FDR4ALT

Products Requirements & Format Specification Document

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Issue	Date	Object
1.0	29/11/19	Creation (Draft)
2.0	20/11/20	Update with inputs from different partners (Intermediate version)
3.0	17/06/21	Update with inputs from different partners and ESA reviews take into account
4.0	25/11/21	Updated version for Phase 1 RM
5.0	25/03/22	Updated version with ESA RIDs taken into account
6.0	11/05/22	Updated version with minor modifications
7.0	04/08/22	Updated version with minor modifications (ESA RIDs)
8.0	02/12/22	Updated version with minor modifications (ESA RIDs)
9.0	02/05/23	Final version for final review meeting
9.1	04/08/23	Minor update before delivery of the final dataset

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1 Introduction

This document has been written in the frame of the FDR4ALT project, ESA contract N°4000128220/19/I-BG.

1.1 The FDR4ALT Project

In the framework of the European Long Term Data Preservation Program (LTDP+) which aims at generating innovative Earth system data records named Fundamental Data Records (basically level 1 altimeter and radiometer data) and Thematic Data Records (basically level 2+ geophysical products), ESA/ESRIN has launched a reprocessing program of ERS-1, ERS-2 and ENVISAT altimeter and radiometer dataset, called the FDR4ALT project (Fundamental Data Records for Altimetry). A large consortium of thematic experts has been formed to perform these activities which are:

1) To define products including the long, harmonized record of uncertainty-quantified observations.

2) To define the most appropriate level 1 and level 2 processing.

3) To reprocess the whole times series according to the predefined processing.

4) To validate the different products and provide them to large communities of users focused on the observation of the atmosphere, ocean topography, ocean waves, coastal, hydrology, sea ice, ice sheet regions.

1.2 Purpose and scope of this document

A main objective of the first task of the project is to provide design, definition, and implementation plan of functional and robust satellite-derived new types of products in the domain of satellite Altimetry, attaining the Fundamental Data Record (FDR) and Thematic Data Product (TDP) status.

The second task aims at developing and testing a novel data processing strategy.

The objective of this document is thus to define the FDR and TDP products in terms of rationale, format, and content. The definition of the products is an essential task for the success of the project and is based on a user-driven approach to maximize the use of the products for a wide range of applications and a wide range of users.

User requirements have been collected both for FDRs and TDPs. They have been analysed, compared, and completed with the ERS/ENVISAT Missions Requirements. A compilation of these requirements and format is provided hereafter.

The document is organized as follow:

1. Section 2 provides a description and all conventions of the FDR4ALT products. It aims at detailing all the aspects that are common to all FDRs/TDPs.
2. Section 2.13 provides the products requirements and format specification for all FDRs and TDPs, with an exhaustive list of all variables for each FDR/TDP. It is divided in sub-sections, corresponding to each FDR and TDP.
3. Section 4 describes auxiliary data files.

1.3 Definition of FDR and TDP products

The FDR and TDP do not address the same needs and objectives:

FDR address spatial agency needs to provide scientific community with robust altimetry mission time series (altimeter and radiometer), including archiving and documentation. This is the first mandatory step to build TDP products for different applications.

TDP address more specifically the user needs by providing dedicated products with suited geophysical parameters.

Definitions of the Fundamental Data Records and Thematic Data Products have been provided in the Statement of Work. These products have been also defined in the frame of the FIDUCEO project. As an example, a proposal that was given at a FIDUCEO workshop and that has been suggested by the FIDUCEO project team to the CEOS Working Group on Climate is:

> *A fundamental data record consists of a long, harmonised record of uncertainty-quantified sensor observations that are calibrated to physical units and located in time and space, together with all ancillary and lower-level instrument data used to calibrate and locate the observations and to estimate uncertainty.*

The FDR provides calibrated, quality-controlled, and uncertainty-quantified sensor data (Level 1) from a series of related satellite sensors where differences between sensors have been reconciled with harmonisation. 'Harmonisation' [**RD-13**] is a process to bring mutual consistency to sensors in a series by recalibrating the sensors – determining new instrument coefficients for the measurement function that converts raw signal to the level 1 product. Harmonisation is distinct from bias correction (which adjusts the determined level 1 product). It also is distinct from 'homogenisation', in that it respects, but does not correct for, differences between sensors (e.g., in their spectral response function).

To be compliant with the CEOS WGCV Quality Assurance Framework for Earth Observation (QA4EO), and to meet the expectations of the definition above, FDRs should provide all uncertainty information necessary for a propagation of uncertainty from Level 1 to higher level products. Such information includes not only pixel level uncertainty[1] information, but also information about error correlation[2] structures in spatial, temporal, and where appropriate spectral dimensions.

As well, for the Thematic Data Products, the main basics that shall apply, are derived from the experience of the consortium in altimetry products and user needs. For sake of clarity, some examples are taken from the Sea Level TDP.

Geophysical parameters relevant for scientific application
The TDP shall provide parameter that could be directly used by end users for their own application. The Sea Level TDP shall provide SSHA parameter, along with the corrections used for the computation to allow more expert users to replace some of the components by their own model.

Simple use with very few fields

[1] The standard uncertainty associated with a measured value is the standard deviation of the probability distribution function for the (unknown) error in that measured value.

[2] While the specific error in a particular measured value is always unknown, it is often possible to describe how this error is correlated with errors in other image pixels, in different spectral channels, and at different times.

The TDP shall provide only a few fields dedicated to the use of the TDP and targeted applications. On the contrary of L2 sea level products that provide a lot of different parameters and flags, the Sea Level TDP only provides the SSHA parameter, and the corrections used to compute this latter parameter.

Uncertainty associated to the parameters

The uncertainty is never provided in the existing altimetry TDP since it is difficult to derive it for each measurement. Nevertheless, the uncertainty is one of the key components in any measurement data set and is useful for the users.

Valid data identified

The TDP shall provide a clear information on the validity of each measurement thanks to a flag field.

Geographic coverage suitable for the TDP parameter

The geographic coverage shall be defined to fulfil the needs of the theme identified in each TDP.

Product organization to maximize TDP use by end users for different applications

The structure and organization of the TDP with respect to the structure of the L2 products shall be optimized to answer the user needs.

Seamless continuity between the altimetry missions

The TDP shall be used easily for the different missions without any need of additional calibrations or biases correction.

Product format following EO data principles

The TDP follows all the rules (NetCDF format, metadata information etc.) so that exploitation can be done over all system platforms and using different software.

Scientific content up to date following altimetry community recommendations

The TDP provides parameters with scientific content that is issued from recommendation of the different fields.

It is clear from the previous FDR and TDP descriptions that these definitions are very generic and must be adapted to the specific context of Altimeter and Radiometer records. This will be detailed in each specific section.

1.3.1 Fundamental Data Records

In the frame of the Long-Term Data Preservation (LTDP+) program, ESA set up a specific line of action aiming at generating and maintaining Fundamental Data Records. The crucial importance of satellite long term data records has been recognised. The objective of the FDR4ALT project is to consolidate such products in order to reinforce multi-disciplinary applications and maximize the scientific return of each mission.

In the context of the FDR4ALT project, altimeter and radiometer instrument measurements are concerned.

FDRs satisfy ESA needs for:

- long term EO data preservation,
- unified and coherent long-term time series,
- quality improvement and valorisation of MWR, RA & RA-2 level 1 products in term of content but also in terms of file format.
-

1.3.2 Thematic Data Products

For the Thematic Data Products, we have collected our understanding of the user needs for the different applications, summarized the context of thematic products in altimetry and radiometry and finally showed how our description of products answers to these needs while respecting the overall picture of the altimetry products.

2 Products Description and Conventions

This section gives an overview of the FDR4ALT products and introduces necessary conventions. It aims at describing as much as possible all that is common between all FDR4ALT products. The FDRs and TDPs are then fully described in section 2.13.

2.1 Global overview

The FDR4ALT project outcome is represented by 8 different data collections, each of them covering a specific FDR or TDP. Two data collections are FDR (Fundamental Data Records) products:

- ✓ FDR Altimetry
- ✓ FDR Radiometry

The six other data collections are TDP (Thematic Data Products):

- ✓ TDP Land-Ice
- ✓ TDP Sea-Ice
- ✓ TDP Ocean & Coastal Topography
- ✓ TDP Ocean Waves
- ✓ TDP Inland Waters
- ✓ TDP Atmosphere

Each of these 8 different product types has a unique identity and an own DOI but shares the same format, notations, conventions, and overall general structure. The FDR4ALT project aims at having unified FDRs and TDPs, while respecting the needs of each FDR/TDP to have the most relevant and useful products possible.

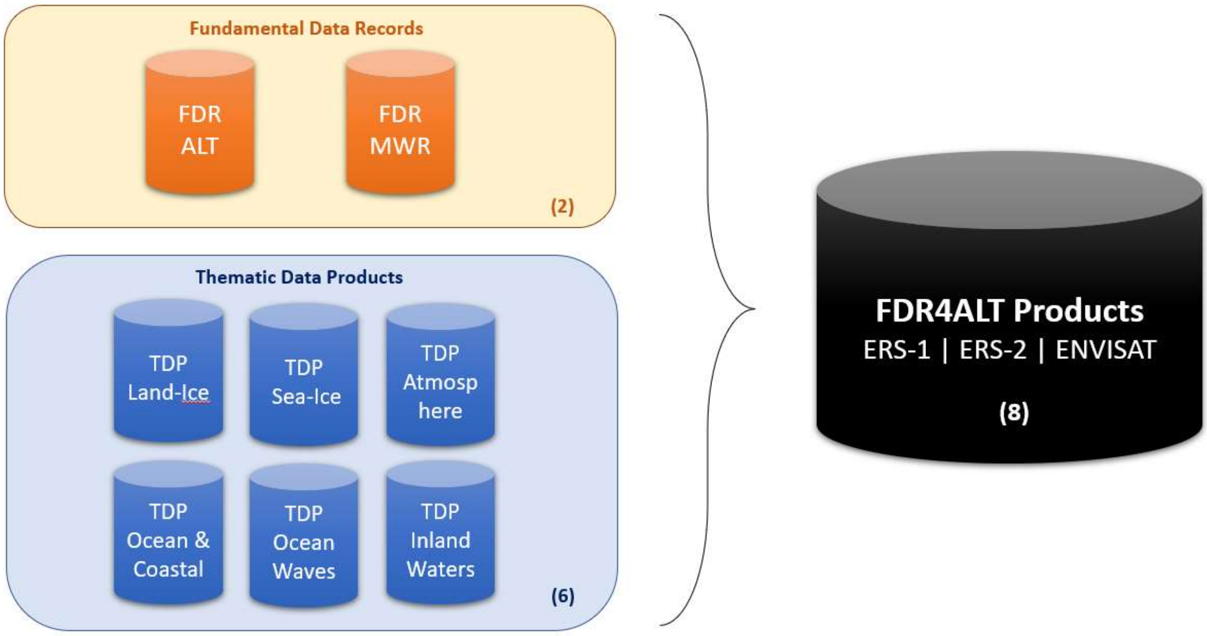


Figure 1 : FDR4ALT products dataset arrangement

2.2 File Format and CF convention

The NetCDF data format has been chosen to store the FDR4ALT products (one NetCDF file per pass). This format is extremely flexible, self-describing and has been adopted as a de-facto standard for many operational Earth Observation (EO) systems. What is more, the format follows the Climate and Forecast NetCDF conventions CF-1.8. A NetCDF file specifies dimensions, variables, groups, and attributes, which all have both a name by which they are identified.

2.3 File naming convention

The file naming convention for the FDR4ALT files is the following:

MMM_F4A_BBBBBBBBBB_LLLLLL_CCC_PPPP_YYYYMMDDTHHmmss_YYYYMMDDTHHmmss_VVV.ZZ

MMM	Mission ID
BBBBBBBBBB	ESA File Type
CCC	Cycle Number
LLLLLL	Region of interest (Land-Ice TDP and Sea-Ice TDP only)
PPPP	Pass Number
VVV	Product Version number

The mission ID is ER1, ER2 or EN1 for ERS-1, ERS-2 and ENVISAT respectively.

The start date and end date respect the ISO 8601 standard using **YYYYMMDDTHHmmss:**

YYYY	Year
MM	Month
DD	Day
HH	Hour
mm	Minutes
ss	Seconds

The ESA File type is 10 chars indicating the type of data (FDR or TDP), sensor (ALT or MWR) and surface (only for TDPs):

FDR Altimetry	ALT_FDR___
FDR Radiometry	MWR_FDR___
TDP Sea-ice	ALT_TDP_SI
TDP Land-ice	ALT_TDP_LI
TDP Inland Water	ALT_TDP_IW
TDP Atmosphere	MWR_TDPATM
TDP Ocean Waves	ALT_TDP_WA
TDP Ocean & Coastal Topography	ALT_TDP_OC

Area of interest is used <u>only for two product types:</u>

- <u>For the Land-Ice TDP:</u> it can be either GREENL or ANTARC, if the file contains data from Greenland and Antarctica, respectively.
- <u>For the Sea-Ice TDP</u>: it can be either NORTH_ or SOUTH_, if the file contains data from the northern or southern hemisphere, respectively.

Products Version number is VXX, XX being the version number.

The filename extension for NetCDF files is `.nc` by convention.

2.4 Time convention

Times are UTC, referenced to January 1, 1990 00:00:00.00 and respect the ISO 8601 implementation.

For example, 29th December 1991 at 01:10:00 UTC will be written "19911229T011000" in the file name and will be written "19911229T011000.000000" in the global attributes *history*, *first_meas_time* and *last_meas_time* (see section 2.8).

2.5 DOI

The Digital Object Identifier (DOI) is the CEOS and ESA preferred technology for a Persistent Identifier (PID). It is a unique long-lasting reference.

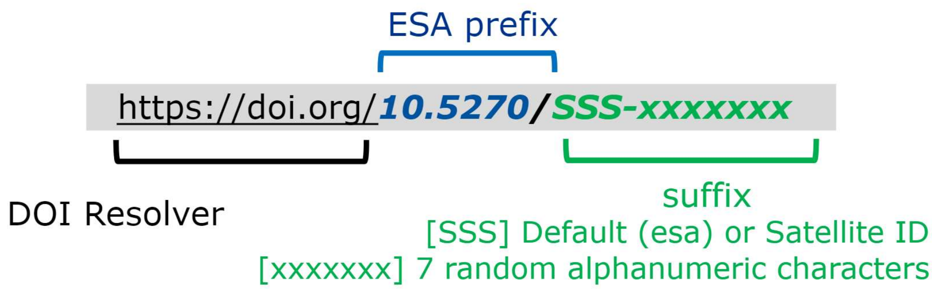


Figure 2 : DOI scheme.

