CP4O

Cryosat Plus for Oceans

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Abstract

This report represents a Requirements Baseline (RB) document resulting from the Scientific Requirements Consolidation task performed within Work Package 1000 (WP 1000) of the Cryosat Plus for Oceans (CP4O) project. The present document aims to:

- analyze the results from the user consultation undertaken with key institutions, and merge these results with those derived from the COASTALT and PISTACH user surveys;
- use these results, previous literature and main outcomes from recent workshops and meetings, to characterize the limitations and drawbacks of existing altimetric products, for achievement of the desired needs for Cryosat-2 data and applications.
- define a list of scientific and operational requirements, based on the work above, detailing when possible the technical and scientific contraints for the methods and models to be developed.
- incorporate any changes and suggestions as a result of the review by ESA.

The tasks listed above are carried out separately for four specific sub-themes, which are: open ocean, high-resolution coastal zone, high-resolution polar ocean and high-resolution sea floor.

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Abbreviations and Definitions

ADT	Absolute Dynamic Topography
BUFR	Binary Universal Form for the Representation of meteorological data
CNES	Centre National d'Etudes Spatiales
CNR	Consiglio Nazionale delle Ricerche
CP4O	Cryosat Plus 4 Oceans
DDA	Delay-Doppler Altimeter
DTU	Danmarks Tekniske Universitet
ECMWF	European Centre for Medium-Range Weather Forecast
ESA	European Space Agency
FBR	Full Bit Rate
FTP	File Transfer Protocol
GDR	Geophysical Data Record
GPD	GNSS-derived Path Delay
GTS	Global Telecommunications System
HDF	Hierarchical Data Format
IGDR	Interim Geophysical Data Record
IMEDEA	Institut Mediterrani d'Estudis Avançats
LRM	Low Resolution Mode
MDT	Mean Dynamic Topography
NetCDF	Network Common Data Form
N-ERM	Near-Exact Repeat Orbit
NOAA	National Oceanic and Atmospheric Administration
NOC	National Oceanography Centre
NRT	Near Real Time
OGDR	Operational Geophysical Data Record
OPeNDAP	Open-source Project for a Network Data Access Protocol
OSTST	Ocean Surface Topography Science Team
RB	Requirements Baseline
RT	Real Time
SAR	Synthetic Aperture Radar
SIRAL	Synthetic aperture Interferometric Radar ALtimeter
SSH	Sea Surface Height
SSB	Sea State Bias
SLA	Sea Level Anomaly
SST	Sea Surface Temperature
STSE	Support To Science Element
SWH	Significant Wave Height
TDS	Thredds Data Server

1 Introduction

The ESA Cryosat-2 mission is the first space mission to carry a radar altimeter that can operate in Synthetic Aperture Radar (SAR) mode, also known as Delay-Doppler Altimeter (DDA). Although the prime objective of the Cryosat-2 mission is dedicated to monitoring land and marine ice, the SAR mode capability of the Cryosat-2 SIRAL altimeter also presents the opportunity of demonstrating significant potential benefits of SAR altimetry for ocean applications, based on expected performance enhancements which include improved range precision and finer along track spatial resolution.

The "Cryosat Plus for Oceans" (CP4O) project is supported under the ESA Support To Science Element Programme (STSE) and brings together an expert consortium comprising, CLS, DTU Space, isardSAT, NOC, Noveltis, SatOC, Starlab, TU Delft, and the University of Porto. The main objectives of CP4O are:

- to build a sound scientific basis for new scientific and operational applications of Cryosat-2 data over four different areas, which are: open ocean, polar ocean, coastal seas and sea-floor mapping.
- to generate and evaluate new methods and products that will enable the full exploitation of the capabilities of the Cryosat-2 SIRAL altimeter, and extend their application beyond the initial mission objectives.
- to ensure that the scientific return of the Cryosat-2 mission is maximised.

This document contains an analysis and consolidation of preliminary scientific requirements for four sub-themes under investigation, which are: **open ocean, high-resolution coastal zone, high-resolution polar ocean and high-resolution sea floor.** To achieve this goal a user consultation has been carried out by the CP4O team, followed by an analysis of limitations and drawbacks of existing products, to finally come up with a list of scientific and operational requirements, per sub-theme.

1.1 Methodology

During the first three months of the CP4O project the WP1000 team designed and distributed a questionnaire to gather feedback from a wide pool of users interested in new products and applications that fully exploit the innovative capabilities of the SAR Altimeter onboard Cryosat-2. The initial task was therefore the identification of key users for the four sub-themes under analysis in CP4O. A list of key users, mostly useful for the coastal zone and also the open ocean sub-themes, was already available from the past user consultation surveys from the COASTALT and PISTACH projects. This list was then expanded by adding some more users for open ocean and coastal areas, and by identifying users working in the field of polar ocean and sea-floor mapping (which were not contained in the COASTALT and PISTACH surveys).

Subsequently, a simple questionnaire was designed for the definition of the user needs. This questionnaire re-exploited most of the questions contained in the questionnaire created for COASTALT, and some of the questions contained in the PISTACH questionnaire (those that were in common with the COASTALT survey). These pre-existing questions were mostly relevant for the open ocean and coastal zone sub-themes. A set of new questions, more specifically related to polar ocean and sea-floor mapping, was also created in the context of CP4O.

The questionnaire was distributed by email to a large number of users. Some of these users had already been contacted for the COASTALT and PISTACH projects, while some others were new and identified within CP4O.

In addition to emails, the questionnaire was distributed to participants of the 6th Coastal Altimetry Workshop in Riva del Garda[1], Italy, from 20th to 21th September 2012, and to the 20 Years of Progress in Radar Altimetry (20YPRA) Symposium and the Ocean Surface Topography Science Team (OSTST'12) meeting, both in Venice, Italy, from 24th to 28th September 2012. Part of the WP1000 team for CP4O (Starlab and SatOC) participated to these conferences through a poster [Clarizia et al., 2012] on the initial results from WP1000.

The questionnaires have been returned partly in printed format and partly in electronic format, and have been analysed. The results of the analysis, containing the limitations and drawbacks of existing products, and the definition and consolidation of the user requirements for the new methods, products and applications from Cryosat-2 data are contained in this document.

This report embedds information from the COASTALT and PISTACH user requirements analyses, which constitute a fundamental part of this survey.

[1] http://www.coastalt.eu/gardaworkshop12

1.2 Questionnaire

The CP4O questionnaire was designed by the WP1000 team (Starlab, NOC, DTU and SatOC) on the basis of the COASTALT and PISTACH questionnaire, with some modifications and with added questions. The questionnaire is attached at the end of this document, under Annex I. Its structure is briefly explained hereafter.

The questionnaire is divided in various sections each with a different objective. The initial sections establish the **user profile**, a **user area of expertise and applications**, with respect to the four sub-themes under analysis, and **the physical processes** that constitute his/her main interest. The subsequent sections focus on the **product characterization** in terms of spatial/temporal sampling and data delivery time requirements, data provision and resolution, and **accuracy** and **precision** requirements. A simple explanation of the concepts of *accuracy* and *precision* was provided at the end of the questionnaire.

Finally, the user is questioned about his/her requirements in terms of **auxiliary data** (including other remote sensing data and a mean dynamic topography) and on the preferred **data format and distribution**. A blank page is also provided to allow for comments or extra inputs.

As it can be noticed, this questionnaire maintains the same structure of the one designed for COASTALT.

2 Questionnaire Analysis

2.1 User Profile

The questionnaire has been distributed to a total of 170 scientists, but only 21 questionnaires have been received. The answer rate has been for CP4O of 12% only, compared to the 40% answer rate of COASTALT and PISTACH together (where 50 answers out of 130 requests were obtained). Such a lower response rate is probably due to the fact that the majority of the users had already been contacted in the past for either COASTALT or PISTACH, and therefore they have probably been reluctant in participating to another similar user survey. In spite of this, it was still possible to carry out a meaningful analysis, by merging of the 21 answered questionnaires from CP4O with the existing answers from COASTALT and PISTACH. It is worth pointing out from the beginning that the number of users providing an answer to a given question vary, and it obviously goes from a larger number for those questions that are present in all of the three surveys (COASTALT, PISTACH AND CP4O), to a lower number for those new questions designed specifically for CP4O (for example, those specifically related to polar ocean and sea-floor mapping). Not all of the interviewed users left their name in the questionnaire, but they reported their institutions and affiliations, which are listed below:

- JOmegak (U.S.)
- Institute of Geodesy and Geophysics, Chinese Academy of Science (China)
- The University of Newcastle (Australia)
- Technical University of Crete (Greece)
- Technical University of Denmark (Denmark)
- Slovenia Environmental Agency (Slovenia)
- National Institute of Oceanography (India)
- National Remote Sensing Centre, ISRO (India)
- Mercator Océan (France)
- Serco/Esrin (Italy)

- NOAA (U.S.)
- Altimetrics LLC (U.S.)
- IFREMER (France)
- Centre National de la Recherche Scientifique (CNRS, France)
- Scripps Institution of Oceanography (U.S.)
- University of Rhode Island (U.S.)
- University of Cadiz (Spain)
- Rutgers University (New Zealand)
- Collecte Localisation Satellite (CLS, France)
- Laboratoire d'Etudes en Géophysique at Océanographie Spatiales (LEGOS, France)

Although the number of returned questionnaires is not large, they cover a wide range of countries mostly European (with a strong presence of France) and from the United States, but also from other continents.

To better characterize user requirements, the answers have been classified by institution type. As in COASTALT, six different institution categories have been defined: public research institution, private research institution, public operational institution, private operational institution, and finally mixed institutions (operational and research) public and mixed institutions private. The previous classification will allow the interpretation of the results under various criteria. For example, it will allow the understanding of the user needs by sector (public or private) and it will also allow differentiating user needs for research and operational purposes. For clarity a graph representation of the results is provided for each question.

The questionnaire accepts multiple answers for most of the questions. The total number of answers (100% in a pie chart) is not equal to the total number of received questionnaires, since sometimes users have provided more than one answer to a single question, or some users did not reply to some of the questions.

For questions that were common among COASTALT, PISTACH and CP4O, the results from the three surveys have been merged. Where this has been done it is explicitly mentioned. Information on user requirements from PISTACH, and the user requirements report for COASTALT can be found in [Dufau et al, 2008a, 2008b], and [Moreno et al., 2008].

2.1.1 *Working institute /enterprise*

Most of the questionnaires received are from oceanographers at public research institutions. Among the 21 new questionnaires received for the CP4O survey, 12 of them come from the public research sector, 3 from the private research sector, 1 from the Operational public sector, 1 from the operational private sector, and finally 3 from the general public sector (both research and operational) and 1 from the general private sector (both research and operational).

Merging these results with the pre-existing ones from COASTALT, the total distribution per institution type is:

- Operational public: **2**
- Research public: **23**
- Operational private: **2**
- Research private: **3**
- Operational + Research public: **8**
- Operational + Research private: **3**

For the analysis, in order to identify the specific needs this distribution can be grouped in:

- Total Research: **26 (63%)**
- Total Operational: **4 (10%)**
- Total Public: **33 (80%)**
- Total Private: **8 (20%)**

As for COASTALT, most of the questionnaires for CP4O still come from the public sector (80%), and the private sector is undersampled with only 20% of the users, even though the number of replies has increased from 3 to 7. Furthermore, we have now three answers for the research private sector (while no answers for this sector were collected with COASTALT). We will still need to consider such low number of questionnaires representative of the sector considered, in the absence of any contradictory evidence.

2.1.2 *Specific study of the ocean and use of Altimetry data*

First, the questionnaire asks the users how they study the ocean, and whether they have already used altimetry products before.

The majority of the users who replied (80%) **have already used altimetry data for their work or research**, and the results correspond to an experienced community of users, as expected from the distribution list defined. However, a small number of them (20%) has not used altimetry data before.

Figure 2-1 shows the percentage of how the users interviewed study the ocean. Some users restrict to one single data type. Others use more than one source of information for their research and/or operational applications. In total, the distribution of data is illustrated below.

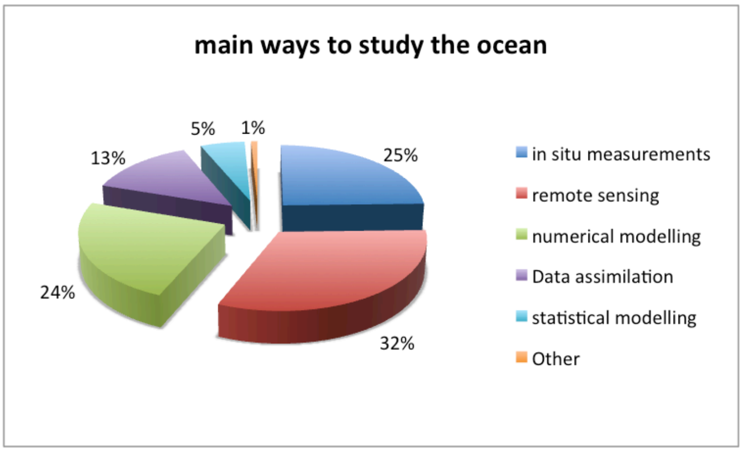


Figure 2-1- Types of data used to study the ocean

The main activities undertaken by users of altimetry data are well defined. The broad headings of remote sensing, in situ measurements and numerical modelling remains the most popular of the users activities. Statistical methodologies like statistical modelling and data assimilation cover the remaining share. **Compared to COASTALT and PISTACH, here remote sensing covers now the largest share of activities or our users, becoming larger than numerical modelling.** Since 2008 (when the PISTACH and COASTALT surveys were made) there has been therefore an increase in the importance and use of remote sensing data. It is worth noting that numerical modelling and in-situ measurements still remain important to study the ocean.

Most of the users interviewed for CP4O have also specified the product and model used for their work. The majority of them makes use of AVISO altimetry data and products, while a smaller number of them uses data from the RADS database. Altimetry data are used in combination with in-situ data mostly from tide gauges, but also from in-situ drifters, gliders, floats, moorings, HF radars and buoys. Some users assimilate altimetry data (along with Sea Surface Temperature and Ocean Color data) in models (predominantly NEMO and regional models). It is worth to point out that some users make use of PISTACH and COASTALT data and products, and some other already use Cryosat-2 data.

2.1.3 Time length and delivery time of altimetry data

This section analyzes the measurement-to-result time delay and the length of the datasets used.

Measurement to Result time delay

As opposed to the result from COASTALT, **the majority of users consider their work to be in delayed mode**.

Figure 2-2, representing the merged COASTALT and CP4O replies, summarizes the type of work currently carried out by our users. The biggest percentage of our collaborators' work is delayed mode, followed by NRT; both imply a certain delay between data reception and production of results. Climate related analysis, which implies long-term studies, is in third place, while RT experiments are less usual among the community at the moment.

