Consortium Members

ESA Sea Level CCI

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Applicable documents

AD 1 Sea level CCI project Management Plan
CLS-DOS-NT-10-013

Reference documents

RD-1 CMUG-RBD, 2010: Climate Modelling User Group - Deliverable 1.2 - Requirement Baseline Document v1.2, 13.September 2010, Centres providing input: MOHC, MPI-M, ECMWF, Météo France

RD-2 CMUG-RBD-1.3, 2010: Climate Modelling User Group - Deliverable 1.2 - Requirement Baseline Document v1.3, 02.November 2010, Centres providing input: MOHC, MPI-M, ECMWF, Météo France

RD-3 GCOS, 2010: Guideline for the Generation of Datasets and Products Meeting GCOS Requirements. -GCOS-143 (WMO/TD No. 1530)

RD-4 GCOS-107, 2006: SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED PRODUCTS FOR CLIMATE, GCOS – 107, composed by WORLD METEOROLOGICAL ORGANIZATION and INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION, September 2006, (WMO/TD No. 1338)

RD-6 WMO-DOR, 2010: WMO Database of Observational Requirements, May 2010 http://www.wmo.int/pages/prog/sat/Databases.html

RD-7 The Next 15 Years of Satellite Altimetry: Ocean Surface Topography Constellation User Requirements Document, Escudier P. And Fellous J.L.,2009, Eumetsat (TBC)

RD-8 A new assessment of the error budget of global mean sea level rate estimated by satellite altimetry over 1993-2008, Ablain M, Cazenave, A., Valladeau G., and Guinehut S., Ocean Sci, 5,193-201, 2009

RD-9 Benveniste, J. and Ménard, Y., Eds., Proceedings of the "15 Years of Progress in Radar Altimetry" Symposium, Venice, Italy, 13-18 March 2006, ESA Special Publication SP-614, 2006.

RD-10 C. Dufau, C. Martin-Puig, and L. Moreno, User Requirements in the Coastal Ocean for Satellite Altimetry, in S. Vignudelli, A.G. Kostianoy, P. Cipollini, J. Benveniste (eds.), *Coastal Altimetry,* Springer-Verlag Berlin Heidelberg, 2011. DOI: 10.1007/978-3-642-12796-0_3

RD-11 Fernandes, M. J., J. Benveniste, and S. Vignudelli (2011), Improved Coastal Altimetry Could Contribute to the Monitoring of Regional Sea Level Trends, Eos Trans. AGU, 92(16), doi:10.1029/2011EO160004.

RD-12 **Development of SAR Altimetry Mode Studies and Applications over Ocean, Coastal Zones and Inland Water (SAMOSA)**

RD-13 Paolo Cipollini, Jèrôme Benveniste, Stefano Vignudelli, “Coastal Altimetry Benefits from CryoSat-2 Synthetic Aperture Measurements”, *Eos Trans. AGU*, v. 94, n. 8, 19 February 2013, doi:10.1002/2013EO080010

RD-14 Paolo Cipollini, Stefano Vignudelli, Jèrôme Benveniste, “The Coastal Zone: A Mission Target for Satellite Altimeters”, *Eos Trans. AGU*, v. 95, No. 8, 25 February 2014, doi: 10.1002/2014EO080006

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1. Introduction

Among the essential variables **sea level** has been identified and selected as one of the primary indicator of global climate change. The ERS-1, TOPEX/POSEIDON, ERS-2, GFO, ENVISAT and Jason radar altimeter archives, starting in 1991, constitute a unique, uninterrupted component of sea level observations. Although the work of the international ocean altimetry science community over the last 20 years has established this as the best calibrated and most consistent set of long-term observations from space, no consolidated FCDR and ECV products has as yet been fully implemented. In consistence with the Global Climate Observing System (GCOS) the ESA initiated CCI on Sea Level is attempting to contribute to improve this deficiency.

This document gathers the User Requirements related to the Sea Level Essential Climate Variable. The analysis consolidates the requirements coming from recent international frameworks, the Ocean Topography community, and to some extent the Climate Modelling Group (CMUG) of the CCI as well as past user requirements surveys such as for instance the Eumetsat Post EPS survey.

The document is organised as followed: The section 2 proposes a review and an analysis of the requirements provided within existing documents that come from 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). The section 3 presents the requirements coming from the Ocean Surface Community. Finally, the list of requirements dedicated to climate applications to be applied to the Sea Level variable is given in section 4.

2. Requirements from existing reference documents

2.1. Requirements from international framework

2.1.1. Requirements from Global Climate Observing System (GCOS)

Under GCOS leadership, and with the involvement of many experts in the climate and satellite communities, high-level requirements on the accuracy, stability and resolution of satellite-based datasets and derived products in support of the GCOS ECVs were defined in 2006 and documented in the "Satellite Supplement" (GCOS-107) to the 2004 GCOS Implementation Plan ([RD-4]). The GCOS ECVs have helped worldwide in framing priority action and in designing programme activities in response to GCOS and climate observation needs in general, and the GCOS satellite-specific requirements have achieved significant attention with many space agencies acting in response to climate needs.

Given advances in science, technology and emerging user needs, and in light of the recent update of the ECV list to now 50 variables (published in the 2010 Update of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC) it was necessary and timely to update the requirements outlined in the 2006 report. The space agencies and international science communities provided their comments on the GCOS satellite requirements as part of a response to a 31 August 2010 call by the Committee on Earth Observation Satellites (CEOS).

Currently, the last responses to the Global Climate Observing System (GCOS) requirements for satellite-based datasets and derived products in support of observing the GCOS Essential Climate Variables document are being solicited from the scientific community. The final report (GCOS: SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED PRODUCTS FOR CLIMATE: Supplemental details to the satellite-based component of the “Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2011 Update)”) is currently under review in the scientific community but all in all the main findings and requirements are not expected to change. They are specified in Table 2-1 below.

For each ECV, the review on the criteria shall focus on the “Target Requirements” for the geophysical product and the “Requirements for satellite instruments and satellite datasets”; In most cases, the “Target Requirements” are stringent, inspirational goals (as implied) corresponding to the most demanding data user needs. This should be borne in mind when reviewing them, and should remain the case as a result of the review. In addition, reviewers are encouraged to complement the “Target Requirements” by defining “Minimum Requirements” as follows:

> Minimum Requirements (MR) for accuracy, resolution (spatial, temporal), and decadal stability of the dataset/product should be specified such that datasets/products with less accuracy than the MR / with coarser resolution than the MR / with less decadal stability than the MR are unlikely to be useful for climate applications (with a focus on climate monitoring needs).

Sea level will continue to rise in the future but the exact amount is presently unknown, Sea level integrates the response to climate change and variability, of many components of the climate system (oceans/atmosphere land ice, land waters) and their interactions. Thus sea level modelling is complex and current climate models do not adequately reproduce neither the 20th century global mean sea level rise nor the regional variability. Projections are also highly uncertain, in particular because of still imperfect understanding of ice sheet dynamics. Past century sea level rise is known from tide gauges (a mean rate of 1.7 +/- 0.4 mm/yr is recorded for the 20th century). Since the early 1990s, satellite altimetry has become the main tool for precisely and continuously measuring sea level with quasi global coverage and a few days revisit time. In addition, satellite altimetry measures ‘absolute’ sea level variations (i.e., not contaminated by land motions). Over the past 18 years (1993-2010), the altimetry-based sea level rise is estimated to 3.3 +/- 0.5 mm/yr. This 0.5 mm/yr uncertainty is based on error budget assessments of all source of errors affecting the sea level measurement-using altimetry.

On the regional and coastal scales, changes in sea level are far larger than the globally averaged value and result from many factors, including changes in temperature and salinity and in surface winds. At ocean basin scale, mass redistributions due to past and current land ice melt also cause regional variations in sea level. Estimations of changes in coastal sea level, on the synoptic scale and smaller, are undersampled by the current altimeter quality. Reprocessing of altimetry radar waveforms can improve coastal sea level observations (in the future, wide swath interferometric altimetry will provide 2-D high-resolution coastal sea level data). Coastal products will be improved by modelling with additional knowledge of winds and tides. Coastal sea level is extremely relevant for understanding societal impacts of climate variability and change.

To monitor global sea-level change, to detect any acceleration in the rate of rise, and to map the regional variability and the temporal variations in spatial trend patterns, satellite ocean surface topography altimetry of the Topex/Poseidon-Jason class is essential on the long term. For studying coastal impacts of sea level rise, satellite altimetry measurements in coastal areas should be used in synergy with high-quality tide gauges corrected for land motion with GPS.

Table 2-1: GCOS Target Sea Level Measurement Requirements

Variable/ Parameter	**Horizontal Res (target)**	**Vertical Res (target)**	**Temp Res (target)**	**Accuracy (target)**	**Stability (target)**
Large-scale and global mean sea level	50 km	NA	10 days	2-4 mm (global mean) 1 cm over a grid mesh	<0.3 mm/yr (global mean)
Regional Sea Level	25km	NA	Weekly	1cm (over grid mesh of 50-100km)	<1mm/yr (for grid mesh of 50-100km)

It is clear that these targeted requirements will be extremely hard to satisfy from existing altimetry missions as well as in view of the approved missions in the coming decade. Moreover the issue of global coverage, in particular in sea ice covered regions such as the Greenland Sea, Barents Sea and the Arctic Ocean will be very challenging.

However, it is important to point out that the requirements produced by the GCOS need to be refined, in particular the requirements related to the accuracy, stability, and spatial and temporal resolution which come from tide gauge community and do not represent now the state of the art for the ocean topography variable which mainly address with altimetry missions.

