Consortium Members

ESA Sea Level CCI+

Sea Level in Coastal Areas: User Requirements Document (URD)

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1. Introduction

The Sea Level project of the Climate Change Initiative (Phase I and II during 2011-2019) has been the opportunity to produce accurate, homogeneous and stable sea level climate Data record (CDR) and Essential Climate Variable (ECV) products. This production was performed after gathering the User Requirements related to the sea level ECV. The SL_cci URD (available at: https://climate.esa.int/media/documents/SLCCI-URD-004_1-6.pdf) included a review and an analysis of the requirements provided within existing documents from the Global Climate Observing system (GCOS), World Meteorological Organisation (WMO), World Climate Research Program (WCRP) on the one hand, and from the Climate Modelling Group (CMUG). These requirements were also presented as well as the list of requirements dedicated to climate applications to be applied to the sea level ECV (in terms of global mean and regional changes). The SL_cci URD included also a description of the user requirements for coastal areas, including the results of a survey dedicated to the coastal sea level.

The extension of the SL_cci activities (SL_cci+ phase 2, started in 2022) had for main objective the production of high-resolution along-track sea level anomalies and associated trends from 2002 to present in the world coastal areas, based on a dedicated reprocessing of the Jason-1, Jason-2 and Jason-3 coastal altimetry data. Another objective was to characterize sea level uncertainties at global, regional and local (coastal) scales. The present document provides an update of the user requirements related to the coastal altimetry sea level products. Available coastal sea level products are described in Benveniste et al. (2020) and Cazenave et al. (2022) (see also https://doi.org/10.17882/74354).

2. Requirements for the satellite observing system

The objective of the ESA CCI Coastal Sea Level project is to develop a dataset of coastal sea level products along the world coastal zones, based on retracked data from LRM altimetry missions (essentially Jason-1, Jason-2 and Jason-3) and dedicated coastal geophysical corrections. This is performed by combining the retracked altimeter range data using the ALES (Adaptive Leading Edge Subwaveform) retracker (Passaro et al, 2015) with the XTRACK system developed at LEGOS (Birol et al., 2017, 2021).

A new version of the X-TRACK processing chain has been developed for that purpose, using most advanced processing algorithms and corrections available. The ALES retracker had proven its efficiency in retrieving more coastal sea level observations than other retrackers, particularly when using high-rate (i.e., 20-Hz) altimeter measurements instead of the standard (1-Hz) data (Passaro et al., 2018 a,b ; Xu et al., 2018). On the other hand, geophysical corrections, in particular the wet tropospheric and tidal corrections, have also been improved in the coastal domain. Different versions of a homogeneous, long-term multi-mission coastal sea level product have been provided along the coastlines of the 13 regions shown in Figure 1. The latest version (v2.4, available here: https://doi.org/10.17882/74354) covers the period January 2002 to June 2021.

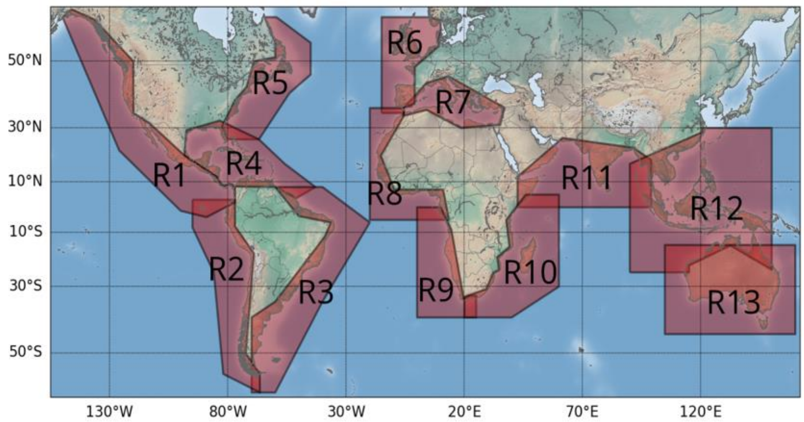

Figure 1: Regions covered by the ESA CCI Coastal Sea Level project

Considering the requirements from the international Earth Observation/EO and modelling communities, the characteristics of the sea level ECV data in coastal areas should include:

- A minimum continuous record length > 1 decade
- A good temporal and spatial resolution (along-track versus gridded product)
- An error characterization
- A quasi global coverage
- An easy access to the data

2.1. Record Length

The length and continuity of the Sea-Level ECV is undoubtedly the most pressing requirement of the EO and modeling communities since the longer the record, the easier to distinguish changes caused by anthropogenic forcing from the natural (internal) climate variability. Analyses of the 30+-year-long global mean sea level record (Ablain et al., 2017, Legeais et al., 2018, Guerou et al., 2023) have confirmed the observed acceleration is a consequence of the anthropogenic global warming. At regional scale, recent results suggest that the anthropogenic forcing begins to emerge in some regions but that the natural variability remains dominant (Nerem and Fasullo, 2020, Cazenave and Moreira, 2022). At local scale, the questions are still open. We expect that a ~20-year-long record can allow us to separate longer-term trends from the natural interannual variability. In addition, combination with other multi-sources datasets (i.e., Argo for the steric contribution, tide gauges, etc.) as well as high resolution coastal oceanographic models will offer constraints on the various processes active in the coastal zones and on their lifetime.

2.2. Temporal and spatial resolution

The CCI Coastal Sea Level project provides monthly coastal sea level time series, as well as trends over 2002-present, with a spatial resolution of 20 Hz (i.e. 350m resolution) along the satellite tracks.

Note that it is not possible to compute high-resolution gridded sea level data in the close vicinity of the coast due to the large inter-track distance of the Jason missions. This may be possible in the future when using data from the SWOT mission.

2.3. Along-track coastal sea level trends derived from these edited monthly sea level anomalies at selected coastal sites. Accuracy

The accuracy of the sea level data at the coast depends on a number of factors, including the quality of the ALES retracker and accuracy of the coastal geophysical corrections. In terms of trend, the requirement would be an accuracy of 1-2 mm/yr over 20 years or longer. Realistic uncertainties of the coastal sea level trends based on the approach developed by Prandi et al. (2021) are currently under study (Nino et al., in preparation, 2024), but not yet available.

2.5 Available coastal sea level products at the date of December 2024

Different versions of the CCI Coastal sea Level product have been provided since the beginning of the project (e.g., v1.1 over June 2002 to May 2018, Benveniste et al., 2020; v2.1 developed in 2022 with both temporal and regional extension, the latter including the whole African continent and North and South America as new regions, Cazenave et al., 2022). Recently, additional versions (v2.2 and v2.3) have been produced. These are based on a number of processing improvements, in particular use of the GDR-F range data for Jason-3, an optimization of the intermission bias calculation, improved geophysical corrections and improved post editing.

The latest version (v2.4) slightly differs from the v2.3 version by adding a new post-editing criteria consisting of only considering along-track points with at least 50% of valid data per Jason mission. Figure 2 shows the distribution of the v2.4 virtual stations, with colors indicating the closest distance to the coast of the first valid points along the satellite track. The v2.4 product provides sea level time series over January 2002- June 2021 and associated trends at 1121 virtual coastal stations.