For the FDR4ALT project, each FDR and each TDP have a dedicated DOI. This unique reference leads to a landing page that contains description, version history and additional data resources.

The DOI is coded as a global attribute and is therefore available in each product file.

Dataset Name	Product Type	DOI
FDR for Altimetry	ALT_FDR___	10.5270/ESA-a681fe7
FDR for Radiometry	MWR_FDR___	10.5270/ESA-79a176b
TDP for Sea-ice	ALT_TDP_SI	10.5270/ESA-2eb13ab
TDP for Land-ice	ALT_TDP_LI	10.5270/ESA-02d6cbf
TDP for Inland Water	ALT_TDP_IW	10.5270/ESA-e3e68ff
TDP for Atmosphere	MWR_TDPATM	10.5270/ESA-2d07033
TDP for Ocean Waves	ALT_TDP_WA	10.5270/ESA-4427c33
TDP for Ocean & Coastal Topography	ALT_TDP_OC	10.5270/ESA-7c37033

Figure 3 : List of DOI for each Product Type

2.6 Products slicing

The FDR4ALT products files are organized according to pass number (half-orbits). So, for instance for ENVISAT, in one cycle during the repetitive orbit, there are 1002 files.

Note that this choice implied for the project to have ORF files (cycle/pass number lists) without any gaps. In the frame of this study, a completeness of existing ORF files has been performed. New ORF files for ERS-2 have been defined to ensure optimal completeness of the products. More information about it can be found in the Roadmap & Product Summary Document [D-1-02]. We also propose to deliver the new ORF file developed in the frame of FDR4ALT to the users along with the products. It is delivered as an auxiliary file and is described is section 4.

2.7 File structure & the common data language

The Common Data Language (CDL) is used to describe the content of a data set. The CDL is a textual notation that describes the NetCDF objects, and it is human readable. The NetCDF utility "**ncdump"** converts NetCDF objects to CDL text. The NetCDF utility "**ncgen**" creates a NetCDF binary file from CDL text file.

For the FDR4ALT project, products use the NetCDF grouping strategy as explained in 2.10. Figure 4 displays the content of an example NetCDF file. All FDR4ALT products follow this structure.

Global attributes appear after the file name. Then, for each group, the description of the dataset takes the form:

group name {

dimension: ...
variables: ...
data: ...

}

NetCDF dimension declarations appear after the dimensions keyword, NetCDF variables and attributes are defined after the variables keyword and variable data assignments appear after the data keyword. CDL statement are terminated by a semicolon. Spaces, tabs, and newlines can be used freely for readability. Comments in CDL follow the characters '//' on any line.

Note that for this project, there are no group attributes but only global attributes.

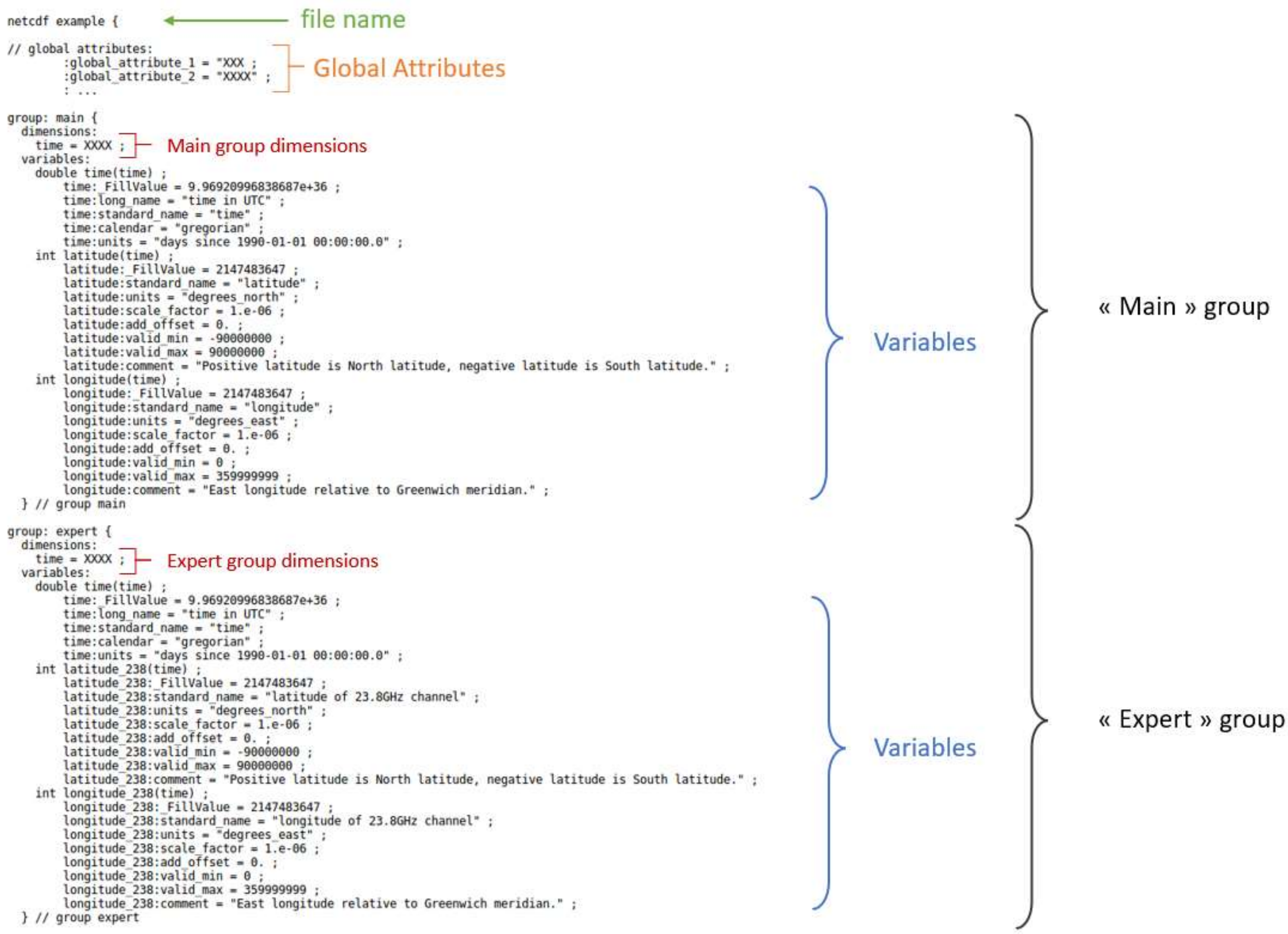


Figure 4 : FDR4ALT NetCDF structure with two groups (main and expert)

2.8 Global attributes

In this section we describe the global attributes.

Attribute name	Format	Description	FDR ALT	FDR MWR	TDP ATM	TDP OC	TDP SI	TDP LI	TDP IW	TDP WA
Conventions	String	NetCDF convention followed: «CF-1.8»	X	X	X	X	X	X	X	X
title	String	The descriptive title for the data set (ex. FDR4ALT Thematic Data Product : Sea-Ice)	X	X	X	X	X	X	X	X
institution	String	The name of the data producer ("ESA")	X	X	X	X	X	X	X	X
source	String	The method of production of the data «FDR4ALT Processing Baseline V1.0»	X	X	X	X	X	X	X	X
FDR_input	String	The FDR (ALT or MWR) and version used ("FDR ALT V1.0")			X	X	X	X	X	X
history	String	date and time of the file creation "Creation YYYYMMDD THHMMSS.mmmmmm"	X	X	X	X	X	X	X	X
contact	String	A text string giving the primary contact for information about the data set «ESA : pierre.femenias@esa.int, CLS : fpiras@groupcls.com, CLS : pthibaut@groupcls.com «	X	X	X	X	X	X	X	X
processing_center	String	Name of the processing center (ex "CNES CST")	X	X	X	X	X	X	X	X
reference_document	String	«FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556CLS-ENV-SP-19-0556"	X	X	X	X	X	X	X	X
mission_name	String	Name of the mission (ex "ERS-1")	X	X	X	X	X	X	X	X
altimeter_sensor_name	String	Name of the altimeter sensor (ex»RA-2»)	X		X	X	X	X	X	X
radiometer_sensor_name	String	Name of the radiometer sensor (ex "MWR")		X	X	X				
cycle_number	short	Cycle number	X	X	X	X	X	X	X	X
pass_number	short	Pass number in the cycle (relative pass number)	X	X	X	X	X	X	X	X

Attribute name	Format	Description	FDR ALT	FDR MWR	TDP ATM	TDP OC	TDP SI	TDP LI	TDP IW	TDP WA
first_meas_time	String	"Date and time of first observation in file (YYYY-MM-DD THHMMSS.mmmmmm)	X	X	X	X	X	X	X	X
last_meas_time	String	Date and time of last observation in file (YYYY-MM-DD THHMMSS.mmmmmm)	X	X	X	X	X	X	X	X
xref_olc_ptr	String	Name of the file containing the OLC Point Target Response parameters	X							
xref_lpf	String	Name of the file containing the Low Pass Filter (IF mask)	X							
xref_radiometer_characterisation_file	String	Name of the file containing the radiometer characterisation parameters		X						
Xref_radiometer_sidelobe_correction_file	String	Name of the file containing the radiometer on-Earth sidelobe correction		X						
ellipsoid_ref	String	WGS84	X	X	X	X	X	X	x	x
large_scale_uncertainty	double	Uncertainty at large scale				X				X
identifier_product_DOI	String	10.5270/esa-XXXXXXX	X	X	X	X	X	X	X	X
identifier_product_DOI_authority	String	http://dx.doi.org/	X	X	X	X	X	X	X	X

Table 2.1 : Global Attributes

2.9 Data Rates

There are different data rates in the FDR4ALT products:

- High rate of 20Hz, which is the standard rate for the FDR ALT products
- Intermediate rate of 5Hz which is the standard for the L2P wave products
- Low rate of 1Hz that is relevant for the Ocean & Coastal TDP
- Intermediate rate of 7Hz that is the native rate for the radiometric data
- Native PRF rate of the RA-2 instrument (1.8KHz) for the FDR ALT products
- Calibration rates, specific to the FDR ALT that store the calibration data

These different rates are managed using the NetCDF4 groups.

Rate	20 Hz	5 Hz	1 Hz	7 Hz	1.8 Khz	PTR data	LPF data
FDR ALT	X				X	X	X
FDR MWR				X			
TDP Atmosphere				X			
TDP Ocean&Coastal	X		X				
TDP Sea-Ice	X						
TDP Land-Ice	X						
TDP Inland-Water	X						
TDP Ocean Waves		X					

Table 2.2 : FDR4ALT products data rates

2.10 NetCDF grouping strategy

NetCDF-4 added support for hierarchical groups within NetCDF files. The FDR4ALT project uses the NetCDF4 grouping strategy. This decision was made upon a dedicated internal meeting among the partners and was validated by ESA. This helps to have user-friendly products, by separating the "main" variables from the more "expert" variables. For instance, geophysical corrections are included in the "expert" group, as they are not the main variables of the product, as opposed to e.g. the Sea Level Anomaly or the Significant Wave Height.

	Number of groups	Group names
FDR ALT	ERS : 3	main, expert/ancillary_cal_ptr, expert/ancillary_cal_lpf
	ENVISAT : 6 main groups (including 2 sub-groups)	Main/Ku, main/S, expert/ancillary_cal_ptr, expert/ancillary_cal_lpf, expert/ancillary_2K
FDR MWR	3	main, expert/ancillary_mwr, expert/ancillary_thermal
TDP Land-Ice	2	main, expert
TDP Sea-Ice	2	main, expert
TDP Ocean & Coastal	4	main, expert (both declined in data_20 and data_01)
TDP Atmosphere	2	main, expert
TDP Inland-Water	2	main, expert
TDP Ocean Waves	1	/

2.11 Variables

Variables are used to store the bulk of the data in a NetCDF file. A variable represents an array of values of the same type. A scalar value is treated as a 0-dimensional array. A variable has a name, a data type, and a shape described by its list of dimensions specified when the variable is created. A variable may also have associated attributes. A variable data type is one of a small set of NetCDF types. In this document the variable types will be represented as follows:

Variable type	Description
char	characters
byte	8-bit data signed
short	16-bit signed integer
int	32-bit signed integer
float	IEEE single precision floating point (32 bits)
double	IEEE double precision floating point (64 bits)

Table 2.3 : Variable types

2.12 Attributes

NetCDF attributes are used to store information about the data (ancillary data or metadata), similar in many ways to the information stored in data dictionaries and schema in conventional database systems. Most attributes provide information about a specific variable. These are identified by the name of that variable, together with the name of the attribute. Some attributes provide information about the data set as a whole. They are called global attributes and are described in Section 2.8. The following table shows the variable attributes used in the FDR4ALT products.

Attribute	Description
_FillValue	A value used to represent missing or undefined data
add_offset	If present, this number is to be added to the data after it is read by an application. If both scale_factor and add_offset attributes are present, the data are first scaled before the offset is added.
calendar	Reference time calendar
comment	Miscellaneous information about the data or the methods used to produce it
coordinates	Identified auxiliary coordinates variables
flag_meanings	Provide descriptive words or phrases for each flag value. Used in conjunction with flag_values.
flag_values	Provide a list of the flag values. Use in conjunction with flag_meanings.
institution	Institution which releases the data
long_name	A descriptive name that indicates a variable's content. This name is not standardized.

quality_flag	Name of the variable(s) (quality flag) representing the quality of the current variable
scale_factor	If present, the data are to be multiplied by this factor after the data are read by an application. See also add_offset attribute
source	Data source (model features, or observation)
standard_name	A standard name that references a description of a variables content in the standard name table from CF convention
units	Unit of a variable's content. The value of this attribute must be a string that can be recognized by the UNIDATA's Udunits package. It refers to values after scaling and offset addition.
valid_max	Largest theoretical valid value of a variable. It must be the same type as the variable (this is not the maximum of actual data)
valid_min	Smallest theoretical valid value of a variable. It must be the same type as the variable (this is not the minimum of actual data).

Table 2.4 : Variable attributes description

Please note that to minimize the storage size and keep adequate numeric precision, some of the parameters are scaled using NetCDF scale_factor and add_offset attributes.

2.13 Products size

Table 2.5**Erreur ! Source du renvoi introuvable.** describes the size of the FDR4ALT products, per FDR/TDP as well as the number of files and the size of the FDR4ALT datasets.