2.1.2. Requirements from WMO and WRCP

The WMO Database of Observational Requirements (WMO-DOR, 2010, [RD-6]) records observational user requirements formulated by WMO and co-sponsored programmes: GCOS, WCRP, GOOs. These requirements are expressed for geophysical variables in terms of 5 criteria: horizontal resolution, vertical resolution (not applicable for sea level variable), observing cycle, delay of availability, accuracy and are reproduced below:

Table 2-2: GCOS requirements

"Requirement from GCOS"	Horizontal Resolution			Observing Cycle			Delay of availability			Accuracy			Confidence	Applicati
Parameter name	Goal	reakthroug	Threshold	Goal	reakthroug	Threshold	Goal	reakthroug	Threshold	Goal	reakthroug	Threshold	CF_NAME	Use
Coastal sea level change	25 km	100 km	1000 km	24 h	50 h	240 h	1 h	3 h	24 h	1 cm	2 cm	10 cm	Reasonable	OOPC
Ocean dynamic topography	25 km	50 km	250 km	1d	3 d	30 d	0.125 d	0.25 d	1d	1cm	1.5 cm	5 cm	Firm	OOPC

Table 2-3: WRCP requirements

"Requirement from WCRP"	Horizontal Resolution			Observing Cycle			Delay of availability			Accuracy		
Parameter name	Goal	Breakthroug	Threshold	Goal	Breakthroug	Threshold	Goal	Breakthroug	Threshold	Goal	Breakthroug	Threshold
Ocean dynamic topography	100 km	126 km	200 km	5 d	6.3 d	10 d	10 d	14.4 d	30 d	2 cm	2.7 cm	5 cm

Table 2-4: GOOS requirements

"Requirements from GOOS"	Horizontal Resolution			Observing Cycle			Delay of availability			Accuracy		
Parameter name	Goal	Breakthroug	Threshold	Goal	Breakthroug	Threshold	Goal	Breakthroug	Threshold	Goal	Breakthroug	Threshold
Ocean dynamic topography	100 km	144.2 km	300 km	10 d	14.4 d	30 d	10 d	14.4 d	30 d	2 cm	2.7 cm	5 cm
Ocean dynamic topography	25 km	39.7 km	100 km	7 d	11.4 d	30 d	2 d	3.9 d	15 d	2 cm	3.4 cm	10 cm

One can note that expect for the GCOS requirements that attempt to define specific requirements by type of applications or at least by spectral characteristics (coastal sea level change and ocean dynamic topography), the requirements do not really cover or define the needs for climate applications.

2.2. Requirements from CMUG

The CMUG which is part of the ESA CCI project has performed an analysis of the satellite climate observations data requirements of the Climate Modeling Community (CMC) ([RD-1], [RD-2]). One of the main objective of the CMC is to confront their models (which includes high-end forced ocean only or ocean/sea ice simulations) with observations to validate their simulations and to understand the causes of the observed variability and change. To achieve this it is highly necessary to:

- include in the CDR the information about error budget for a specific variable and if possible characterize the correlation between the variables
- provide long term monitoring datasets

One strong and very interesting outcome of the CMUG URD is the identification of different applications areas for which the need and usefulness of sea level information, among others, is specified. They are summarized for the ocean variables in Table 2-5 according to a range of applications. Our understanding of the role of the Sea Level ECV variable for each type of application is slightly different from what has been stated by the CMUG and we would like to take the opportunity of the SL user requirements analysis to provide feedback to the CMUG (Table 2-6).

First, one can note that sea level is not identified for reanalysis and model devel*opment and validation* applications whereas sea level is identified for *model initialization*. Indeed, the paragraph related to the reanalysis (§2.4) includes the ocean reanalysis for which the sea level ECV is one of the most important data set. Consequently, the key requirement for data that will be assimilated (§2.4 and also §2.5) which is to provide a multidecadal and homogeneous data set is also applicable to sea level variable. That's why we think that SL variable should be identified for these reanalyses applications. As mean sea level trend is obtained with enough accuracy, it seems also reasonable to identify the SL variable for model development and evaluation. Finally, we had two specific lines dedicated to sea level shown in Table 2-5, in which we first highlighted the usefulness of SL variable of each type of applications. The second line provides a proposition of SL products that should be used for these applications.

Table 2-5: Use of CCI ECVs for different climate applications.

GCOS ECV	Model Initialisation	Prescribe Boundary Conditions	Reanalyses	Data Assimilation	Model Development and Validation	Climate Monitoring/ Attribution	Q/C in situ data
SST	X	X	X	X	X	X	X
Sea-Ice	X	X	X		X	X	X
Ocean colour				X	X	X	
Sea Level	X	X		X		X	X
Sea Level	**o**	**+**	**+ +**	**+ +**	**+ +**	**+ +**	**+ +**
Sea Level	?	?	ATSLA MSLA	ATSLA MSLA	MSLT	MSLT Large scale MSLA	ATSLA

(O = Not relevant, +=Useful, ++=Very Useful)
MSLT: Mean sea level trend; SLA : Sea Level anomalies;
ATSLA: Along track SLA MSLA : Maps of Sea Level anomalies

The CMUG also produced a table containing specific requirements for the sea level observations which are reproduced in the Table 2-6. The review of SL requirements undertaken by the CMUG is more precise that the ones provided by GCOS because applications areas has been defined. This initiative is very well welcome. For CMUG, goal values for revisit and stability can be kept but it is suggested to give as a target breakthrough, values of 0.2 cm/decade and 2 days and 0.5 cm/decade and 5 days for threshold. The SL CCI project proposes to move forward further by proposing specific requirements for several temporal and spatial scales that allows us to fulfil more accurately the requirements by applications areas (see §4).

Table 2-6: Requirements for satellite sea level observations defined by the CMUG

Parameter	Application	Horizontal resolution	Observing cycle	Precision	Accuracy	Stability	Types of error
Ocean dynamic topography	Model development and Evaluation	50 km	30d		1 cm	2mm/decade	SSEOB
	Long term trend monitoring and attribution	25 km	2d		1 cm	2mm/decade	SSEOB
Coastal sea level change	Model development and Evaluation	25 km	10d		1 cm	2mm/decade	SSEOB

	Long term trend monitoring and attribution	25 km	2d		1 cm	2mm/decade	SSEOB

3. Requirements collected by the Ocean Surface Topography community

3.1. Introduction

This section gathers the requirements coming from the Ocean surface topography community itself that essentially contains mission requirements. It is composed by two parts. The first one provides an analysis of the questionnaires done in the past and specifically done in the frame of Sea Level CCI projects. The second part extracts the requirement coming from a recent document aiming to harmonize ocean surface topography constellation user requirements (RD-7; RD-9)

3.2. User consultations analysis

3.2.1. Summary of past users consultation

Several user consultations have been recently performed to better understand and characterize the users' needs. These consultations are not specifically focused on the climate applications but relevant feedbacks concerning this application could be extracted from these consultations. In the following we describe the requirements coming from the open ocean community that was consulted through the SLOOP CNES project. We also discuss here the requirements coming from the community that was consulted from the PISTACH (CNES) and COASTALT (ESA) projects, but note that these are now complemented and refined by the new survey on accuracy and stability of coastal products specifically carried out for the SL CCI in May 2014, appended as Annex A, whose results are detailed in section 3.3.3.

- Requirements from SLOOP project

  The main motivation of this survey was to update the requirements identified in 1999 that has permitted to develop new generation of products (CorSSH for instance). This new survey aims to refine the needs in term of format, data distribution mean, physical content of the products. The survey was sent to 250 users covering all kind of applications, from climate research to operational oceanography (ocean forecasting,...). 13% of the users consulted have provided an answer. Among the users, 30 % are interested by the ocean and 25% by climate applications. All the spatial and temporal scales are studies from (sub) mesoscale to climate ones. More than 90% of the users request for Delayed Time data. The remaining users asking for NRT data are centers involved in ocean and atmospheric forecasting.

The main requirements expressed for climate applications are:

- A large panel of product is requested with a priority for level 3 and level 4
- Consistency in term of accuracy, resolution and physical content
- Continuity of the temporal series
- Continuity between open ocean and coastal
- Netcdf is the format the most requested (49%)
- Data distribution: Ftp preferred (56%)

- User Requirements in the coastal ocean for satellite altimetry

Two past initiatives, PISTACH from CNES and COASTALT from ESA were set up to answer to the growing request to have specific altimetric products for coastal area. Both projects aimed at developing and implementing and testing prototype of new generation of coastal products for Jason-2 (PISTACH) and ENVISAT (COASTALT). As the requirement for such products were not predetermined it was decided to conduct two complementary surveys to collect the requirements from the coastal community. A synthesis of the main requirements was written by Dufau et al. (2010 ,User requirements in the Coastal ocean for satellite altimetry) by considering the 54 answers received and also remarks that emerged from the two first workshops on coastal altimetry in Silver Spring (USA, Feb 2008), and Pisa (Italy, Nov 2008):

- Be provided *along-track* even though a large number of respondents also asked for 2D-gridded products.
- Be provided at the *maximum posting rate* compatible *with an acceptable signal-to-noise ratio* (certainly between 1 and 10 Hz)
- Provide not only the SSH, but also *anomaly and mean value*, and *a coastal mean dynamic topography* (*MDT*). Be provided with *individual corrections* (HF dynamics, for example) to ease its use in synergy with 2D and 3D models. Each user would then be able to apply the best combination of correction for its study.
- Include not only sea surface height, but also *significant wave height* and *wind speed*.
- *Initially* be developed as a *delayed product*, but with a processing chain *compatible with the delivery of near-real-time and real-time data*, as it is already a clear requirement for some respondents.
- Must be in *NetCDF format and distributed via FTP or OPeNDAP*.
- However *DVD distribution* should be retained for the benefit of those users with bandwidth constraints.
- Include data *as close to the coast as possible*, even when none of the main estimated parameters are considered reliable.
- Put in place all those *improvements in corrections* (including local corrections) *and retracking* so that *accuracy and precision are optimized*.
- Provide the users with *an error budget* and clear documentation on the characteristics and limitations of the products.
- Provide *quality flags*
- Be *easy to merge across missions*, with a common correction scenario that should make possible the cross-calibration of SSH, wind, and wave information between the different altimetric missions.
- Present *continuity with* the altimeter products provided over *open ocean.*

3.2.2. Sea Level CCI Users consultation

A simple and user friendly questionnaire was developed and circulated to 20 university departments, scientific research institutes, operational centre and agencies, both in Europe and intercontinental. The aim of the questionnaire was to reach a quantitative understanding of the physical content, precision, format and distribution means of the sea level products consistent with the different user groups' needs and specific applications. The questionnaire contained 3 key areas of specific altimetry applications, including: (i) what is your activity and study area; (ii) what altimeter product type are you using; and (iii) what format and delivery method do you prefer.