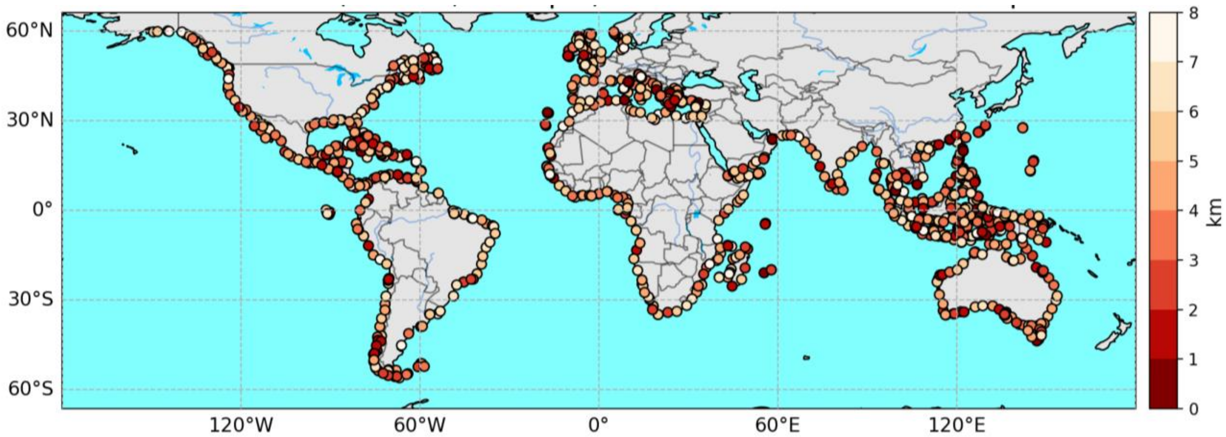

Fig.2: Distribution of the 1121 virtual coastal stations of the v2.4 product. The colors indicate the closest distance to the coast of the first valid point along the satellite track.

3. Requirements for the validation

To validate the coastal sea level trends provided by the project, two methods can be used:

- Comparison with tide gauges
- Comparison with high resolution ocean simulations

Tide gauges provide the only direct measurements of coastal sea level against which the altimetry product can be validated. Tide-gauge observations, however, are spatially sparse, and thus they only allow for a validation at a very limited number of locations. This is an issue because the spatio-temporal scales of sea-level changes greatly vary from region to region according to bathymetric and regional climate conditions, meaning that a good match between altimetry and tide-gauge observations at one location cannot be extrapolated to other locations. In addition to this issue, tide gauges are located on the coast and hence they only measure coastal relative sea-level, i.e., include vertical land motions (VLMs). This is another issue because altimetry measures absolute sea level in a geocentric reference frame (i.e., does not includes VLMs). Thus for the comparisons, tide gauge records must be corrected for VLMs using either GNSS or InSAR data. This highly limits the number of sites where tide gauge and altimetry data can be compared since VLMs are not available at most tide gauge sites.

Another approach to validate coastal altimetry data is to compare with sea level computed by high-resolution ocean models. An advantage of comparing coastal altimetry data with model outputs relies on the fact that the model may be able to resolve small-scale processes (e.g., wind, waves and atmospheric pressure forcing, small-scale shelf currents, freshwater input from rivers) that are important at the coast. Such models also enable us to investigate how sea-level changes evolve as we move from the open ocean to the coast. Finally, while performing the validation, it is important to quantify and account for the uncertainty associated with the altimetry-based coastal sea level estimates, particularly for the trends.

In designing the validation strategy, a number of issues merit consideration. First, it is important to recognize that variability and trends in sea-level are driven by different mechanisms and hence have different spatial length scales; the former is largely associated with internal variability in the ocean-atmosphere system the latter is the superposition of various processes causing global mean and regional sea level variations (i.e., ocean warming and land-ice melting, fingerprints of land ice melt and mass redistribution), plus local processes occurring at the coast (wind, waves and atmospheric pressure forcing, small-scale shelf currents, fresh water input from rivers). This implies that the agreement between altimetry observations and other types of data (e.g., tide gauges and models) might be different depending on the temporal scales of variability that one is looking at. This means that a good agreement in terms of trend does not imply the same for the variability and vice versa, and hence the validation needs to be conducted specifically for each temporal component. Secondly, the regimes of sea-level variability can be very different between the coastal zone and the deep ocean, which demands that we validate both coastal and open-ocean altimetry observations. A further reason for the distinction between coast and open ocean is the need to explicitly assess the performance of the new coastal altimetry products in the coastal zone.

3.1 Comparison with tide gauges

Several series of comparisons between the coastal sea level time series and tide gauge records (data from the Permanent Service for Mean Sea Level/PSMSL, Holgate et al., 2013) have been performed since the beginning of the project. E.g., for the v1.1 product (Gouzenes et al., 2020, Benveniste et al., 2020, Dieng et al., 2021) and v2.3 product in the Gulf of Mexico (Leclercq et al., 2024).

