ones
			Support for the production of the whole dataset in netcdf files to be delivered to IFREMER (definition of the product, generation, validation of the completness)
Envisat / RA-2	idem ERS-1 and ERS-2. This study has been proposed as an option of the main contract funded by ESRIN (FDR4ALT) and managed by CLS.	Two peculiarities of the Envisat waveforms have to be investigated. A Hamming function is applied in the across track direction. This has to be accounted for in the Adaptive retracker. The slope of the deramping chirp (positive slope for RA-2) is reversed wrt Jason series (negative slope). This characteristic has to be carefully considered for long term drift. This should not be a big issue.	None. Sea State CCI could directly use the FDR4ALT L2+ Thematic Data products
Jason-2	Jason-2 mission has already been reprocessed in CNES/CLS databases (PTR not dynamically accounted for but this is not considered as an issue as the PTR is very stable over time)	No major issues have been identified as Jason-2 is very similar to Jason-3.	None except the support for the production of the whole dataset in netcdf files to be delivered to IFREMER (definition of the product, generation, validation of the completness)
Jason-3	The algorithm is already implemented, tuned and validated on CNES facilities. Sea State Round Robin dataset have been produced with Jason-3 data.	All the production has been done already.	Delivery to IFREMER of a stand alone version (in C) of the processing. This code could be used for Jason-1/2/3. + support to IFREMER for implementation and validation wrt a dataset
			Production of the whole dataset in netcdf files to be delivered to IFREMER (definition of the product, generation, validation of the completness)
Cryosat-2 LRM	Nothing has been planned yet.	Cryosat-2 has an elliptical antenna. The applicability of the Adaptive retracker to CS-2 has to be checked. Mitigation can be found but requires more studies and validation tests. Databases are alreay available (ESA GOP products) (but without the Adaptive)	CS-2 not being a priority, we propose to evaluate later the effort requested for such an activity if it was selected.
Saral	Nothing has been planned yet.	R&D activities have still to be done for optimizing the Adaptive retracker (Gaussian approximation for the antenna diagram is no more valid in Ka band and raises modelling difficulties over the ocean). We are already conducting some researches to analyse the most efficient way to implement the antenna diagram in the model. We envisage to propose a solution that could perform well for well pointed periods. For mispointed periods, it could be more touchy and we propose to only consider well pointed periods.	Integration of the Antenna Pattern in the retracker and analysis of the performances
			Delivery to IFREMER of a stand alone version (in C) of the processing. This code could be a slight deviation wrt to the one used for Jason-1/2/3. + support to IFREMER for implementation and validation wrt a dataset provided by CLS
			Production of the whole Saral dataset (till end of 2019) in our databases (on CNES facilities)
			Production of the whole dataset in netcdf files to be delivered to IFREMER (definition of the product, generation, validation of the completness)
CFOSAT / SWIM	The ground processing is already using an Adaptive algorithm (similar to the one of Jason-3)	The tunning has already been done. The products have been produced and delivered to the users. CCI could use them. Be careful, no HFA correction has been implemented yet (TBC). See below .	None

The following table contains the status and shortcoming for the HFA correction.

