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ESA Sea Level CCI+

# Algorithm Selection Report

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List of Contents

## 1. Introduction

In the context of the ESA's climate change initiative sea-level project, the Centre of Topography of the Oceans and the Hydrosphere (CTOH, http://ctoh.legos.obs-mip.fr) produces a Level 2P multi-mission altimeter along-track sea level product in in coastal zones of thirteen regions: Northeast Atlantic, Mediterranean Sea, West Africa, Benguela, Southeast Africa, North Indian Ocean, Southeast Asia, Australia, Northwest America, Gulfstream, Caribbean, Atlantic South America and Humboldt. In order to provide accurate altimeter Sea Level Anomalies (SLA) time series as close to the coast as possible, the product benefits from the spatial resolution provided by high-rate data, the Adaptive Leading Edge Subwaveform Retracker (ALES, *Passaro et al.*; 2014, 2015, 2017) and the post-processing strategy of the X-TRACK algorithm (*Birol et al.*, 2017, adapted to 20 Hz data as in *Birol and Delebecque*, 2014) both developed for the processing of coastal altimetry data, as well as the best possible set of geophysical corrections.

By merging X-TRACK and ALES altimetry processing tools, we compute 20-Hz along-track sea surface height (SSH) time series for Envisat, Jason-1, Jason-2 and Jason-3 missions and 40-Hz along-track SSH time series for SARAL/AltiKa mission (20 Hz, i.e., 300 m resolution; 40 Hz, i.e., 150 m resolution). In the versions v2.1 and v2.2, the X-TRACK software reprocesses corrections and parameters from delayed-time geophysical data records provided by space agencies (GDR products) and combines them with the ALES retracker product (range, sigma0 and sea state bias) to compute the SSH, after a robust editing of the measurements and corrections (described in *Birol et al.*, 2017). The full data processing is explained in Birol et al. 2021. The list of altimetry parameters and geophysical corrections used in the computation of the versions v2.1 and v2.2 of XTRACK/ALES coastal sea level product is provided in Table 1.

The dataset of the successive missions Jason-1, 2 and 3 have been combined with dedicated inter-bias missions. This has allowed the computation of timeseries of along-track high-resolution (20Hz) sea level anomalies and associated trends. These coastal sea level timeseries and associated trends available every 300m along-track, validated against tide gauges where possible, have benefited from a severe editing and selection, which has led to a dataset of 756 coastal sea level virtual stations covering January 2002 to December 2019 (described in detail in Cazenave et al., 2022).

In 2024, an evolution of the coastal sea level product is being considered in order to integrate new altimeter standards. The latest version of the FES (Finite Element Solution) ocean tide model, called FES2022 will be available soon (Tchilibou et al., 2023). This new tidal solution uses higher spatial resolution in coastal areas, upgraded model bathymetry and an improved hydrodynamic modelling. The improvement observed in the FES2022 hydrodynamic solution compared to FES2014 is expected to result in an improvement in the coastal sea level product. In parallel, a new retracker product (range, sigma0 and sea state bias) called the Adaptive retracker is also available (Tourain et al., 2021; Thibaut et al., 2021).

In 2026, the product's temporal coverage is extended to include the Sentinel-6A mission, by using the selected algorithms for Jason-1, Jason-2 and Jason-3, creating the J1+J2+J3+S6A combined mission.

The main objective is to select the best algorithms among those tested and to analyse how far this selection will improve the accuracy of coastal seal level data. This document presents the methodological approach used to perform this algorithm selection. The results of the evaluation and validation will be presented once available in the SL_cci+ Product Validation and Inter comparison report (PVIR).

## 2. Overview of the algorithm selection process

The evolution of the coastal sea level product will be decided on the basis of the output of a selection process in which all the altimeter and oceanographic experts involved in the Sea-Level CCI+ project will be invited to participate. In order to facilitate their work, the validation reports with the thorough analyses of all the new algorithms related to the same altimetry components (range and ocean tide) will be shared within the project. An executive summary of the validation reports where the recommendations and main results have been synthesised will be provided at the end of the selection process.