3.2.2.1. Synthesis of the questionnaire

Although the number of replies has been below expectation. The main explanation probably comes from the fact that several questionnaires have already been circulated during the last years. These questionnaire have been developed by several projects as PISTACH (CNES), COASTALT(ESA) or SLOOP (CNES). These questionnaires did not specifically cover the climate application but they contain questions related to this topic that are taken into account in this analysis (RD-10). A synthesis that collects that the response for each item of the SL CCI questionnaire has been generated as shown below:

1. **<u>What is your activity and study area</u>**

- Yours activities are: ☒ research ☒ operational
- What is your domain of interest?

Ocean:	☒ Large scale circulation	☒ Mesoscale activity	☒ Tides
	☒ Large scale circulation		
Climate:	☒ Interannual variability	☒ Seasonal forecasting	☒ Decadal forecasting

- What is your study area?

  ☒ Global ☒ Basin / Continent ☒ Regional

- Are you interested in coastal areas? ☒ Yes ☒ No

  If yes, specify the minimal distance from the coast you consider. Please precise unit: **7 km**

- Are you interested in high latitude areas? ☒ Yes ☐ No

- What are the typical spatial and temporal scales you study?

  Spatial scale: **7 km, 25 - 1000 km**

  Temporal scale: **1 day , daily , seasonal, interannual, decadal**

2. What altimeter product type are you using?

- **Which data level do you use/need?**

  ☒ Level 2:(Geophysical Data Record, GDR): along track data + additional information related to the processing (geophysical corrections). Not intercalibrated

  ☒ Level 3: Intercalibrated along track data containing sea level information only

  ☒ Level 4: Multi-mission gridded data

  ☒ Mean sea level trends for instance

- **Which physical parameter do you use/need?**

  ☒ Sea Surface Height with respect to reference ellipsoid (SSH)

  ☒ Sea Surface Height with respect to Mean Sea Surface (Sea Level Anomaly or SLA)

  ☒ Sea Surface Height with respect to geoid (Absolute Dynamic Topography or ADT)

  ☒Geostrophic velocity

- **Which time-delay product do you use/need?**

  ☒ Real time (RT) (using data produced within few hours from the measurements)

  ☒Near Real Time (NRT) (using data produced within 2-3 days from the measurements)

  ☒ Delayed Time (DT) (using data with precise orbit, produced more than one month after the measurements)

  ☒ Re-Analysis (RAN) (homogeneous reprocessing of data covering the whole period)

- **Does temporal discontinuity (linked to a change of the version of the product) affect the quality of your applications?**

  ☒ Yes ☒ No

- **Does sampling discontinuity (link to a change in the observing system 1,2,..4 satellite missions) affect the quality of yours applications? Which kind of gridded products do you prefer?**

- Reference series: homogeneous datasets based on two satellites (*Jason*-2 / Envisat or *Jason*-1 / Envisat or *Topex/Poseidon* / *ERS*) with the same ground track. Sampling is stable in time.
- Updated series: up-to-date datasets with up to four satellites at a given time. Sampling and Long Wavelength Errors determination are improved, but quality of the series is not homogeneous.

☐ Reference ☒ Updated ☒ Both

For along-track products users (Level 3)

Spatial/temporal resolution and precision of the product

- **Do the current noise level (precision) and spatial/temporal resolution on the sea surface topography products fit your applications needs?** ☒ Yes ☐ No

  If no, which spatial resolution and associated noise level do you wish to find in the products?

  ☐ 20 Hz (~0.3km) with an acceptable noise level of ………………………………………………

  ☒ 1 Hz (~7km) with an acceptable noise level of **3 cm…**

  ☐ Other resolution of ……….………… with acceptable noise level of ……….……

For all users: Is it important for you to find a continuity/compatibility between open sea products and regional or coastal dedicated products? ☒ Yes ☒ No

Content and quality of the product

- **Are you interested in accessing altimeter measurement deduced from different retracking methods and/or orbit determination and/or geophysical corrections?**

  ☒ Yes ☒ No

- **Large part of the parameters currently included in GDR products (level 2) are the standard ones recognised by the expert community. Are you interested in accessing alternative parameters different than the standard ones?** ☐ Yes ☒ No
- **Quality flags and indicators: Do you like quality information to be provided ?**

  ☒ Yes ☐ No

  If yes, precise the flag family you use:

  ☒ Quality flags/indicators associated with geophysical corrections, orbit, etc…

  ☒ Quality flags/indicators associated to each the sea level anomaly measurement

  ☒ Instrumental flags

- **Is it interesting for you to access a quality flag indicating the relevance of the data for specifics applications** (e.g. mesoscale studies, climate studies,…)? ☒ Yes ☒ No

  If yes, precise for which activity(ies):

  Reanalyses (data assimilation into dynamical models) for climate studies

- **What accuracy of the sea level product (in mm) do you require?**

  ☒ Threshold (minimum acceptable accuracy) : **30-100**

  ☒ Target (mean acceptable accuracy): **30**

  ☒ Breakthrough (where should it be in 2020): **10-20**

For gridded products users (Level 4)

Spatial/temporal resolution and precision of the product

- **Do the current noise level and spatial/temporal resolution on the sea surface topography products fit your applications needs?** ☒ Yes ☐ No

For all users: Is it important for you to find a continuity/compatibility between open sea product and regional or coastal dedicated products? ☒Yes ☐No

Content of the product

For Sea Surface Topography users:

- Current sea level gridded products distributed by AVISO are deduced from the standard parameters/corrections recognised by the expert community. Are you interested in accessing alternative products using different parameters/corrections than the standard ones?

  ☐ Yes ☒No

For all users:

- Do you want to access the formal mapping errors? ☒ Yes ☐ No
- **What accuracy of the sea level product (in mm) do you require?**

☒ Threshold (minimum acceptable accuracy) : **30-50**

☒ Target (mean acceptable accuracy) : **30**

☒ Breakthrough (where should it be in 2020) : **20**

3. What format and delivery method do you prefer?

- **Which data format do you prefer?**

  ☒ NetCDF ☐ ASCII ☐ Binary

  ☐ Graphical ☐ GIS-compatible

  ☐ Other (precise)………………………………………………………………………………………………

- **Which delivery mode do you prefer?**

  ☐ DVD ☒ FTP ☒ OpenDap / Direct upload from remote servers

  ☐ Other (precise)………………………………………………………………………………………………

- **How often do you need to access the altimeter data?**

  ☒ within a month ☒ within a year

  ☒ within a quarterly ☐ within 2-3 years

- **For an improved flexibility of altimeter data access, which selection(s) would you like to have access to ?:**

  ☐ Geographical selection ☒ Temporal selection

  ☒ Physical parameters selection ☐ Other (precise)………………………………

The main outcome of this questionnaire is the following one:

- both ocean researchers and operational users with either ocean or climate interests,
- interests are from the global ocean to regional and coastal seas, high latitudes is also required

- spatial resolutions range from 10 km to the basin scale,
- Level 3 and Level 4 products are wanted,
- No clear request to access to alternative parameters different than from standard ones (both for level 3 and 4 data)
- Quality flags and indicators are required
- data availability are from real time to delayed time in NetCDF format using FTP (or OpenDAP)

3.3. Requirement coming from Ocean Topography community

After over fifteen years of satellite altimetry, the community of ocean altimetry data users has grown from a narrow group of selected PIs to a broad family of users, ranging from researchers to operational ocean forecasters. The progress and main achievements of altimetry have been highlighted during the Venice conference in March 2006 ([RD-9]). After the CEOS Ocean surface Topography constellation workshop (held at Assmannshausen in January 2008) that has provided recommendations for future altimetry mission planning, a document that lists high level requirements placed upon the altimetry satellite constellation for the next 15 years to meet the major operational and science objectives to monitor the ocean topography has been written (RD-7). This document is considered here as the reference document providing the requirements coming from the Ocean Topography community. This document contains a thorough analysis covering all the kind of applications, such as, ocean forecast, coastal applications, extreme events, sea level rise and in general climate application. The requirements that are related to the climate applications are reproduced in the following. They are essentially gathered in the Science applications that are composed by mean sea level trend, mean global circulation, intra-seasonal to interannual variability and also mesoscale and coastal oceanography.

3.3.1. High-level user requirements for the altimeter constellation

We reproduced the table gathering the high level requirements for the sea level for which we have added a column showing the relevancy with respect to the CCI objectives.