Low Resolution Mode ==> HFA			
Missions	Status of the current developments	Shortcoming	Study to be done
GFO	Nothing has been done yet on this mission.	None	None
ERS-1	The generation of a SWH dataset for the whole mission is under study in the frame of the Fundamental Data Record For Altimetry Project (FDR4ALT). This study is funded by ESRIN and managed by CLS.	If the FDR4LT option is accepted, the HFA correction will be included in the FDR4ALT reprocessing activity	None
ERS-2	idem ERS-1	idem ERS-1	None
Topex	Nothing. JPL (Jean Damien Desjonqueres) is conducting an activity to reprocess the whole dataset with a numerical retracker (not an adaptive one). We have not yet a clear planning saying when the dataset will be available.	None	None
Jason-1	Nothing has been done yet on this mission.	HFA correction defined for Jason-3 should be used for Jason-1. No issue foreseen	Computation of the HFA correction based on Jason-3 table on the hole dataset and verification
Envisat / RA-2	idem ERS-1 and ERS-2	HFA correction is included in the FDR4ALT reprocessing activity	None
Jason-2	The Jason-2 mission has already been reprocessed in CNES/CLS databases.	The HFA correction defined for Jason-3 should be used for Jason-1. No issue foreseen	Computation of the HFA correction based on Jason-3 table on the hole dataset and verification
Jason-3	The algorithm is already implemented, tuned and validated.	None. There is only to extend the computation of the HFA on the whoe dataset (as for Adaptive)	None
Cryosat-2 LRM	Nothing has been planned yet.	The HFA correction has to be computed on CS-2 dataset. No issue are foreseen. Should be done only if an adaptive retracker is developed for CS-1	Computation of the HFA to be done + application + validation
Saral	Nothing has been planned yet on CNES/CLS side	HFA correction could be computed for MLE4 output. Then, if the Adaptive retracker has been defined and provides good results, it should be compute as well with Adaptive	For the MLE4, the computation of a HFA correction has already been proposed in the frame of the SALP project as an option (LOT 3.5)
			For the Adaptive, a HFA solution could to be
CFOSAT / SWIM	The ground processing is already using an Adaptive algorithm.	No HFA correction has been implemented yet. No issue to compute one but has to be done	The computation of a HFA correction has already been proposed in the frame of the SALP project as an option (LOT 3.5)

2.2 Altimeter (DD)

ADP-3: WHALES for SAR (TUM)

Initial Plan

Originally, the Technical Proposal planned the adoption and evaluation of the SAMOSA algorithm, to be evaluated in the Round Robin by TUM and PML. This strategy was slightly changed for the following reasons:

1) isardSAT, which works on improvements of the SAMOSA Algorithm in the version developed by Ray et al. 2015 (see ATBD-5 in this document), entered the Consortium
2) The SAMOSA algorithm is the official algorithm of Sentinel-3A and has been therefore analysed in the Round Robin evaluation as a reference dataset

The SAMOSA algorithm in its version described in the document “SAMOSA Team, Detailed Processing Model of the Sentinel-3 SRAL SAR altimeter ocean waveform retracker” was nevertheless used by TUM to create a waveform simulator. This was used to calibrate a new empirical algorithm, called “WHALES for SAR”. This algorithm builds on WHALES (see ATBD-1) and the ALES+ algorithm developed for ESA in the context of Sea Level CCI (Passaro et al., 2018). It consists of an empirical application of a modified Brown-Hayne functional form in order to estimate the rising time of the leading edge of a SAR waveform. The assumption is that, while the SWH in SAR waveforms affects both the leading edge and the trailing edge, only the leading edge is necessary to estimate it. This plan corresponds to the plan described in the Technical Proposal in the sub-chapter “Planned investigation on new algorithms and development of existing algorithms - Empirical Hs retracking”.

Shortcoming

1) E. Börgens (working on WHALES for SAR) left TUM in January 2019.

2) First results show a great potential in the coastal zone for such a subwaveform SAR retracker. In the open ocean nevertheless, higher noise than the standard S3 data is observed for SWH>3 m (better performances instead for SWH<3 m).

Mitigation

1) New personnel to replace E. Börgens has been hired (PhD student). The new personnel will carry on the work of Algorithm Development subsequent to the Round Robin.
2) One possibility could be to try to apply directly the SAMOSA functional form on a subwaveform in order to exploit the current findings and check whether these can be applied on a physical retracker. Unless other reasons for the higher noise for SWH>3m are found, this will be investigated in the following stages of the project.

Updated plan

The WHALES for SAR scored second in the Round Robin, showing some of the best performances in the coastal zone. This has demonstrated that:

1) The subwaveform strategy followed for LRM can be used successfully to the SAR case, despite the fact that in the latter the trailing edge is also affected by a change in SWH.
2) An empirical use of a functional form that is not adapted to the SAR strategy (i.e. WHALES for SAR) performs better than the current SAMOSA-based physical retracker of the official baseline in S3. This is true not only at the coast, but also considering the analysis of the power spectrum.

TUM has communicated to the Consortium that it can provide assistance to the main contractor to obtain a WHALES for SAR version based on the documentation. Nevertheless, TUM is not going to update the WHALES for SAR code since the shortcomings are not solvable following the current empirical approach.