However, it is worth pointing that the poor sampling of both the private and the operational sector might be responsible for the low preferences of data available in RT, since most of the interviewed users still come from the research public sector. Furthermore, **the RT and NRT options together still comprise a good percentage of the total users.**

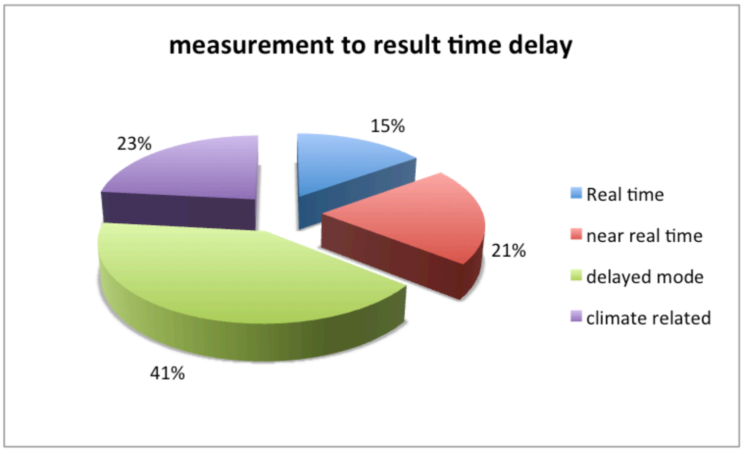


Figure 2-2.- Measurement to result time delay

2.1.3.1 Length of used datasets

The merged COASTALT and CP4O community responses are provided in the following graph:

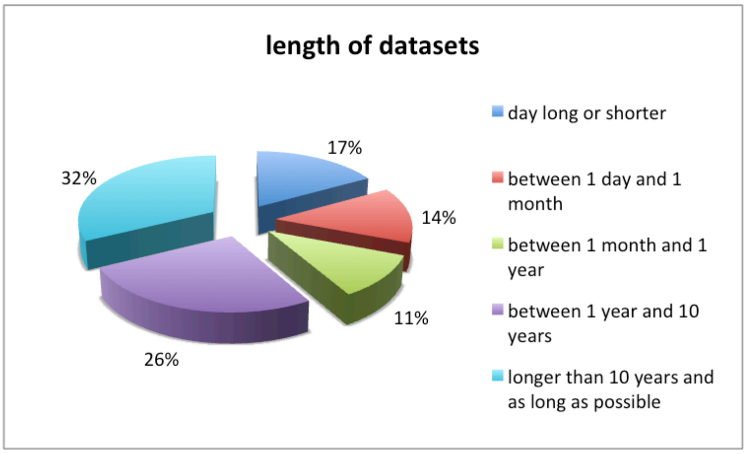
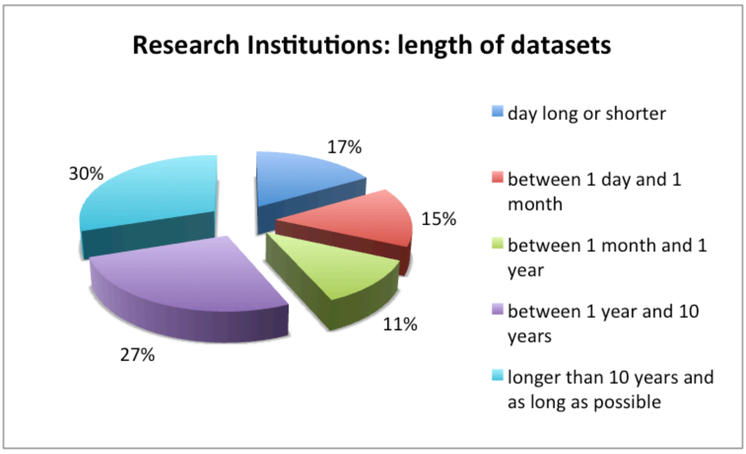


Figure 2-3- Length of the datasets used by the altimetry community

Datasets longer than one year are the preferred ones by the majority of the users. The largest temporal length (longer than 10 years and as long as possible) is the largest preference among users, followed by datasets between 1 and 10 years long.

However, the length of datasets is strongly related to the type of work or research carried out by users. For this reason the previous figure is repeated for research institution and operational institutions in Figure 2-4.

a)



b)

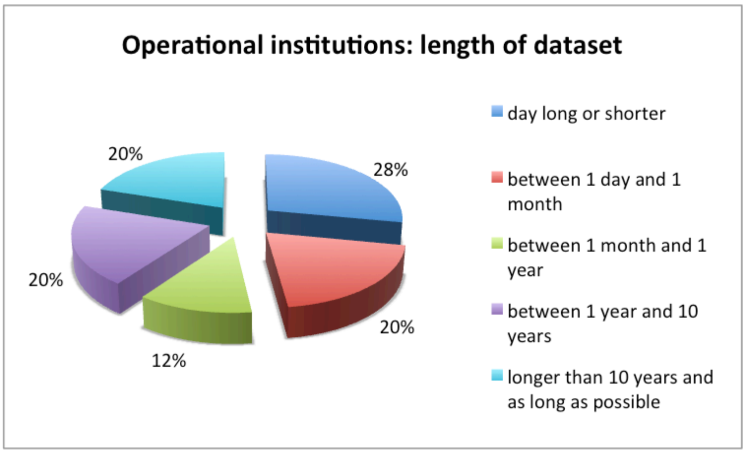


Figure 2-4 – Temporal length of the data sets for research (a) and operational (b) institutions.

We notice the longer datasets (over 1 year) are mostly preferred among the research institutions as illustrated in Figure 2-4 a). Operational institutions tend instead to use shorter (less than 1 year) data sets. Operational institutions usually rely more frequently on real time or almost real time services.

2.2 User Area of Expertise and Applications

In this section, the users are characterized in terms of their predominant expertise(s), with respect to the four sub-themes under analysis in CP4O, and in terms of the most important physical processes or parameters for their work.

2.2.1 Area of Expertise

Here the user is asked to choose the main area of expertise with regards to the four sub-themes under analysis (Open Ocean, Coastal Areas, Polar Ocean and Sea-floor mapping). In order to preserve consistency with respect to the question designed in COASTALT, and to be able to re-use the results from COASTALT, the distinction between near-shore and coastal zone has been maintained even for the CP4O questionnaire, so the users had 5 choices instead of 4.

The merged COASTALT , PISTACH and CP4O results are presented in figure 2-5.

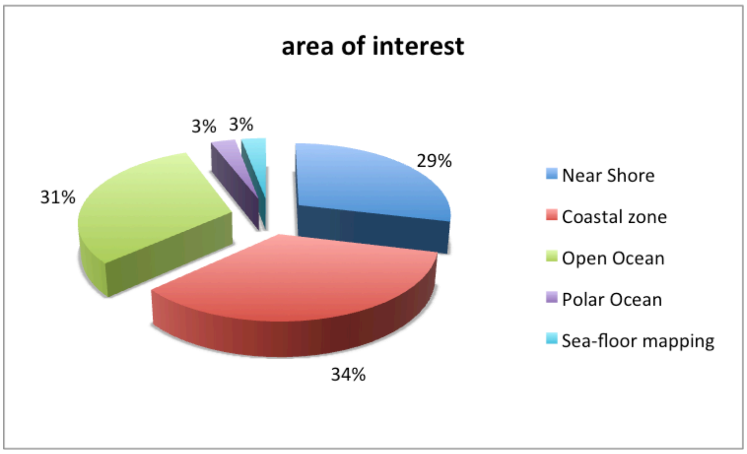


Figure 2-5: Areas of Interest

Figure 2-5 shows that **the predominant area of expertise of the users is the coastal area (including both near-shore and coastal zone)**. However, this might be due to the fact that we have here merged results from COASTALT and PISTACH, which were specifically oriented to coastal altimetry, and therefore were targeting coastal users. Nevertheless, the coastal areas have become particularly important in recent years, and the community of coastal users is expected to be wide, given both the huge implications of climate changes in coastal areas, and the importance of such areas for operational purposes. Unfortunately, the Polar Ocean users and sea-floor mapping users are instead very few, because among all those contacted only a small number of them decided to take part in the survey.

2.2.2 Purpose of the altimetry product

The user is asked to provide the purpose of altimetry products, to better understand the work/application needs of the user relates to such purpose. The answers to the question are provided in the following graph:

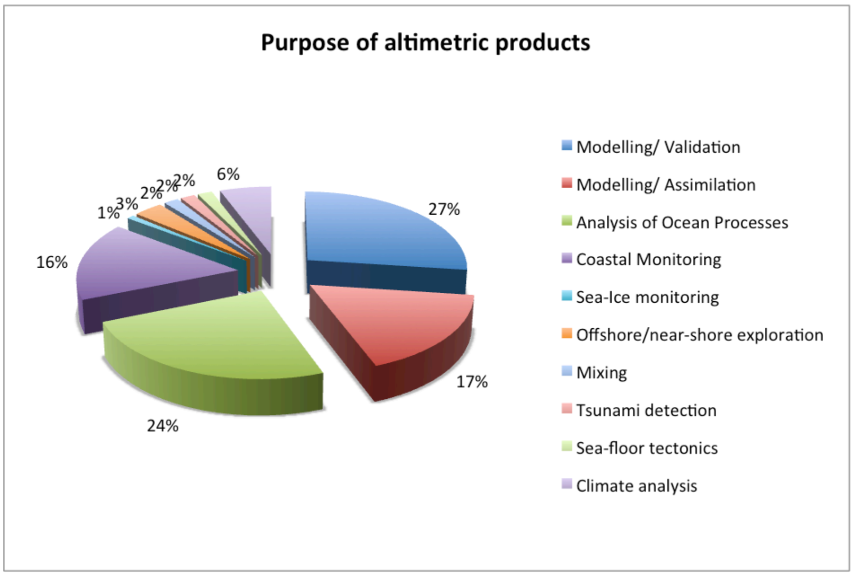


Figure 2-6.- Purpose of the altimetry products

Figure 2-6 reveals that two sectors presently dominate the use of altimetry data. **The altimetric products are mostly used for model validation, and as a diagnostic for oceanic processes.** These are then followed by the use of altimetry products for assimilation into models, and equally for coastal monitoring. The other purposes are all very small and comparable to each other, because the user community for these sectors is undersampled. At this point, the users are asked to provide answers to geographical questions individually related to the four-sub-themes and area of expertise. These questions are analysed in the following sub-paragraphs.

2.2.3 Open Ocean

Here the experts of open ocean are asked whether their need for altimetric data is limited to only one particular region, or more than one. **The majority of them (70%) need altimetry data in several**

regions around the globe, while only 30% of the users need data only in one region. The specified regions are indeed numerous, ranging from smaller specific areas (i.e. Gulf of Cadiz, Strait of Gibraltar, Seas around Greece, Western and North-Western Mediterranean, Bay of Biscay) to larger areas (Indian Ocean; China Seas; US Coasts) to entire oceans or worldwide (all tropical/subtropical oceans in which tropical cyclones exist, North Atlantic, Pacific Ocean).

2.2.4 Coastal Zone

For this sub-theme, we use results for the CP4O survey and those questions from the COASTALT survey that addressed specifically the coastal zone. As for the open ocean, the coastal users also express the need for altimetry data in several coastal locations, and not just one (from the COASTALT survey). The coastal users are asked to provide the distance from the shoreline representing the area of their major interest. The result of this question is merged across COASTALT, PISTACH and CP4O, and it is provided below:

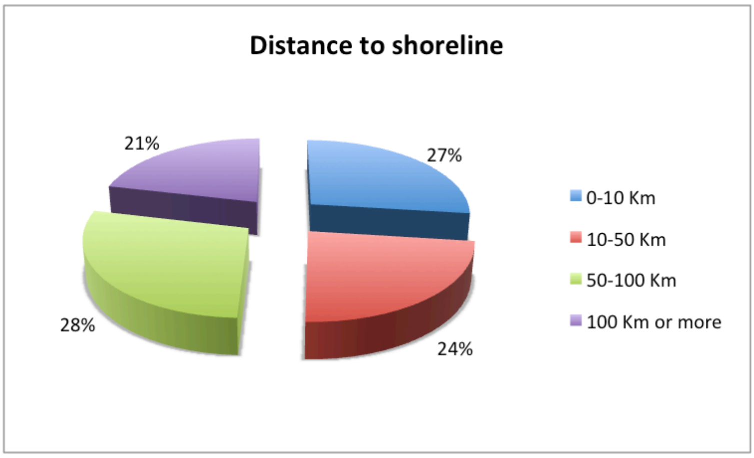


Figure 2-7.- Distance to shoreline

It is worth specifying that the COASTALT and PISTACH surveys contained only one single option in the questionnaire, which was 0-50 km, whereas in CP4O the option has been split into 0-10 km and 10-50 km. In order to be able to merge the results from all the surveys, the total score for 0-50 km in COASTALT and PISTACH has been equally split between the 0-10 km and the 10-50 km options. The result we obtain is still consistent with the one from COASTALT and PISTACH, in that **the majority of the users are interested in the coastal strip between 0-50 km,** followed by the strip between 50 and 100 km. Even in this case, the users were asked to provide details about the regions of interest, and the answers were different (i.e. Middle Atlantic Bight and gulf of Maine, coastal and shelf regions off the

Indian coast, the great barrier reef in Australia, coastal zones of gulf of Cadiz, strait of Gibraltar and western Mediterranean, North Adriatic coastal areas; bay of Biscay, Provencal and Ligurian coasts and Ligurian basin, all Arctic etc.). A few users working also in the sea-floor mapping field expressed explicitly the need to get as close to the coast as possible for gravity recovery.

2.2.5 Polar Ocean

A very small number of users (3) have indicated the polar seas as their main area of interest. In terms of areas of interest, there is a slightly higher preference for southern seas (2 users) than for northern seas (1 user). Among these three users, there is a predominant interest for the American/Canadian/Greenland sector in the north, and for the Atlantic Weddell Sea in the south. However, these preferences are clearly not statistically very significant.

2.2.6 Sea-floor Mapping

Even in this case, only 3 users have a specific expertise in sea-floor mapping and they all come from the public research sector. Two of these users are interested in areas both in open ocean and close to the coast, while the third users is only interested in coastal areas.

2.2.7 Physical Processes and Parameters of interest

The users have been asked to indicate the physical processes they mostly work with, and to provide a degree of importance (from 0 to 4) to a list of parameters, with respect to their particular work or research. The result of this investigation (merged with COASTALT and PISTACH results) is illustrated in figures 2-8 and 2-9:

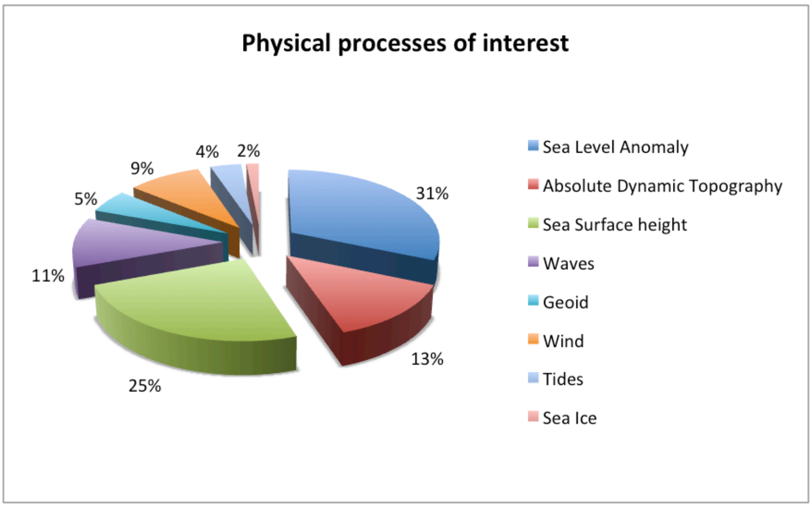


Figure 2-8.- The distribution of the physical processes of interest among users

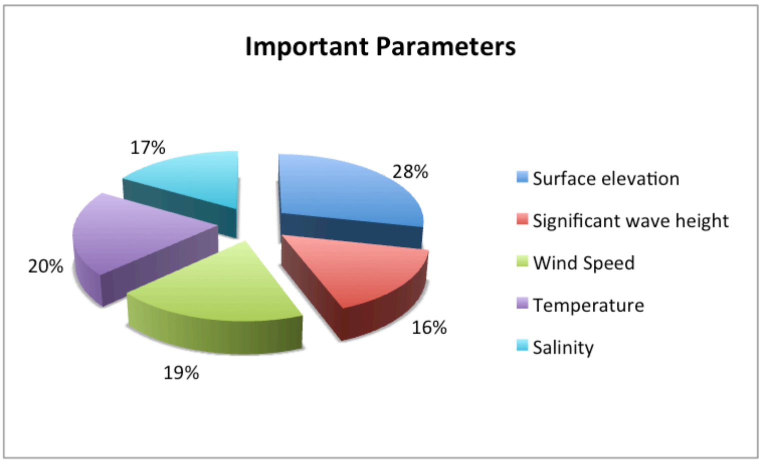


Figure 2-9.- The distribution of the importance of physical parameters according to the users

As for COASTALT and PISTACH, in figure 2-8 **the physical process of major interest among the users remains the Sea Level Anomaly (SLA), followed by the Sea Surface height (SSH).** Following these two the Absolute Dynamic Topography (ADT) is the third most studied parameter. Wind and waves share a similar percentage, and together they cover a non-negligible share. Geoid, tides and sea-ice are the least considered one, but here we recall once again that the community of polar ocean and sea-floor mapping users is very undersampled. A few users also specified other physical processes, like sea surface slopes along track, and geostrophic currents.