General	A balanced ocean observing system including altimetry plus other space and *in situ* techniques shall be developed and maintained.	++
Operational services	Near-real-time and short term products are necessary to support operational oceanography.	0
Mesoscale and coastal applications	The altimetry constellation shall allow monitoring of ocean mesoscale features having typical scales of 30-300 km and 20-90 days.	+
Climate applications	The altimetry constellation shall provide continuous coverage of the ocean to support climate monitoring and operational services. Continuity of a reference mission with Topex/Jason-type accuracy is needed to detect and monitor ocean climate signals.	++
Marine meteorology applications	In complement to altimetry products the altimetry constellation shall provide near real-time sea state measurements (wind speed and significant wave height) to support marine meteorology.	0
Other near-real-time applications and extreme events	The altimetry constellation shall provide mesoscale information of the ocean to support monitoring and forecast of hurricane and weather extreme events.	+

Mean sea level trend	The altimetry constellation shall provide continuous monitoring of the mean sea level rise with an overall error budget better that 1mm/year.	++
Mean global circulation	A reference mission with Jason type accuracy is needed to retrieve the mean dynamic ocean topography and global ocean circulation. This retrieval also requires the availability of an independent and accurate geoid.	++
Intra-seasonal to interannual variability	Ground track repeatability of ±1 km has to be maintained for the altimetry missions (reference and core missions) as long as geoid uncertainties will require the use of reference mean tracks to process the data. The altimetry constellation shall provide continuous coverage of the ocean seasonal cycle with an accuracy of 1 cm on every basin to support climate modelling and seasonal forecast. The altimetry constellation shall provide continuous coverage of the ocean interannual variability with an accuracy of 1 cm on every basin to support climate modelling and seasonal forecast of events such as El Niño.	++
Mesoscale and coastal oceanography	The altimetry constellation shall provide continuous coverage of the mesoscale variability (50-300 km, 0.5-3 months) with accuracy consistent with the 3-40 cm amplitude of such phenomenon. This implies the processing and distribution of multi-mission products.	+
Tides	The altimetry constellation shall provide monitoring of tides, which imply specific selection of the orbit of the reference mission to avoid aliasing of the major constituents at periods larger than 180 days.	+

3.3.2. Climate applications requirements

The set of requirements reproduced below concerns requirements for the altimetry constellation that should be able to provide long term observations of oceanic circulation and its variability. The requirements that only deal with climate applications are extracted.

3.3.2.1. Mission requirements

- REQ-5.1b: The constellation shall be designed to provide 15 years minimum of continuous monitoring, in order to ensure the long term observation monitoring objective until new technology may become available
- REQ-5.1f: The altimetry constellation shall at least include two subsets: a series of overlapping reference mission delivering high-quality altimetry measurements, and a complementary set of at least two and preferably three satellites providing an improved geographic coverage for mesoscale circulation.
- REQ-5.1h: The altimetry “reference component” shall meet the accuracy, continuity and coverage of the Topex/Poseidon, Jason-1 and Jason-2/OSTM missions for describing and understanding the ocean circulation, and its influence on climate. This mission shall also support tide modelling effort

- REQ-5.1i: The “mesoscale component” shall continue the Geosat; GFO, ERS-1, ERS-2, Envisat missions for describing, understanding and forecasting the mesoscale variability of the ocean. It shall allow also the monitoring of sea state, wind and wave, at global scale.

3.3.2.2. CalVal requirements

- REQ-5.2c: Each mission shall include a science verification phase, with a minimum duration of 6 months after launch for recurring missions, 9 months when new technology is used or when there is no overlap with a previous mission, intended to qualify the system with respect to the science requirements. This phase shall be concluded by a final verification workshop followed by the observational phase and shall focus on consistency with previous missions in order to guaranty the continuity of the data set.
- **REQ-5.2.d** During the verification phase of the mission, all ground-processing algorithms and all critical output quantities and associated errors shall be verified and calibrated. It shall be done through statistical analysis and by comparison with external measurements. The calibration/verification accuracy shall be compatible with error budget specifications The parameters to be verified include altimetry range and associated corrections, orbit, wind speed and SWH. In addition to the biases, the calibration process shall provide an estimation of the individual drifts of the system components.
- **REQ-5.2.e** The system shall allow performing external independent calibration of the measurement.
- **REQ-5.2.i** GDR production shall start at the end of the science verification phase with the last updated algorithms. Calibrations (internal and external) shall be introduced into processing so that GDR quantities provide correct geophysical measurements.
-
- REQ-5.2k: Specific care shall be taken to guarantee the continuity and homogeneity of climate time series of mean sea level. This shall allow meeting an overall stability of 0.1 mm/year for the mean sea level trend. It implies inter-calibration between various altimetry mission and inter-calibration with *in situ* tide gauge network. Proper allocation of this global error budget to altimetric measurement, radiometric measurement and Precise Orbit Determination shall be made.
- REQ-5.2i: Mission planning shall take into account the necessity to ensure an overlap of at least 6 months between a satellite follow up and its predecessor. In case new technology is used for the new satellite this overlap shall be extended to 9 months

3.3.2.3. Data requirements

REQ-5.3.a Each mission shall produce, validate, archive and distribute three types of products:

The level 2 Geophysical Data Records (GDR) shall be distributed in a timely, complete and well-documented manner to data users and shall contain all the parameters required to compute the derived ocean and geophysical parameters.

REQ-5.3.d A complete documentation of the various products shall be distributed including the format of the files, definition of all the parameters and flags, the way to use the data and the algorithms used to generate the data. Any change in the data generation and/or processing shall be communicated to data users in a timely manner, and documentation shall be updated.

REQ-5.3.e The GDR shall be made available to users, on a cycle basis, within 40 days of data acquisition by the satellite. They shall contain at least 95% of the ocean data during any 12 month period with no systematic geographical gaps, plus all the land and ice data for which the altimeter is tracking. The GDR shall constitute the final and fully validated products. They shall be archived and systematically delivered to data users.

REQ-5.3.f The GDR shall contain, at a rate of 1 record per second, the best estimates of altimetric range measurement, the time tag and earth location, plus the best associated instrumental and environmental corrections and the most accurate orbit altitude. They shall contain additional geophysical parameters, i.e. wave-height, sigma-naught and derived wind speed, atmospheric surface pressure, tides, mean sea surface and geoid. They shall also contain altimeter at a rate equivalent or larger than 10 measurements per second (see Table A in annex for reference).

REQ-5.3.m All information needed to connect time series between satellites shall be provided to data users. This includes the altimeter and radiometer radar instrument bias and drift and the relative biases.

TARG-5.3.l For all products a specific effort will be conducted to provide valid data as close as possible to the coast, as well as over ice and inland waters.

REQ-5.3.p It shall be possible to re-process and distribute all GDRs products when improved algorithms are available. This requirement shall in particular support the long term climate analysis.

REQ-5.3.q Multi-mission, inter-calibrated level 3 products shall be produced, validated, archived and distributed. These products shall be designed to deliver homogeneous data sets to user. Relative biases, long wavelength and medium wavelength, that can be retrieved by intercomparison of the different missions shall be identified and removed in these products. This process shall allow to take benefit of the reference missions to enhance the accuracy of the other missions.

REQ-5.3.r Multi-mission products shall include:

Multi-mission offline products based on the combination of every missions GDRs and produced within 2 months of data acquisition,

3.3.2.4. Altimetry measurement system requirements

REQ-6.k The overall altimetry constellation shall allow to properly monitor the oceanic variability from short scales of 100 km up to basin scale of 10 000 km. In order to do that the accuracy of the merged altimetry product combining every available satellite shall be a decade below the dynamic of the observed signal as illustrated in Figure 14.

TARG-6.l The overall altimetry constellation will allow proper monitoring of the oceanic variability from short scales of 10 km up to 100 km. In order to do that the accuracy of the merged altimetry product combining every available satellite shall be below the dynamic of the observed signal as illustrated in Figure 14.

- The reference mission sampling characteristics shall be:

The reference altimetry mission satellites shall meet two sets of specific requirements:

  - Specific orbit selection to allow proper monitoring of diurnal effects such as tides, and,
  - Specific error budget to monitor large scale oceanic signals.

Aliasing of diurnal signals is a function of altitude and inclination of the orbit used by the satellite. Flying on sun-synchronous orbits is the worst case, which prevents from monitoring such signals. Flying in high inclination orbits induce long aliased periods of this diurnal signal, which prevents from adequate sampling. Other signals with precise repeat characteristics such as the various tidal components may be aliased into long term signals, which prevents precise monitoring. A large number of papers have documented these effects and analysed the adequate orbital parameters to be used to minimize those effects. The EUMETSAT study on optimisation of future altimeter orbits provides a state of the art synthesis of the adequate range. In particular those constraints lead to the selection of non sun-synchronous orbits having inclination comprised between 66° and 78°.

- **REQ-6.1.a** Orbit selection for the reference missions shall be optimized to allow adequate sampling of tides signal.

Table 3-1: Reference mission sampling characteristics

Application	Parameter	Spatial Resolution	Time Resolution	Latency	Accuracy
Global mean sea level change	Sea surface topography	500 km	10 days	10 days	0.5 mm yr-1
Seasonal to interannual prediction	Sea surface topography	300 km	5 days	5 days	4 cm
Large scale variability	Sea surface topography	300 km	10 days	3 days	2 cm
Tides (Sun-synchronous)	Tidal constants—sea surface height	100 km	non-sun-synchronous Orbit >100 visits to each location	N/A	2 cm

- **REQ-6.1.1.1b**: The reference mission accuracy shall be equivalent or better than the Jason-2/OSTM performance.
- **REQ-6.1.1d**: The reference mission error budget shall be (for 1 sec average, 2 meters SWH, 11 dB sigma naught):
- **REQ-6.1.1.e** The performance of the reference mission shall be at least as good as that of the Jason-2/OSTM system. Consequently, the requirements, in terms of error budget are summarized in Table 2-2 and are similar for the GDR to the post-launch Jason-2/OSTM error budget.