The SAMOSA waveform simulator that has already been used for the approach in ADP-3, and will now be used for the implementation of a standard SAMOSA retracker/L2 Processor (see DPM document “SAMOSA Team, Detailed Processing Model of the Sentinel-3 SRAL SAR altimeter ocean waveform retracker” v2.5.2). On top of that, the coastal retrackers SAMOSA+ and SAMOSA++ (SAM+/SAM++), as published in Dinardo (2020), will be implemented and serve as a reference for future retracker development. SAM+ has made improvements in coastal scenarios, e.g. when peaky signals arise from wetlands or sand banks, or for land-sea (and vice versa) transitions, in which the tracker loses its synchronisation. SAM++ takes also into account the range-integrated-power (RIP) function, which lets the retracker adapt to arbitrary surfaces.

In addition to the enhancements of SAM+, a novel retracking algorithm for coastal scenarios will be developed to tackle spurious interference that typically occurs in the coastal zone. An adaptive interference mitigation scheme will detect those interfering signal within the waveform and mitigate those during the waveform fitting procedure. The focus of the retracker will also be on the maximisation of valid 20-Hz measurements in the coastal zone.

ADP-4: L1A to L1B-S/L1B processing chain (isardSAT)

Initial Plan

To evaluate the optimisation of the Delay-Doppler (DD) processing starting from L1A data, the core of the **DeDop** processor implemented by isardSAT (Cotton et. al 2018) has been used for the production of the L1B product (input for ADP-5). This processor can provide conventional[1] L1B products (multilook DD waveforms) as well as L1B-S products (stacks[2]). Different processing baseline can be easily configured in order to to optimise the Delay-Doppler processing, e.g., intra-burst windowing, zero-padding in range, exact or approximate beamforming, among others (the list of potential options can be found in the Sea State CCI ATBD document).

The developments included in this processor are mostly constrained to: i) finalising the algorithms related to the different processing options, and ii) adapting the conventional L1B as well as the L1B-S products so that all the information required by the conventional DD or SAR ocean retracker (ATBD-5) and by the ACDC processor (ATBD-6), are included, respectively, in the L1B and L1B-S.

Shortcoming

DeDop core processor has already been implemented and used during the round robin (May 2019). DeDop is based on the long experience of isardSAT in the development of Delay-Doppler or SAR mode processors, like ground prototype processor (GPP) for Sentinel-6 (Moyano et al. 2018) or in-house processor for CryoSat-2 data (Makhoul et al. 2018).

Differences of surface positions between the IPF L1B products and Dedop L1B products surface positions should be considered.

Mitigation

Differences of surface positions between the IPF L1B products and Dedop L1B products surface positions were removed by moving the DeDop surface locations to IPF ones. This may increase the noise in the geophysical retrievals and has also shown some oscillations in the spectrum.

After analysis of the round robin results, it is being considered to include along-track weighting in this processor.

[1] By conventional it is understood the normal Delay-Doppler or SAR processing without the inclusion of the ACDC processing (also considered in the frame of the Sea State CCI project) before the multilook final waveform is formed.

[2] In Delay-Doppler processing, the stack is an intermediate product that contains the different waveforms from different bursts that have been focused to a specific surface location (analogous to the so called Delay-Doppler map). An incoherent averaging of them produces the final multilook DD waveform.

ADP-5: Conventional SAR mode Ocean retracker (isardSAT)

Initial Plan

The basis of this ocean SAR mode or **Waver** is the in-house isardSAT implementation of the SAR ocean model developed by Ray et. al 2015a. This in-house retracker has been developed for Sentinel-6, and adapted and exploited to process CryoSat-2 data (Makhoul et al. 2018). Hence, the development plan for this algorithm has mainly focused on its adaptation to Sentinel-3 data processed by DeDop chain and to the specific configuration of data generated by ADP-4. The whole chain (ADP 4 and ADP 5) is named **DeDop-Waver**. Implementation and testing has finished in May 2019.

Shortcoming

No major shortcoming was foreseen for this algorithm since it is based on the in-house isardSAT SAR ocean retracker.

Differences on the retrieved SWH (e.g. precision and accuracies) provided by DeDop-Waver compared to the nominal Sentinel-3 IPF L2 (ocean retracking in SAR mode) were present due to different implementation.