Product		Nb of variables per file	Single file size	Cycle size (1002 files)	Total number of files	Full Dataset size after compression (*)
ALT_FDR___	ERS-1	78	~16 M	~16G	48995	266G
	ERS-2	78	~16 M	~16G	80352	476G
	ENVISAT	99	~30M	~30G	99770	1900G
MWR_FDR___	ERS-1	49	~3.8M	~3.7G	49067	57G
	ERS-2	49	~3.8M	~3.7G	150549	107G
	ENVISAT	49	~3.8M	~3.7G	101167	115G
ALT_TDP_SI	ERS-1	27	~1.2M	~1.2G	32310 (NH) 34850 (SH)	17G
	ERS-2	27	~1.2M	~1.2G	49448 (NH) 50668 (SH)	28G
	ENVISAT	27	~1.2M	~1.2G	66468 (NH) 32420 (SH)	28G
ALT_TDP_LI	ERS-1	51	~10M	~10G	44241 (Antarc) 17395 (Greenl)	119G
	ERS-2	51	~10M	~10G	76032 (Antarc) 18469 (Greenl)	201G
	ENVISAT	51	~10M	~2G	86657 (Antarc) 20621 (Greenl)	227G
ALT_TDP_IW	ERS-1	23	~0.09M	~90M	47942	1.7G
	ERS-2	23	~0.09M	~90M	78893	2.9G
	ENVISAT	23	~0.09M	~90M	98356	5G
MWR_TDPATM	ERS-1	19	~1.8M	~1.8G	49067	31G
	ERS-2	19	~1.8M	~1.8G	150549	62G
	ENVISAT	19	~1.8M	~1.8G	101167	63G

ALT_TDP_WA	ERS-1	5	~0.35M	~0.35G	48995	11G
	ERS-2	5	~0.35M	~0.35G	80352	18G
	ENVISAT	5	~0.35M	~0.35G	99770	19G
ALT_TDP_OC	ERS-1	50	~4.1M	~4.1G	48995	81G
	ERS-2	50			80306	134G
	ENVISAT	50			99770	156G
ALL PRODUCTS	/	**413**	**~36M**	**~36G**	**2 043 641**	**4.1T**

Table 2.5 : Description of FDR4ALT product and dataset sizes

(*) Here the compression corresponds to the EO-SIP encapsulation which is the final data format delivered to ESA.

Note that the product file size is an approximation: indeed, products are sliced by passes so the product size will vary depending on the number of points of the given pass.

3 User Requirements & Format Specifications

In this section, requirements & format specifications are fully described for each FDR and TDP. Each sub-section is organized as follow:

- An introduction giving an overview of the FDR/TDP
- User requirements (only for TDPs)
- Metadata description (number of variables, group names)
- List of global attributes used for the FDR/TDP
- Exhaustive list of all variables with their attributes

3.1 Common variables

In this section are described variables that are common for all FDRs and TDPs and are used for all NetCDF groups within the products.

To avoid redundancy and potential inconsistency, they will not be described again in each FDR and TDP section.

double time(time)	
_FillValue	9.969209968386869e+36
long_name	time in UTC
standard_name	time
calendar	gregorian
units	days since 1990-01-01 00:00:00
int latitude(time)	
_FillValue	2147483647
standard_name	latitude
units	degrees_north
scale_factor	1.e-06
valid_min	-90000000
valid_max	90000000
comment	Positive latitude is North latitude, negative latitude is South latitude
int longitude(time)	
_FillValue	2147483647
standard_name	longitude
units	degrees_east
scale_factor	1.e-06

valid_min	0
valid_max	359999999
comment	East longitude relative to Greenwich meridian

Please note that the time variable can be inside or outside groups depending on the situation:

- If the time variable is identical for all groups, it will be outside the groups to avoid redundancy. This concerns the Sea-Ice TDP and the Inland Waters TDP
- It the time variable changes depending on the group, it will be implemented within each group. This concerns the ALT FDR, the MWR FDR, the Ocean & Coastal TDP, the Land-Ice TDP, the Atmospheric TDP and the Ocean Waves TDP.

3.2 MWR Fundamental Data Records (FDR)

3.2.1 Introduction

The Fundamental Data Records mainly address level 1 information which consists in brightness temperatures. The MWR FDR products have the same format for ERS-1, ERS-2 and ENVISAT. Indeed, the microwave radiometers aboard the three missions are very similar in terms of:

- observation frequencies (23.8GHz, 36.5GHz)
- instrument architecture (unbalanced Dicke radiometer) which means they have the same calibration parameters and the same radiometric model

The section 3.2.4 provides the parameters composing the Fundamental Data Record. It is divided into the two following groups:

- main: homogenized and harmonized brightness temperatures collocated to the radiometer nadir time tag, along with its uncertainty and quality flag, and some user-friendly variables such as surface classification and coastal distance.
- expert: ancillary data, provided for long-term preservation purpose and to ease possible studies at instrument level without reprocessing the whole L0 dataset. This data is addressed to expert users, while for basic users, all relevant FDR parameters are available in main group.

3.2.2 Global attributes

Attribute	Value
Conventions	CF-1.8
title	FDR4ALT Fundamental Data Record: Radiometer
institution	ESA
source	FDR4ALT Processing baseline V1.0
history	Creation YYYYMMDDTHHMMSS.mmmmmm
contact	ESA: pierre.femenias@esa.int, CLS: fpiras@groupcls.com, msimeon@groupcls.com
processing center	CLS core system; CNES CST

reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556
mission_name	[ERS-1/ERS-2/ENVISAT]
radiometer_sensor_name	[ATSR-MW/ATSR-MW/MWR]
cycle_number	Cycle number
pass_number	Pass number in the cycle (relative pass number)
first_meas_time	Date and time of the first observation in file (YYYYMDDTHHMMSS.mmmmmm)
last_meas_time	Date and time of the last observation in file (YYYYMMDDTHHMMSS.mmmmmm)
xref_radiometer_characterisation_file	CONF_E1_FDRALT
xref_sidelobe_correction_file	S3A_MW_1_SLC_AX_20000101T000000_20991231T235959_20190620T120000___________________MPC_O_AL_004.SEN3/MWR_Side_Lobe_correction_v3-0.nc
ellipsoid_ref	WGS84
identifier_product_DOI	10.5270/ESA-79a176b
identifier_product_DOI_authority	http://dx.doi.org/

3.2.3 Metadata

Group	Number of variables	Dimensions
main	13	time
expert/ancillary_mwr	15	time
expert/ancillary_thermal	21	time

The expert group itself contains two sub-groups:

ancillary_mwr: homogenized antenna and brightness temperatures prior to colocalization, with averaged values of gain and residual temperature. This group has a different time and locations from main group since MWR data are not yet coregistered on nadir time tag.

ancillary_thermal: thermistances at instrumental sampling level. This group has also a different time and location from main group and ancillary_mwr since the thermal sampling level is different from measurement sampling.

Please note that in order to minimize storage size, some of the parameters are scaled using NetCDF scale_factor and add_offset attributes. This allows reducing the data size by truncating floats while keeping at least four digits precision.

3.2.4 Variables definition

Group: main
time variable is common with other products and described in section 3.1
latitude variable is common with other products and described in section 3.1
longitude variable is common with other products and described in section 3.1
int tb_238(time)

_FillValue	2147483647
long_name	Radiometer top-of-atmosphere brightness temperature at 23.8 GHz
standard_name	toa_brightness_temperature
units	K
scale_factor	1.e-04
coordinates	longitude latitude
quality_flag	tb_238_qual
valid_min	1200000
valid_max	3200000
int tb_365(time)	
_FillValue	2147483647
long_name	Radiometer top-of-atmosphere brightness temperature at 36.5 GHz
standard_name	toa_brightness_temperature
units	K
scale_factor	1.e-04
coordinates	longitude latitude
quality_flag	tb_365_qual
valid_min	1200000
valid_max	3200000
byte tb_238_qual (time)	
_FillValue	127b
long_name	Quality flag for top-of-atmosphere brightness temperature at 23.8 GHz
standard_name	quality_flag
units	1
flag_meanings	good degraded bad
flag_values	0b, 1b, 2b
valid_min	0b
valid_max	2b
coordinates	longitude latitude
byte tb_365_qual (time)	
_FillValue	127b
long_name	Quality flag for top-of-atmosphere brightness temperature at 36.5 GHz
standard_name	quality_flag
units	1
flag_meanings	good degraded bad
flag_values	0b, 1b, 2b
valid_min	0b
valid_max	2b
coordinates	longitude latitude
int tb_238_bias_adjusted (time)	
_FillValue	2147483647
long_name	Bias adjusted top-of-atmosphere brightness temperature at 23.8 GHz
standard_name	toa_brightness_temperature
units	K
scale_factor	1.e-04
coordinates	longitude latitude
int tb_365_bias_adjusted (time)	
_FillValue	2147483647
long_name	Bias adjusted top-of-atmosphere brightness temperature at 36 GHz
standard_name	toa_brightness_temperature
units	K
scale_factor	1.e-04
coordinates	longitude latitude
short tb_238_uncertainty(time)	
_FillValue	32767
long_name	Uncertainty on top-of-atmosphere brightness temperature at 23.8 GHz

standard_name	toa_brightness_temperature standard_error
units	K
scale_factor	1.e-04
coordinates	longitude latitude
short tb_365_uncertainty(time)	
_FillValue	32767
long_name	Uncertainty on top-of-atmosphere brightness temperature at 36.5 GHz
standard_name	toa_brightness_temperature_standard_error
units	K
scale_factor	1.e-04
coordinates	longitude latitude
int distance_to_coast(time)	
_FillValue	2147483647
long_name	distance to the coastline from GSHHG
units	m
scale_factor	100.0
coordinates	longitude latitude
comment	GSHHG data version 2.3.7
valid_min	-2147483646
valid_max	2147483646
byte surface_type_flag(time)	
_FillValue	127b
long_name	surface type from GSHHG
units	1
flag_values	0b, 1b, 2b, 3b, 4b
flag_meanings	ocean land lake island_in_lake pond_in_island
coordinates	longitude latitude
comment	GSHHG data version 2.3.7
valid_min	0b
valid_max	4b

Group: expert	
Group: expert/ancillary_mwr	
time variable is common with other products and is described in section 3.1	
int latitude_238(time)	
_FillValue	2147483647
long_name	latitude of 23.8GHz channel
standard_name	latitude
units	degree_north
scale_factor	1.e-06
valid_min	-90000000
valid_max	90000000
comment	Positive latitude is North latitude, negative latitude is South latitude
int longitude_238(time)	
_FillValue	2147483647
long_name	longitude of 23.8GHz channel
standard_name	longitude
units	degree_east
valid_min	0
valid_max	359999999
comment	East longitude relative to Greenwich meridian
scale_factor	1.e-06

int latitude_365(time)	
_FillValue	2147483647
long_name	latitude of 36.5GHz channel
standard_name	latitude
units	degree_north
scale_factor	1.e-06
valid_min	-90000000
valid_max	90000000
comment	Positive latitude is North latitude, negative latitude is South latitude
int longitude_365(time)	
_FillValue	2147483647
long_name	longitude of 36.5GHz channel
standard_name	longitude
units	degree_east
valid_min	0
valid_max	359999999
comment	East longitude relative to Greenwich meridian
scale_factor	1.e-06
int ta_238(time)	
_FillValue	2147483647
long_name	Radiometer antenna temperature at 23.8 GHz
units	K
scale_factor	1.e-04
valid_min	0
valid_max	3600000
coordinates	longitude_238 latitude_238
int ta_365(time)	
_FillValue	2147483647
long_name	Radiometer antenna temperature at 36.5 GHz
units	K
scale_factor	1.e-04
coordinates	longitude_365 latitude_365
valid_min	0
valid_max	3600000
int tb_238(time)	
_FillValue	2147483647
long_name	Radiometer top-of-atmosphere brightness temperature at 23.8 GHz
standard_name	toa_brightness_temperature
units	K
scale_factor	1.e-04
coordinates	longitude_238 latitude_238
quality_flag	tb_238_qual
valid_min	1200000
valid_max	3200000
int tb_365(time)	
_FillValue	2147483647
long_name	Radiometer top-of-atmosphere brightness temperature at 36.5 GHz
standard_name	toa_brightness_temperature
units	K
scale_factor	1.e-04
coordinates	longitude_365 latitude_365
quality flag	tb_365_qual
valid_min	1200000
valid_max	3200000
byte tb_238_qual (time)	
_FillValue	127b

long_name	Quality flag for top-of-atmosphere brightness temperature at 23.8 GHz
standard_name	quality_flag
units	1
flag_meanings	good degraded_orbit missing_cal invalid_cal outside_valid_range
flag_values	0b, 1b, 2b, 3b, 4b
valid_min	0b
valid_max	4b
coordinates	longitude_238 latitude_238
byte tb_365_qual (time)	
_FillValue	127b
long_name	Quality flag for top-of-atmosphere brightness temperature at 36.5 GHz
standard_name	quality_flag
units	1
flag_meanings	good degraded_orbit missing_cal invalid_cal outside_valid_range
flag_values	0b, 1b, 2b, 3b, 4b
valid_min	0b
valid_max	4b
coordinates	longitude_365 latitude_365
int gain_238(time)	
_FillValue	2147483647
long_name	Radiometer averaged gain for 23.8 GHz
units	mV/K
scale_factor	1.e-04
valid_min	0
valid_max	1000000
coordinates	longitude_238 latitude_238
int gain_365(time)	
_FillValue	214748364
long_name	Radiometer averaged gain for 36.5 GHz
units	mV/K
scale_factor	1.e-04
valid_min	0
valid_max	1000000
coordinates	longitude_365 latitude_365
int residual_temperature_238(time)	
_FillValue	214748364
long_name	Radiometer averaged residual temperature for 23.8 GHz
units	K
scale_factor	1.e-04
valid_min	-10000000
valid_max	10000000
coordinates	longitude_238 latitude_238
int residual_temperature_365(time)	
_FillValue	214748364
long_name	Radiometer averaged residual temperature for 36.5 GHz
units	K
scale_factor	1.e-04
valid_min	-10000000
valid_max	10000000
coordinates	longitude_365 latitude_365
Group: expert/ancillary_thermal	
time variable is common with other products and described in section 3.1	
latitude variable is common with other products and described in section 3.1	
longitude variable is common with other products and described in section 3.1	
int reflector_temperature (time)	

_FillValue	2147483647
long_name	Reflector temperature (Tp in radiometric model equations)
units	K
scale_factor	1.e-04
valid_min	0
valid_max	3600000
coordinates	longitude latitude
int skyhorn_feed_temperature (time)	
_FillValue	2147483647
long_name	Skyhorn feed temperature (Tcc in radiometric model equations)
units	K
scale_factor	1.e-04
valid_min	0
valid_max	3600000
coordinates	longitude latitude
int feedhorn_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz feedhorn temperature (Tfeed1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int feedhorn_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz feedhorn temperature (Tfeed2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int skyhorn_wg_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz skyhorn waveguide temperature (Tcw1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int skyhorn_wg_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz skyhorn waveguide temperature (Tcw2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int feedhorn_wg_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz feedhorn waveguide temperature (Tr1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000

int feedhorn_wg_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz feedhorn waveguide temperature (Tr2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int hccal_switch_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz Hot-Cold calibration switch temperature (Thc1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int hccal_switch_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz Hot-Cold calibration switch temperature (Thc2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int cal_switch_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz main antenna / calibration switch temperature (Tcal1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int cal_switch_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz main antenna / calibration switch temperature (Tcal2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int dicke_switch_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz Dicke switch temperature (Td1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int dicke_switch_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz Dicke switch temperature (Td2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude

valid_min	0
valid_max	3600000
int dicke_load_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz Dicke load temperature (Tref1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int dicke_load_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz Dicke load temperature (Tref2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int hot_load_temperature_238(time)	
_FillValue	2147483647
long_name	23.8GHz Hot load temperature (Th1 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000
int hot_load_temperature_365(time)	
_FillValue	2147483647
long_name	36.5GHz Hot load temperature (Th2 in radiometric model equations)
units	K
scale_factor	1.e-04
coordinates	longitude latitude
valid_min	0
valid_max	3600000

3.3 ALT Fundamental Data Records (FDR)

3.3.1 Introduction

The ALT Fundamental Data Record addresses level 1 information which mainly consists of waveforms and all instrumental information in particular those relative to the tracker (range and power). In this project, we also added some valued and user-friendly parameters like:

Distance to the shoreline (ERS, ENVISAT)
Surface type flag (ERS, ENVISAT)
Waveform classification (ERS, ENVISAT)
Offset tracking flag (ENVISAT)

It is obvious that being a direct measurement provided by the altimeter, the waveform cannot be provided in a different way than it is done in the current level 1 products (no corrections or alignment can be applied between missions for instance). However, a characterization of these waveforms can be provided in addition to the waveform itself. It can be provided thanks to classifier algorithms able to identify the different waveform shapes and to attribute a “classification number” to each of them.