The performance in Table 3-2 may be summarized as follows:

- **REQ-6.1.1.f** The sea surface height shall be provided with a global and ultimate rms accuracy of 3.4 cm (1 sigma) over 1 second averages along satellite ground-tracks for typical sea-state conditions of 2 m SWH and 11 dB sigma-naught.
- **TARG-6.1.1.g** The reference system and ground-processing algorithms will be designed to minimize the geographically and temporally correlated errors.
- **REQ-6.1.1.h** The instrumental corrections, environmental corrections, and precise orbit determination shall be provided with the appropriate accuracy to meet the 3.4 cm requirement on the sea level height. This corresponds to a corrected range RMS error of 3 cm and precise orbit RMS error of 1.5 cm on the radial component.
- **REQ-6.1.1.i** The drift of the system (after calibration) shall not exceed 1mm/year.
- **TARG-6.1.1.j** The drift of the system (after calibration) shall not exceed 0.5mm/year.
- **TARG-6.1.1.k** In addition to these requirements, targets have been established. Such targets are based on expected off-line ground processing improvements and are likely to reduce the error to 2.5 cm rms on the sea level height over 1 second averages.
- **TARG-6.1.1.l** STC altimeter range and accompanying geophysical corrections will have the same accuracy as the GDR but are not fully validated.
- **REQ-6.1.1.m** The STC orbit shall be a 2.5 cm class orbit. The derived sea level measurement shall have 3.9 cm accuracy for typical sea-state conditions of 2m SWH and 11 dB sigma-naught.
- **REQ-6.1.1.n** Requirements on the accuracy of significant wave height measurements shall be equivalent to the one defined for mesoscale constellation for all type of products.

- **REQ-6.1.1.o** Requirements on the accuracy of three-hour NRT operational products measurements shall be equivalent to the one defined for mesoscale constellation.

Table 3-2: Reference mission error budget

	REQ- GDR 40 days	TARGET
Altimeter range RMS	3 cm	2.25 cm
RMS Orbit (Radial component)	1.5 cm	1 cm
Total RSS sea surface height	3.4 cm	2.5 cm
System bias and drift (on global mean sea level after calibration)	5 mm and 1 mm/year	3mm and 0.1 mm/year

The mesoscale altimetry mission constellation shall meet two sets of specific requirements:

REQ-6.2.a Specific orbit selection shall be performed to allow proper sampling of all time and space oceanographic signals, complementary to the reference mission.

TARG-6.2.b As a complementary goal this constellation will also allow proper sampling of non ocean signals: river, lakes, ice.

REQ-6.2.c The orbits of the different satellites shall be optimized to the extent possible to allow tracking of mesoscale features over long periods (>3 months).

REQ-6.2.d Specific error budget to monitor the corresponding signals shall be performed.

REQ-6.2.1a: The constellation shall allow sampling the earth surface with the following time and space characteristics delivering measurement of the following accuracy:

Table 3-3: Sampling requirements

Application	Parameter	Spatial Resolution	Time Resolution	Latency	Accuracy
Mesoscale variability	Sea surface topography	25-50 km	5 days	3 days	2-4 cm

TARG-6.2.1.b For high resolution altimetry applications the constellation will allow to sample the earth with the following time and space characteristics:

Table 3-4: Sampling requirements for high-accuracy applications

Application	Parameter	Spatial Resolution	Time Resolution	Latency	Accuracy
Sub- mesoscale variability and Coastal features	Sea surface topography	10 km	1-2 days	1 day	1-2 cm
Tides near coasts and Topography	Tidal constants—sea surface height	10 km	> 100 visits	N/A	1-2 cm
Barotropic tides	Tidal constants—sea surface height	5 km	> 100 visits	N/A	2 cm

Non-linear tides	Tidal constants—sea surface height	5 km	> 100 visits	N/A	1 cm

3.3.3. Coastal area requirements

As described previously (see § 3.2.1) a list of requirements for coastal applications had been collected since 2008 thanks to the consultations performed by PISTACH (CNES) and COASTALT (ESA) projects. Related challenging initiatives (SAMOSA(ESA), Alti Dopler (CNES)) have also contributed to the improvement of the coastal sea level monitoring from space by means of SAR mode altimetry, demonstrating that this technology has improved potential to study the smaller scales of the coastal circulation and their impacts on the sea level change in these regions.

Since the PISTACH and COASTALT surveys, a number of Coastal Altimetry Workshops (see http://www.coastalt.eu/community) have provided the opportunity to discuss a wide range of topics related to the coastal altimetry including the monitoring of regional sea level trends and expected error budgets. Summaries of the most recent Workshops have been published in EOS journal by Fernandes et al. (RD-11) and Cipollini et al (RD-13, RD-14). Overall, the community recognizes that much progress has been made, particularly on wet tropospheric correction and on retracking, and that the generation of coastal altimetry products is bound to have a great impact in synergy with other data sets to better monitor coastal zones.

One of the next challenges is to demonstrate that coastal altimetry can contribute to the monitoring of regional sea level trends. Phase 2 of the Sea Level CCI project includes specific workpackages to investigate this issue (WP2300 and the “Option” WP1100), but a necessary preamble to this work is a quantification of the requirements for accuracy and long-term stability for climate-quality observations of sea level in the coastal zone, which has been carried out and is summarized in this section.

3.3.3.1. Coastal Requirements Survey

The requirements for climate-quality observations of sea level in the coastal zone have been assessed by means of a dedicated survey, conducted by NOC Southampton. NOC designed and distributed in early May 2014 a questionnaire (appended in Annex A – Coastal requirements questionnaire) to a number of altimeter specialists, i.e. experts of the processing and/or analysis of altimetric data, drawn from the International Coastal Altimetry Community, from 14 different countries. Out of 40 distributed questionnaires, 15 replies (38%) were collected, allowing some simple statistics to be computed.

The first section of the questionnaire had some questions with multiple-choice answers to help characterize the respondents and their use of altimeter data. The vast majority of respondents (13/15) would define themselves as “satellite oceanographers”, but a good share (9/15) are also “physical oceanographers”. All but one declared that they are involved in “analysis of altimeter data”, while about half (8/15) also ‘process’ the data. A high share (13/15) compare the data with in situ measurements, either for cal/val or for synergistic applications. The overall picture that emerges is that of a user group mainly comprised of expert observationalists, familiar with the complementarities between satellite and in situ measurements, while modellers are underrepresented and only 4 out of 15 respondent use the data for assimilation into models, so future editions of this survey may want to address this unbalance. In terms of missions used, everyone (15/15) has had to do with J-1 and J-2 data, and almost everyone with past ESA missions (14/15 for Envisat, 12/15 for Ers-1/2). The newer missions are becoming of common use: Cryosat is used by 8/15 and AltiKa by 9/15.

The second and core section of the questionnaire asked the experts to give their estimates of some levels of **accuracy** and **stability** of coastal altimetric measurements of sea level, based on their experience. It was explicitly said in the introduction to the questionnaire that the requirements in question are those **for climate applications** – i.e. where one uses repeated observations to derive some statistical properties of the phenomena. A simple example was given to illustrate this concept: a one-off observation of some ‘extreme’ event does not belong to the ‘climate’ category; but observations of the distribution of extremes over several years would qualify as a climate application.

Accuracy and stability in this context are defined as:

- Accuracy: congruence of the single value (‘single’ = ‘averaged over one space and time grid cell’) to the true value, expressed in cm.
- Long-term stability: consistency over time of the instrument calibration and corrections. Two different estimates of stability were considered, one that would be expected/required on a relatively short time window of one year, and one that would be expected/required over a longer period of 10 years. Both, however, are expressed in the same units of mm/y for ease of comparison.

In accord with previous surveys for each parameter the respondent was asked to specify TWO values:

- a THRESHOLD value (= the minimum value that makes that parameter usable for at least one climate application)
- a TARGET value (= a “nice-to-have” value that will enable a fuller range of applications – with the caveat that target values should be stringent but realistic at the same time!)

Finally, in terms of geographical domain two options were considered:

- First the respondent was asked to consider a “local” product, i.e. sea level on a single grid cell in the coastal zone (say a 15 km x 15 km stretch along the coast) and with a time resolution (i.e. time average) of one month (i.e. the standard time resolution of SL CCI maps)
- Subsequently the respondent was asked about the requirements for a “global coastal” product, i.e. one generated by quality-controlling and averaging all the measurements in the global coastal strip (0-15 km from coast) and still with a time resolution of one month.

3.3.3.2. Results of the survey

A summary of the results of the survey for what concerns the accuracy of the coastal sea level estimates is in Table 3-5. Alongside the median (which we consider a more robust statistics than the mean, given the nature of the estimates and the relatively small number of samples) we present the full range *[min, max]* of the estimates, and in the bottom half of the table the 1st and 3rd quartiles of the population (i.e. the 25th and 75th percentile).

Table 3-5 - Statistics of the survey results for accuracy requirements in the coastal zone

ACCURACY (cm)		
Median and *[range]*		
LOCAL	THRESHOLD **3.0** *[1.0 , 15.0]*	TARGET **1.0** *[0.1 , 5.0]*
GLOBAL COASTAL	THRESHOLD **1.8** *[0.5 , 5.0]*	TARGET **1.0** *[0.1 , 3.0]*

ACCURACY (cm)		
First–Third quartile		
LOCAL	THRESHOLD **2.0–4.5**	TARGET **0.8–1.8**
GLOBAL COASTAL	THRESHOLD **0.6–2.0**	TARGET **0.4–1.0**

Table 3-6 displays the results for the stability of the estimates over a time window of one year. One would need to have this figure in mind when, for instance, trying to assess whether the mean sea level over a given coastal location over one year is significantly higher or lower than the previous year.