Mitigation

To mitigate the impact of large discrepancies on SWH (biases as a function of SWH) between the in-house isardSAT SAR mode ocean retracker against nominal Sentinel-3 IPF, specific validation activities have been considered.

Updated plan

Large SWH biases have been significantly reduced by modification of the width of the model radar point target response.

As a result of the Round Robin exercise, spurious ripples were apparent in the tail of the power spectrum density (PSD) function of SWH series in space, which appeared to be periodic. The investigations performed to determine the causes of these artifacts were based on the observation that ripples in the PSD are the result of sidelobes existing in the frequency characteristic of a window function applied in the processing chain. In previous studies it had been proven that SWH estimates are very sensitive to the selected initial values for curve fitting and optimization. Hence, because initial estimates were computed as the simple moving average of previous 10 estimates, in the frequency domain oscillations appeared as a consequence of the sidelobes of the sinc function, and this effect had a direct impact on the power distribution of the final SWH estimates. The oscillations were finally removed by adjusting the frequency characteristic of the selected window, that is, using a cumulative moving average. A cumulative moving average presented fairly low noise levels and stability in the estimates.

ADP-6: ACDC (isardSAT)[3]

Initial Plan

The innovative Amplitude Compensation and Dilation Compensation (ACDC) algorithm proposed in Ray et al. 2015b, is planned to be implemented at stack level differently from the burst-based original approach in Ray et al. 2015b. The algorithm is being adapted to Sentinel-3 through its integration in the DeDop processing chain.
The implementation of the following integral algorithms is planned for the first version (details and description can be found in the ATBD):

- amplitude compensation: equalization of the stack amplitude;
- dilation compensation: equalization of the waveforms' broadening when moving away from central beam in the Delay-Doppler Stack;
- multilooking: generation of equivalent ACDC multilook waveform;
- ACDC retracking: ACDC model fitting to the multilook waveform (epoch, SWH and sigma0 are provided).

The planned schedule to complete:

- algorithm definition → done;
- implementation and testing → done;
- data production → ongoing.

Shortcoming

The following shortcomings have been identified

- ACDC operation requires an initial estimate of the epoch (rise point of leading edge) and the SWH. Hence an ill-suited setting of these initial parameters can lead to a non-convergent ACDC operation.
- ACDC was developed to operate over open ocean, and so it will perform unexpectedly over land areas. This can have a direct impact on the ACDC operation when moving from land to ocean, since, depending on the initial seeds propagation approach, the ocean surface can take the ACDC outcome of previous land surface.
- Discrepancies between the estimated SWH and the nominal Sentinel-3 IPF might be present.

Mitigation

The following approaches will be considered to mitigate the impact of the previous identified shortcomings:

- To mitigate the impact of the initial estimates in the operation of the ACDC and facilitate the convergence of the method the following strategy will be implemented:
    - ACDC will be run over the whole track several times (set by configuration parameter).
        - For the first iteration over the whole track: the initial epoch value is extracted from a threshold retracker over the conventional Delay-Doppler L1B waveform (as a percentage of peak); the SWH is extracted from configuration file, and it is set to a value typically above 5 m., to ensure ACDC convergence for low SWH cases. Then, ACDC

[3] This algorithm was not part of the round robin exercise. It has been included for completeness on the ATBD as it is part of isardSAT research activities within the WP2000, and it may provide insights on how the optimized processing from L1A to L1B shall be considered.

iterates over the same surface (using initial epoch and SWH from previous estimates).
      - For subsequent iterations over the whole track: the initial estimates for each surface are obtained directly from the smoothed version, using a running window, of the final estimates provided in the previous iteration over the track and no feedback between surfaces is considered in each iteration.
- To mitigate the impact of the operation on land to be propagated into ACDC over ocean:
  - Based on the previous seeding strategy (specifically for the 1st iteration over whole track) and to avoid seeding subsequent surfaces with estimates from a land surface, a flag available in the L1A product ("surf_type_l1a_echo_sar_ku")[4] is used to define the typology of surface being processed. In this way, for each surface being processed it is checked whether the previous one was labelled as land, in that case the initial estimates are considered as for the very first surface (SWH from configuration and epoch based on threshold retracker).
- To mitigate the impact of discrepancies on SWH (biases as a function of SWH) between outcome of ACDC and Sentinel-3 IPF L2, specific validation activities will be carried out.