For the FDR4ALT project, a dedicated neural network has been developed and implemented in order to classify both ERS-1 and ERS-2 waveforms. The same principles and methods already used in the ENVISAT/RA-2 classification (**RD-19**) have been implemented to ensure the continuity and the consistency between all the missions. The neural network waveform classification is provided in the ALT FDR. It is a new parameter that was not in the REAPER products (**RD-21**) nor in the ENVISAT V3.0 (**RD-21**) and that is very useful for all TDPs. For more information, one should refer to the Detail Processing Model document [D-2-01], the Validation Plan document [D-4-01] and the RoadMap & Products Summary document [D-1-02] where the algorithm and results are fully developed and explained.

For the instrumental information that is very specific to the altimeter itself, we chose to keep the names like the REAPER project and the ENVISAT reprocessing V3.1 respectively. This is done mainly to ensure continuity.

3.3.2 Global attributes

Attribute	Value
Conventions	CF-1.8
title	FDR4ALT Fundamental Data Record: Altimeter
institution	ESA
source	FDR4ALT Processing baseline V1.0
history	Creation YYYYMMDDTHHmmss.mmmmmm
contact	ESA: pierre.femenias@esa.int, CLS : jdaguze@groupcls.com, fpiras@groupcls.com,
processing center	CLS core system; CNES CST
reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556
mission_name	[ERS-1/ERS-2/ENVISAT]
altimeter_sensor_name	[RA/RA/RA-2]
cycle_number	relative cycle number int
pass_number	Pass number in the cycle (relative pass number)
first_meas_time	date and time of the first observation in file (YYYYMMDDTHHmmss.mmmmmm)
last_meas_time	date and time of the last observation in file (YYYYMMDDTHHmmss.mmmmmm)
xref_olc_ptr (ERS only)	E[X]_REAP_AUX_PTROLC_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMDD_RP01.DBL
xref_lpf	E[X]_TEST_AUX_IFFXXX_YYYYMMDDTHHMMSS_YYYYMMDDTHHMMSS_0001.DBL/RA2_IFF_AXVISAYYYYMMDD_HHMMSS_YYYYMMDD_HHMMSS
ellipsoid_ref	WGS84
identifier_product_DOI	10.5270/ESA-a681fe7
identifier_product_DOI_authority	http://dx.doi.org/

[X] being “1” or “2” respectively referring to ERS-1 and ERS-2 missions

3.3.3 Metadata

For the ALT FDR, the products fall into two different products for each mission (ERS/ENVISAT). Indeed, NetCDF are built with groups and subgroups to separate data origin and may be different according to the mission specificities. Groups and dimensions are detailed in the following tables:

For ERS-1 and ERS-2:

Group	Number of variables	Dimensions
main	59	time, fft_sample_ind_ku
expert/ancillary_cal_ptr	10	time
expert/ancillary_cal_lpf	1	fft_sample_ind_ku

The main group contains instrumental parameters from the Ku-band altimeters and the associated quality flags. Also, as described in section 3.3.1, additional user-friendly variables are provided to encourage product use.

The expert group contains two subgroups:

ancillary_cal_ptr: Point Target Response related parameters
ancillary_cal_lpf: Low Pass Filter array

For ENVISAT:

Group	Number of variables	Dimensions
main	43	time, fft_sample_ind_ku ,fft_sample_ind_s , dft_sample_ind_ku
main/Ku	26	time, fft_sample_ind_ku , dft_sample_ind_ku
main/S	15	time, fft_sample_ind_s
expert/ancillary_2K	12	time, fft_sample_ind_ku
expert/ancillary_cal_ptr	4	ind_ptr
expert/ancillary_cal_lpf	1	fft_sample_ind_ku

The main group contains two subgroups for Ku and S band related instrumental parameters. Also, as described in section 3.3.1, additional user-friendly variables are provided to encourage product use. The expert group contains three subgroups:

ancillary_cal_ptr: Point Target Response array for both Ku and S band
ancillary_cal_lpf: Low Pass Filter array
ancillary_2K: 1.8KHz data

3.3.4 Variables definition

The following tables provide the parameters composing the Fundamental Data Record.

Even if some fields are common between the three missions, we provide two different tables for ERS and ENVISAT because of the substantial differences between those missions and for the sake of clarity.

To minimize the storage size, some of the parameters are scaled using NetCDF scale_factor and add_offset attributes. This allows to reduce the data size by truncating floats while keeping at least four digits precision.

ERS-1/ERS-2(RA)

The following table concerns all data given at a 20 Hz rate.

Group: main	
Time, latitude and longitude variables are in common with other products and described in section 3.1	
byte fft_sample_ind_ku(fft_sample_ind_ku)	
units	count
long name	waveform index
byte alt_state_flag (time)	
units	1
_FillValue	127b
long_name	altimeter status flag: altimeter
flag_values	0b, 1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b
flag_meanings	occurrence dummy_ptr tracking_ocean tracking_ice ptr if other_status incoherent_status time_jump
coordinates	longitude latitude
comment	status for the current record, derived by the L1b processing. Time_jump is corruption of the SBC (Satellite Binary Clock) sufficient to put the time stamp outside the current file start/stop times.
byte alt_state_flag_tracking_surface (time)	
units	1
_FillValue	127b
long_name	altimeter status flag: tracking surface
flag_values	0b, 1b
flag_meanings	ocean ice
coordinates	longitude latitude
comment	applied tracking mode.
byte alt_state_flag_tracking_type (time)	
units	1
_FillValue	127b
long_name	altimeter status flag: tracking type
flag_values	0b, 1b, 2b
flag_meanings	tracking_from_acquisition tracking_preset tracking_from_tracking
coordinates	longitude latitude
comment	applied tracking method.
byte alt_state_flag_lost_track_assert (time)	
units	1
_FillValue	127b
long_name	altimeter status flag: lost track assert
flag_values	0b, 1b
flag_meanings	no yes
coordinates	longitude latitude
comment	indicates if the counter for the number of non-tracked waveforms is non-zero.
byte alt_state_flag_lost_track_alarm (time)	

units	1
_FillValue	127b
long_name	altimeter status flag: lost track alarm
flag_values	0b, 1b
flag_meanings	no yes
coordinates	longitude latitude
comment	indicates if the threshold for non-tracking waveforms have been reached, triggering a return to occurrence.
byte alt_state_flag_chirp_type (time)	
units	1
_FillValue	127b
long_name	altimeter status flag: transmitted chirp type
flag_values	0b, 1b
flag_meanings	ocean_chirp ice_chirp
coordinates	longitude latitude
comment	defines the type of chirp transmitted for the current record.
byte surface_type (time)	
_FillValue	127b
long_name	surface type from GSHHG
units	1
flag_values	0b, 1b, 2b, 3b, 4b
flag_meanings	ocean land lake island_in_lake pond_in_island
coordinates	longitude latitude
comment	GSHHG data version 2.3.7
valid_min	0b
valid_max	4b
int distance_to_coast (time)	
_FillValue	2147483647
long_name	distance to the coastline from GSHHG
units	m
coordinates	longitude latitude
comment	GSHHG data version 2.3.7
bytes avail_orbit_flag (time)	
units	1
_FillValue	127b
long_name	orbit availability flag
flag_values	0b, 1b
flag_meanings	cnes_poe_f esa_proc_v3.0
coordinates	longitude latitude
comment	when cnes_poe_f is not available, esa_proc_v3.0 is provided instead to fill some potential gaps.
int altitude (time)	
units	m
_FillValue	2147483647
long_name	altitude of the satellite: 18Hz
standard_name	height_above_reference_ellipsoid
scale_factor	1e-4
coordinates	longitude latitude
comment	altitude of satellite above the reference ellipsoid
short altitude_rate (time)	
units	m/s
_FillValue	32767
long_name	orbital altitude rate
scale_factor	1e-2
coordinates	longitude latitude

comment	altitude rate of satellite with respect to the reference ellipsoid.
int tracker_range (time)	
units	m
_FillValue	2147483647
long_name	ku-band altimeter range (no retracking)
standard_name	altimeter_range
scale_factor	1e-4
coordinates	longitude latitude
comment	all instrumental corrections included.
short peakiness (time)	
units	1
_FillValue	32767
long_name	peakiness on Ku band waveforms
scale_factor	1e-3
coordinates	longitude latitude
short range_cor_cog (time)	
units	m
_FillValue	32767
long_name	center of gravity correction to altimeter range
scale_factor	1e-3
coordinates	longitude latitude
comment	this value has been applied to the range estimates in the product to reference them to the antenna.
int range_cor_net_instr (time)	
units	m
_FillValue	2147483647
long_name	instrument correction to range
scale_factor	1e-3
coordinates	longitude latitude
comment	this instrument correction to range was applied to the onboard tracker value at L1.
byte qual_range_cor_net_instr (time)	
units	1
_FillValue	127b
long_name	quality flag for the instrument corrections to range
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	set if range_cor_net_instr = 0 (due to the filtering applied to the PTR correction)
short range_cor_doppler (time)	
units	m
_FillValue	32767
long_name	doppler correction to altimeter range
scale_factor	1e-3
coordinates	longitude latitude
comment	the Doppler correction to range is applied at L1 and included in the onboard tracker value.
short range_cor_doppler_slope (time)	
units	m
_FillValue	32767
long_name	delta Doppler correction to altimeter range
scale_factor	1e-3
coordinates	longitude latitude

comment	this value has been added to the range used to compute the offset_elevation_20hz value to correct for the effect of sloping terrain.
byte qual_wf_low_power (time)	
units	1
_FillValue	127b
long_name	quality flag for 20 Hz waveform data
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	bad: average waveform power is lower than configurable multiple of noise level
byte qual_wf_low_peakiness (time)	
units	1
_FillValue	127b
long_name	quality flag for 20 Hz waveform data
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	bad: waveform peakiness lower than threshold
byte qual_wf_high_peakiness (time)	
units	1
_FillValue	127b
long_name	quality flag for 20 Hz waveform data
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	bad: waveform peakiness higher than threshold
byte qual_wf_noisy (time)	
units	1
_FillValue	127b
long_name	quality flag for 20 Hz waveform data
flag_values	0b, 1b
flag_meanings	good bad
Coordinates	longitude latitude
comment	bad: power in noise gates is above threshold
byte qual_wf_bad_le (time)	
units	1
_FillValue	127b
long_name	quality flag for 20 Hz waveform data
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	bad: no significant leading edge detected by comparison of weighted sums of two range window gates
byte qual_wf_low_var (time)	
units	1
_FillValue	127b
long_name	quality flag for 20 Hz waveform data
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	bad: variance of waveform is below threshold
byte qual_wf_not_tracking (time)	
units	1
_FillValue	127b

long_name	quality flag for 20 Hz waveform data: waveform is not a tracking
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	indicates if the altimeter is tracking or not
byte qual_wf_reject (time)	
units	1
_FillValue	127b
long_name	quality flag for 20 Hz waveform data
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	master waveform QA rejection flag: set if any other flag rejects the waveform. This can be used as a master flag to filter on.
short agc (time)	
units	dB
_FillValue	32767
long_name	Ku band corrected AGC
scale_factor	1e-2
coordinates	longitude latitude
comment	AGC is corrected for instrumental errors due to the imperfections of the on-board attenuators.
int scaling_factor (time)	
units	dB
long_name	scaling factor for backscatter coefficient
_FillValue	2147483647
scale_factor	1e-2
coordinates	longitude latitude
comment	this scaling factor represents the backscatter coefficient for a retracked waveform amplitude equal to 1.
short inst_agc_corr (time)	
units	dB
_FillValue	32767
long_name	sigma 0 flight calibration factor
scale_factor	1e-2
coordinates	longitude latitude
comment	Sigma 0 Flight Calibration Factor, copied from the L1b product.
short agc_cal_factor (time)	
units	dB
_FillValue	32767
long_name	AGC calibration factor
scale_factor	1e-2
coordinates	longitude latitude
comment	AGC calibration factor, copied from the L1b product.
int p_ref (time)	
units	count
_FillValue	2147483647
long_name	power reference value
scale_factor	1e-2
coordinates	longitude latitude
comment	Power Reference Value, copied from the L1b product.
int sptr_jumps_corr (time)	
units	s
_FillValue	2147483647
long_name	SPTR jumps correction to range.