In figure 2-9, **we notice a higher percentage for surface elevation,** and an overall balanced distribution of the importance of the other proposed parameters. Temperature and salinity are also considered important parameters, particularly from the modellers who assimilate them, while wind speed and SWH are important for operational purposes. Some of the extra parameters mentioned by the users were once again sea surface slope, and ocean colour.

2.3 Products Characterization

The subsequent section of the questionnaire is dedicated to the product characterization in terms of optimal along-track frequency sampling, resolution, data provision and accuracy and precision requirements.

The users were asked to provide information on their presently preferred product and, in addition, on the characteristics they wish the new product to have. In this way the necessary improvements in the present products are to be identified. These results could not be merged with the ones provided by the PISTACH questionnaires since the nature of the questions is different, therefore they were only merged with results from the COASTALT survey. First, the users were questioned about the current and desired along-track frequency sampling (or posting rate), and the results are provided in the figure below:

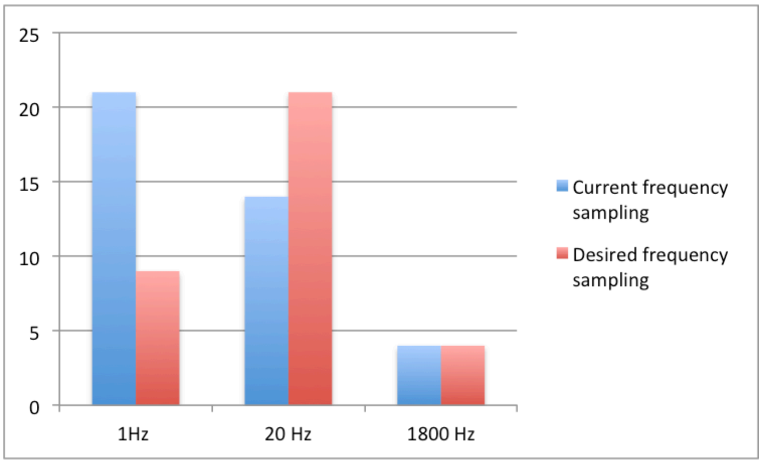


Figure 2-10.- Current vs desired along-track frequency sampling

The most commonly used frequency sampling by the community is 1 Hz, but a clear preference emerges for the one at 20 Hz. Additional comments recommend keeping the 1 Hz frequency as complementary to the desired 20 Hz. A few users are interested in individual echoes, and thus in the 1800 Hz posting rate. In the PISTACH survey this question was asked in a different way, but the results still indicate that the preference of the PISTACH sample is clearly 20 Hz, and that the 1 Hz should be retained as indicated in the results from this survey.
It is also worth mentioning that one user indicates the 5 Hz posting rate of PISTACH products as both the currently used and the desired one. Moreover, some users indicate the Full Bit Rate (FBR) data from Cryosat-2 as the type of data currently used, and **express the clear wish to have FBR data available for the future.**

2.3.1 Spatial resolution (Along track)

In order to be able to merge the results from the CP4O survey with those from COASTALT, the question about the spatial resolution has been left rather generic, as it was the case for COASTALT, but giving the possibility to the users to specify the value for the desired resolution. The merged CP4O+COASTALT result about what is the currently used and the desired spatial resolution for users is shown in figure 2-11.

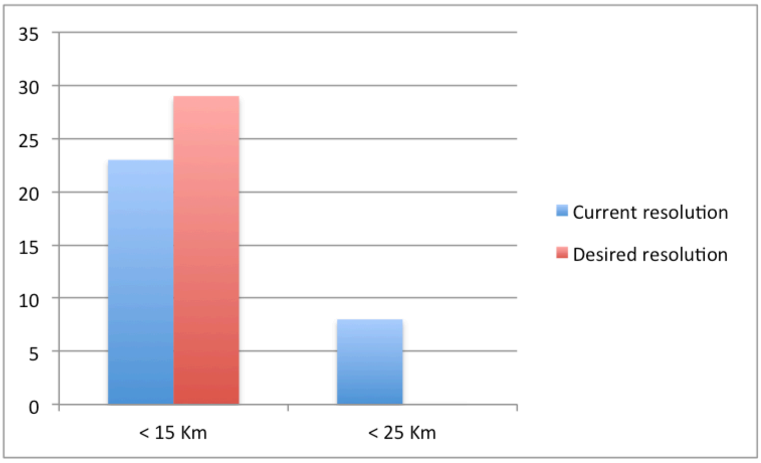


Figure 2-11.- Current vs desired along-track spatial resolution

Although the majority of users already make use of data with a spatial resolution of less than 15 km, **there is clearly a need for a better spatial resolution**, and a need for all of the users (including those who currently use low-resolution products) to start using products with a better resolution. This is enforced by some specific comments left by the users on the desired product, where they mention spatial resolution of 7 km, less than 3 km, less than 1 km, and of 300 meters.

2.3.2 Data delivery delay versus accuracy

In terms of accuracy versus delivery delay, the merged results between CP4O and COASTALT (shown in figure 2-12) highlight that **most of the users still uses and prefers offline data**. However, the number of users that wish to have offline data (compared to those who are already using them) is decreasing, while **there is an increasing need for Real-Time (RT) or Near-Real Time (NRT) data**. We checked that the users requesting NT and NRT data come mainly from the public sector, and both from research and from research+operational institutions.

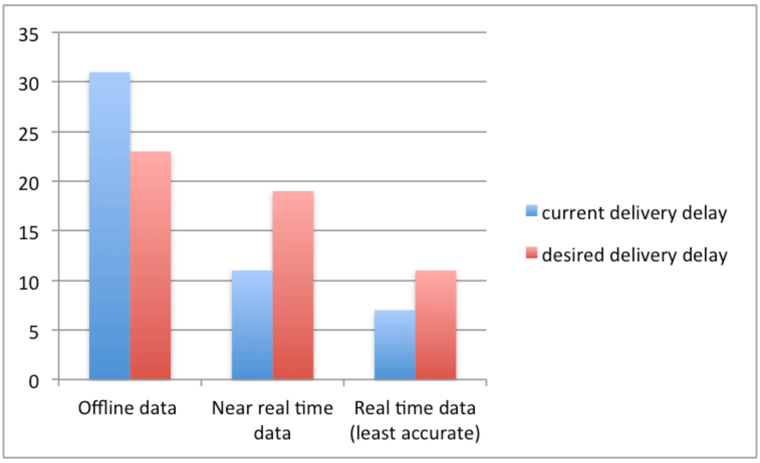


Figure 2-12.- Delay delivery vs data accuracy

2.3.3 Data provision and resolution

About 60% of users prefer the option higher spatial resolution and lower temporal resolution, while 40% of them tend to vote for of higher temporal resolution but lower spatial resolution. A number of users prefer not to provide an answer to this question, which has been introduced in CP4O.

The spatial resolution seems to be considered slightly more important than the temporal resolution, therefore allowing to conclude that non-repeating observations might be considered more suitable than repeating observations, because they ensure a higher spatial density. However, it should be noted that the desired temporal and spatial resolutions still depend on the type of phenomena that the user is interested in. As an example, the study of dynamic phenomena for oceanography calls for repeated observations along pre-defined ground tracks, whereas geodesy studies require non-repeating observations with the highest spatial density.

In terms of data provision, 61% of users still prefer the products to be provided along-track, while the remaining 39% are happier with 2D gridded products.

2.4 Accuracy Requirements

Three questions in the questionnaire referred to product accuracy. The questions focused on: accuracy for height measurements, accuracy for SWH, and radiometric accuracy. All the people interviewed were requested to specify the accuracy of these parameters currently used, and the desired accuracy of these parameters in the new products to be released under this project. It is worth mentioning from the beginning that a number of users did not answer these questions, especially those related to the radiometric accuracy, but also to height and SWH accuracy. The reason for this is unknown. The analysis of the merged responses between CP4O and COASTALT (no PISTACH data) is provided hereafter.

2.4.1 Accuracy for Height Measurements and SWH

Generally speaking, **users prefer the products to have the best possible accuracy for both height and SWH**; that is, better than three centimetres accuracy for height measurement and better than 5% of SWH. One user specifies a desired accuracy even lower than 1 cm, and another expert user suggests that long-term stability should be at the level of better than 1 mm/year.

It is worth noting once again that as for COASTALT, the majority of users interviewed for CP4O considers the present products to have an accuracy better than 3 cm. If this is true in open ocean, it is certainly questionable in marginal seas and when approaching the coast. This suggests that users tend to overrate the capabilities of current altimeter data in particular areas (i.e. the coastal area), and calls for better information to the users, including a rigorous explanation of the error budget.

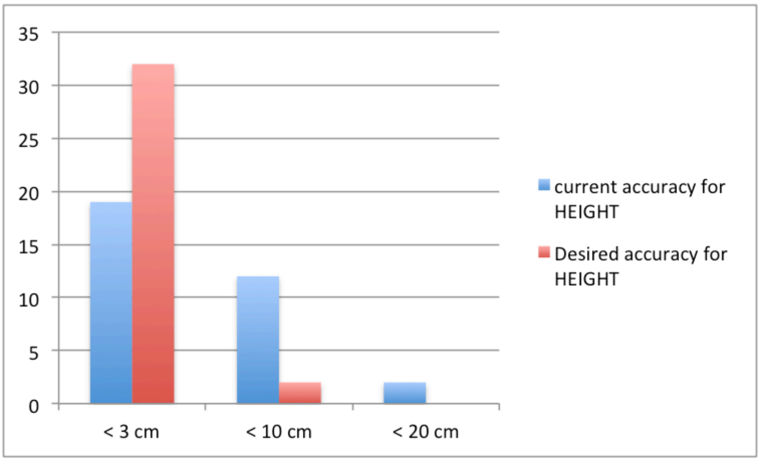


Figure 2-13.- Accuracy for height measurements

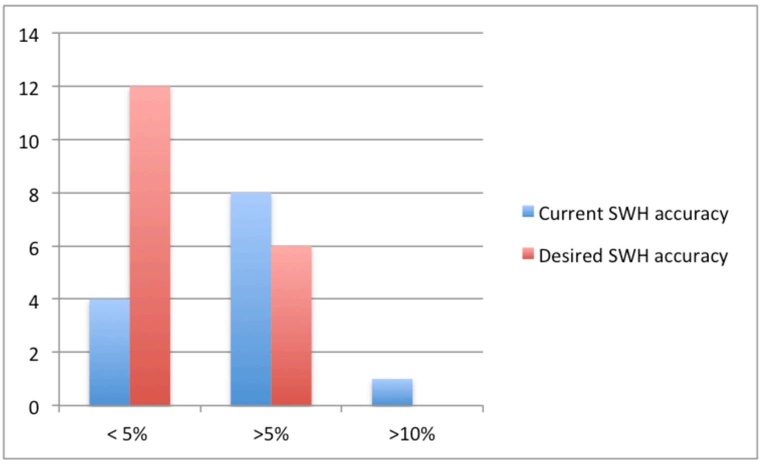


Figure 2-14.- Accuracy for SWH

2.4.2 Radiometric Accuracy

Only a few users (roughly 15/41) have responded to this question. The result from this question are therefore not very conclusive, and not statistically very significant. However, the tendency of those who have responded is equally distributed as far as the desired accuracy is concerned. Most of the people who responded prefer a radiometric resolution better than 0.2dB, while a few of them are still happy with a radiometric resolution better than 0.5dB. Currently, more tend to work with radiometric accuracy less than 0.5dB, but **there is clearly a need for a better radiometric accuracy.**

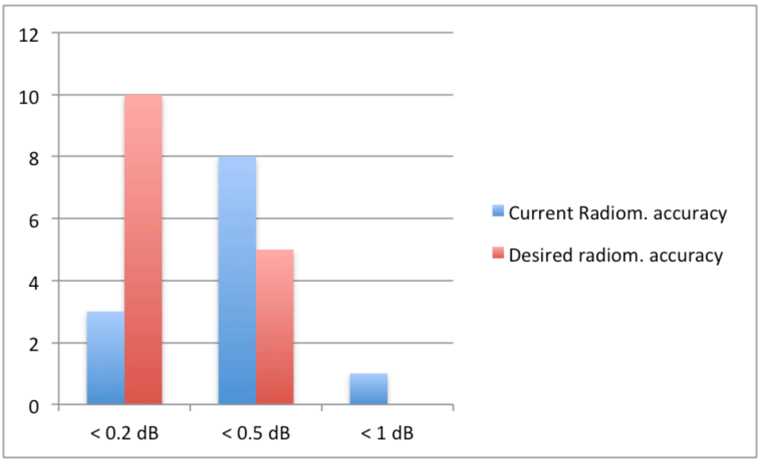


Figure 2-15.- Radiometric accuracy

2.5 Precision Requirements

The same parameters as in the previous section have been analyzed for precision. The results are merged between CP4O and COASTALT only, as no precision requirements have been asked to the PISTACH sample. Even in this case, a number of users did not reply to these questions, particularly that concerning the radiometric precision.

2.5.1 Precision for Height Measurements and SWH

Similar results to the accuracy analysis are shown in 2-16 and Figure 2-17 compared to their equivalents in the previous section.

The majority of the users interviewed tend not to prefer lower precisions and to ask for improved precision for both height and SWH measurements. Again, a number of users declare to work already with high height precision, which is not always the case for certain areas of the ocean (the coastal zone). This calls for better information to the users, including a rigorous explanation of the error budget as mentioned in §2.4.1.

In the case of SWH, most users would like to have improved products with precision better than 5%.

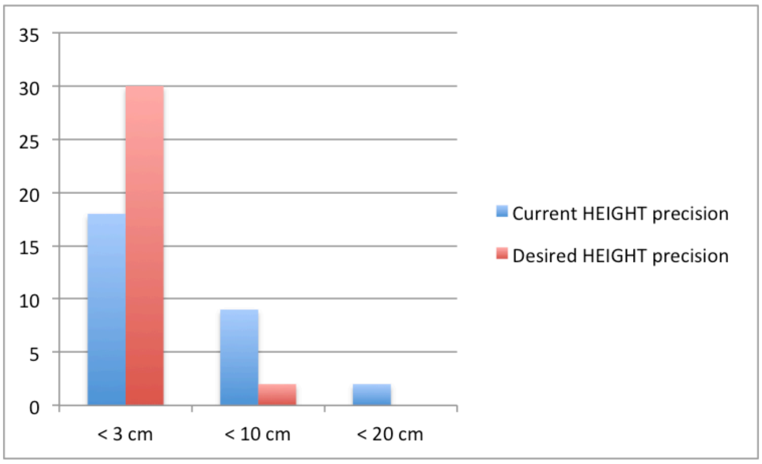


Figure 2-16.- Precision for height measurements

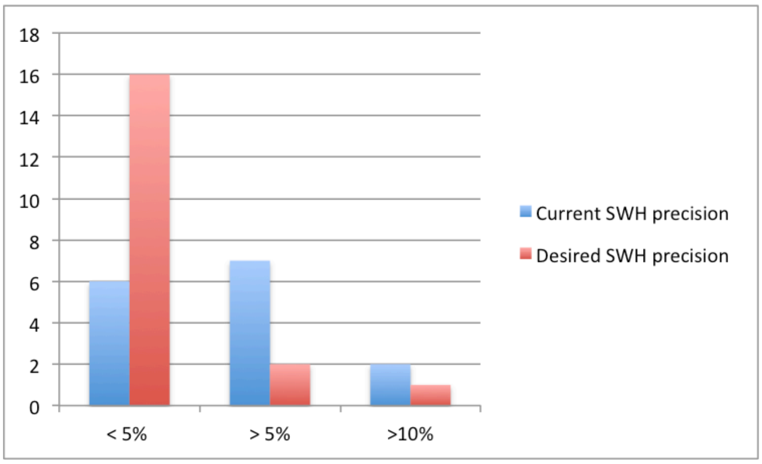


Figure 2-17.- Precision for SWH measurements

2.5.2 Radiometric Precision

Similarly for the accuracy, the results provided in Figure 2-18 show that **the majority of users also call for a better radiometric precision**. Two users are currently working with the worse radiometric precision, and do not require any improvements for it, probably because it is suitable for the type of application they work on.