Two reprocessed coastal sea level datasets from Jason-1,2,3 missions will be produced:

- **Dataset 1**: compared to the sea level product version v2.2, **only the ocean tide correction (and its loading effect) will be changed in order to use FES2022** instead of FES2014.
- **Dataset 2**: compared to the sea level product version v2.2, **the ocean tide correction (and its loading effect) will be changed in order to use FES2022** instead of FES2014, **and the Adaptive retracker (range, sigma0 and sea state bias) will be used** instead of the ALES retracker (range, sigma0 and sea state bias).

In order to minimise the sources of differences between the sea level data sets, they will be processed with the same processing chain used to compute **the coastal sea level V2.2 which will be considered as a reference** (called **Dataset Ref** hereinafter).

In parallel of the validation reports, all sea level datasets (Dataset Ref, Dataset 1 and Dataset 2) will be made available for all the altimeter and oceanographic experts involved in the Sea-Level CCI project.

Note that Datasets 1 and 2 have not been produced yet and only a description of the method used is provided here.

| Parameter | Source | Jason-1 | Jason-2 | Jason-3 | Envisat | SARAL |
|---|---|---|---|---|---|---|
| L2 standards | GDR | GDR-E | GDR-E | GDR-D | GDR V2.1 | GDR-T |
| Altitude | GDR | Altitude of satellite | | | | |
| Range | ALES | 20 Hz ku band ALES corrected altimeter range (*Passaro et al.*, 2014) | | | | |
| Ionosphere | GDR | From dual-frequency altimeter range measurements, further filtered by X-TRACK | | | From GIM model (Iijima et al. 1999) | |
| Dry troposphere | GDR | From ECMWF model | | | | |
| Wet troposphere | GPD+ | GPD+ radiometer correction (*Fernandes and Lazaro*, 2016) | | | | |
| Sea state bias | ALES | Sea state bias correction in ku band, ALES retracking (*Passaro et al*., 2018) | | | | |
| Solid tide | RADS | From tide potential model (*Cartwright and Taylor*, 1971, *Cartwright and Eden*, 1973) | | | | |
| Pole tide | GDR | From *Wahr*, 1985 | | | | |
| Loading effect | RADS | From FES 2014 (*Carrere et al*., 2012) | | | | |
| Atmospheric correction | RADS | From MOG2D-G high frequencies (*Carrere and Lyard*, 2003) + inverse barometer | | | | |
| Ocean tide | RADS | From FES 2014 (*Carrere et al*., 2012) including ocean tide, long period equilibrium tide, S1 tide | | | | |

**Table 1:** List of altimetry parameters and geophysical corrections used in the computation of the versions 2.1 and 2.2 of the XTRACK/ALES coastal sea level product.

# 3. Ocean tide correction: FES 2022

## 3.1. Description and processing

The geocentric (elastic) ocean tide is the sum of the ocean tide and the load tide. It is a major contributor to sea level variability and is observed by altimeters on board satellites. In order to produce Dataset 1, the geocentric ocean tide computed from FES2014 in Dataset Ref will be replaced by the geocentric ocean tide computed from FES2022.

In practice, in comparison to Table 1, two components will be replaced in the sea level computation:

- the ocean tide (computed from FES2022 harmonic components)
- the loading effect (computed from FES2022 harmonic components).

High-resolution (20 Hz), along-track sea level datasets of the successive missions Jason-1, 2 and 3 will be computed. The latter will then be combined with their dedicated inter-bias missions (same algorithm used than in product version 2.2).