Scale_factor	1e-12
coordinates	longitude latitude
comment	SPTR jumps correction, copied from the L1b product.
int mcd (time)	
units	1
_FillValue	2147483647
long_name	L1b MCD bitfield
coordinates	longitude latitude
comment	MCD bitmask taken from the L1b product.
short power_waveform (time, fft_sample_ind_ku)	
units	count
_FillValue	32767
long_name	ku band power waveform
coordinates	longitude latitude
comment	ku-band waveform. Waveforms are corrected for the Low Pass Filter effects.
byte waveform_main_class (time)	
units	1
long_name	20 Hz Ku-band waveform main class
_FillValue	127b
flag_values	1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, 10b, 11b, 12b, 13b, 14b, 15b, 16b, 17b, 18b, 19b, 20b
flag_meanings	brown_ocean peaky noisy strong_peak brown_peak_trailing_edge brown_peak_leading_edge brown_flat_trailing_edge peak_end unknown brown_noise two_leading_edges shifted_brown, altered_leading_edge distorted_brown linear_rise_noise shifted_brown2 breakage_leading_edge linear_decrease_noise step_leading_edge peak_and_brown
coordinates	longitude latitude
comment	waveform classification: main class predicted by classification neural network and trained on feature shape of the waveforms. ERS-1/ERS-2 non applicable classes : 8, 12, 14, 19, 20.
byte waveform_second_class (time)	
units	1
long_name	20 Hz Ku-band waveform second class
_FillValue	127b
flag_values	1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, 10b, 11b, 12b, 13b, 14b, 15b, 16b, 17b, 18b, 19b, 20b
flag_meanings	brown_ocean peaky noisy strong_peak brown_peak_trailing_edge brown_peak_leading_edge brown_flat_trailing_edge peak_end unknown brown_noise two_leading_edges shifted_brown, altered_leading_edge distorted_brown linear_rise_noise shifted_brown2 breakage_leading_edge linear_decrease_noise step_leading_edge peak_and_brown
coordinates	longitude latitude
comment	Waveform classification: second most likely class predicted by classification neural network trained on feature shape of the waveforms. ERS-1/ERS-2 non applicable classes : 8, 12, 14, 19, 20.
short waveform_main_class_score (time)	
units	1
long_name	20 Hz waveform main class score

_FillValue	32767
scale_factor	1e-2
coordinates	longitude latitude
comment	waveform classification: probability associated to the main class (between 0 and 100, 100=strongest probability)
short waveform_second_class_score (time)	
units	1
long_name	20 Hz waveform second class score
_FillValue	32767
scale_factor	1e-2
coordinates	longitude latitude
comment	waveform classification: probability associated to the second most likely class (between 0 and 1, 100=strongest probability)
double window_delay (time)	
units	s
_FillValue	9.969209968386869e+36
long_name	window delay
scale_factor	1e-12
coordinates	longitude latitude
comment	window delay, copied from the L1b product.
short rx_dist_coarse (time)	
units	s
_FillValue	32767
long_name	coarse time delay
scale_factor	1.25e-08
valid_min	0
valid_max	-1
coordinates	longitude latitude
comment	coarse time delay, copied from the L1b product.
short rx_dist_fine (time)	
units	s
_FillValue	32767
long_name	fine time delay
scale_factor	1.25e-08
valid_min	0
valid_max	-1
coordinates	longitude latitude
comment	fine time delay, copied from the L1b product.
short num_flight_cal_meas (time)	
units	count
_FillValue	32767
long_name	number of flight calibration measurements
scale_factor	1.0
coordinates	longitude latitude
Comment	number of flight calibration measurements, copied from the L1b product.
int noise_floor (time)	
units	count
_FillValue	2147483647
long_name	noise floor estimate
scale_factor	1e-2
coordinates	longitude latitude
comment	noise floor estimate, copied from the L1b product.
int stl_disc_out (time)	

units	1
_FillValue	2147483647
long_name	STL discriminator output
scale_factor	1e-2
coordinates	longitude latitude
comment	STL discriminator output in slope units, copied from the L1b product.
int htl_disc_out (time)	
units	s
_FillValue	2147483647
long_name	HTL discrimator output
scale_factor	1.25e-12
coordinates	longitude latitude
comment	HTL discriminator output, copied from the L1b product.
int agc_disc_out (time)	
units	count
_FillValue	2147483647
long_name	AGC discriminator output
scale_factor	1e-1
coordinates	longitude latitude
comment	AGC discriminator output, copied from the L1b product.
htl_beta_branch (time)	
units	1
_FillValue	2147483647
long_name	HTL beta branch output
scale_factor	1.25e-14
coordinates	longitude latitude
comment	HTL beta branch output, per PRI, copied from the L1b product.
int rx_offset (time)	
units	s
_FillValue	2147483647
long_name	Receiver time offset
scale_factor	1.25e-11
coordinates	longitude latitude
comment	receiver time offset, copied from the L1b product.
int a_htl_coeff (time)	
units	1
_FillValue	2147483647
long_name	HTL filter alpha coefficient
scale_factor	1e-3
coordinates	longitude latitude
comment	HTL filter alpha coefficient, copied from the L1b product.
int b_htl_coeff (time)	
units	1
_FillValue	2147483647
long_name	HTL filter beta coefficient
scale_factor	1e-5
coordinates	longitude latitude
comment	HTL filter beta coefficient, copied from the L1b product.
int a_agc_coeff (time)	
units	1
_FillValue	2147483647
long_name	AGC filter alpha coefficient
scale_factor	1e-2
coordinates	longitude latitude
comment	AGC filter alpha coefficient, copied from the L1b product.

int b_agc_coeff (time)	
units	1
_FillValue	2147483647
long_name	AGC filter beta coefficient
scale_factor	1e-2
coordinates	longitude latitude
comment	AGC filter beta coefficient, copied from the L1b product.
int a_stl_coeff (time)	
units	1
_FillValue	2147483647
long_name	STL filter alpha coefficient
scale_factor	1e-1
coordinates	longitude latitude
comment	the STL filter alpha coefficient, copied from the L1b product.
int b_stl_coeff (time)	
units	1
_FillValue	2147483647
long_name	STL filter beta coefficient
scale_factor	1e-3
coordinates	longitude latitude
comment	STL filter beta coefficient, copied from the L1b product.
int slope (time)	
units	1
_FillValue	2147483647
long_name	slope parameter
scale_factor	1e-2
coordinates	longitude latitude
comment	slope parameter, in slope units, copied from the L1b product.

Calibration data are provided in an expert group with two subgroups (PTR and LPF related data) for the sake of clarity.

Group: expert	
Group: expert/ancillary_cal_ptr	
Time is in common with other products and is described in section 3.1	
int counter (time)	
units	1
_FillValue	2147483647
long name	ptr_counter
comment	record ptr counter associated to each Point Target Response data record. From OLC PTR auxiliary files
double time_delay_ocean (time)	
units	s
FillValue	9.969209968386869e+36
scale_factor	1e-12
long name	time delay ocean (position)
comment	from OLC Point Target Response auxiliary files
double time_delay_ice (time)	
units	s
FillValue	9.969209968386869e+36
scale_factor	1e-12
long name	time delay ice (position)
comment	from OLC Point Target Response auxiliary files
int main_lobe_width_ocean (time)	

units	s
FillValue	2147483647
Scale_factor	1e-8
long name	Point Target Response main lobe width ocean
comment	from OLC Point Target Response auxiliary files
int main_lobe_width_ice (time)	
FillValue	2147483647
scale_factor	1e-8
units	s
long name	Point Target Response main lobe width ice
comment	from OLC Point Target Response auxiliary files
int main_lobe_amplitude_ocean (time)	
FillValue	2147483647
scale_factor	1e-3
units	dB
long name	Point Target Response main lobe amplitude ocean
comment	from OLC Point Target Response auxiliary files
double main_lobe_amplitude_ice (time)	
FillValue	2147483647
scale_factor	1e-3
units	dB
long name	Point Target Response main lobe amplitude ice
comment	from OLC Point Target Response auxiliary files
byte ptr_method (time)	
units	1
_FillValue	127b
long name	final method calibration used
flag_values	0b, 1b
flag_meanings	simple_gaussian_fitting three_points_fitting
comment	from OLC Point Target Response auxiliary files
int n_stack (time)	
units	1
_FillValue	2147483647
long name	number of Ku flight calibration measurement
comment	Number of measures for Ku Flight calibration factor evaluation. From OLC PTR auxiliary files
Group: expert/ancillary_cal_lpf	
double lpf_ku (fft_sample_ind_ku)	
units	count
long_name	Ku-band Low Pass Filter
comment	Ku-band Low Pass Filter from the CAL2 measurement.

ENVISAT(RA-2)

The following table concerns all data given at 18 Hz.

Group: main	
Time, latitude, and longitude variables are in common with other products and described in section 3.1	
byte fft_sample_ind_ku(fft_sample_ind_ku)	
long_name	index of fft samples in the waveforms: Ku band
units	count

byte fft_sample_ind_s(fft_sample_ind_s)	
long_name	index of fft samples in the waveforms: S band
units	count
short dft_sample_ind_ku(dft_sample_ind_ku)	
long_name	index of dft samples in the waveforms: Ku band
units	count
scale_factor	1e-1
_FillValue	32767
int seq_count (time)	
units	count
_FillValue	2147483647
long_name	sequence count
coordinates	longitude latitude
comment	Copy from 1Hz.
byte offset_tracking_flag (time)	
units	1
_FillValue	127b
long_name	reference tracking point offset flag: 18Hz
flag_values	0b, 1b
flag_meanings	nominal shifted
coordinates	longitude latitude
comment	possible values are: 0 meaning 'nominal tracking offset, 1 meaning 'shifted tracking offset
byte instr_mode_id_sp (time)	
units	1
_FillValue	127b
long_name	instrument mode id at source packet level: 18 Hz
flag_values	0b, 1b, 2b
flag_meanings	tracking pset_trk pset_loop_out
coordinates	longitude latitude
comment	copy from 1Hz
byte nominal_tracking (time)	
units	1
_FillValue	127b
long_name	nominal tracking data identifier: 18 Hz
flag_values	0b, 1b
flag_meanings	yes no
coordinates	longitude latitude
comment	possible values are: 0 nominal tracking data, 1 not nominal tracking data
byte mcd_flag_orb_state_rest (time)	
units	1
_FillValue	127b
long_name	MCD flag orbital processing status
flag_values	3b, 4b, 5b, 6b, 7b, 8b
flag_meanings	op_adjusted op_maneuver pre_interpolated_gap pre_extrapolated_L1 pre_extrapolated_L1S2 pre_extrapolated_S2
coordinates	longitude latitude
comment	MCD flag: Orbital processing status for OFL products. Possible values are: 3 meaning 'adjusted DORIS orbit', 4 meaning 'estimated DORIS orbit during maneuver', 5 meaning 'estimated DORIS orbit after

	interpolation (data gap)', 6 meaning 'estimated DORIS orbit extrapolated on a time interval less than 1 day', 7 meaning 'estimated DORIS orbit extrapolated on a time interval from 1 day to 2 days', 8 meaning 'estimated DORIS orbit extrapolated on a time interval larger than 2 days or after maneuver'. The nominal value is 3. Copy from 1Hz.
byte mcd_flag_proc_error (time)	
units	1
_FillValue	127b
long_name	MCD flag processing error
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: Absence of processing error (arithmetic faults). Copy from 1Hz.
byte mcd_flag_waveform_fault_id (time)	
units	1
_FillValue	127b
long_name	MCD flag waveform sample fault id
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: Waveform samples fault Identifier. 'bad' meaning 'Ku-band and/or S-band waveforms samples equal to zero'. Copy from 1hz.
byte mcd_flag_rx_delay_fault_id (time)	
units	1
_FillValue	127b
long_name	MCD flag rx delay fault id
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: Rx delay Fault Identifier. 'bad' meaning 'out of range'. Copy from 1Hz.
byte mcd_flag_agc_fault_id (time)	
units	1
_FillValue	127b
long_name	MCD flag agc fault id
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: AGC Fault Identifier. 'bad' meaning 'out of range'. Copy from 1Hz.
byte mcd_flag_fault_id (time)	
units	1
_FillValue	127b
long_name	MCD flag fault id
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: Fault Identifier. 'bad' meaning 'error detected by on-board'. Copy from 1Hz.
byte mcd_flag_uso (time)	
units	1
_FillValue	127b

long_name	MCD flag uso
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: USO validity flag. ‘bad’ meaning ‘anomaly in USO value detected’. Copy from 1Hz.
byte mcd_flag_obdh (time)	
units	1
_FillValue	127b
long_name	MCD flag obdh
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: OBDH validity flag. ‘bad’ meaning ‘anomaly in OBDH value detected’. Copy from 1Hz.
byte mcd_flag_packet_length (time)	
units	1
_FillValue	127b
long_name	MCD flag packet length: 18 Hz
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	MCD flag: Packet Length Error flag. ‘bad’ meaning ‘error detected and attempt to recover made’. Copy from 1Hz.
byte surface_type (time)	
_FillValue	127b
long_name	surface type from GSHHG
units	1
flag_values	0b, 1b, 2b, 3b, 4b
flag_meanings	ocean land lake island_in_lake pond_in_island
coordinates	longitude latitude
comment	GSHHG data version 2.3.7
valid_min	0b
valid_max	4b
int distance_to_coast (time)	
_FillValue	2147483647
long_name	distance to the coastline from GSHHG: 18Hz
units	m
coordinates	longitude latitude
comment	GSHHG data version 2.3.7
int altitude (time)	
_FillValue	2147483647
long_name	altitude of the satellite: 18 Hz
units	m
standard_name	height_above_reference_ellipsoid
add_offset	700000
scale_factor	1e-4
coordinates	longitude latitude
comment	Altitude of satellite above the reference ellipsoid.
short altitude_rate (time)	
_FillValue	32767
long_name	orbital altitude rate: 18 Hz
units	m/s
scale_factor	1e-2

coordinates	longitude latitude
comment	The reference surface for the orbital altitude rate is the combined mean_sea_surface/geoid surface. It is used to compute the Doppler correction on the altimeter range.
double uso_clock_smoothed (time)	
_FillValue	1.84467440737096e+19
long_name	USO clock smoothed: 18 Hz
units	s
coordinates	longitude latitude
comment	USO smoothed period
int offset_tracking (time)	
_FillValue	2147483647
long_name	reference tracking point offset (1/256): 18 Hz
units	count
coordinates	longitude latitude
comment	offset for reference tracking point
int range_cor_uso (time)	
_FillValue	2147483647
long_name	USO frequency drift correction: 18 Hz
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	correction of the USO frequency drift on the altimeter range.
short range_cor_cog (time)	
_FillValue	32767
long_name	18Hz distance antenna-COG correction on altimeter range
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	copy from 1Hz
short off_nadir_angle_pf (time)	
_FillValue	32767
long_name	off nadir angle derived from platform data:
units	degrees
scale_factor	1e-4
coordinates	longitude latitude
comment	copy from 1Hz.
byte alt_instr_flag_ptr_band_id (time)	
units	1
_FillValue	127b
long_name	altimeter instrument flag ptr band id
flag_values	0b, 1b, 2b, 4b, 7b
flag_meanings	ku_320 ku_80 ku_20 s_160 not_available
coordinates	longitude latitude
comment	altimeter instrument flag: PTR calibration band identifier field. Possible values are: 0 meaning '320 MHz (Ku)', 1 meaning '80 MHz (Ku)', 2 meaning '20 MHz (Ku)', 4 meaning '160 MHz (S)', 7 meaning 'PTR samples not available. Copy from 1Hz.
byte alt_instr_flag_chain_id (time)	