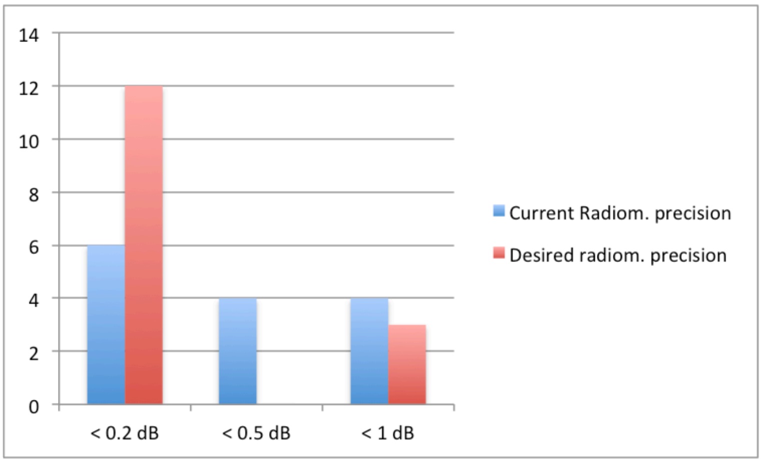


Figure 2-18.-Radiometric precision

2.6 Auxiliary Data

This section of the questionnaire concerns the auxiliary data that are used to complement the information from altimetry data. The results are provided in the sub-paragraphs below.

2.6.1 Required supplementary data

In terms of supplementary data required to complement the altimetric data, the users were provided with five different choices. A few users did not reply to this question. The merged answers between CP4O and COASTALT are illustrated in figure 2-19.

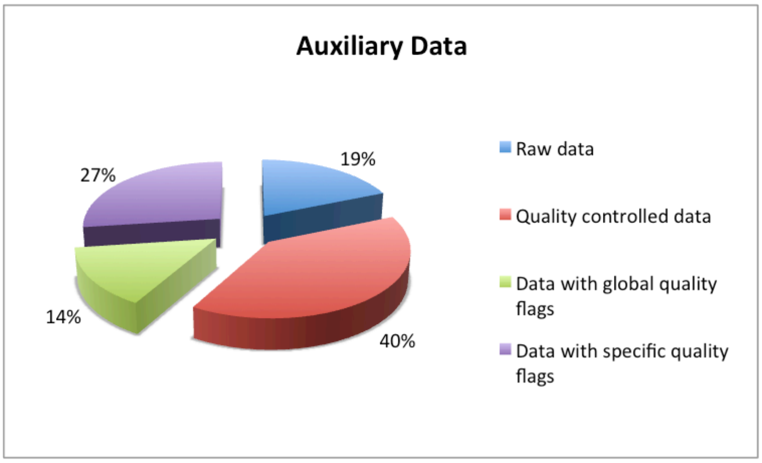


Figure 2-19.- Auxiliary data required

Most users still show a strong interest in quality-controlled data (as it was from the COASTALT survey). Two other popular options are specific quality flags, and raw data. It is worth mentioning a couple of relevant comments from two users. One requests FBR data as supplementary data. The other points out that for SARIn mode the cross-track angle information has to complement all the geophysical parameters (SSH) extracted from SARIn processing. Therefore, for coastal applications, auxiliary parameters such as distance to the coast, ground-track orientation with respect to the coast, land fraction in SAR footprint etc. are all relevant parameters that should be added in the list of auxiliary data.

2.6.2 *Complementary Information*

In terms of the reason for the need of complementary information, the result merged between CP4O and COASTALT is **fairly equally distributed among the four options** provided in the questionnaire, as shown in figure 2-20. **A slightly major interest is shown for applied atmospheric and geophysical corrections.** HF fields and instrument corrections with equal percentage follow the previous two. This is in line with the distribution of altimetry data in the form of GDRs (Geophysical Data Record), containing all the additional fields.

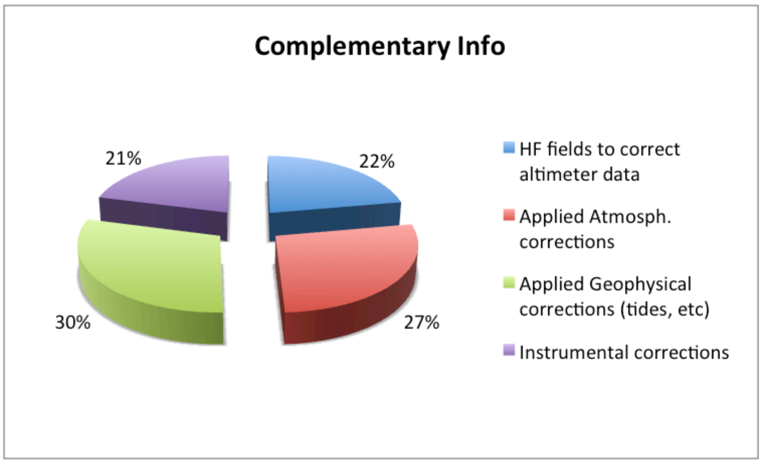


Figure 2-20.- Reason for need of complementary information

2.6.3 *Auxiliary Reference Data*

The users are asked whether they need the MDT to reference data, and the geoid. The results from the first is merged with those from COASTALT, while the need for geoid was only asked in the CP4O survey.

Looking at figure 2-21, it is clear that **users working in the public sector and in the research institutions consider a MDT important for their work.** For the private sector and operational institutions, only half of the users deem it important. A number of users are not aware about whether they need it or not.

The result can be compared to the one gathered in PISTACH, where no segmentation of the users was done. In that case, 77% of the community answered positively to the question, 19% answered negatively, and 4% were not sure whether they require the MDT or not.

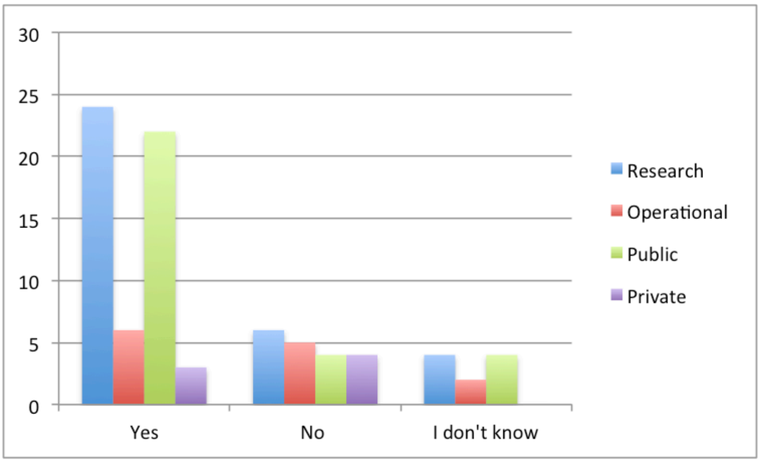


Figure 2-21.- Need for a MDT to reference data

The results for the need of geoid by the users is shown in figure 2-22, segmented again between public and private sector, and between research and operational institutions.

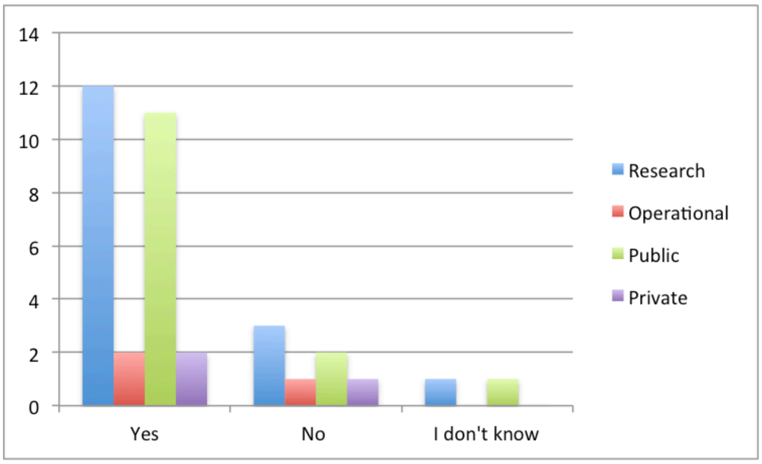


Figure 2-22.- Need for geoid

Even in this case, **users coming mostly from the public sector and from research institutions consider the geoid important for their work**.

2.6.4 Additional Remote Sensing data Products Synergic with Altimetry Applications

Altimetry data are sometimes interpreted in synergy with other remote sensing products. The questionnaire included as options those products most commonly used by the altimetry community. The results presented in figure 2-23 are the merged COASTALT/PISTACH and CP4O ones.

Optical and SAR data are the most used ones, followed by infrared (SST) data. Scatterometric data are less used, as well as ocean colour data (mentioned by a few users in the section available for extra inputs).

Some users also specified the application or product for which they use other remote sensing data in synergy with altimetric products. The mentioned ones were ecosystem and sediment export from estuaries, ocean model simulations, coastal altimetry, shoreline and bathymetry studies, observations of small scale structures and their dynamics, ships and sea surface pollution.

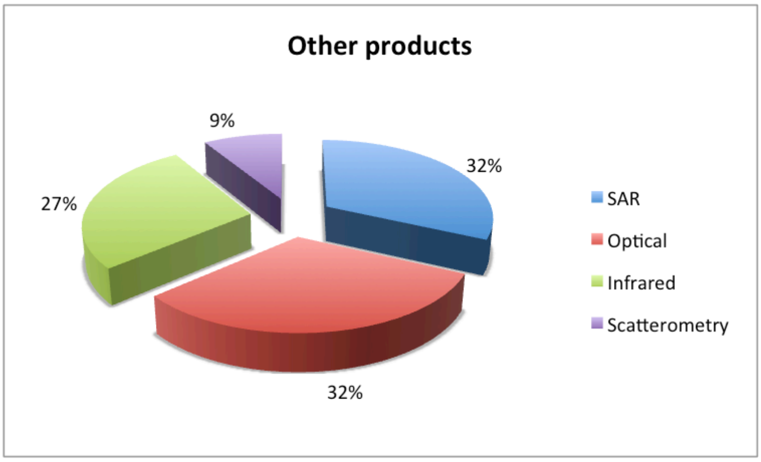


Figure 2-23.- Other remote sensing data products needed

2.7 Data Format and Distribution

The last section of the questionnaire was focused on data format and distribution. This is an important characteristic to be considered in a product description phase. The questions asked to the collaborators concerned specifically the data format, the delivery mode, and the rate of update of altimeter datasets.

In this case, the nature of the question was the same in COASTALT and PISTACH, but the questions were slightly different so the answers of the PISTACH community will be discussed separately.

2.7.1 Data format

The data format preference distribution among users is shown in figure 2-24.

The most frequency used data format is NetCDF, and it is also the preferred one. The second mostly used format is ASCII. Another reasonably popular format is binary, while HDF is less required. In addition, another format not listed previously, like BUFR[2], as well as Thredds Data Servers (TDS), were specified by two collaborators.

[2] The Binary Universal Form for the Representation of meteorological data (BUFR) is a binary data format maintained by the World Meteorological Organization (WMO). The latest version is BUFR Edition 4. BUFR Edition 3 is also considered current for operational use.

The preferred format for the PISTACH community was also NetCDF followed by ASCII.

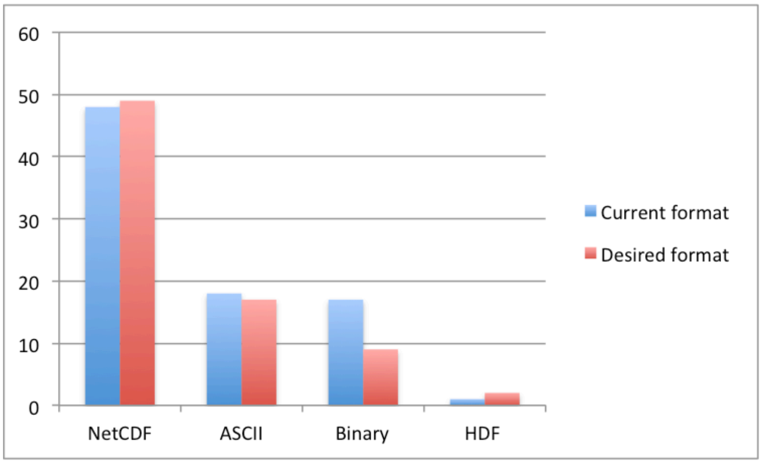


Figure 2-24.- Data formats

2.7.2 Delivery mode

Looking at figure 2-25, ***ftp* is the most common and most preferred delivery mode among the altimetry community**. It is interesting to note that with the integration of answers from CP4O, *ftp* becomes now the favourite option, while the desired one for COASTALT was *OPeNDAP*. The second most used and preferred mode for future delivery is the direct upload of the data directly into the program from remote servers, followed by *OPeNDAP*. The DVD mode is the less popular. The *GTS* [3]delivery mode was suggested by one user as both the currently used and the preferred mode. The preferred delivery mode for the PISTACH community was also *ftp*, followed by *OPeNDAP* and remote servers.

[3] For more details on GTS, the Global Telecommunication System used in meteorology, see http://en.wikipedia.org/wiki/Global_Telecommunications_System. Note that EUMETSAT have also recently proposed a system called EUMETCast and based on standard Digital Video Broadcast (DVB) technology – see http://www.eumetsat.int/HOME/Main/What_We_Do/EUMETCast/index.htm

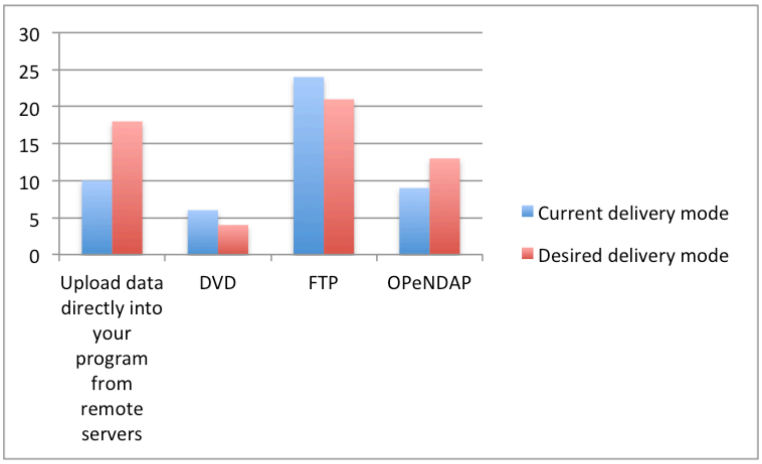


Figure 2-25.- Delivery Mode

2.7.3 Data Latency

Looking at both distributions, current and preferred, it emerges from figure 2-26 that **the majority of the users both use and would prefer the altimeter dataset to be updated daily.** One user specified a preferred hourly update rate.

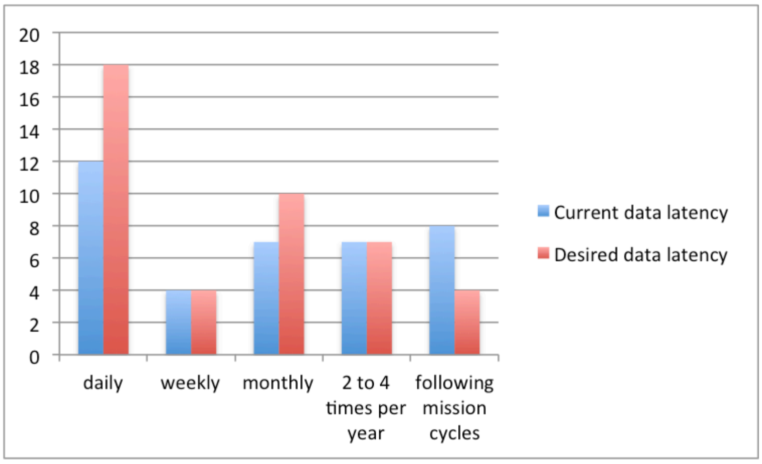


Figure 2-26.- Altimeter Dataset Update time

Some users still prefer data to be updated less frequently regardless of whether they are research or operational. Most probably those not requiring frequent updates are mainly focusing on climate research.

