# 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 |

# 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 |
| 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).

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 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.

### 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 digitied 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.

### 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 leading 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 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.

### 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. A High Frequency Adjustment is being developed to account for the correlation between range and Hs noises.
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.

The planned schedule to complete:

- implementation and testing →April 2019;
- data production → June 2019.

#### *Shortcoming*

No major shortcoming is envisaged for this processor.

#### *Mitigation*

We do not anticipate the need of any mitigation plan considering the fact that the study, the generation of the dataset should not encounter any issues.

## 2.2 Altimeter (DD)

### ADP-3: WHALES for SAR (TUM)

#### *Initial Plan*

Originally, the Technical Proposal planned the adoption and evaluation of 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) has 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

### 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

[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.

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 IPT ones. This may increase the noise in the geophysical retrievals.

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

## 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.

## 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 will be 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 → April 2020;
- data production → May 2020.

### *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.

[3] This specific algorithm is not going to be 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.

### *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:
    - For the first surface: 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 iterates over the same surface (using initial epoch and SWH from previous estimates).
    - For subsequent surfaces: the outcome (epoch and SWH) of the previous surface is used.
  - 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.

## 2.3 Synthetic Aperture Radar

### ADP-7: 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 recently published by Pleskachevsky et. Al. in 2019. The initial plan was

[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.

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 functions should be adopted for estimation of significant wave direction and significant wave length.

The planned schedule to complete:
- algorithm definition → done;
- implementation and testing → April 2020;
- data production → May 2020.

#### *Shortcoming*

No major shortcoming is foreseen for this algorithm since it is based on the in-house DLR SAR sea state processor (SSP), which was designed for medium and high resolution images similar to Sentinel-1 IW.

As the original functionality of the SSP was not designed for estimation of the secondary parameters significant wave direction and significant wave length, the accuracy of parameter estimation might prove insufficient.

#### *Mitigation*

In case of insufficient accuracy of parameter estimation, the extraction of additional features from the SAR images and re-tuning of the empirical model functions might be required.

### ADP-8: Sentinel-1 wave mode optimal training (OceanDataLab)

#### *Initial Plan*

A new SAR wave mode algorithm was planned to be developed that builds on new machine learning capabilities and direct SAR imaging simulations.

#### *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 (theoretically the future best sea state satellite measurement instrument ever). This has delayed the algorithm development activities and only the significant wave height estimation has been developed.

#### *Mitigation*

The ESA EE9 UCM was on July 16/17 and the key personnel will recover the situation in the second half of 2019.

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