units	1
_FillValue	127b
long_name	altimeter instrument flag chain id
flag_values	0b, 1b
flag_meanings	chain_a chain_b
coordinates	longitude latitude
comment	altimeter instrument flag: chain A or chain B (redundant altimeter) identifier.
byte alt_instr_flag_red_error (time)	
units	1
_FillValue	127b
long_name	altimeter instrument flag decoded redundancy error
flag_values	0b, 1b, 2b, 3b
flag_meanings	no_mismatch mismatch_hpa mismatch_rfss mismatch_hpa_rfss
coordinates	longitude latitude
comment	altimeter instrument flag: Error flag for decoded redundancy flags. Copy from 1Hz.
byte fault_id (time)	
units	1
_FillValue	127b
long_name	fault identifier: 18 Hz
flag_values	0b, 1b
flag_meanings	ok error
coordinates	longitude latitude
comment	0 meaning ‘no error’, 1 meaning ‘error detected by on-board’
byte waveform_fault_id (time)	
units	1
_FillValue	127b
long_name	waveform samples fault identifier: 18 Hz
flag_values	0b, 1b
flag_meanings	ok error
coordinates	longitude latitude
comment	0 meaning ‘no error’, 1 meaning ‘error’
byte instr_mode_id_db (time)	
units	1
_FillValue	127b
long_name	instrument mode id at data block level: 18 Hz
flag_values	0b, 1b, 2b
flag_meanings	tracking_pset trk_pset loop_out
coordinates	longitude latitude
byte flag_cal_selection (time)	
units	1
_FillValue	127b
long_name	calibration repository selection flag: 18 Hz
flag_values	1b, 2b, 3b, 4b
flag_meanings	good extrapol_1 extrapol_2 bad
coordinates	longitude latitude
comment	Possible values are: 1 meaning ‘calibration data found less than 1 second away’, 2 meaning ‘calibration data found more than 1 second away and less than 10 minutes away’, 3 meaning ‘calibration data found more than 10 minutes away and less than 100 minutes

	away', 4 meaning 'calibration data not found in less than 100 minutes away'. The nominal value is 1.
byte flag_uso_anomaly (time)	
units	1
_FillValue	127b
long_name	USO anomaly flag: 18 Hz
flag_values	0b, 1b
flag_meanings	no_anomaly anomaly
coordinates	longitude latitude
byte flag_uso_qual (time)	
units	1
_FillValue	127b
long_name	USO quality flag
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
comment	Set to 'bad' if the USO anomaly flag (flag_uso_anomaly) is set to 'anomaly' and if the calibration repository selection flag (flag_cal_selection) is not set to 'good' for one of the 18 Hz measurement. Set to 'good' otherwise. Copy from 1Hz.
byte flag_man_pres (time)	
units	1
_FillValue	127b
long_name	manoeuvre presence flag: 18 Hz
flag_values	0b, 1b
flag_meanings	no_manoeuvre ongoing_manoeuvre
coordinates	longitude latitude
byte flag_man_plane (time)	
units	1
_FillValue	127b
long_name	manoeuvre plane flag: 18 Hz
flag_values	0b, 1b
flag_meanings	in_plane out_of_plane
coordinates	longitude latitude
short noise_power (time)	
_FillValue	32767
long_name	noise power measurement (1/2048 FFT power unit): 18 Hz
units	count
scale_factor	1e-2
coordinates	longitude latitude
int agc_noise_power (time)	
_FillValue	2147483647
long_name	AGC noise power measurement: 18 Hz
units	dB
scale_factor	1e-2
coordinates	longitude latitude
comment	AGC of noise power measurement
int p_ref(time)	
_FillValue	2147483647
long_name	reference power value: 18 Hz
units	dB
scale_factor	1e-2
coordinates	longitude latitude

Group: main/Ku	
Time, latitude and longitude variable are common with other products and described in section 3.1	
int tracker_range (time)	
_FillValue	2147483647
long_name	corrected tracker range: 18 Hz Ku band
units	m
add_offset	700000.0
scale_factor	1e-3
coordinates	longitude latitude
comment	tracker range corrected for USO frequency drift (range_cor_uso), internal path correction (range_cor_internal_path), Doppler correction (range_cor_doppler) and distance antenna-COG. It is the distance between the altimeter antenna and the surface height associated to the on-board tracking range gate inside the tracking window.
byte tracker_range_qual (time)	
units	1
_FillValue	127b
long_name	quality flag for the tracker range: 18 Hz Ku band
flag_values	0b, 1b
flag_meanings	good bad
coordinates	longitude latitude
int rx_delay_coarse (time)	
_FillValue	2147483647
long_name	rx coarse delay (multiple of 12.5ns): 18 Hz Ku band
units	count
coordinates	longitude latitude
int rx_delay_fine (time)	
_FillValue	2147483647
long_name	rx fine delay (multiple of 12.5ns/256): 18 Hz Ku band
units	count
coordinates	longitude latitude
short agc (time)	
_FillValue	32767
long_name	corrected AGC: 18 Hz Ku band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
comment	AGC corrected for instrumental errors (agc_cor)
int scaling_factor (time)	
_FillValue	2147483647
long_name	scaling factor for backscatter coefficient evaluation: 18 Hz Ku band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
comment	This scaling factor represents the backscatter coefficient for a waveform amplitude equal to 1. It is corrected for AGC instrumental errors (agc_cor) and internal calibration (sig0_cor_calibration)
int range_cor_internal_path_diff (time)	
_FillValue	2147483647

long_name	internal path correction difference on the altimeter range: 18 Hz Ku band
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	This correction represents the difference between range_cor_internal_path and the recomputed internal path delay derived from ptr_ku (group expert/ancillary_cal_ptr) using half-power method.
int range_cor_internal_path (time)	
_FillValue	2147483647
long_name	internal path correction on the altimeter range: 18 Hz Ku band
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	Internal calibration correction on the altimeter range
short range_cor_doppler (time)	
_FillValue	32767
long_name	doppler correction on the altimeter range: 18 Hz Ku
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	Nadir Doppler correction on the altimeter range, computed from restituted orbit.
short range_cor_doppler_slope (time)	
_FillValue	32767
long_name	slope-corrected doppler correction on the altimeter range: 18 Hz Ku band
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	Slope-corrected Doppler correction on the altimeter range.
int agc_cor (time)	
_FillValue	2147483647
long_name	correction for instrumental errors on AGC: 18 Hz Ku band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
short sig0_cor_calibration (time)	
_FillValue	32767
long_name	internal calibration correction on the backscatter coefficient: 18 Hz Ku band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
int peakiness (time)	
_FillValue	2147483647
long_name	peakiness: 18 Hz Ku band
units	count
scale_factor	1e-3

coordinates	longitude latitude
byte chirp_band (time)	
units	1
_FillValue	127b
long_name	chirp band identifier: 18 Hz Ku band
flag_values	0b, 1b, 2b
flag_meanings	ku_320 ku_80 ku_20
coordinates	longitude latitude
byte chirp_band_qual (time)	
units	1
_FillValue	127b
long_name	error flag for the chirp band id: 18 Hz Ku band
flag_values	0b, 1b
flag_meanings	ok error
coordinates	longitude latitude
byte alt_instr_flag_flight_cal (time)	
units	1
_FillValue	127b
long_name	altimeter instrument flag flight calibration: Ku band
flag_values	0b, 1b
flag_meanings	ok error
coordinates	longitude latitude
comment	altimeter instrument flag: Flag for availability of Ku Flight calibration corrections. Possible values are: 0 meaning 'calibration parameters available', 1 meaning 'calibration parameters not available – default values used'. Copy from 1Hz.
short flight_cal_numval (time)	
units	count
_FillValue	32767
long_name	number of measurements for flight calibration factor evaluation: Ku band
coordinates	longitude latitude
comment	copy from 1Hz.
short power_waveform (time, fft_sample_ind_ku)	
_FillValue	32767
long_name	waveform samples (I2+Q2, 1/2048 FFT power unit): 18 Hz Ku band
units	count
add_offset	32768.0
scale_factor	1.0
comment	the echo is corrected for the intermediate frequency filter effect
short waveform_dft (time, dft_sample_ind_ku)	
_FillValue	32767
long_name	waveform samples from DFT (I2+Q2, 1/2048 FFT power unit): 18 Hz Ku band
units	count
add_offset	32768.0
scale_factor	1.0
comment	the echo is corrected for the intermediate frequency filter effect
byte flag_waveform_dft (time)	
units	1

long_name	waveform DFT flag
_FillValue	127b
flag_values	0b, 1b
flag_meanings	nominal other
coordinates	longitude latitude
comment	DFT scenario flag: nominal refers to gates 44.5 and 45.5
byte waveform_main_class (time)	
units	1
long_name	waveform main class: 18Hz Ku band
_FillValue	127b
flag_values	1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, 10b, 11b, 12b, 13b, 14b, 15b, 16b, 17b, 18b, 19b, 20b
flag_meanings	brown_ocean peaky noisy strong_peak brown_peak_trailing_edge brown_peak_leading_edge brown_flat_trailing_edge peak_end unknown brown_noise two_leading_edges shifted_brown, altered_leading_edge distorted_brown linear_rise_noise shifted_brown2 breakage_leading_edge linear_decrease_noise step_leading_edge peak_and_brown
coordinates	longitude latitude
comment	waveform classification: main class predicted by classification neural network and trained on feature shape of the waveforms. ENVISAT non applicable classes :17, 18, 19, 20.
byte waveform_second_class (time)	
units	1
long_name	waveform second class: 18Hz Ku band
_FillValue	127b
flag_values	1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, 10b, 11b, 12b, 13b, 14b, 15b, 16b, 17b, 18b, 19b, 20b
flag_meanings	brown_ocean peaky noisy strong_peak brown_peak_trailing_edge brown_peak_leading_edge brown_flat_trailing_edge peak_end unknown brown_noise two_leading_edges shifted_brown, altered_leading_edge distorted_brown linear_rise_noise shifted_brown2 breakage_leading_edge linear_decrease_noise step_leading_edge peak_and_brown
coordinates	longitude latitude
comment	waveform classification: main class predicted by classification neural network and trained on feature shape of the waveforms. ENVISAT non applicable classes :17, 18, 19, 20.
short waveform_main_class_score (time)	
units	1
long_name	waveform main class probability: 18Hz Ku band
_FillValue	32767
scale_factor	1e-2
coordinates	longitude latitude
comment	waveform classification: probability associated to the main class (between 0 and 1, 100=strongest probability).
short waveform_second_class_score (time)	
units	1

long_name	waveform second class probability: 18Hz Ku band
_FillValue	32767
scale_factor	1e-2
coordinates	longitude latitude
comment	waveform classification: probability associated to the second most likely class (between 0 and 1, 100=strongest probability)
int range_cor_net_instr (time)	
unit	m
_FillValue	2147483647
long_name	net instrumental correction on the altimeter range: 18Hz Ku band
scale_factor	1e-4
coordinates	longitude latitude
comment	sum of distance antenna-COG, internal path correction (range_cor_internal_path), Doppler correction (range_cor_doppler), instrumental errors correction and system bias.
Group: main/S	
Time, latitude and longitude variables are in common with other products and described in section 3.1 Erreur ! Source du renvoi introuvable.	
short power_waveform (time, fft_sample_ind_s)	
_FillValue	32767
long_name	waveform samples (I2+Q2, 1/8192 FFT power unit): 18 Hz S band
units	count
add_offset	32768.0
scale_factor	1.0
comment	the echo is corrected for the intermediate frequency filter effect.
byte flag_loss (time)	
units	1
_FillValue	127b
long_name	loss band flag: S band
flag_values	0b, 1b
flag_meanings	no_loss loss
coordinates	longitude latitude
comment	copy from 1Hz.
short flight_cal_numval (time)	
units	count
_FillValue	32767
long_name	number of measurements for flight calibration factor evaluation: S band
coordinates	longitude latitude
comment	copy from 1 Hz.
byte alt_instr_flag_flight_cal (time)	
units	1
_FillValue	127b
long_name	altimeter instrument flag flight calibration: S band
flag_values	0b, 1b
flag_meanings	ok error
coordinates	longitude latitude
comment	altimeter instrument flag: Flag for availability of S Flight calibration corrections. Possible values are: 0 meaning ‘calibration parameters available’, 1 meaning ‘calibration parameters not available – default values used’. Copy from 1Hz.

int peakiness (time_20)	
_FillValue	2147483647
long_name	peakiness: 18 Hz S band
units	count
scale_factor	1e-3
coordinates	longitude latitude
short sig0_cor_calibration (time)	
_FillValue	32767
long_name	internal calibration correction on the backscatter coefficient: 18 Hz S band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
int agc_cor (time)	
_FillValue	2147483647
long_name	correction for instrumental errors on AGC: 18 Hz S band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
short range_cor_doppler_slope (time)	
_FillValue	32767
long_name	slope-corrected doppler correction on the altimeter range: 18 Hz S band
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	Slope-corrected Doppler correction on the altimeter range
short range_cor_doppler (time)	
_FillValue	32767
long_name	doppler correction on the altimeter range: 18 Hz S band
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	nadir Doppler correction on the altimeter range, computed from restituted orbit
int range_cor_net_instr (time)	
_FillValue	2147483647
long_name	net instrumental correction on the altimeter range: 18 Hz S band
units	m
scale_factor	1e-4
coordiantes	longitude latitude
comment	sum of distance antenna-COG, internal path correction (range_cor_internal_path), Doppler correction (range_cor_doppler), instrumental errors correction and system bias.
int range_cor_internal_path (time)	
_FillValue	2147483647
long_name	internal path correction on the altimeter range: 18 Hz S band
units	m
scale_factor	1e-4
coordinates	longitude latitude
comment	internal calibration correction on the altimeter range
int scaling_factor (time)	
_FillValue	2147483647

long_name	scaling factor for backscatter coefficient evaluation: 18 Hz S band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
comment	this scaling factor represents the backscatter coefficient for a waveform amplitude equal to 1. It is corrected for AGC instrumental errors (agc_cor) and internal calibration (sig0_cor_calibration)
short agc (time)	
_FillValue	32767
long_name	corrected AGC: 18 Hz S band
units	dB
scale_factor	1e-2
coordinates	longitude latitude
comment	AGC corrected for instrumental errors (agc_cor)
int tracker_range (time)	
_FillValue	2147483647
long_name	corrected tracker range: 18 Hz S band
units	m
add_offset	700000.0
scale_factor	1e-4
coordinates	longitude latitude
comment	tracker range corrected for USO frequency drift (range_cor_uso), internal path correction (range_cor_internal_path), Doppler correction (range_cor_doppler) and distance antenna-COG. It is the distance between the altimeter antenna and the surface height associated to the on-board tracking range gate inside the tracking window.
byte mcd_flag_anomaly (time)	
units	1
_FillValue	127b
long_name	MCD flag anomaly: S band
flag_values	0b, 1b
flag_meanings	ok error
coordinates	longitude latitude
comment	MCD flag: Flag for S-band anomaly. Copy from 1Hz.