The most recent comparison is made between detrended time series from the v2.4 product and detrended tide gauges records at 150 sites located at less than 50 km from the virtual station. The correlations are high (>0.7) is most coastal regions except at a few sites of south America and of the Northeast Atlantic. In the latter region, the low correlation likely results from the respective configurations of the satellite track (hence virtual station position) and tide gauge, with both virtual station and tide gauge being often separated by a portion of land, thus influenced by quite different ocean dynamical conditions.

2.4. Comparison with high resolution ocean simulations

Another objective is to compare coastal altimetry time series with output of high resolution ocean models. This task has not yet been started and is left for the near future. Different models will be considered:

- The model provided by the Copernicus Marine Service (CMEMS) and MERCATOR-Ocean. These numerical simulations use different high-resolution versions of NEMO (a global version at 1/12°, and regional versions over the northeast Atlantic and Mediterranean Sea at 1/12° and 1/36°, allowing to have information very close to the coast (within a few km).
- The ECMWF ocean reanalyses, in particular ORA-S5 (https://www.ecmwf.int/en/forecasts/datasets/browse-reanalysis-datasets).
- The Synphonie model optimized for the Gulf of Tonkin. SYMPHONIE is a numerical model that solves the primitive, Boussinesq, hydrostatic equations of the ocean circulation on a curvilinear bipolar Arakawa C-grid with regular sigma vertical levels. The reference configuration is an update of the configuration of Piton et al. (2021). The model domain covers the whole Gulf of Tonkin. The horizontal grid has a variable mesh size: the coastal area near the Red River mouths has a horizontal resolution of 300 m, while near the open boundary, the grid size can increase up to 4500 m.
- The IBI ocean simulation with a resolution of 1/36° in the Atlantic -Iberian Biscay Irish sector (http://cmems-resources.cls.fr/documents/PUM/CMEMS-IBI-PUM-005-001.pdf).

Focusing on interannual variability and trends, we will compare the model-based and altimetry-based signals from the open ocean to the coast.

3. Requirements for the understanding of the different processes

To explain observed trends at the coast, a number of auxiliary data sets are needed in the studied coastal zones:

- Temperature T and salinity S fields
- High-resolution wind and waves data
- Surface pressure P data
- River discharge data in estuaries
- Bathymetry

- …..

In general, such coastal observations do not exist. However, at some locations, data sets can be found, for example sea surface salinity SSS and sea surface temperature SST in the Mediterranean Sea. In addition, coastal T/S fields can be found on the COPERNICUS Marine Service (CMEMS; https://marine.copernicus.eu).

Winds and waves in the coastal zone can be derived from retracked altimetry data at the same points as the sea level anomalies (hence same spatio-temporal coverage and resolution -20 Hz-).

Global gridded data sets of waves and winds are also available (e.g., from reanalyses) but the resolution may not be high enough to quantify processes close to the coast. We will have to examine whether downscaling can be performed. Other data bases exist, e.g., the Integrated Surface Dataset (Global) from NOAA (https://catalog.data.gov/dataset/integrated-surface-global-hourly-data), composed of worldwide surface weather observations from over 35,000 stations, though the best spatial coverage is evident in North America, Europe, Australia, and parts of Asia. Parameters included are: air quality, atmospheric pressure, atmospheric temperature/dew point, atmospheric winds, clouds, precipitation, ocean waves, tides and more. For some stations, data may go as far back as 1901, though most data show a substantial increase in volume in the 1940s and again in the early 1970s. Currently, there are over 14,000 "active" stations updated daily in the database.
For river discharges in estuaries, in situ data exist at some locations but the coverage is far from being optimal. When in situ data sets are unavailable, altimetry-based river discharges (deduced from river water height after adapted calibration) will be used where available (http://hydroweb.theia-land.fr/).

An inventory of available data sets with information on location, record length, time and space resolution, etc.is currently under investigation.

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