Table 3-6 - Statistics of the survey results for stability requirements in the coastal zone (over a 1-year time window)

STABILITY over 1 year (mm/y)		
Median and *[range]*		
LOCAL	THRESHOLD **3.0** *[0.5 , 10.0]*	TARGET **1.0** *[0.2 , 6.0]*
GLOBAL COASTAL	THRESHOLD **1.0** *[0.3 , 5.0]*	TARGET **0.5** *[0.1 , 2.0]*

STABILITY over 1 year (mm/y)		
First–Third quartile		
LOCAL	THRESHOLD **1.0–7.5**	TARGET **0.5–2.5**
GLOBAL COASTAL	THRESHOLD **0.6–2.0**	TARGET **0.3–1.0**

Table 3-7 is as Table 3-6, but for a 10-year time window so its figures are more relevant to long-term estimates of sea level trends.

Table 3-7 - Statistics of the survey results for stability requirements in the coastal zone (over a 10-year time window)

STABILITY over 10 years (mm/y)		
	Median and *[range]*	
LOCAL	THRESHOLD **1.5** *[0.3 , 5.0]*	TARGET **1.0** *[0.2 , 3.0]*
GLOBAL COASTAL	THRESHOLD **0.9** *[0.1 , 2.0]*	TARGET **0.4** *[0.1 , 1.0]*

STABILITY over 10 years (mm/y)		
	First–Third quartile	
LOCAL	THRESHOLD **1.0–3.0**	TARGET **0.5–1.0**
GLOBAL COASTAL	THRESHOLD **0.5–1.0**	TARGET **0.2–0.5**

3.3.3.3. Discussion and adoption of coastal requirements

From the results presented in the tables in the previous sections, and in virtue of the knowledge and experience of the respondents, we believe it is legitimate to attempt a first quantization of the requirements for climate applications of coastal altimetry.

The figures present a common, and somewhat expected from experience, pattern, i. e. the global coastal estimates are expected (or required) to be more accurate and stable than the local one. A similar pattern appears for stability where the long-term (10-year) figures are better than the shorter-term (1 year) ones, albeit by not much. This perhaps reflects the belief that if the instrument is not highly stable also in the short term it is unlikely to enable meaningful climate applications. The median values are a robust estimator and as a matter of fact we adopt the **target median values** as the current requirements for the summary in Table 14 at the end of this document. The 1^{st} and 3^{rd} quartiles however do appear as an informative estimate of a possible range of variability of the requirement.

A look at the range of estimates for the various parameters, which in some cases is rather wide, highlights that there is still room for improved consensus. The widest variations are often on ‘threshold’ values and may depend by the different view of the various experts on what an acceptable ‘application’ is. Undoubtedly this issue will be a matter for discussion in the continuation of Phase 2 of the Sea Level CCI and at forthcoming Coastal Altimetry Workshops.

3.3.4. High latitudes requirements

Most of the data available in the high latitude and Arctic Ocean do not have the same quality as is usual for other regions of the World Ocean. Lack of long time series of in-situ data at adequate spatial and temporal coverage are challenging our knowledge about sea level change in the high latitude and Arctic Ocean. In addition, the quality and availability of satellite altimetry is hampered by presence of sea ice, and existing data gap above 82°N for radar altimetry and above 86°N for laser altimetry. The operation of Cryosat 2 with the inclination of 88°has improved this data gap slightly in recent years but the length of the time series is unfortunately rather short. Hence the variability of the Arctic Ocean circulation and sea level change during the most recent decades are not adequately known. In fact several existing model simulations of the circulation in the high latitude and Arctic Ocean show significant discrepancies in their basic description of the major currents, water masses, mean dynamic topography and sea level as well as in their variability. Using the GOCE data (release 3), Johannessen et al. (2014) showed that the GOCE - based MDT (MSS-G) the circulation estimates from gravimetry and altimetry has improved, while gradients in the MDT are still too smooth for resolving some of the observed surface currents. In the ice-covered Arctic Ocean precise quantitative requirements are consequently much less mature than as expressed for the world oceans in general and as now addressed and specified for the coastal altimetry in section 3.3.3. Without such a precise quantitative picture it will be very difficult to understand the role of the high latitude and Arctic Ocean in shaping the global ocean circulation and sea level changes due to mass loss from the Greenland ice sheet and changes in fresh water input into the Arctic from Siberian rivers. New merged data from remote sensing (ENVISAT, ICESat and CryoSat altimetry combined with GRACE mass changes estimates and recent new geoid models) may resolve some of these discrepancies.

The tide gauge data are specifically important for calibration and validation of both satellite altimetry and hydrodynamic models (see Figure 3.3.4.1). Tide Gauge data from the Permanent Service for Mean Sea Level (PSMSL) has been gathered in the Arctic region since 1933. All available tide gauges from the PSMSL were investigated by the LEGOS group as part of the Monarch-A study. A total of 66 gauges were found in the Russian and Norwegian sector of the Arctic Ocean, but no stations with long enough temporal coverage were found in the American and Canadian sector. Consequently only the Russian and Norwegian stations could be used for this investigation, which will bias the result towards these sectors. Whereas the phases of the tide gauge data agree well with the results obtained from simulation models such as GECCO, the amplitude of the tide gauges are, however, nearly a factor 2 too small in simulations. The averaged sea level trend from 66 tide gauges in the Arctic Ocean for the 1950 – 2010 period is shown in Figure 3.3.4.2. Over the period 1950-1980 the trend is practically insignificant whereas the average over the period 1980-2010 is slightly higher than 2 mm year. The average over the entire period is 1.4 mm/year. A detailed study of tide gauges on the Norwegian coast (Richter et al. 2012) shows SSH trends for 1960-2010 to vary between 1.7–3.7 mm/yr along the coast and with differences in trends of around 1 mm/yr even between neighboring cities (about 100 km apart). Such regional differences puts demands on the precision of the altimetry for useful sea level rise estimation (see section 3.3.3).

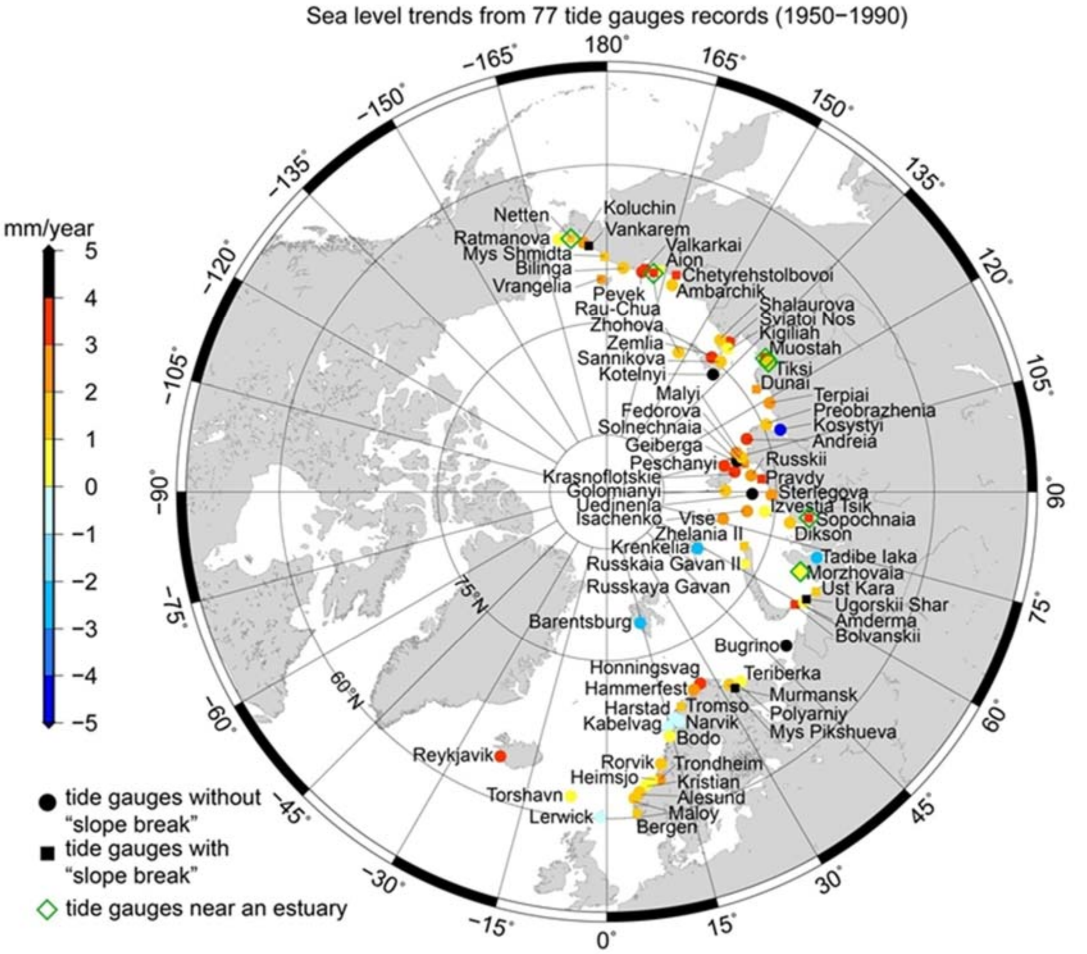

Figure 3.3.4.1. Sea level trend from all available tide gauges in the Arctic for the period 1950-2010 period. GIA correction using the ICE-5G model has been applied to the tide gauge readings. (Courtesy O. Henry, LEGOS)

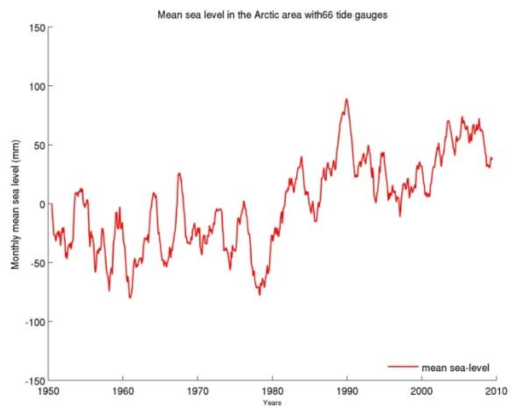

Figure 3.3.4.2. Averaged sea level trend from 66 tide gauges in the Arctic Ocean for the 1950 – 2010 period.(Courtesy O. Henry, LEGOS).