The following table concerns all data given at a 1.8 KHz rate

Group: expert	
Time is in common with other products and is described in section 3.1	
Group: expert/ancillary_2K	
byte ind_meas_18hz (time)	
long_name	index of the 2 kHz measurement
units	1
byte db_conf_flag (time)	
units	1
_FillValue	127b
long_name	data block confidence flag: 2 kHz
flag_values	0b, 1b
flag_meanings	confident_db not_confident_db

comment	confidence flag for Ies data block identification as first measurement after a macro_command, to be considered as warning.
int altitude (time)	
_FillValue	2147483647
long_name	altitude of the satellite: 2 kHz
units	m
standard_name	height_above_reference_ellipsoid
add_offset	700000
scale_factor	1e-3
comment	altitude of the satellite above the reference ellipsoid
short altitude_rate (time)	
_FillValue	32767
long_name	orbital altitude rate: 2 kHz
units	m/s
coordinates	longitude latitude
scale_factor	1e-3
comment	spacecraft height rate provided by Orbit Propagator SW
int tracker_range (time)	
_FillValue	2147483647
long_name	corrected tracker range: 2 kHz Ku band
units	m
coordinates	longitude latitude
scale_factor	1e-4
comment	tracker range corrected USO frequency drift (range_cor_uso), internal path correction (range_cor_internal_path) and Doppler correction (range_cor_doppler). It is the distance between the altimeter CoG and the surface height associated to the zero-frequency range gate.
short agc (time)	
_FillValue	32767
long_name	corrected AGC: 2 kHz Ku band
units	dB
coordinates	longitude latitude
scale_factor	1e-2
comment	AGC corrected for instrumental errors (agc_cor)
short scaling_factor (time)	
_FillValue	32767
long_name	scaling factor for backscatter coefficient evaluation: 2 kHz Ku band
units	dB
coordinates	longitude latitude
scale_factor	1e-2
comment	this scaling factor represents the backscatter coefficient for a waveform amplitude equal to 1. It is corrected for AGC instrumental errors (agc_cor) and internal calibration (sig0_cor_calibration)
int power_waveform (time)	

_FillValue	2147483647
long_name	waveform samples (I2+Q2, FFT power unit): 2 kHz Ku band
units	count
scale_factor	4.8828125e-4
comment	Individual Echoes Power waveforms
int power_waveform_phase (time)	
_FillValue	2147483647
long_name	waveform phases: 2 kHz Ku band
units	radian
scale_factor	1e-06
comment	individual Echoes Phase waveforms. Phase is within [-pi, pi]

Calibration data (i.e. PTR and CAL2 data) is provided in the same NetCDF file than above for the sake of the long term data preservation but with a specific time tag.

Group: expert/ancillary_cal_ptr	
double ptr_ku (ind_ptr)	
units	count
_FillValue	1.84467440737096e+19
long_name	point target response in ku-band
comment	smoothed ku-band Point Target Response from the CAL1 measurement. To select chain A or chain B use alt_instr_flag_chain_id.
double ptr_s (ind_ptr)	
units	count
_FillValue	1.84467440737096e+19
long_name	point target response in s-band
comment	smoothed s-band Point Target Response from the CAL1 measurement. To select chain A or chain B use alt_instr_flag_chain_id.
Group: expert/ancillary_cal_lpf	
double lpf_ku (fft_sample_ind_ku)	
units	count
_FillValue	1.84467440737096e+19
long_name	low pass filter
coordinates	longitude latitude
comment	Ku-band Low Pass Filter from the CAL2 measurement. To select chain A or chain B use alt_instr_flag_chain_id.

3.4 Land-Ice Thematic Data Products (TDP)

3.4.1 Introduction

The capability to make long-term, systematic measurements of ice sheet topography and elevation change constitutes a key requirement for a broad user community. Radar altimetry measurements provide the community with one of the key data sources for Digital Elevation Models (DEM's); delivering information about the topography of ice sheets, and important geophysical parameters such as elevation and surface slope. By acquiring measurements through time, estimates of elevation change, ice mass imbalance and sea level contribution can be made. Elevation measurements have a range of applications, encompassing fieldwork planning, climate modelling and satellite Earth Observation. Topographic information forms an important boundary condition for both regional climate models, and dynamical ice sheet models, which in turn are an essential component of climate projections of future sea level rise. Surface topography can also be used to derive information about subglacial conditions at the ice sheet base, which is an important boundary conditions for physical models. Within the field of Earth Observation, surface elevation measurements can be used to delineate drainage basins and to calculate ice thickness. They are also commonly used as an auxiliary input when defining the Open Loop Tracking Command for radar altimeters, and during the processing of non-interferometric radar altimetry and interferometric imaging Synthetic Aperture Radar data.

This broad range of applications spans both specialist and non-specialist users. For the latter there is a demand for L2+ products that are easy to use and who's error sources are well characterised. Many of these applications require long-term, seamless datasets, meaning that measurements from multiple missions must be processed in a consistent and coherent manner.

In recent years, several detailed user consultations have provided a clear picture of the requirements that users have for altimetry data over ice sheets. In particular, they have served to identify the key priorities that non-specialist users have for the provision of higher-level products, and the improvements they require to the offerings already available. Here, we firstly review the evidence base of user requirements. Then we compare these findings to the datasets currently available, in order to identify the key gaps in data provision. Finally, we use this information to define the proposed Land-Ice TDP, and detail how it addresses the aforementioned user requirements.

3.4.2 User Requirements

GCOS User Requirements

The Global Climate Observing System (GCOS) is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). GCOS is designed to be a long-term operational system capable of providing information on the total climate system. GCOS reflects the scientific and technical requirements of the Global Climate Observing System on behalf of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). In terms of relevance to the current TDP definition, GCOS maintains a list of User Requirements for Essential Climate Variables; one of which is Ice Sheet Surface Elevation Change. For this parameter, users specified their requirements for spatial resolution, temporal resolution, measurement accuracy and stability, which were then consolidated to form the GCOS recommendations (Table 1).

Parameter	Spatial Resolution	Temporal Resolution	Accuracy	Stability
Surface Elevation Change	100 m	Monthly	0.1 m/yr	0.1 m/yr

*Table 3.1: GCOS User Requirements (from [**RD-8**])*

CMUG User Requirements

The Climate Modelling User Group (CMUG) is ESA's climate modelling expert group within the CCI project and provides valuable insight into the requirements that the modelling community have for Earth Observation datasets. CMUG comprises experts from the UK Met Office Hadley Centre, the Max Planck Institute for Meteorology, the European Centre for Medium-Range Weather Forecasts (ECMWF), Météo-France and the Swedish Hydro-Meteorological Institute (SHMI). One of their responsibilities has been to define the modelling user requirements; for both an ice sheet wide model, and for a higher-complexity regional ice sheet model. Their requirements are specifically focused on the necessary spatial and temporal resolution of the EO datasets (rather than accuracy and precision). However, they do cover both parameters relevant to the current study; that is *elevation* and the *rate of elevation* change. The CMUG User Requirements are summarised in Table 2:

Parameter	Domain	Spatial Resolution	Temporal Resolution
Surface Elevation	Ice sheet wide	5 km	Decadal
Surface Elevation	Regional	0.1 km	Monthly
Surface Elevation Change	Ice Sheet wide	5 km	Decadal
Surface Elevation Change	Regional	0.1 km	Monthly

*Table 3.2 : CMUG User Requirements [as defined in **RD-6**].*

Ice Sheets CCI User Requirements

Within the frame of ESA's CCI projects, extensive, ongoing user surveys are undertaken on a periodic basis to inform on the requirements of the wider scientific community. These surveys take the form of an open call to complete an online survey, and the targeted eliciting of responses from representative expert users. These surveys provide a valuable complement to the User Requirement information outlined above. The most recent CCI surveys ([**RD-6**];[**RD-7**]) elicited over 200 respondents, providing information on (1) the type of product, (2) the characteristics of the product (e.g. spatial and temporal resolution) and (3) the data type and volume of the product. With regards to the current task, the key findings are summarised in Table 3.

Parameter	Requirement
Surface Elevation Change	Minimum spatial resolution of 1-5 km. Optimum spatial resolution of < 0.5 km.
Surface Elevation Change	Minimum accuracy of 0.1-0.5 m/yr. Optimum accuracy of < 0.1 m/yr.
Surface Elevation Change	Annual temporal sampling frequency over grounded ice.
Surface Elevation Change	Seasonal temporal sampling frequency over floating ice.

*Table 3.3 : ESA CCI User Requirements ([**RD-6**];[**RD-7**])*

Copernicus User Requirements & Polar Expert Group Findings

Finally, we review several community and expert activities that have taken place in recent years ([**RD-1**],[**RD-2**],[**RD-3**]) within the frame of future Copernicus activities. Although these provide a snapshot of User

Requirements for future missions, they are nonetheless valuable in terms of informing us as to user expectations, with respect to a Land Ice TDP.

In 2016, the European Commission (EC) initiated a workshop (Copernicus Polar and Snow Cover Applications User Requirements Workshop 23 June 2016, Brussels;) to gather the user requirements for the Next Generation of the Copernicus Space Component (CSC). The workshop was attended by a broad spectrum of relevant parties, including users, service providers, representatives from the scientific community, the European Commission, ESA and EUMETSAT. Following the strong interest displayed at this workshop, a Polar Experts Group (PEG) was established in 2017, to consolidate and update the user requirements for a Copernicus Expansion Mission dedicated to Polar and Snow Monitoring. Two workshops were held, in April and May 2017, to facilitate these activities. During these workshops, user requirements were further consolidated, both in terms of the application domain (e.g. ice sheets) and in terms of the parameters and products (e.g. elevation, elevation change), with particular attention given to prioritisation. In this regard, ice sheet surface elevation and elevation change were both identified to sit within the two highest-priority categories for user requirements.

In addition to prioritization, these community activities dedicated considerable effort to defining the detailed specifications required by the user community for each parameter, such as accuracy, resolution and sampling frequency. This has led to the following User Requirements with respect to monitoring ice sheet elevation and elevation change (Table 3.4).

Requirement	Value	Source
Absolute accuracy of surface elevation measurement	Goal: 0.5 metres absolute; 0.2 metres relative.	[**RD-2**]; Table 8.
Accuracy & stability of surface elevation change measurement	Goal: 0.1 m/yr	GCOS/CEOS Action T20 [**RD-4**].
Temporal sampling frequency	Goal: Monthly-seasonal (ice margin); annual (interior).	[**RD-2**]; Table 8.
Spatial resolution	Goal: 1000 m (interior) and 50-100 m (ice margin).	[**RD-2**]; Table 8.

*Table 3.4 : Summary of User Requirements over ice sheets (from [**RD-1**]-[**RD-4**]).*

Synthesis of User Requirements

From this comprehensive survey of User Requirements consultations, we can draw the following conclusions about the desired datasets. We have chosen to focus on the 'best-case' scenarios, as they define the most useable product for the community:

Elevation spatial resolution: 100 m – 1 km.
Elevation temporal resolution: monthly.
Elevation accuracy: 0.5 m.
Elevation change spatial resolution: 100 m – 1 km.
Elevation change temporal resolution: monthly.
Elevation change accuracy: 0.1 m/yr.

3.4.3 Review of Existing Higher-Level Products

Beyond existing Level 2 products, the main ice sheet datasets available to the non-specialist user are produced by the CCI and C3S projects. In summary, these provide products with the following characteristics:

CCI:

5 x 5 km gridded product.
5-year rates of elevation change.
No dedicated elevation information.

C3S:

25 x 25 km gridded product.
5-year rates of elevation change.
No dedicated elevation information.

We can therefore conclude the following gap analysis:

In terms of **elevation**, there currently exists no consolidated elevation dataset beyond Level-2 for the non-expert user; gridded datasets (DEM's) do exist, but these constitute data that is averaged in space and time, and do not meet the spatial and temporal resolution defined by our review of User Requirements.
In terms of **elevation rates**, existing products give an average rate of change over a 5-year period and are therefore limited in their ability to resolve short-term change, as specified by our review of User Requirements.

3.4.4 Definition of Land Ice TDP

Based upon this review of existing datasets and User Requirements, we propose the following definition for Land Ice TDP. Specifically, we aim to satisfy the TDP philosophy, which is to:

«process a limited number of measurement fields, which are important to the description of a certain phenomenon and focus on specific thematic applications.»

As identified in the SoW, here our focus is to define a TDP that provides measurements of the Greenland and Antarctic ice surface. We therefore propose a Level-2P product that sits between the existing L2 (ESA ground segment) and L3 (gridded CCI and C3S) products. The dataset is designed to meet the specific needs of the Land Ice community, to provide:

- A consolidated elevation dataset that can be more easily used by the non-expert than the existing L2 product.
- A higher spatial resolution dataset than is currently offered by existing L3 products (i.e. < 5 km); thereby addressing one of the key user requirements.
- A higher temporal sampling frequency, which better meets the needs of users, and which allows the user greater flexibility to derive timeseries of change at the temporal scale of their choosing.

The TDP is therefore defined to provide users with a consolidated, homogenous elevation product that stays as close to the nominal spatial and temporal resolution of the satellite as possible. Its core comprises geolocated elevation measurements at nodes along the reference ground track, together with associated uncertainty, plus several auxiliary fields related to waveform characteristics and surface classification that will be useful to many users.

As such, the product contains all fields required to calculate elevation at any epoch, and changes in elevation through time. By *consolidated* and *homogeneous* we mean that standard Level-2 data have been processed so that elevations are derived and delivered at defined nodes along the reference ground track for all cycles, eliminating sampling artefacts that arise due to different cycles sampling different ground points (along track; and across-track due to orbit drift). Reference ground tracks are determined for both ice sheets Greenland and Antarctica, as such there will be two data products, one for the Antarctic Ice Sheet and one for the Greenland Ice Sheet. This provides an easily accessible dataset, which is the first of its kind; thereby opening up the long-term altimetry record to a new set of non-expert users.