3 Summary of User Survey

3.1 Main Conclusions

The information provided through the user survey can be used in combination with pre-existing literature to draw the limitations and drawbacks of existing altimetry products, as well as the user requirements for the new altimetry product. A total of 21 users responded to the CP4O questionnaire, and their response has been merged with those from the past COASTALT survey, for a total of 41 replies. In some cases, the answers has also been merged to those from the PISTACH survey, achieving a total of 71 replies.

It has to be taken into account that the majority of the users who responded to the COASTALT and CP4O surveys come from public sector (80%) and the research field, and the majority of users are experts in coastal areas (63%) and open ocean (31%). There is a lack of participation from the private sector (20%) and from the polar ocean and sea-floor mapping community (only 3% each).

Generally speaking, the main points of the questionnaire can be summarized as follows:

I. **The majority of the users have already used altimetry data for their work or research**.

II. **Most users study the ocean through remote sensing data, followed by numerical modelling and in-situ measurements;**

III. **The majority of users still consider their work to be in delayed mode. However, a non-negligible percentage of them works with Real Time (RT) or Near Real Time (NRT) data;**

IV. **Datasets longer than one year are the preferred ones by the majority of the users;**

V. **The predominant area of expertise of the users interviewed is the coastal area (including both near-shore and coastal zone), followed by open ocean.**

VI. **The altimetric products are mostly used for model validation, and as a diagnostic for oceanic processes.**

VII. **For open ocean, the majority of users need altimetry data in several regions around the globe;**

VIII. **For coastal zone, the majority of users are interested in the coastal strip between 0 km and 50 km, and they are also interested in several coastal locations.**

IX. **The two major physical processes of interest are Sea Level Anomaly (SLA) and Sea Surface Height (SSH); Surface Elevation is considered the most important parameter.**

X. **The along-track posting rate mostly used is 1Hz, but a clear preference emerges for 20 Hz. Some users express the wish to have FBR data available.**

XI. **The users express a need for a better along-track resolution for the future.**

XII. **Most users still use and prefer offline data, but there is a clear shift of the demand towards data with shorter latency (NRT and RT).**

XIII. **Users want the products to have the best possible accuracy and precision for height and SWH;**

XIV. **Even though only a few users responded to this question, there is also a need for a better precision and accuracy in sigma0 (radiometric) measurements;**

XV. **Users call for products that include quality control information, auxiliary data for instrument and geophysical corrections (atmospheric, tides, etc.) and auxiliary reference data (e.g. MDT, geoid);**

XVI. **Optical and SAR data are the most used ones as synergistic remote sensing data;**

XVII. **The most used and preferred data format and delivery remain NetCDF and *ftp* respectively;**

XVIII. **The majority of users both use and prefer altimetry datasets to be updated on a daily basis.**

As a general consideration, we can say that the results after merging the CP4O survey contributions confirm the previous user needs from the COASTALT and PISTACH survey. Only a few aspects have changed (i.e. there are now more users using remote sensing than those using numerical modelling), while some important needs, already emerging from the COASTALT and PISTACH surveys, have been strengthened by the CP4O survey (i.e. need for better resolution, need for better precisión and accuracy).

4 Analysis of Limitations and Drawbacks of existing Altimetry Products

This section presents an analysis of limitations and drawbacks of existing altimetric products, based on the results from the CP4O user consultation survey (presented in Sections 1 to 3), as well as on reports and documentation available from other projects ([Cotton et al., 2004], [Moreno et al, 2008], [Cotton et al., 2008], [Dufau et al., 2008a, 2008b], [Cotton, 2010]) and important outcomes from recent altimetry workshops and meetings. This analysis constitutes the main input for the definition of a list of scientific and operational requirements for the new methods, products and applications developed in the context of CP4O, and presented in section 5. Even though some of the limitations and drawbacks of current products will be shared across different sub-themes, they are separately identified and analysed for the four sub-themes under analysis in CP4O, and they are presented in four separate paragraphs.

4.1 Limitations/Drawbacks in Open Ocean

An important and useful aid for the analysis of limitations and drawbacks of existing altimetry products in open ocean is given by Figure 4-1, which summarises clearly the most important oceanic phenomena, where they are located in terms of spatial and temporal resolution, and whether they need precision or accuracy (or both) in the measured parameter.

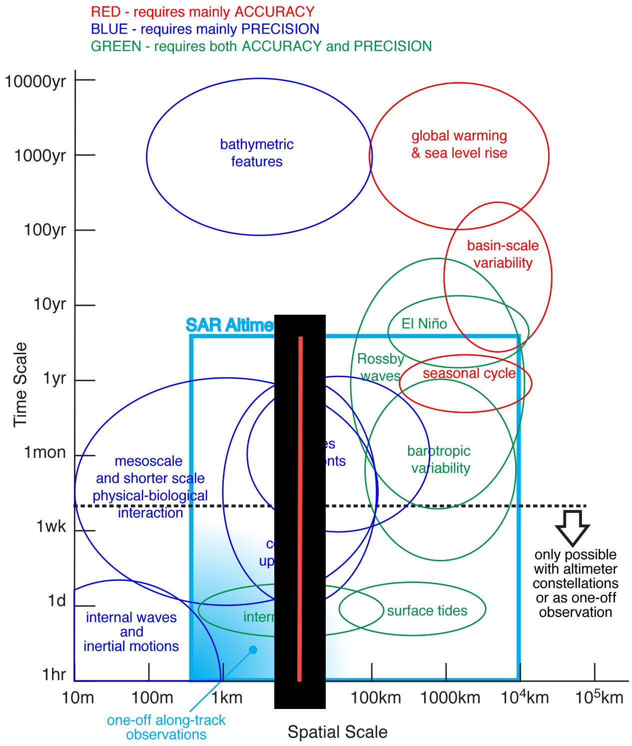


Figure 4-1.- Space and time scales of phenomena of interest that could be investigated from altimetric measurements of ocean topography, with adequate spatial and temporal resolution [Cotton et al., 2008]. The dashed line indicates the approximate lower bound of the time scale resolved (with repeated observations) by a single nadir-viewing altimeter mission. The cyan square encompasses the overall range of scales that can be resolved by a single non-repeat SAR altimeter (in this case for the lower bound we have used the along-track resolution). The cyan shaded area indicates ranges that can be resolved by one-off along-track observations. Phenomena are color-coded according on whether their observation mainly requires accuracy (red), precision (blue) or both (green). The red line marks the approximate limit in the spatial resolution achievable with standard altimetry.

4.1.1 Limitations in Resolution

A key point that emerges from the user consultation survey is the need for an improved spatial resolution (Figure 2-14). **The resolution of conventional altimetry represents an important limitation for accessing small spatial scales.** Conversely, SAR altimetry on board Cryosat-2 represents an unprecedented improvement that should allow reaching the smallest spatial scales, at least in the along track direction.

Low Resolution Mode (LRM) altimeters provide measurements which refer to a large footprint**.** The size of the footprint is different for each altimeter, and generally speaking can vary between about 3 and 12 km. In addition to this, the size of the LRM footprint is dependent upon the sea state, and more specifically on the SWH.

For conventional altimeters, the resolution of the altimeter coincides with the size of the altimeter footprint, and ultimately limits the capability to adequately observe ocean phenomena, assimilate altimetry data into models, and validate the altimetry products themselves.

Theoretically, 1 Hz LRM data are limited to 14 km resolution (twice the 7 km sampling), while 20 Hz LRM data are only limited by the footprint size. For this reason, the 20 Hz data help to extend the data coverage near the coasts, and allow a better detection of outliers in open ocean (mainly sigma bloom and rain cells).

Nevertheless, the reachable scales are not very small in existing LRM data sets. Beside the coarse resolution linked to the large footprint, this is also due to the fact that existing altimeters show a suspicious energy in the Sea Level Anomaly (SLA) spectrum between 10 and 80 km scales, so-called SLA spectral "bump" [Boy et al., 2012]. Some correlated errors dominate the signal at these wavelengths over most of the open ocean regions. As a consequence, some studies even claim that LRM altimetry is not trustable below 80 km [Xu and Fu, 2011]. This limitation affects both the 1 Hz data and the 20 Hz data of conventional altimeters, and the reason for it is not yet well understood.

However, it has been recently shown that the SLA spectral bump is much mitigated in SAR altimeters, in particular it is considerably reduced in pseudo-LRM, and apparently removed with full SAR processing [Boy et al., 2012]. This improvement is shown in figure 4.3, and it is thought to be linked to the footprint of the SAR altimeter itself, which does not overlap among consecutive measurements.

In the following sub-paragraphs, the limitations in resolution of existing altimetry products are separately identified for three different applications: observations of ocean phenomena, model assimilation and comparison with in-situ data.

4.1.1.1 Observations of Ocean Phenomena

Generally speaking, **limitations in the achievable spatial resolution can translate into limited capabilities to observe some phenomena occurring in the open ocean, particularly those at smaller scale.** As already said, all ocean structures with a spatial scale smaller than 14 km (drawn as a red line in figure 4-1), cannot be resolved with standard altimetry. Short spatial-scale open ocean phenomena like some small eddies and sharp fronts, coastal upwelling, and some of the mesoscale and shorter-scale physical-biological variations (figure 4-1) cannot be detected. In addition to this, internal waves and tides, important for ocean mixing, as well as natural and man-made slicks, rain cells, or small-scale wind bursts and convective cells in an unstable atmospheric boundary layer, would all cause rapid variations of the altimetric backscattered coefficient (σ_0) [Cotton et al., 2008]. Intuitively, these variations cannot be detected when the footprint is too large, as for conventional altimetry.

Some big uncertainties also lay in gaining accurate knowledge of ocean currents. Currents derived from altimetry often seem lower than those directly observed offshore, and a non-sufficient spatial resolution seems to contribute to such underestimation [Cotton et al., 2004].

From these considerations, **it clearly emerges that the improved along-track resolution from SAR mode data can largely contribute to a new or improved way to observe such phenomena, at least in the along-track direction.**

4.1.1.2 Model Assimilation

For operational ocean circulation models, altimeter data are required to constrain the mesoscale circulation through data assimilation. The current suite of altimeters provide information at the accuracy level required for this purpose, but they do not provide the time-space resolution with which to properly constrain the circulation [Cotton, 2010]. **Assimilation of spatially denser altimetry observations into models, and in this case of observations with higher along-track resolution, might have therefore the potentials to improve the forecasts, especially for regional and local models where the observations need a higher spatial resolution.**

Nevertheless, most of the assimilation schemes rely on the use of several altimeters (at least 2 satellites), with a coverage that is spatially homogeneous. In this sense, the Cryosat-2 mission samples very finely some areas of the globe, but leaves some other areas uncovered during several days (figure 4-2). This obviously makes the Cryosat-2 mission alone not suitable for ocean observation in near real time and model assimilation. Despite this, the higher spatial along-track resolution and finer sampling might still offer opportunities for improvements in some specific areas, and for those users who wish to observe small-scale phenomena in such areas.

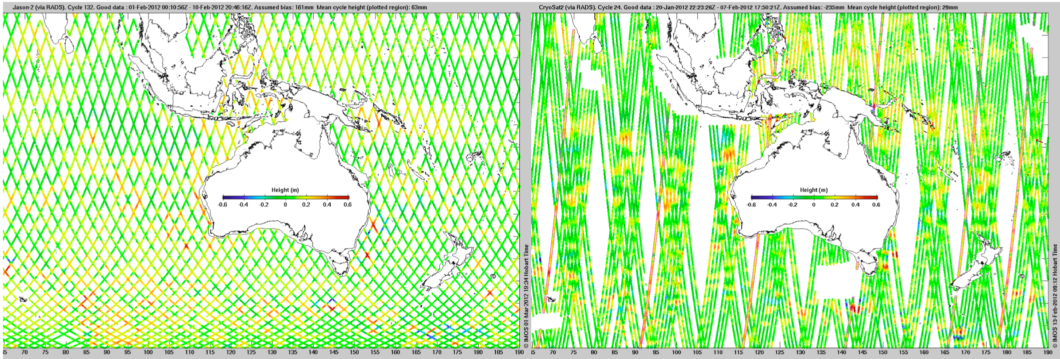


Figure 4-2.-. Left: coverage provided by Jason-2, cycle 132, from February 1st to February 10th 2012, around the coasts of Australia and Japan; right: coverage provided by Cryosat-2, cycle 24, from January 20th 2011 to February 7th 2012 [Griffin & Cahill, 2012].

An improved spatial along-track resolution brought about by Cryosat-2 could also potentially improve the coupled hurricane-ocean model forecasting. These models ingest altimetry-derived SSH and also zonal (U) and meridional (V) velocities with the best possible resolution and precision, together with temperature and salinity observations, into the coupled hurricane-ocean model at intervals of 5 days to produce a 5-day forecast of the hurricane.

A final aspect worth being mentioned is the opportunity that Cryosat-2 offers in improving the existing climatologies of the open ocean wind and wave fields. In some cases (notably wind speed) present-day sampling is inadequate for a complete monthly climatology at a scale appropriate to the auto-correlation length scale [Cotton et al., 2004]. In this context, any satellite that adds to this sampling would be welcome, and the resulting improved near-real time capability is paramount for shipping and offshore operations.

4.1.1.3 Comparison of Altimetry Products with in situ data

Another limitation that can be identified in current altimetric products is related to the validation of the products themselves. **Conventional altimetry measurements essentially represent a mean measurement of a large and variable footprint, while most of the in-situ data used to validate these measurements** (i.e. tide gauges, oceanographic buoys), **are essentially relative to a single point in space.** This often makes the comparison between altimetry measurements and in-situ data questionable, as the spatial scale to which they refer can be very different. Even in this case, any improvement in spatial resolution is considered as a positive factor contributing to make the two types of measurements more comparable.

4.1.2 Limitations in Precision and Accuracy

A second important aspect for open ocean issues, that has emerged from the survey is the need for a better precision and accuracy, for sea surface height, SWH and radiometric measurements.

As illustrated in figure 4-1, an improved precision (lower noise) in the altimetry measurements can lead to improved observations of open ocean phenomena like eddies and fronts, coastal upwelling, and mesoscale and short-scale physical biological-interactions. Phenomena that would benefit from an improved accuracy are instead global warming and sea-level rise and seasonal cycles. El Niño, Rossby waves, internal and surface tides and barotropic variability need both a high precision and high accuracy to be properly observed.

As far as precision is concerned, it has been shown (figure 4-3) that a reduction of the noise plateau of 30% can be achieved through SAR processing of Cryosat-2 data, compared to the noise level of Jason-2 spectral data [Boy et al., 2012].

In terms of SWH and wind speed, these are parameters that require a high spatio-temporal sampling, as well as a high accuracy and precision of the observations, for the purpose of offshore and shipping operations, operational oceanography and prediction of dangerous sea states, extreme events and rogue wave formation, as well as into wave model assimilation and validation. It has also been demonstrated that a higher precision in the estimation of both wind speed and SWH measurements would allow better estimation of air-sea fluxes (in particular the estimation of global mean air-sea gas transfer velocities), whose climatologies are centrally important in climate studies [Cotton et al., 2004].

Radiometric measurements from altimetry, related to wind speed, have always been particularly difficult, due to the difficulty in calibrating the measurement of backscattered coefficient. Even though it has been claimed that an improvement in the wind speed measurement of about 20% can be reached with SAR altimetry, this calibration issue will have to be tackled and overcome for Cryosat-2, as for conventional altimeters, to be able to obtain better measurements of wind speed and also of Sea State Bias (SSB).