The seasonal, annual to decadal trends in sea level change are also now regularly investigated from ocean climate models. However, they show large discrepancies in the interior Arctic Ocean where no tide gauge data are available for validation and where altimetry are influenced by the presence of sea ice. The tide gauge observed 1.4 mm/year on the shelves and coastal regions has therefore been extrapolated to the entire Arctic Ocean leading to a mean sea level rise in the Arctic Ocean of nearly 3 cm over the last 20 years. These values are roughly 50% in of the global (excluding the Arctic Ocean) mean trend and total rise of respectively about 3 mm/year and 6 cm derived from altimetry over the last 20 years. All in all the observation requirements specified in the GCOS document (see Table 1) are not necessarily representative or applicable for the Arctic Ocean (see Table 3-8).

Table 3-8: Comparison of GCOS target global and regional requirements versus tentative Arctic Ocean requirements

Variable/ Parameter	**Horizontal Res (target)**	**Vertical Res (target)**	**Temp Res (target)**	**Accuracy (target)**	**Stability (target)**
Global mean sea level	50 km	NA	10 days	2-4 mm (global mean) 1 cm over a grid mesh	<0.3 mm/yr (global mean)
Regional Sea Level	25km	NA	Weekly	1cm (over grid mesh of 50-100km)	<1mm/yr (for grid mesh of 50-100km)
Arctic Ocean sea level	25 km	NA	Monthly	2-3 mm	< 0.3 mm/yr

4. Summary of the User Requirement session of the Sea Level CCI Progress Meeting 2

The measurement requirements for sea level, specified in the frame of the Sea Level CCI project, are collected from a broad range of user requirement reports (see previous § of this report, outcome from SL CCI user consultation and survey, and from discussion with climate modellers (representing CMUG) at progress meeting (PM2). Table 4-1 provides a more detailed overview of the the relevant communities (programme, projects, panels, etc…) that have expressed interests in sea level, being global, regional or local.

Table 4-1: Links between the Sea Level CCI project and other International bodies and the corresponding involved person from the SLCCI project

	Person from SLCCI involved	Role	Description	Related activity within the SL CCI project
GCOS	A Cazenave (LEGOS)	Member of the GCOS steering committee	GCOS defines a list of ECVs 'Essential Climate Variables (ECVs), the needed accuracy and spatio-temporal sampling. Sea level is a GCOS ECV. –Link with CCI : Contribution to the URD writing	Link with CMUG activity, WP1 (URD) and all others WP
IPCC	A Cazenave (LEGOS) Detlef Stammer (UoH)	Member and lead author of the sea level chapter	IPCC makes an assessment of current and recent past climate change and discusses projections of future changes Sea level is one of the climate variables discussed by IPCC. There is only an in- direct link with the ESA/CCI.	All WP; Links with CMUG
WRCP/ CLIVAR	D Stammer (UoH) Detlef, could precise what role you play in WRCP as I understood that you are no longer chairman of the CLIVAR/GSOP ?	Member	Use of sea level products for assimilation and validation	WP2, WP4
CEOS	AVISO (contact point M. Ablain)	Data provider	Provision of GMSL indicator	WP3
OOPC	J. A. Johannessen (NERSC)	Members of the board	Sponsored by GCOS, GOOS and WCRP. These in turn are programs that connect and depend on IOC (UNESCO), WMO,	Link with CMUG activity

			ICSU and UNEP. Also coordination with other international bodies	
OOPC	AVISO (contact point M. Ablain)	Data provider	Provision of GMSL indicator	WP3
MyOcean	G. Larnicol (CLS)	Leader of Sea Level TAC (Thematic Assembly Center)	Coordination and responsible for the provision of sea level product. Strong synergy with SALP/DUACS. Not specifically focused on climate applications. Except the fact that GMSL is provided to EEA (European Environment Agency)	Link with CMUG activity , WP1,WP2
MyOcean	J. Dorandeu (CLS)	Leader of the System engineering WP	Definition and development of the MyOcean integrated system (central system + web portal)	WP5
MyOcean	J. Johannessen (NERSC)	Members of the MyOcean board	Coordination with other European bodies and stakeholders (EuroGOOS, EEA, EUMETSAT, ECMWF)	Link with CMUG activity
Monarch-a	J.A. Johannessen, D. Stammer, A. Cazenave	Coordinator and partners	Provide time series of sea level change in the high latitude and Arctic Ocean.	Link with CMUG activity , WP1,WP2
GODAE	G. Larnicol (CLS)	Co-chair of the OSEval task team (Observing system Evaluation)	Provision of recommendations for ocean observing system (in particular for surface topography)	Link with CMUG activity, WP2, WP4
JCOMM (GLOSS)	M. Ablain (CLS)	Data user	Use of Tide gauges time series to validate altimetry-based sea level	WP2
JCOMM	J. Johannessen	Member of Management Team, Lead Task Team on sat. req.	Validation of satellite altimetry. Merging of altimeter missions to improve coverage and reduce gaps.	All WPs
OSTST	All partner of the WP2	Chairman of session (CLS, DTU), Altimeter expert	Direct link with ESA/CCI/Sea level project. Several members of OSTST are external experts to the project (S. Nerem, CK Shum, etc.). Comparisons between the CCI sea level products with similar products produced by other teams is essential to the	WP2

			project	
Coastal Altimetry community	All partner of the WP2	Chair of OrgComm, Coastal Altimetry Workshops (P. Cipollini, NOC) Altimeter Expert	Review and adaptation of accuracy and stability requirements to the coastal zone Improvement of estimates of coastal sea level	WP1 WP2
GLOSS	Per Knudsen	Chairman of the European implementation of GLOSS - ESEAS	Coordination of tide gauges in Europe	

5. List of requirements synthesized by the Sea Level CCI project

5.1. General requirements

5.1.1. Requirements for satellite observing system

- UR-SLCCI-GEN-01: To provide long term monitoring datasets with at least a period covering 30 years
- UR-SLCCI-GEN-02: Continuous coverage from at least one high-precision satellite altimeter at all times (Jason type accuracy, table 8), with planned extensive overlaps between successive missions and two complementary altimeters in different orbits with lower precision but higher resolution
- UR-SLCCI-GEN-03: Mission planning shall take into account the necessity to ensure an overlap of 6 months between a satellite follow up and its predecessor. It is of particular importance for the monitoring the global mean sea level trends
- UR-SLCCI-GEN-04: Mean sea level trend has the most demanding requirements in term of accuracy continuity and overlap between consecutive missions. Precision altimetry requires the establishment of an ongoing series (T/P, Jason series) of follow-on missions in the same orbit. Continuity beyond Jason-C is a goal of primary importance to establish a long-term, climate-related, sea level record.
- UR-SLCCI-GEN-05: Increased spatial and temporal sampling is needed for mesoscale and coastal areas. Similarly, covering high-latitudes region is also requested
- UR-SLCCI-GEN-06: Altimetry observing system shall provide monitoring of tides which imply selection of orbit that avoids aliasing of the majors constituents at long periods (> 180 days)
- UR-SLCCI-GEN-07: A balanced ocean observing system including altimetry plus other space and *in situ* techniques shall be developed and maintained.

5.1.2. Requirements for validation and calibration

- UR-SLCCI-GEN-08: Other in situ and space observing systems (e.g., high-quality tide gauges network with co-located GPS, Argo, GRACE space gravimetry, calibration sites, etc.) must be considered as part of the altimetry missions: these additional observing systems should be used for calibration/validation of altimetric systems and for computing the sea level budget (closure of the sea level budget provides an independent check and helps validating altimetry-based sea level change). Continuity of space gravimetry missions (GRACE Follow-on missions) is necessary.
- UR-SLCCI-GEN-08: Uncertainties need to be fully characterized (be able to provide full error budget)

5.1.3. Requirements for data format and access

- UR-SLCCI-GEN-09: Requirement to access to data at least once a year
- UR-SLCCI-GEN-10: Requirement to have CF-compliant NetCDF data format
- UR-SLCCI-GEN-11: Requirement to access to data through ftp and/or OpenDap

5.2. Requirements for Sea Level variable

The analysis of the different contributions and in particular coming from the GCOS, the Ocean Topography community (purple book and questionnaire to users) and the CCI CMUG clearly point out the need to refine the requirement provided by GCOS.

At this stage it seems useful to recall that the requirements defined for the GCOS and those refined by the Sea Level CCI project only concern the climate application. This application both deals with the provision of short term products to the ocean community involved in short term and seasonal monitoring and forecasting as well as the science application which is interested by a large range of signals from mesoscale and coastal to interannual and decadal timescales. Indeed, apart from the very short timescale events (storm surge, tsunamis, tides) for which no evidence on their impact on climate has been demonstrated, climate variability relies on a large range of temporal and spatial scales, from several days to years and from several kilometers to basin and global scales. Consequently, the way we choose to refine the present GCOS requirements consists in distinguishing three kinds of signals: Global mean sea level, regional sea level, mesoscale and coastal as detailed in Table 14.