Updated plan

To mitigate the impact of the initial estimates in the operation of the ACDC, a different mitigation strategy has been followed in order to avoid increasing computational time. For the first surface, initial values of SWH and epoch are selected from the configuration file. For subsequent surfaces, a cumulative moving average is used to compute the initial estimates at each surface. Notable stability has been gained by this method.

To mitigate the impact of the operation on land to be propagated into ACDC over ocean in the seeding procedure, an alternative strategy that does not require additional input variables has been implemented. Outliers present in the previous estimates filtered by the moving average are removed before seeding the minimization process at a particular surface location.

As large SWH biases have been analysed in the in-house conventional SAR mode Ocean retracker, no specific modifications have been considered in the ACDC processing chain.

ADP-7: Level 1 LR-RMC processing on Delay Doppler (CLS)

Initial Plan

[4] This flag indicates the type of surface beneath the satellite for each burst. Then, from all the bursts that conform the stack of the DD (Delay-Doppler) pointing to a given surface, the one closest to the nadir is used.

The basis of this ocean SAR mode processing is an algorithm that has been developed in CNES/CLS to reduce the impact of swell effects. These effects have been evidence on S3 data and numerous presentations have been done at the different OSTST for instance.
This algorithm is a Level 1 algorithm which differs from the classical SAR processing by the fact that it process the SAR over one burst (SAR processing, echo migration) and then it incoherently averages 4 consecutive SAR waveforms to produce a 20Hz LR-RMC waveform that can be retracked as it is done for SAR processing. A paper (Moreau et al, 2021) is in preparation detailing the complete processing and main results compared to the ones obtained with a classical SAR processing. As for the LRM mode, we have proposed and successfully validated the possibility to apply a High Frequency Correction (HFA correction).

Shortcoming

Extensive validation has been done on CNES/CLS side to demonstrate the potential and the performances of this algorithm. The adaptation of this processing to the different missions and the potential issues that can be encountered are described in the table below.

Mitigation

A description of the different potential issues on each SAR mission is provided hereafter.

Doppler Mode ==> LR-RMC L1 processing			
Missions	Status of the current developments	Shortcoming	Study to be done
Cryosat-2	The processing has not been implemented as it is not adapted for sea ice surfaces where the SAR mode is activated. For SAR patches in the pacific ocean, we consider that these areas are small and not critical; The processing is thus not mandatory for CS-2	None	None
Sentinel-3A	The processing is already defined and validated. It has been applied on 2 years of S3A from July 2016 to end of 2018. The period could be extended to cover the entire life time of the mission till 2020.	None	Production and delivery to IFREMER of a stand alone version (in python) of the processing. This code could be used for S3B as well. + support to IFREMER for implementation and validation wrt a dataset provided by CLS
			Run of the algorithm over the entire period (from beginning of 2019 to end 2020). This extension could be covered by CNES in the frame of the L2EHR contract.
			Production of the whole dataset in netcdf files to be delivered to IFREMER (definition of the product, generation, validation of the completness)
Sentinel-3B	The processing has not been implemented at all for S3B but S3B being very similar to S3A, the same processing could be used for both missions	None	Adaptation of the S3A prototype to S3B configuration
			Run of the algorithm over the entire S3B period
			Production of the whole dataset in netcdf files to be delivered to IFREMER (definition of the product, generation, validation of the completness)

The following table contains the status and shortcoming for the HFA correction.