Cryosat-2 SAR data can therefore provide measurements of range and SWH with a theoretical two-fold improvement in precision (see fig. 4-4), compared to standard altimeters [Jensen and Raney, 1998, Phalippou and Enjolras, 2007]. Recent results have approached that theoretical limit [Gommenginge et al., 2011] [Phalippou and Demeestere, 2011].

The accuracy shown by Cryosat-2 is also quite compelling, especially given that it does not carry a radiometer onboard. However, there are current limitations intrinsically linked to the SAR altimeters, in particular the lack of sensitivity to low SWH highlighted in [Smith, 2012], the current lack of a Sea State Bias (SSB) correction, and several problems and limitations specifically linked to the SIRAL altimeter onboard Cryosat-2 (non-optimal design of pulse transmission mode for ocean, oversampling and hamming window applied to Cryosat-2 data for sea-ice monitoring purposes, which is not optimal for ocean observation). These problems will have to be soon addressed to improve the performance of the SIRAL altimetry onboard Cryosat-2 and of the forthcoming SAR altimeters.

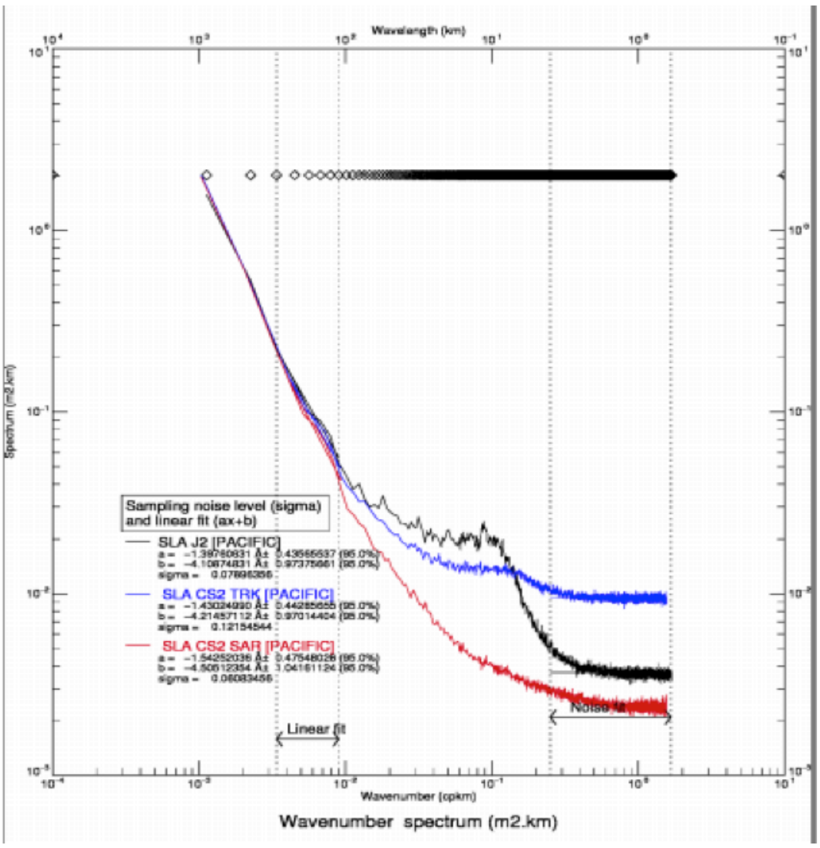


Figure 4-3.-. SLA spectra for Jason 2 data (black), Pseudo-LRM waveforms from Cryosat-2 data (blue), and SAR waveforms from Cryosat-2 data (red). The spectral bump is clearly visible and it is located at spectral wavenumbers between 10^{-2} and 10^{-1} 1/km, corresponding to wavelengths of 80 to 10 km, respectively. The

spectral bump is strongly attenuated for pseudo-LRM waveforms, and it is instead totally removed with SAR processing [Boy et al., 2012].

4.2 Limitations/Drawbacks in Coastal Areas

The outcome of the user consultation highlights that the majority of respondents state their area of expertise to be in the near-shore and coastal zone. This includes both operational and research users. Although the coastal community may be over-represented because of the inclusion of previous results from COASTALT and PISTACH, it nevertheless **confirms the strong demand for altimetry products in the coastal zone**.

4.2.1 General Limitations in Conventional Coastal Altimetry

Radiometer corrections and the retracking techniques represent the most important current limitations of conventional coastal altimetry.

Radiometer corrections are very difficult from 50 km up to the coast, mostly due to land contamination in the radiometer footprint (which makes the wet tropospheric correction particularly critical in coastal areas). Some important progress has been made in this field within the COASTALT project (www.COASTALT.eu), where an innovative correction (GPD) has been developed by measuring the water vapour delay through GPS signals [Fernandes et al., 2010]. However, this technique still relies on the presence of a number of GPS stations, as well as on integration of measurements with numerical models. It is therefore clear that progress in the improvements of such correction needs to be sustained.

As far as retracking is concerned, this usually affects a narrower coastal strip (approximately from 10 km away from the coast), but it is an even more complicated issue. Conventional Brown retracking is unsatisfactory in that strip, due to the land contamination in the footprint of the altimeter. Furthermore, the impact on the waveform strongly depends on the type of contamination (i.e. bay, sheltered area, land, or even from rain cells), and the effect on the waveform can be so far fully modelled only in some specific cases.

At present, there is not yet a universal approach for retracking close to the coast, which would work in all coastal conditions. A number of specialized retrackers have been developed within the

COASTALT and PISTACH projects, but some of them work for specific types of contamination. In addition to this, discrepancies and biases have been observed between different retrackers [Thibaut et al., 2012]. Beside the difficulty in comparing the results from different coastal retrackers, **this also poses a threat on the continuity of results between open ocean and coastal areas** [Quartly et al., 2012]**.**

It is clear that, despite such limitations, some important results have been achieved in the last years through COASTALT and PISTACH, and **the effort to recover the information from conventional altimeters close to the coast should be supported in the future, given the current availability of several years of altimetry data in the coastal zone still largely unexploited.**

4.2.2 General Limitations in SAR Coastal Altimetry

SAR altimetry can clearly bring numerous advantages, in that the higher along-track resolution and smaller footprint will imply a weaker land contamination, and the capability to get closer to coastal areas. However, it is worth to point out that this still depends on the orientation of the SAR altimetry footprint with respect to the coast (which is believed to affect the retrieval of SWH in particular [Thibaut et al., 2012]), and the morphology of the coast itself.

In terms of retracking, and as for the open ocean, a continuity and consistency of results needs to be achieved with both SAR and pseudo-LRM retrackers, with respect to conventional altimetry retrackers near the coast.

As far as radiometric corrections are concerned, Cryosat-2 does not carry a radiometer onboard, and does not perform dual-frequency measurements to implement the ionospheric correction. Even though the performance of the SIRAL altimeter seems to be quite good even without such corrections, **it is important to assess in the near future the impact of radiometric corrections in SAR altimetry, to what extent they are needed, and which of them is more important, particularly for coastal areas.**

Furthermore, several aspects like the effect of swell direction (given the footprint, which is no longer elliptically symmetric) and mispointing on SAR waveforms are not yet well understood, and need a proper investigation and characterization.

For these considerations, it emerges that **dedicated studies on the exploitation of SAR altimetry data specifically for the coastal zone should be addressed in the near future, in parallel with continuity of support for coastal altimetry from conventional altimetry datasets.**

4.2.3 *Limitations in Sampling and Resolution*

The user survey has highlighted a need for along-track measurements from (at least) 50km from land, right up to the coast, with high spatial resolution and high frequency posting rate (i.e. 20Hz). For conventional altimetry, 20-Hz data provide a better resolution and therefore better availability near land, but they are also much noisier. Nevertheless, the increased capabilities of high posting rate data to observe small-scale ocean structures near the coast have been recently highlighted with respect to 1-Hz products [Birol, 2012].

These demands are well met by the capabilities of Cryosat-2 SAR mode in coastal regions, where the higher along-track resolution is combined with a larger number of incoherently accumulated looks to reduce the speckle noise and therefore improve the precision of the measurements.

Sampling in general still remains one of the major limitations of the products, both from conventional altimeters and for Cryosat-2 data. The combined spatial/temporal sampling of a single mission is still not favourable for many coastal applications (sustained monitoring of coastal dynamics). As a result of this, altimetry at the coast still needs to be used in combination with in situ measurements and models, but it is currently believed that a full solution to this problem will only come from a constellation of altimeters [Cotton, 2010].

An interest for long (>1 year and for many users "as long as possible") datasets clearly emerges from the survey. **This implies a reprocessing of both all Cryosat-2 SAR data in the coastal zone since science products have become available (July 2010), and also the extraction and exploitation of all available coastal information from coastal datasets from conventional altimetry missions.** Current operational Cryosat-2 L2 SAR and LRM products are unable to meet this demand at present. Retracked Cryosat-2 LRM ocean data are available from RADS, but only at 1Hz. WP4000 of the CP4O project will develop the means to retrack Cryosat-2 SAR data with the SAM3 model, but only limited processing in a few case study regions will be undertaken within the scope of CP4O.

4.2.4 *Limitations in Accuracy and Precision*

The demand for high precision measurements of height (< 3cm) can be met by Cryosat-2 SAR mode data processed with the SAMOSA 3 model [Gommenginger et al., 2012]. However, **Cryosat-2 SAR mode is unlikely to meet the (strict) demand for height accuracy (bias) less than 3 cm. This is in view of the lack of correction for sea state bias in SAR mode, particularly in the coastal zone (but also for open ocean).**

While not many users replied to the questions related to Sigma0 wind speed, it is expected that these parameters will be extremely useful for SAR mode in the coastal zone, and in some cases essential to address the problem of SSB in the coastal areas. Indeed, the higher spatial resolution, and the short-scale changes of wave field in the coastal environment are likely to have an impact on corrections like SSB, which is not yet well-understood. It is also worth recalling that sigma0 (from which the SSB is derived) remains the most difficult parameters to measure from altimetry, mainly due to the difficulty in calibrating the altimetry returns.

4.2.5 Other Limitations and Drawbacks

The demand for instrument and geophysical corrections to be included in the Cryosat-2 SAR products is only partially met by operational products at present. Further work is needed to determine to what extent the information in existing Cryosat-2 L1B and L2 products addresses the needs of ocean and coastal users.

The request for Mean Dynamic Topography in Cryosat-2 SAR products in the coastal zone will also need to be given further consideration. The spatial resolution and accuracy in the coastal zone of existing MDT products is inadequate at present for coastal applications and it is questionable whether MDT would be of any value to altimetry users in the coastal zone.

4.3 Limitations/Drawbacks in Polar Ocean

The main conclusions from the survey with respect to Polar Ocean largely follow the conclusions for the Open Ocean as the Polar Ocean is basically an Open Ocean with the complication of the presence of sea ice.

4.3.1 Limitation in sampling and resolution

Conventional Altimetry naturally suffers from a polar Gap, which means that the orbit of conventional altimeters is such that only data within a certain latitude has always been available. Such limitation has been overcome with Cryosat-2, which is a satellite primarily dedicated to monitor sea-ice and polar regions. With its 369 days repeat orbit, at an inclination of about 92 degrees and an altitude of 717 km, Cryosat-2 covers almost all polar regions. Furthermore, the orbit configuration is chosen for optimum mapping of the cryosphere and ice-sheets, where the interferometric capabilities of the instrument provides uniform along-track and across-track coverage with this configuration.

As opposed to the Open Ocean, the Polar Ocean is located at such high latitude that the across-track distance (8 km at the Equator for a 369 days repeat) will become less than 3 km at 70° latitude, which is the southernmost limitation of the Arctic Ocean. With an across-track distance of 8 km on average, the tracks are very close to each other, and will have more than 60% identical footprint. Consequently, this type of orbit can be considered to be a near-repeat orbit. Moreover, some of the Polar Ocean oceanographic phenomena (approximately those with an extension > 10 km) are sampled with an equivalent repeat period that is much much shorter than the nominal 369 day repeat period of CryoSat-2.

The temporal sampling of CryoSat-2 altimetry is therefore even improved the Polar Regions, where the track distance narrows as mentioned previously. Parameters like SWH and wind speed, which require a high spatio-temporal sampling, can in this sense be in principle better sampled in the Polar Ocean than in general in the Open Ocean. However, a thorough investigation should be made to establish the accuracy of this statement. The limitation in resolution presented for Open Ocean, and linked to the footprint of LRM altimeters, is also largely reduced in the Polar Region as SAR mode is used in Cryosat-2 throughout most of the Polar Regions. However, in a very small and limited part of the North Atlantic the LRM is still applied up to 78N, and this still constitutes an important drawback. Nevertheless, the Cryosat-2 mask is not constant in time, and the LRM mode for such region is only applied during the summer month. In some coastal region and some test regions the SARIn mode is also applied.

Another important limitation is linked to the Cryosat-2 mode mask, which is not kept constant in time in the perimeter of the Polar Ocean. As a result of this, large and still unresolved jumps of magnitudes up to meters between the LRM and SAR model data are seen in the ESA GDR products [Andersen, 2012].

While some ocean phenomena (particularly the small-scale phenomena) could not be detected so far with conventional altimetry in polar oceans (i.e. Envisat, ERS-2 and ERS-1), these can be now in principle better seen using SAR altimetry, at least in the along-track direction. Generally speaking, improved along-track resolution from SAR mode data can largely contribute to a new or improved way to observe small-scale phenomena in polar oceans, provided that the accuracy of the measurements is sufficiently high.

It is very important that with the SAR mode the comparison between in-situ observations and altimetry will become "more comparable", and particularly for the Polar Regions where the SAR mode is applied throughout. Validation is of utmost importance to maintain altimetric accuracy. While most of the in-situ data used to validate these measurements (i.e. tide gauges, oceanographic buoys), are essentially relative to a single point in space with the SAR mode applied the comparison is naturally over a region, but a far smaller region than for LRM data.

4.3.2 Limitations in Precision and Accuracy

Generally speaking, the considerations on limitations in precision related to conventional altimeters, and the precision improvements brought about by Cryosat-2 SAR mode data, illustrated for open ocean in section 4.1.2, apply also for Polar oceans.

However, there are some differences between the two types of ocean in terms of accuracy. **Measurements in Polar regions are frequently characterized by lower accuracy, due to the presence of sea ice which contaminate the radar reflections. This might result in periodic out-takes of data, as well as less accurate data compared with the open ocean.** Even the accuracy of the CryoSat-2 in the Arctic Ocean is far from the standard of existing satellite observations from Envisat / ERS-1 / ERS-2, as CryoSat-2 is not considered operational and as processing is constantly updated in the ESA records which clearly limit the accuracy over time [Andersen, 2012].

4.4 Limitations/Drawbacks for Sea-Floor Mapping

First, it should be noted that the user consultation survey can only provide limited input to the analysis of the limitations / drawback for sea floor mapping. The user survey also concluded that very few scientists work towards improving this parameter. However, this is not surprising, as the questionnaire was originally thought to target primarily the scientific research community, and only a very small community of scientists worldwide works in the field of using either conventional LRM or CryoSat-2 LRM/SAR to improve sea floor mapping and marine gravity field mapping.

However there are clearly thousands of general users who would benefit from improved sea floor mapping simply to obtain an improved bathymetry. Bathymetry is a key parameter in all ocean modelling and forecasting, as well as for operational purposes (e.g. shipping), and a better bathymetry can provide great improvements on a number of applications. As an example, it is expected that more than 50000 undersea mountains of height greater than 1 km exist, which are still unknown and uncharted [Smith, 2004; Andersen, 2008].

Cryosat-2 SAR data has the potential to detect and resolve ocean bathymetric features with an accuracy not achievable before. This is due to the increased along-track resolution offered by the SAR mode and the across track resolution offered by the 369 days repeat, the independence of the along-track length of the footprint from SWH, and the increased range precision provided by the SAR instrument/processing.