Global mean sea level (UR-SLCCI-GEN-01) corresponds to the global mean sea level trend which is one the most relevant indicator of the climate change. Provided with a high accuracy by altimetry observing system for last 15 years, it integrates changes due to water mass transfer from the cryosphere, atmosphere and land and the volume changes due to expansion from temperature and salinity.

Regional sea level (UR-SLCCI-GEN-02) corresponds to the ocean signal comprised between Global mean sea level and mesoscale and coastal signal. Referring to the Ocean Surface Topography constellation URD (RD-7) it gathers the signals associated with mean global circulation (e.g. the mean dynamic topography) to intra-seasonal (10 to 100 days) and inter-annual variability. For the later signal, the variability is associated with the atmosphere forcing (wind, heat flux) and fresh water fluxes at scales from hundred kilometers to thousands of kilometers. They are link to phenomena as ENSO (El Nino Southern Oscillation), western boundary currents (e.g. Gulf Stream, Kuroshio, Agulhas) but also signals associated with propagation of planetary Kelvin and Rossby waves. Regional sea level change in the high latitude and Arctic Ocean needs particular attention due to the presence of sea ice and lack of precise knowledge of the sea ice freeboard height, which inhibits the direct estimate of sea level from altimetry.

Mesoscale (UR-SLCCI-GEN-05) is characterized by scales from 50 km to 300 km and 15 days to 3 months. It is mainly associated with formation and propagation of eddies which play a key role in the horizontal and vertical transport of heat and other properties as carbon and nutrients. Provision of accurate sea level products containing mesoscale signals is crucial for ocean monitoring and forecasting centers. In the previous version of the URD this included the coastal requirements, but the latter are now dealt with separately, in consideration of the ever growing importance of coastal altimetry as a whole.

Coastal is an area of primary importance because knowing and monitoring the sea level rise and changes is crucial for coastal residents and decision-makers. This means that we should be able to extract climate change signal within the coastal high frequency variability. As a rule of thumb we refer to the coastal strip within 15-20 km of the coastline, but some of the problems encountered in estimating sea level from altimetry in this zone (for instance, those due to inaccurate tidal corrections) may extend over whole shelf areas. The requirements in terms of accuracy and stability for the coastal area have been completely reviewed with a dedicated survey as explained in section 3.3.3, and the table below is a summary of those requirements, also including **Coastal Global** which means an average over the entirety of the world ocean’s coasts

FORM-NT-GB-7-1

Table 5-1: Synthesis of the sea level requirements gathered by the sea level CCI project.

Variable/paramer	Requirement number	Horizontal resolution	Temporal resolution	Accuracy	Stability
Global Mean sea level	UR-SLCCI-SPC-01	Global mean	NA	2-4 mm over an orbital cycle[1]	Long term drift <0.3 mm/y Annual time scale <0.5 mm/y over 12 months
Regional sea level	UR-SLCCI-GEN-02	25-50 km	week	1 cm over a grid mesh of 50-100 km	<1 mm/y over a grid mesh of 50-100 km
Mesoscale[2]	UR-SLCCI-GEN-05	15 km	daily	0.5 cm	No strong requirements
Coastal (local)	UR-SLCCI-GEN-05	15 km	monthly	1.0 cm	Long term drift <1.0 mm/y Annual time scale <1.0 mm/y over 12 months
Global Coastal	UR-SLCCI-GEN-05	Global coastal mean	monthly	1.0 cm	Long term drift <0.4 mm/y Annual time scale <0.5 mm/y over 12 months

[1] Individual global mean sea level values are obtained by geographically averaging sea surface heights measured over the ocean during an orbital cycle (the period needed to cover the whole oceanic domain – 10 days for Topex and Jason satellites; 35 days for ERS and Envisat). To reach the above accuracy, individual sea surface height measurements must be accurate to 1-2 cm.

[2] Requirement for smallest signal to be sampled.

The sea level CCI project also identified the specific key areas of **high latitudes** seas (Arctic and Antarctic) that require a special focus for climate applications However, as noticed from Table 5-1, distinct user requirements for the high latitude and Arctic Ocean have not been listed. This evidently results from less adequate quantitative knowledge as available data is more sparse, except along the Siberian coast. Nevertheless, it could be anticipated that in consistence with the global and local coastal as well as the regional seas the corresponding numbers are also valid for the high latitude seas and Arctic Ocean.

Annex A - Coastal requirements questionnaire

Coastal Sea Level Questionnaire
v1.0 Apr 2014

A short questionnaire on

Requirements for climate-quality monitoring of coastal sea level from satellite altimetry

Prepared by Paolo Cipollini, National Oceanography Centre, UK, cipo@noc.ac.uk
for the ESA Sea Level CCI Project, Phase 2 – WP1

Why this questionnaire?

Within Phase 2 of the ESA Sea Level CCI Project there is a specific task to update the User Requirements for climate-quality monitoring of sea level from satellite altimetry. Phase 1 of the project had summarized the requirements from different sources (including GCOS, WMO/WCRP, GOOS, OSTST, the Coastal Altimetry Community and the CCI's Climate Modelling User Group) in the following table[1]:

Synthesis of target sea level requirements from Sea Level CCI phase 1.

Observable	Horizontal resolution	Temporal resolution	Accuracy	Long-term Stability
Global mean sea level	Global mean	one orbital cycle[2]	**2-4 mm**	Decadal scale: < **0.3 mm/y** Annual scale: < **0.5 mm/y**
Regional sea level	50-100km	weekly	**1 cm**	**< 1 mm/y**
Mesoscale	15 km	daily	**0.5 cm**	(No strong requirements)

One issue that requires a dedicated focus in Phase 2 is **the coastal zone.** The purpose of this questionnaire – targeted to altimetry specialist and expert users of altimetry data – is to help us to define **specific requirements for altimetry in the coastal zone, in terms of:**
- Accuracy: congruence of the single value ('single' = 'averaged over one space and time grid cell') to the true value
- Long-term stability: consistency over time of the instrument calibration and corrections

Note that the requirements in question are those **for climate applications** – i.e. where one uses repeated observations to derive some statistical properties of the phenomena. A simple example to illustrate this concept: a one-off observation of some 'extreme' event does not belong to the 'climate' category;

[1] The full User Requirement Document that this table is taken from is available at http://www.esa-sealevel-cci.org/webfm_send/90

[2] Individual global mean sea level values are obtained by geographically averaging sea surface heights measured over the ocean during an orbital cycle (10 days for Topex and Jason satellites; 35 days for ERS and Envisat). To reach a 2-4 mm accuracy, individual (1Hz) sea surface height measurements must be accurate to 1-2 cm.

but observations of the distribution of extremes over several years would qualify as a climate application.

This questionnaire should not take more than 15 min of your time, but I know how precious your time is anyway, so many THANKS for filling this! – Paolo

First, a bit about yourself and your work…

Fill as many fields as you like or leave them blank – the questionnaire can be anonymous

Name

Affiliation

e-mail

I am: (tick all that apply)

- ☐ Modeller
- ☐ Physical oceanographer
- ☐ Satellite oceanographer
- ☐ In situ / seagoing oceanographer
- ☐ Coastal oceanographer
- ☐ Tidal scientist
- ☐ Other - please specify

How I deal with altimetry: (tick all that apply)

- ☐ I process altimeter data (retracking, apply corrections, derive products, etc)
- ☐ I analyze altimeter data (to find trends, stats, variability, etc)
- ☐ I assimilate altimeter data into models
- ☐ I compare data with in situ measurements (for cal/val or synergistic apps)
- ☐ Other – please specify

Altimeters that I work with: (tick all that apply)

- ☐ Geosat/GFO
- ☐ ERS-1/2
- ☐ Topex/Poseidon
- ☐ Jason-1
- ☐ Envisat
- ☐ Jason-2
- ☐ Cryosat-2
- ☐ AltiKa

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…and then just a few questions: please answer them based on your own experience.

Note that for each question you are asked to specify TWO values:

- *a THRESHOLD value (= the MINIMUM value that makes that parameter usable for at least one climate application)*
- *a TARGET value (= a "nice-to-have" value that will enable a fuller range of applications – TARGET values should be STRINGENT but REALISTIC at the same time!)*

Let us first focus on a LOCAL product, i.e. sea level on a single grid cell in the coastal zone (say a 15 km x 15 km stretch along the coast) and with a time resolution (i.e. time average) of ONE MONTH.

Q1) What level of ACCURACY of LOCAL altimetric measurements of sea level would be required?

THRESHOLD cm TARGET cm

Q2) What level of LONG-TERM STABILITY of LOCAL altimetric measurements of sea level would be required?

On an ANNUAL SCALE: THRESHOLD mm/y TARGET mm/y

On a DECADAL SCALE: THRESHOLD mm/y TARGET mm/y

Then let us think of a GLOBAL COASTAL product, i.e. one generated by quality-controlling and averaging all the measurements in the global coastal strip (0-15 km from coast) and with a time resolution of ONE MONTH.

Q3) What level of ACCURACY of GLOBAL COASTAL altimetric measurements of sea level would be required?

THRESHOLD cm TARGET cm

Q4) What level of LONG-TERM STABILITY of GLOBAL COASTAL altimetric measurements of sea level would be required?

On an ANNUAL SCALE: THRESHOLD mm/y TARGET mm/y

On a DECADAL SCALE: THRESHOLD mm/y TARGET mm/y

Space available for specific comments:

Done, thanks!

The results will be made available in the updated User Requirement Document (via http://www.esa-sealevel-cci.org) and discussed at ESA symposia, OSTST Meetings and Coastal Altimetry Workshops.

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