## 3.2. Validation diagnostics

The objective here is to validate Dataset 1 and to evaluate its performance relative to Dataset Ref. Therefore, the following diagnoses will be carried out for the two datasets:

- Regional maps of the number of valid 20-Hz sea level anomaly data
- Regional maps of the difference in the number of valid 20-Hz sea level anomaly data between Dataset 1 and Dataset Ref
- Regional maps of the standard deviation of sea level anomaly data
- Regional maps of the difference in standard deviation of sea level anomaly data between Dataset 1 and Dataset Ref
- Mean number of valid 20-Hz sea level anomaly data represented as a function of distance to the coast
- Mean standard deviation of sea level anomaly data represented as a function of distance to the coast
- Histograms of the sea level anomaly data
- Statistics between altimetry and tide gauge sea level time series over Jason-3 period: local maps of correlation, of standard deviation and of the root-Mean-Square Deviation, as well as Taylor diagrams.

## 3.3. Selected Ocean Tide correction

In light of the results of the validation diagnostics, the FES 2022 tidal correction was chosen and implemented in the final production for all missions, as it improves the accuracy of coastal sea level data.

# 4. Altimeter adaptive retracking

## 4.1. Description and processing

Described in Tourain et al. (2021) and Thibaut et al. (2021), the “Adaptive” retracker is a new retracker which combines the improvements brought by Poisson et al (2018) for the estimation of surface parameters from peaked waveforms over sea-ice, improvements in the way the instrumental characteristics are taken into account in the model (mispointing, point target response) and a more accurate consideration of speckle statistics. In this study it was shown that, with respect to the classical MLE4 retracker, this new algorithm allows significant noise reduction on all geophysical variables (and especially the significant wave height), and performance of inversion over a large set of echo shapes, resulting from standard oceanic scenes as well as highly specular conditions such as over bloom or sea-ice. Here, we aim to assess its performance relative to the ALES retracker and in coastal ocean condition.

In order to produce Dataset 2, the geocentric ocean tide computed from FES2014 in Dataset Ref will be replaced by the geocentric ocean tide computed from FES2022 (same as for Dataset 1).

In practice, in comparison to Table 1, two components will be replaced in the sea level computation:

- the ocean tide (computed from FES2022 harmonic components)
- the loading effect (computed from FES2022 harmonic components).

In addition, the outputs of the ALES retracker used to compute Dataset ref will also be replaced by the outputs of the Adaptive retracker.

In comparison to Table 1, two components will be replaced in the sea level computation:

- the range (computed from the Adaptive retracker)
- the sea state bias (computed from the Adaptive retracker)

During the X-TRACK editing process, the σ0 (retrodiffusion coefficient) from ALES will also be replaced by the σ0 from Adaptive.

High-resolution (20 Hz), along-track sea level datasets of the successive missions Jason-1, 2 and 3 will be computed. The latter will then be combined with their dedicated inter-bias missions (same algorithm used than in product version 2.2).

## 4.2. Validation diagnostics

The objective here is to validate Dataset 2 and to evaluate its performance relative to Dataset 1. Therefore, the following diagnostics will be carried out for the two datasets:

- Regional maps of the number of valid 20-Hz sea level anomaly data
- Regional maps of the difference in the number of valid 20-Hz sea level anomaly data between Dataset 2 and Dataset 1
- Regional maps of the standard deviation of sea level anomaly data
- Regional maps of the difference in standard deviation of sea level anomaly data between Dataset 2 and Dataset 1
- Regional maps of sea level trends
- Regional maps of the difference in sea level trend between Dataset 2 and Dataset 1
- Mean number of valid 20-Hz sea level anomaly data represented as a function of distance to the coast
- Mean standard deviation of sea level anomaly data represented as a function of distance to the coast
- Histograms of the sea level anomaly data
- Statistics between altimetry and tide gauge sea level time series over Jason-3 period: local maps of correlation, of standard deviation and of the root-Mean-Square Deviation, as well as Taylor diagrams.

### 4.3. Selected retracker

The adaptive retracking was only tested on the Jason-3 mission. It was not selected as it was not available for all missions. The ALES retraking was used for the final production.

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