The improvements offered by a SAR altimeter are graphically illustrated in figure 4.4.

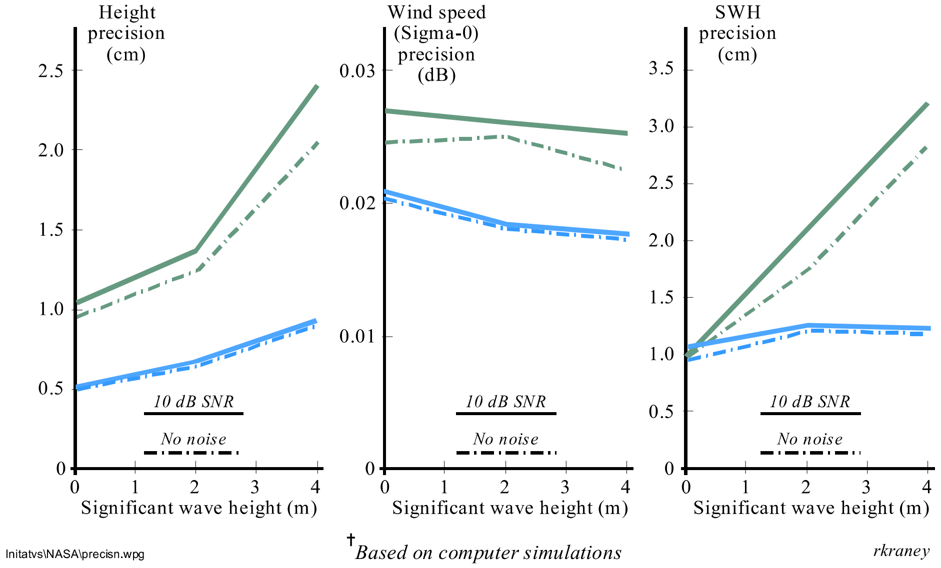


Figure 4-4.- The simulated height precision, wind speed precision and SWH precision of 1 Hz observations derived with a DD instrument (bright blue curve) compared with a conventional satellite altimeter (green curve) [Jensen and Raney, 1998].

As mentioned this has a great potential to ocean modelling and climate, but also to geology, as shown in Table 4.1.

Table 1. Wavelength and amplitude resolution required for typical geologic targets.		
Target	**Wavelength**	**Amplitude**
Buried cavities, tunnels, tanks	1 - 10 m	5 - 100 μGal
Pediment and seismic weathering layer thickness, shallow gas pockets, karst	10 - 200 m	.05 mGal - 0.2 mGal (200 μGal)
Shallow salt domes and cap rock	200m - 1 km	0.1 - 0.3 mGal
Anticlines, faults, deep salt dome flanks and overhang	500m - 4 km	0.2 - 2.0 mGal
Deep sedi-mentary basin structure	2 km - 20 km	5 mGal
Sedimentary basin outlines and boundaries, plate tectonic structures	10 km - 100 km	10 mGal

Table 4.1 A list of wavelength and amplitude resolution required for typical geological targets which can be mapped from satellite altimetry.

Although SAR altimetry offers a potentially significant improvement in the along-track mapping of global marine gravity and sea floor topography, the major drawback remains in that the across-track resolution is not improved and still remains of roughly 8 km.

Without lowering the cross-track distance to a few kilometers, a large number of un-charted sea-mounts will still remain unmapped. The cross-track distance can be indeed lowered by flying the satellite in a geodetic mission mode where the satellite at random covers the Earth with denser and denser ground-tracks as times goes by (the configuration applied to GEOSAT in its geodetic mission).

However a far better choice would be a Near-Exact Repeat Mission (N-ERM). The advantage of such a mission would be that the cryospheric and oceanographic observations would suffer nearly no degradation.

In the N-ERM orbit, the ground tracks will not be repeated, but the earth will gradually be covered with denser and denser ground-tracks throughout the duration of the mission. It is estimated that a SAR altimeter on board an N-ERM would gradually increase the density of tracks and result in 2 km cross-track distance after 4 years and 1 km track distance after 8 years [Andersen, 2008]. For most oceanographic and cryospheric studies the data can be considered as repeating, whereas for geodetic and geophysical studies this could lead to noticeable improvements.

A choice of a N-ERM seems to be the best possible choice to satisfy both the needs of cryospheric science, geodesists/geophysical science and oceanographic science. For oceanography and cryospheric science the analysis of near-repeated observations should not affect the quality of the measurements, but this would need to be investigated in more detail.

4.4.1 Limitations in Resolution

It is of high importance to improve the resolution of current LRM sea surface height observations in order to accurate map sea floor bathymetric features. LRM altimeters provide measurements which refer to a large footprint, whose size can vary between 2 and 8 km giving **a minimum spatial resolution of features on the sea bottom of 16 km that can be resolved**. This represents an important limitations for current bathymetric charts.

The smallest resolvable scale of bathymetric features degrades even more close to the coast, where wavelengths shorter than 30-40 km cannot be interpreted with sufficient confidence, and the raw altimeter data are often missing or unreliable close to the coast [Cotton et al., 2008]. The offshore exploration industry would benefit from having altimeter data with as much resolution as possible and extending as near-shore as possible, since most sedimentary basins lie close to the shore.

Another drawback of LRM altimeters is that their footprint (their resolution) is not constant, but depends on the sea state, and more specifically on the SWH, and it is well known that the Southern Ocean has very large SWH which further limits accuracy of bathymetric maps from altimetry in this region.

In this context, the SAR altimeter offer the only realistic method for mapping small seamounts. The mapping of the morphology of geophysical structures in the 10-20 km spatial range is of vital importance to a number of geophysical and oceanographic disciplines, including tsunami warning, ocean current steering, ship safety and mineral exploration [Andersen, 2008].

4.4.2 Limitations in Accuracy

The accuracy of sea surface height observations is not the prime quantity for sea floor mapping. This is because only limited wavelength band (typically between 5 and 100 km spatial wavelength can be determined from satellite altimetry. Longer wavelength is more accurately determined from a combination of marine gravity observations and satellite based gravity observations from GOCE and GRACE. At shorter wavelength than 5 km attenuation due to the "upward continuation" (the attenuaton of signals from short wavelength features, which also increases for increasing depth of the ocean) will limit the possibility to detect undersea mountains [Andersen, 2008].

4.4.3 Limitations in Precision

From the user survey the need for a better sea surface height precision was highlighted. **Improved precision is highly correlated with improvement in sea floor bathymetry.** This is because the ability with which the sea surface height or sea surface slope can be determined directly linked with the ability to produce better gravity field and sea floor bathymetric maps from satellite altimetry.

It is important to be also aware of the fact that existing geophysical exploration maps have been derived from geodetic mission altimetry from GEOSAT (1985-1986) and ERS-1 (1994). Current day altimeters are more accurate and the potential improvement in the Precision of the SAR altimeter compared with these "old" instruments is most likely to be even higher than the factor of two to three indicated in Figure 4.4.

The SAR altimetry observations can offer the combination of high resolution and increased range precision which is the key element to improved sea floor bathymetry maps. The ability to use LRM data for sea floor mapping using existing altimetric observations (retracked geodetic mission from ERS-1 and Geosat have been exhausted with the DTU10 bathymetry [Andersen et al., 2005] and Sandwell and Smith V18.1 bathymetry [Sandwell and Smith, 1997].

4.5 Data Limitations

In this last paragraph we present some technical limitations, more specifically related to data (format, delivery, latency etc.).

4.5.1 Limitations in Data Format

One important issue emerging from the survey for SAR data, is the explicit need from the user to access Full Bit Rate (FBR) data, or stack data, as well as to have access to information about how the SAR L1b processing is carried out. This reflects the desire from the users to start using low-level data and waveforms for their research more and more often, rather than relying only on the standard and averaged products.

Another issue that has been encountered in the user survey is the difficulty sometimes experienced by the users to access 1800 Hz data (individual echoes) from conventional altimeters.

One user expresses the wish to have dedicated data processing software and tools for the future, to work with altimetry data (whereas from the PISTACH survey it emerged that most of the users currently use the general-purpose Matlab software).

An expert user highlights instead the problem of the existence of widely varying data formats (even for the same mission), some of which of impractical structures, as well as of the need for fixing bugs in the data and upgrade products more quickly in the future.

4.5.2 Limitations in Data Timeliness and Delivery

Even though the delayed mode is still predominant among users, a non-negligible and increasing number of them expressed **the need for data availability in Real Time (RT) and Near-Real Time (NRT)**. RT and NRT products are nowadays routinely available from standard altimetry, in the form of Operational Geophysical Data Record (OGDR) for RT applications (produced within 1-2 hours of the satellite overflight) or in the form of Interim Geophysical Data Record (IGDR) for NRT applications (produced within 1-2 days of the overflight).

However, for SAR altimetry the need for data delivery in near real time introduces additional demands on the data processing chain that are difficult to meet at present. Retracked Cryosat-2 LRM ocean data are currently available from RADS, but only at 1Hz. WP4000 of the CP4O project will develop the means to retrack Cryosat-2 SAR data with the SAM3 model, but only limited processing in a few case study regions will be undertaken within the scope of CP4O.

It has also been noted by some users that the most used delivery mode (FTP) is often very slow.

5 Scientific and Operational User Requirements

This section contains a list of scientific and operational user requirements, together with some technical and scientific constraints needed to implement such requirements, for each analysed sub-theme. Some of the requirements drawn here are based on the results from WP1100 and WP1200, and from reports from previous projects.

Some of these recommendations have been inherited from the COASTALT and PISTACH projects, because the result of the merged present survey has not changed with respect to the past surveys. However, a number of recommendations, closely related to Cryosat-2 data and SAR altimetry in general, are quite new.

Furthermore, it is important to stress that a number of requirements presented have been derived from important remarks and presentations from the recent the 6th Coastal Altimetry Workshop and the OSTST'12 meeting.

Some of the requirements apply to both open ocean and coastal areas, and therefore they are repeated for each sub-theme. However, some of the technical and scientific constraints may change between the two different sub-themes.

5.1 Requirements For Open Ocean

This paragraph presents the list of user requirements for open ocean, both for products and for future R&D from Cryosat-2 data.

#	Requirements	Technical & Scientific constraints
1	**The SAR mode mask of Cryosat-2 should be applied to as many regions of the open ocean as possible.**	*Some key regions in the open ocean characterized by small-scale circulation patterns should be identified, and the SAR mode mask should at least be used for those regions.*

2	**Provision of SAR mode retracked SSH and SWH in open ocean as high-frequency (20Hz) products, mainly along-track, but also 2D-gridded.** **It is recommended to retain also 1 Hz products as complementary information.**	*Optimal SAR altimeter waveform retracking methods (e.g. fully analytical vs numerical or semi-analytical) need to be defined.* *The issue of a computationally efficient implementation (i.e. through the use of LUT) should be addressed, particularly for NRT and RT applications.* *The quality of operational Cryosat-2 L1B multi-looked waveforms needs to be assessed (e.g. check stacking, impact of datation error).* *Investigations on how to improve the capability of SAR altimeters (i.e. in low sea state conditions) are needed.* *Studies on the impact of other factors like swell direction and mis-pointing need to be addressed.* *The inter-calibration (or absolute calibration) of the different open ocean retrackers (i.e. conventional Brown retrackers, SAR retrackers, pseudo-LRM retrackers) should be addressed to guarantee continuity and consistency of results.*
3	**Auxiliary reference data (i.e. MDT) for open ocean should be provided to the users.**	
4	**SAR-derived Sigma0 and wind speed data in open ocean should be provided.**	*Algorithm to derive Sigma0 from the retracker output (Pu) needs to be defined.* *The applicability of LRM-derived wind speed algorithms to SAR-mode data needs to be established. If existing models cannot be applied, new SAR-specific wind speed algorithms need to be developed.*
5	**A SSB correction for SAR mode altimetry over open ocean has to be developed.**	*Need for an increase of the amount of SAR mode data, currently insufficient to apply the standard methods to develop SSB models (e.g. non-parametric method).* *A proper derivation of Sigma0 and wind speed is necessary to derive a SSB correction (see point 4).*
8	**Assessment of the accuracy of the results from Cryosat-2 data without radiometric corrections in open ocean**	*Identification of the most crucial and urgent atmospheric corrections for SAR altimetry (if any), to improve the performances in open ocean. Development of atmospheric corrections for Cryosat-2 data in open ocean.*
7	**Independent validation datasets should be extended to improve the reliability of results from open ocean altimetry.**	*The standard validation with Tide Gauges should be always complemented with additional in-situ data from oceanographic buoys, HR radars etc. whenever possible.*
8	**Inclusion of retracked SSH/SWH from Pseudo-LRM in the same SAR Product for reference purposes**	*Allow straight forward cross-validation of SAR mode products with currently existing LRM retrackers.*

5.2 Requirements For Coastal Zones

A list of scientific and operational requirements for SAR mode altimeter data in the coastal zone, including details of technical and scientific constraints for the methods and models to be developed, is presented.

#	Requirements	Technical & Scientific constraints
1	**Provision of SAR mode retracked SSH and SWH in coastal areas, as high-frequency (20Hz) products, mainly along-track, but also 2D-gridded.** **It is recommended to retain also 1 Hz products as complementary information.**	*Optimal SAR altimeter waveform retracking methods (i.e. fully analytical vs numerical or semi-analytical) need to be defined.* *The issue of a computationally efficient implementation (i.e. through the use of LUT) should be addressed, particularly for NRT and RT applications.* *The quality of operational Cryosat-2 L1B multi-looked waveforms needs to be assessed (e.g. check stacking, impact of datation error).* *Investigations on how to improve the capability of SAR altimeters (i.e. in low sea state conditions) are needed.* *Studies on the impact of other factors like swell direction and mis-pointing need to be addressed.*
2	**Re-processing of all the past altimetry datasets in the coastal zone.**	*Further studies are needed on improving wet tropospheric corrections in the coastal areas.* *Further development on retracking techniques in coastal areas are needed.*
3	**Processing of all Cryosat-2 SAR mode data in coastal zone since July 2010.**	*Means, facilities and resources required to process full Cryosat-2 SAR mode data archive need to be identified.*
4	**Provision of SAR-derived Sigma0 and wind speed data in coastal areas**	*Algorithm to derive Sigma0 from the retracker output (Pu) needs to be defined.* *The applicability of LRM-derived wind speed algorithms to SAR-mode data needs to be established. If existing models cannot be applied, new SAR-specific wind speed algorithms need to be developed.*
5	**Development of sea state bias correction for SAR**	*Quantity of SAR mode data over water is insufficient to apply the standard methods to develop SSB models (e.g. non-parametric*

	mode altimetry in coastal zone.	*method).* *A proper derivation of Sigma0 and wind speed is needed to derive a SSB correction (see point 4).* *Continuity and consistency of SSB corrections between open ocean and coastal areas has to be ensured.*
6	**Different SAR data processing methods (particularly focusing and retracking methods) need to be identified and/or developed for the coastal zone, compared to open ocean.**	*Dedicated coastal retrackers might have to be developed for SAR altimetry data in the coastal zone (as for conventional coastal altimetry).* *The impact of ground-track orientation with respect to the coast should be addressed in SAR altimetry in the coastal zone.* *SAR data also need to be complemented with pseudo-LRM data (for reference purposes).*
7	**Provision of SAR mode retracked data with necessary quality flags, instrument and Level 2 geophysical corrections.**	*Quality of instrument and geophysical corrections in operational Cryosat-2 SAR products needs to be assessed. If necessary, alternative corrections need to be developed or sourced.* *Some new quality flags and auxiliary data specific to SAR/SARIn in coastal zone need to be developed (e.g. coastal proximity parameter for SAR mode, cross-track angle for SARIn, land fraction in SAR footprint, misfit etc.).*
8	**Continuity and seamless transition in the results between open ocean and coastal areas need to be fully ensured.**	*Biases, offsets and discrepancies between SAR, pseudo-LRM and LRM, and coastal retrackers need to be analysed and removed.*
9	**An error budget, and a clear documentation on the characteristics and limitations of the products should be provided to the users.**	*The users need to be fully aware of what are the limitations in resolution, accuracy and precision of altimetry in different areas of the ocean, particularly in the coastal areas.*
10	**Assessment of the accuracy of the results in the coastal zone from Cryosat-2 data without radiometric corrections**	*Identification of the most crucial and urgent atmospheric corrections for SAR altimetry (if any), to improve the performances in coastal areas. Development of atmospheric corrections for Cryosat-2 data in coastal areas(i.e. as a combination of existing radiometer data and models).*
11	**Independent validation datasets should be extended to improve the reliability of results from coastal altimetry.**	*The standard validation with Tide Gauges should be always complemented with additional in-situ data from oceanographic buoys, HR radars etc. whenever possible.*

5.3 Requirements For Polar Ocean

The list of user requirements and technical and scientific constraints for polar ocean is presented below.