Doppler Mode ==> HFA			
Missions	Status of the current developments	Shortcoming	Study to be done
Cryosat-2	As said for the LR-RMC, not a priority	None	None
Sentinel-3A	A HFA solution has been already developed and provided for the Sea State Round Robin;	There is only to complement the whole dataset (as for LR-RMC) with this correction	Complement the databases over the entire period and verification
Sentinel-3B	Nothing has been done yet on this mission.	No issue to use the HFA correction defined for S3A	Application of the correction the the entire period and verification

2.3 Synthetic Aperture Radar

ADP-8: CWAVE_S1-WV (DLR)

Initial Plan

At DLR a sea state processor (SSP) software for estimation of significant wave height (SWH) from Sentinel-1 IW and TerraSAR-X imagery with the names CWAVE_S1-IW and XWAVE was developed and published by Pleskachevsky et. Al. in 2019. The initial plan was to re-tune CWAVE_S1-IW and XWAVE for the estimation of SWH from Sentinel-1 WV imagery. As a secondary goal the applied empirical model function should be adopted for estimation of significant wave direction and significant wave length.

The planned schedule to complete:

- algorithm definition → done;
- implementation and testing → done;
- data production → done.

Shortcoming

In the round robin (RR) comparisons in March 2020, the DLR CWAVE algorithm, retuned for Sentinel-1 WV, reached a better score than the competing IFREMER algorithm. However, as later presented, a new algorithm, which uses machine learning and was developed by Quach and Stopa, achieved even better results. Further improvements were carried out on CWAVE_S1_WV also based on machine learning. The resulting postprocessing (reprocessing) uses the support vector machine technique (SVM). The accuracy of the initial SWH for S1 WV (CMEMS-hindcast validation) estimated using CWAVE linear regression with RMSE of ~0.35m was improved to RMSE of ~0.25m using SVM. The SVM based reprocessor was created in May 2020 and the complete archive for Sentinel-1 WV Dec.2014-Feb.2021 was processed in February 2021.

Estimation of wavelength: estimation of the whole set of wave periods (mean period, Tm1, Tm2, wind-sea period) were developed and validated with an error RMSE of ~0.5 sec. The wavelength can be directly estimated from the period using dispersion relation for deep water *L=(g*PERIOD^2)/(2*PI)*. As the ground truth wavelength has been also estimated from the period, the direct comparisons of the periods are more meaningful.

Estimation of wave direction: the tests with mean direction estimation shows that a simple retuning of the model function is not enough to create an automatic method, valid for most S1 WV imagettes. The main reason is that the stored SAR features are developed with focus on SWH estimation. For example, the GLCM frequency matrixes were primarily extracted for both x (i+1) and y (j+1) directions but later averaged for feature calculations. In this way, although the direction can be deduced in ~80% of all cases with acceptable accuracy around 20°, outliers and large errors during automatic processing are encountered. Additional effort is needed in terms of automatic filtering and corrections for the following issues:

- no wave pattern visible in the clutter (while SWH can also be estimated from the noise)
- two or more comparable wave systems with different directions are superimposed: fluctuating direction form one system to the other, if SWH of swell-1 exceeds SWH of swell-2 (this fluctuation is also an additional uncertainty in ground truth)
- automatically solving the 180° ambiguity (going to or coming from).

Mitigation

n.a.

ADP-9: Sentinel-1 wave mode optimal training (OceanDataLab)

Initial Plan

On top of the significant wave height algorithm developed from Sentinel-1 wave mode using machine learning, a new SAR wave mode algorithm was planned to be developed that builds on new machine learning capabilities and direct SAR imaging simulations to retrieve the full 2D wave spectra.

Shortcoming

No major shortcoming but key personnel for SAR algorithm has been heavily involved in the report for mission selection and UCM preparation for the EE9 candidate SKIM and Cal/Val activities of newly launched SWIM wave scatterometer onboard CFOSAT. This has delayed the algorithm development activities and only the significant wave height estimation has been developed, validated and run on the whole Sentinel-1 archive. As for the new wave spectra estimation algorithm, based on machine learning, the non-linear SAR imaging simulations have been developed but not yet applied to the reference wave model spectra.

Mitigation

The key personnel has been able to run the SAR Round Robin before summer 2020 with the first hs parameter available from both concurrent algorithms and 2D wave spectral parameters will be produced in a second iteration. In the second half of 2021, the SAR learning set will be developed using a SAR simulator with wave model spectra and collocated Sentinel-1 SAR spectra. A CNN training will be used to learn the expected wave spectra from an observed Sentinel-1 SAR spectra. A dedicated researcher has been hired at OceanDataLab for this machine learning training in April 2021 and a PHD student on this topic will start in January 2022.

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