#	Requirements	Technical & Scientific constraints
1	**The SAR mode mask of Cryosat-2 should be applied to as many regions of the polar ocean as possible.**	*The LRM mode mask applied during the summer months in the small region in the North Atlantic up to 78N should be replaced by the SAR mode mask.*
1	**Elimination of the switching jumps between different mode masks for Polar areas.**	*A fixed mode switching mask for the Polar Ocean should be maintained until this issue is resolved. Any oceanographic studies using Cryosat-2 is currently (nearly) impossible in regions where these mode jumps appear.*
2	**Identification of strategies to deal with gappy data in Polar areas**	
3	**Assessment of the use of SAR measurements in the Arctic Ocean as near repeat observations.**	*Investigation to determine if SAR observations in the Arctic Ocean can be analysed and used as near repeat observation with a higher temporal resolution in the Arctic Ocean, with a repeat period much shorter than the 369 day repeat period of CryoSat-2.*

5.4 Requirements For the Sea Floor Mapping

The list of user requirements and technical and scientific constraints for Sea-Floor Mapping is presented in the table below.

#	Requirements	Technical & Scientific constraints
1	**Use of SAR mode mask for Cryosat-2 data on as many regions of the open ocean as possible, to improve sea-floor mapping.**	*The SAR mode mask should be maintained for at least one cycle of 369 days to explore the full potential of CryoSat-2 for sea floor mapping.* *Regions of high density of undersea mountains like the western north Pacific region are recommended to be selected for investigating of SAR data for at least 369 days.* *The SAR mode mask currently operating in the region in the southern Pacific ocean should be maintained for at least 369 days.*
2	**Request from the marine geophysical society with Jason-1 in a new geodetic phase to have more accurate and high resolution tide models,**	

	particularly in the coastal region.	
	Use of a Near-Exact Repeat Mission (N-ERM) configuration towards the end of life of Cryosat-2 phase in order to allow a full Earth Sea Floor Mapping.	- *By increasing the cross-track distance of consecutive ground tracks, the earth could be gradually covered in successive passes.* - In the N-ERM orbit, the ground tracks will not be repeated, but the earth will gradually be covered with denser and denser ground-tracks throughout the duration of the mission. - The data could thus be considered as repeating for most oceanographic and cryospheric studies, whereas it could be a remarkable improvement for geodetic and geophysical studies.

5.5 Requirements for Data Format, Delivery and Latency

In this section, we include a few requirements and technical constraints to data format, delivery and latency, which apply to all the subthemes. These are presented in the table below.

#	Requirements	Technical & Scientific constraints
1	**Development of the new products as delayed products, but with a processing chain compatible with the delivery of NRT or RT data**	*Means, facilities and resources to deliver SAR mode data in RT and NRT need to be identified.*
2	**Provision of quality flags with the new products.**	
3	**Provision of new products in NetCDF format, and distribution via *ftp*.**	
4	**Frequent update of altimetry datasets, to support in particular RT and NRT applications.**	*Datasets should be updated on a daily basis, or even every few hours if possible.*
5	**Definition of strategies to deal with the increased data volume from Cryosat-2 data.**	*Methods to deal with the large amount of hi-resolution SAR altimetry data (on the order of 20 times larger than the existing conventional altimetry ones) needs to be defined.*
6	**Improvements in data and data formats are needed**	*Data need to be reliable, bug-free, and products need to be upgraded more often.* *Data formats need to be standardized and uniform, with practical*

		structures.
7	**Provision of public documentation of SAR data processing**	*Public documentation for all stages of the SAR data processing should be provided for the benefit of the users.* *This should include clear information about how the SAR data are focused, stacked and retracked*
8	**Provision of full archive of SAR FBR and/or stack data in critical areas**	This should allow final scientific users to derive specially tailored applications especially in critical areas, such as coastal zones, and in-land waters.

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7 Annex I – CP4O Dossier / Questionnaire

CP4O: The Cryosat Plus 4 Oceans project

Scientific requirement consolidation

The ESA Cryosat-2 mission is the first space mission to carry an innovative radar altimeter that can operate in Synthetic Aperture Radar (SAR) mode. **The SAR mode capability of the Cryosat-2 altimeter offers a number of important benefits for ocean applications**.

The "Cryosat Plus for Oceans" (CP4O) project aims at **developing new products and methods** that fully exploit the capabilities of the Cryosat-2 SAR Altimeter, and **new scientific and operational applications of Cryosat-2 data** for four sub-themes: **open ocean, coastal seas, polar ocean and sea-floor mapping**.

One of the first tasks within the project is to undertake a USER CONSULTATION, to derive an updated analysis of the high-level needs per sub-theme, and WE NEED YOUR HELP to define these needs.

The following questionnaire is aimed at gathering feedback from a wide community of scientists and researchers, in order to match the requirements of the new products and methods with **your expectations**.

We kindly ask you to fill in the questionnaire, and to return it to the registration desk of the 6th Coastal Altimetry Workshop.

We thank you in advance for your valuable contribution to the project. Please, do not hesitate to contact us if you need any additional information.

Best Regards,

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Questionnaire Instructions

The following is an integrated questionnaire that covers all the sub-themes of interest for CP4O: **open ocean, coastal seas, polar ocean and sea-floor mapping**.

In the question is relevant for your work/research, provide one (or more) answers to it. If it does not apply to your area of expertise, leave it blank.

If you have already taken part to the user consultation survey for COASTALT, please ignore the questions with the WHITE heading (questions from the COASTALT questionnaire) and answer if possible to those with the RED heading (new questions for CP4O project).

USER PROFILE					
What kind of institution/enterprise do you work for?	Operational (public)	Research (public)	Operational (private)	Research (private)	Other
Specify the name:					

How do you study the ocean?	*In situ* measure-ments	Remote sensing	Numerical modelling	Data assimilation	Statistical modelling	Other
Specify data product and model:						

Do you consider your work to be?	Real-time	Near real-time	Delayed mode	Climate-related

Have you already used altimetry products for your work/research?	Yes	No
Please specify data product and parameter used:		
Please specify any problems encountered:		

How long are your usual datasets?	1 day long or shorter	Between 1 day and 1 month	Between 1 month and 1 year	Between 1 year and 10 years	Longer than 10 years and as long as possible

USER AREA OF EXPERTISE/APPLICATIONS				
Which one is your area(s) of expertise	Open Ocean	Coastal zone	Polar Ocean	Sea-floor mapping
Other important specifications:				

Purpose of use of the altimetry products	Modelling/ Validation	Modelling/ Assimilation	Analysis of Ocean Processes	Coastal Monitoring	Sea-ice monitoring
	Off-shore/near-shore exploration	Mixing	Tsunami detection	Sea-floor tectonics	Other (please specify)

OPEN OCEAN		
Do you need altimetry data in several regions of the open ocean?	Yes	No, just one
Which regions of the open ocean are of major interest for your work/research? Please specify:		

COASTAL ZONE			
If you work with COASTAL ZONE areas, what distance from the shoreline?	0-10 km	10-50 km	50-100 km
Please specify the region if possible:			

POLAR OCEAN			
If you work with POLAR OCEANS, where do your data come from?	North	South	both

Which NORTHERN sea is of interest for your work/research?	North Atlantic Barents Sea	Russian Sector	American/ Canadian/ Greenland sector	Other (please specify)

Which SOUTHERN sea is of interest for your work/research?	Atlantic Weddell Sea	Pacific Ocean	Indian Ocean	Other (please specify)

SEA-FLOOR MAPPING			
If you work with SEA-FLOOR MAPPING, are you mostly interested in areas	In open ocean	Close to the coast	both

PHYSICAL PROCESSES						
Which physical variables or processes do you work with?	Sea Level Anomaly	Absolute Dynamic Topography	Sea Surface Height	Waves	Geoid	
	Wind	Tides	Sea Ice	Other (please specify):		

Which of the following parameters do you USE? Give a score using 4 (very important to you) to 1 (marginal). Use 0 for parameters you do not use at all	Surface elevation	Significant Wave Height	Sea level anomaly	Wind speed	Temperature	Salinity	Other (specify)

PRODUCT CHARACTERIZATION				
Along-track frequency sampling	1Hz	20 Hz	1800 Hz	Other (please specify)
Which one do you currently use?				
Preferred/desired for the new product				

Spatial resolution (along-track)	< 15 Km	< 25 Km	Other (please specify)
Which one do you use currently?			
Preferred/desired for the new product (please specify a value for desired spatial resolution if possible)			

Data delivery delay vs. accuracy	Offline data (most accurate)	Near real-time data	Real time-data (least accurate)
Which one do you currently use?			
Preferred/desired for the new product			

PRODUCT CHARACTERIZATION (DATA PROVISION & RESOLUTION)		
What would be your preference? (please provide an estimation of the desired spatial and temporal resolution, if any)?	Higher temporal resolution and Lower spatial resolution	Higher spatial resolution and lower temporal resolution

How do you want products to be provided?	Along-track	2-D gridded

ACCURACY REQUIREMENTS				
Accuracy for height measurements	< 3 cm	< 10 cm	< 20 cm	Other (please specify)
Current product				
Preferred/desired for the new product				

Accuracy for significant wave height (SWH)	< 5%	< 10%	< 20%	Other (please specify)
Current product				
Preferred/desired for the new product				

Radiometric accuracy (=on σ_0 measurement)	< 0.2 dB	< 0.5 dB	< 1 dB	Other (please specify)
Current product				
Preferred/desired for the new product				

PRECISION REQUIREMENTS				
Precision for height measurement	< 3 cm	< 10 cm	< 20 cm	Other (please specify)
Current product				
Preferred/desired for the new product				

Precision for Significant Wave Height (SWH)	< 5%	> 5%	>10%	Other (please specify)
Current product				
Preferred/desired for the new product				

Radiometric precision (=on σ_0 measurement)	<0.2 dB	<0.5 dB	<1 dB	Other (please specify)
Current product				
Preferred/desired for the new product				

AUXILIARY DATA					
Supplementary data required for the new product:	Raw data	Quality controlled data	Data with global quality flags	Data with specific quality flags	Other
Please specify:					
Complementary information needed for:	HF fields to correct altimeter data	Applied atmospheric corrections	Applied geophysical corrections (tides, etc.)	Instrumental corrections	Other

AUXILIARY REFERENCE DATA			
Need of mean dynamic topography (MDT) to reference data?	Yes	No	I don't know

Need of geoid?	Yes	No	I don't know

Which other remote-sensing data products would be synergistic to your applications?	SAR	Optical	Infrared	Scatterometry	Others (please specify)
For which application/product?					

DATA FORMAT AND DISTRIBUTION					
What data format do you use?	NetCDF	ASCII	Binary	HDF	Other
Current					
Preferred/desired for the new product					

What delivery mode is easiest for you?	Upload data directly from remote servers	DVD	FTP	OPeNDAP	Other
Current					
Preferred/desired for the new product					

How often do you need the altimeter dataset to be updated?	Daily	Weekly	Monthly	2 to 4 times per year	Following mission cycles	Other
Current						
Preferred/desired for the new product						

OTHER REMARKS
Other comments and suggestions (i.e. any other needs you think may be met by a SAR type altimeter, any other limitations/drawbacks you find in current product, etc. which have not been reflected in the questionnaire's answers):

Annex: Altimeter products

Parameters that can be measured with altimetry

An altimeter on board a satellite measures the distance (range) between the reflecting surface and the satellite by processing the time delay between emission of the radar pulse and reception of its echo (waveform). The measurements are taken along the ground track, i.e. the projection of the altimeter orbit on the Earth's surface.

When the surface is water, (usually) the derived elevation of the surface is called **Sea Surface Height** (SSH). It is referenced to an ellipsoid and can be deduced from the range measurement by using a positioning system and knowing the orbit of the satellite. SSH is composed of two parts: a variable oceanic part, the Absolute Dynamic Topography (ADT), and a geophysical constant, the Geoid.

The measure of the Geoid at small scale is not known with enough accuracy; therefore the separation of SSH into ADT+ Geoid cannot be done. The SSH is instead decomposed into a mean (time-invariant) component, the Mean Sea Surface (MSS) and a Sea Level Anomaly SLA which takes into account the variation of height around the MSS due to the variability of the ocean dynamics (eddies, fronts, mean sea level change, tides, …).

$$SSH = MSS + SLA = Geoid + ADT$$

The MSS contains then both the Geoid and the permanent part of the ADT called the Mean Dynamic Topography MDT, which is due to the stationary part of the ocean currents. Its knowledge permits to bypass the Geoid to study the ADT of the ocean

$$ADT = MDT + SLA$$

which can then be used to compute absolute geostrophic currents.

Other parameters that can be estimated from the altimeter waveforms are the **significant wave height (SWH),** derived from the slope of the leading edge of the echo waveform, and the normalized radar cross-section **sigma0 (σ^0), which can be directly related to wind speed.**

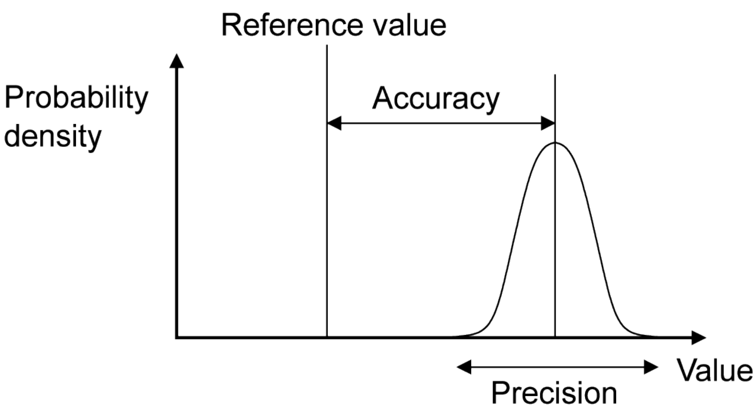
Product levels

Altimeter product levels range from Level 0 to Level 4 data depending on their processing stage:

- Level 0 corresponds to raw data received without any extra processing.
- Level 1 corresponds to positioned and timed raw data.
- Level 2 applies some corrections to level 1 data to rise above the instrumental and geophysical measurement errors (atmospheric perturbations, tides etc...). Level 2 data are given along-track separately for each mission. They are also called Geophysical Data Records (GDR).
- Level 3 data come from a data processing chain including multi-mission calibration and validation (SLA, SSH, ADT).
- Level 4 data refer to gridded products (as opposed to along-track), multi-mission intercalibrated.

A note on accuracy and precision of altimetric measurements

We assume that the altimeter's measurements are sample values from probabilistic distributions. Then *accuracy* is the relationship between the mean of measurement distribution and its "true" value, whereas *precision*, also called reproducibility or repeatability, refers to the width of the distribution with respect to the mean. The following figure illustrates these concepts graphically:



Different applications may have different requirements in terms of accuracy and/or precision. For instance, the estimation of the rate of global sea level rise from altimetry requires accuracy, but not necessarily precision given the huge numbers of measurements available to compute the mean rate. Instead, studies of El Niño require *both* accuracy (to discriminate the anomalous raised or lowered SSH value with respect to the mean) *and* precision, while the detection of fronts or bathymetric features requires only precision.