3.4.5 Global Attributes

Attribute	Value
Conventions	CF-1.8
title	FDR4ALT Thematic Data Product: Land Ice
institution	ESA
source	FDR4ALT Processing Baseline V1.0
FDR_input	FDR ALT V1.0
history	Creation YYYYMMDDTHHMMSS.mmmmm
Contact	ESA pierre.femenias@esa.int Lancaster Unversity: m.mcmillan@lancaster.ac.uk
processing_center	CLS core system; CNES CST; Lancaster University

reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556
mission_name	[ERS-1/ERS-2/ENVISAT]
altimeter_sensor_name	[RA/RA/RA-2]
cycle_number	Cycle number
pass_number	Pass number in the cycle (relative pass number)
first_meas_time	Date and time of first observation in file (YYYYMMDDTHHMMSS.mmmmmm
last_meas_time	Date and time of last observation in file (YYYYMM-DDTHHMMSS.mmmmmm)
ellipsoid_ref	WGS84
identifier_product_DOI	10.5270/esa-XXXXXXX
identifier_product_DOI_authority	http://dx.doi.org/

3.4.6 Metadata

The Land Ice variables are separated in two groups. The variables in the main group are adequate for the majority of users and allow easier access to the most important parameters, including ice sheet elevation sampled at regular nodes along the reference ground track. The second group contains further parameters, allowing expert users access to additional fields useful for more detailed analysis.

Please note that the Land-Ice TDP files are separated in two. For each pass, there are two files containing data for Greenland in one file and Antarctica in the other.

Group	Number of variables	Dimensions
Main	8	time
Expert	41	time

3.4.7 Variable definition

Group: main	
Variables in common with other products are described in section 3.1	
float surface_elevation(time)	
_FillValue	9.969209968386869e+36
long_name	ice sheet surface elevation
units	m
scale_factor	1
comment	ice sheet surface elevation sampled along the satellite track. Instrument corrections, geophysical corrections and correction for across-track surface slope are all applied.
int surface_elevation_uncertainty(time)	
_FillValue	2147483647
long_name	ice sheet surface elevation uncertainty
units	m
scale_factor	1e-2
comment	uncertainty associated with ice sheet surface elevation measurement: surface_elevation.
byte surface_type(time)	
_FillValue	127b

long_name	surface type classification flag
units	1
flag_values	0b, 1b, 2b, 3b, 4b
flag_meanings	ocean grounded_ice floating_ice ice_free_land non_greenland_land(used for tracks over Greenland only)
comment	surface type identifier, for use in discriminating different surfaces types within the Land Ice TDP domain; derived from the BedMachine Greenland version 3 (Morlighem et al., 2017).
byte waveform_class (time)	
_FillValue	127b
long_name	20 Hz Ku-band waveform main class
units	1
scale_factor	1
flag_values	1b,2b,3b,4b,5b,6b,7b,8b,9b,10b,11b,12b,13b,14b,15b,16b,17b,18b,19b,20b
flag_meanings	brown_ocean peaky noisy strong_peak brown_peak_trailing_edge brown_peak_leading_edge brown_flat_trailing_edge peak_end unknown brown_noise two_leading_edges shifted_brown, altered_leading_edge distorted_brown linear_rise_noise shifted_brown2 breakage_leading_edge linear_decrease_noise step_leading_edge peak_and_brown
comment	Waveform classification from ALT FDR: main class predicted by classification neural network and trained on feature shape of the waveforms. ENVISAT non applicable classes :17, 18, 19, 20. ERS-1/ERS-2 non applicable classes : 8, 12, 14, 19, 20.
float reference_elevation(time)	
_FillValue	9.969209968386869e+36
long_name	ice sheet surface reference elevation
units	m
scale_factor	1
comment	ice sheet reference elevation derived from auxiliary high resolution Digital Elevation Model.
int sigma0(time)	
_FillValue	2147483647
long_name	backscatter coefficient of radar wave
units	dB
scale_factor	1e-2
comment	fully corrected backscatter coefficient.

Group : expert	
int int_path_cor (time)	
_FillValue	2147483647
long_name	internal path delay correction
units	m
scale_factor	1E-6
comment	internal path delay correction in main band
int inv_bar_cor (time)	
_FillValue	2147483647
long_name	inverted barometer height correction: 20 Hz
units	m
scale_factor	1E-4
comment	Computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag.
Source	European Centre for Medium Range Weather Forecasting (ECMWF)
int iono_cor_gim (time)	

_FillValue	2147483647
long_name	GIM ionospheric correction : 20 Hz
standard_name	Altimeter_range_correction_due_to_ionoshpere
units	m
scale_factor	1E-4
comment	An ionospheric correction must be added (negative value) to the instrument range to correct this range measurement for ionospheric range delays of the radar pulse
int load_tide_fes14b (time)	
_FillValue	2147483647
long_name	FES14b model load tide height
units	m
scale_factor	1E-4
comment	Load tide FES2014b
institution	LEGOS/CNES
source	FES2014b
int load_tide_got4v10 (time)	
_FillValue	2147483647
long_name	load tide height for geocentric ocean tide (solution 1): 20 Hz
units	m
scale_factor	1E-4
comment	This value has already been added to the corresponding ocean tide height value recorded in the product (ocean_tide_sol1_01)
source	GOT4.10
int load_tide_fes14 (time)	
_FillValue	2147483647
long_name	FES model load tide height
units	m
scale_factor	1E-4
comment	This value has already been added to the corresponding ocean tide height value recorded in the product (corr_ocean_tide_height_model_fes)
source	FES2014
int mod_dry_tropo_cor (time)	
_FillValue	2147483647
long_name	model dry tropospheric correction: 20 Hz
standard_name	altimeter_range_correction_due_to_dry_troposphere
units	m
scale_factor	1E-4
comment	computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag, from 3D meteorological reanalysis at measurement altitude. A dry tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for dry tropospheric range delays of the radar pulse
source	ERA Interim re-analysis
int mod_wet_tropo_cor (time)	
_FillValue	2147483647
long_name	wet dry tropospheric correction: 20 Hz
standard_name	altimeter_range_correction_due_to_wet_troposphere
units	m

scale_factor	1E-4
comment	computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag, from 3D meteorological reanalysis at measurement altitude. A dry tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for dry tropospheric range delays of the radar pulse
source	ERA Interim re-analysis
int ocean_tide_fes14b (time)	
_FillValue	2147483647
long_name	FES14b model geocentric ocean tide height
standard_name	sea_surface_height_amplitude_due_to_geocentric_ocean_tide
units	m
scale_factor	1E-4
comment	Ocean tide FES2014b
source	FES2014b
int ocean_tide_got4v10 (time)	
_FillValue	2147483647
long_name	geocentric ocean tide height (solution 1): 20 Hz
units	m
scale_factor	1E-4
comment	Solution 1 corresponds to GOT model. Includes the corresponding loading tide (load_tide_sol1_01) and equilibrium long-period ocean tide height (ocean_tide_eq_01). The permanent tide (zero frequency) is not included in this parameter because it is included in the geoid and mean sea surface (geoid_01, mean_sea_surf_01)
source	GOT4.10
int ocean_tide_fes14 (time)	
_FillValue	2147483647
long_name	FES model geocentric ocean tide height
units	m
scale_factor	1E-4
comment	Ocean tide FES2014
source	FES2014
int pole_tide (time)	
_FillValue	2147483647
long_name	geocentric tide height : 20 Hz
units	m
scale_factor	1E-4
source	Wahr [1985] Deformation of the Earth induced by polar motion – J. Geophys. Res. (Solid Earth), 90, 9363-9368.
int solid_earth_tide (time)	
_FillValue	2147483647
long_name	solid earth tide height: 1 Hz: 20 Hz
units	m
scale_factor	1E-4
comment	Calculated using Cartwright and Tayler tables and consisting of the second and third degree constituents. The permanent tide (zero frequency) is not included.
Source	Cartwright and Edden [1973] Corrected tables of tidal harmonics – J. Geophys. J. R. Astr. Soc., 33, 253-264.

int range_cor_uso (time) (ENVISAT only)	
_FillValue	2147483647
long_name	USO frequency correction on the altimeter range
units	m
scale_factor	1E-5
comment	Correction of the USO frequency drift on the altimeter range
short range_cor_doppler (time)	
_FillValue	32767
long_name	doppler correction on the altimeter range: 18 Hz Ku band
units	m
scale_factor	1E-4
comment	Doppler correction on the altimeter range
short range_cor_doppler_slope (time)	
_FillValue	32767
long_name	Doppler slope correction
units	m
scale_factor	1E-4
comment	Slope-corrected Doppler correction on the altimeter range
double ice_sheet_elevation_ice1_roemer (time)	
_FillValue	9.969209968386869e+36
long_name	ice sheet / ice shelve elevation at POCA
units	m
scale_factor	1
quality_flag	ice_sheet_qual_relocation
comment	Negative correction for range; positive correction for surface elevation. Relocation using REMA over Antarctica / ArcticDEM over Greenland. Method from Roemer et al. [2007]
double ice_sheet_elevation_tfmra_roemer (time)	
_FillValue	9.969209968386869e+36
long_name	ice sheet / ice shelve elevation at POCA
units	m
scale_factor	1
comment	altitude of satellite (alt) – ice-1 corrected altimeter range (ice1_range) – geophysical corrections (depend on surface type between grounded ice / floating ice, see handbook for details) + ice sheet relocation correction. Calculated even if iono_corr_gim is at default value
quality_flag	ice_sheet_qual_relocation
double ice_sheet_elevation_correction_poca (time)	
_FillValue	9.969209968386869e+36
long_name	correction to adjust range/elevation at POCA]
units	m
scale_factor	1E-6
comment	Negative correction for range ; positive correction for surface elevation. Relocation using REMA over Antarctica / ArcticDEM over Greenland. Method from Roemer et al. [2007]
int ice_sheet_lat_poca (time)	
_FillValue	2147483647
long_name	latitude of the estimated echo location at Point Of Closest Approach (POCA)
units	degrees_north

scale_factor	1e-6
quality_flag	ice_sheet_qual_relocation
comment	Relocation using REMA over Antarctica / ArcticDEM over Greenland. Method from Roemer et al. [2007]
int ice_sheet_lon_poca (time)	
_FillValue	2147483647
long_name	longitude of the estimated echo location at Point Of Closest Approach (POCA)
units	degrees_east
scale_factor	1E-6
quality_flag	ice_sheet_qual_relocation
comment	Relocation using REMA over Antarctica / ArcticDEM over Greenland. Method from Roemer et al. [2007]
short ice_sheet_qual_relocation (time)	
_FillValue	32767
long_name	relocation processing flag
flag_values	0b, 1b, 2b, 3b
flag_meanings	successful relocation / relocation processing failure / POCA considered too far from nadir / measurement outside of ice sheets area
int latitude (time)	
_FillValue	2147483647
long_name	latitude 18Hz at nadir
standard_name	latitude
units	degrees_north
scale_factor	1E-6
comment	Positive latitude is North latitude, negative latitude is South latitude (NADIR latitude)
int longitude (time)	
_FillValue	2147483647
long_name	longitude 18Hz at nadir
standard_name	longitude
units	degrees_east
scale_factor	1E-6
comment	East longitude relative to Greenwich meridian (NADIR longitude)
double distance_nadir_poca_roemer (time)	
_FillValue	2147483647
long_name	Horizontal distance between nadir and POCA after Roemer relocation
units	m
comment	Relocation using REMA over Antarctica / ArcticDEM over Greenland. Method from Roemer et al.[2007]
int ice_sheet_elevation_model (time)	
_FillValue	2147483647
long_name	nadir surface elevation from DEM
units	m
scale_factor	1E-5
comment	Antarctica: computed using REMA (200m resolution, filled version). Greenland : computed using ArcticDEM (100m resolution)
double time (time)	
_FillValue	1.8446744073709552E19
long_name	UTC 18Hz

standard_name	time
units	seconds since 1950-01-01 00 :00 :00.00
int range_ice1 (time)	
_FillValue	2147483647
long_name	corrected 'ice-1' altimeter range: 18 Hz Ku band
standard_name	altimeter range
units	m
add_offset	700000.0
scale_factor	1E-5
comment	Ocog retracking. Instrumental corrections included: USO drift correction (range_cor_uso), internal path correction (range_cor_internal_path), distance antenna-COG
	* Note, range_ice1 is written as int64 to avoid loss of precision.
int range_tfmra (time)	
_FillValue	2147483647
long_name	corrected 'TFMRA' altimeter range: 18 Hz Ku band
standard_name	altimeter range
units	m
add_offset	700000.0
scale_factor	1E-4
comment	TFMRA retracking. Instrumental corrections included: USO drift correction (range_cor_uso), internal path correction (range_cor_internal_path), distance antenna-COG and doppler correction (range_cor_doppler)
	* Note, range_tfmra is written as int64 to avoid loss of precision.
byte retracking_ice1_qual (time)	
_FillValue	127b
long_name	quality flag for the ice-1 retracking: 18 Hz Ku band
flag_values	0b, 1b
flag_meanings	good , bad
comment	ocog retracking
byte retracking_tfmra_qual (time)	
_FillValue	127b
long_name	quality flag for the TFMRA retracking: 18 Hz Ku band
flag_values	0b, 1b
flag_meanings	good , bad
comment	TFMRA retracking
int sigma0_ice1 (time)	
_FillValue	2147483647
long_name	corrected ice-1 backscatter coefficient: 18 Hz Ku band
units	dB
scale_factor	1E-2
comment	Ocog retracking. Instrumental corrections included: AGC instrumental errors correction (agc_cor) and internal calibration correction (sig0_cor_calibration)
int sigma0_tfmra (time)	
_FillValue	2147483647
long_name	corrected TFMRA backscatter coefficient: 18 Hz Ku band
units	dB

scale_factor	1E-2
comment	TFMRA retracking. Instrumental corrections included: AGC instrumental errors correction (agc_cor) and internal calibration correction (sig0_cor_calibration)
byte waveform_class (time)	
_FillValue	127b
long_name	20 Hz Ku-band waveform main class
units	1
flag_values	1b,2b,3b,4b,5b,6b,7b,8b,9b,10b,11b,12b,13b,14b,15,16b
flag_meanings	brown_ocean, peaky, noisy, strong_peak, brown_peak_trailing_edge, brown_peak_leading_edge, brown_flat_trailing_edge, peak_end, unknown, brown_noise, two_leading_edges, shifted_brown, distorted_brown, linear_noise, shifted_brown2
comment	Waveform main class derived from the ALT FDR L1 neural network classification.
Short waveform_class_score (time)	
_FillValue	32767
long_name	waveform classification: Probability of the First most probable class
units	1
scale_factor	1E-3
comment	Neural network waveform classification from CLS
int width_leading_edge_ice2 (time)	
_FillValue	2147483647
long_name	width of the leading edge derived from ICE2_ADVANCED algorithm
units	s
scale_factor	1E-4
comment	Width of the rising edge (composite sigma) in the main band from the \'ice-2\' advanced retracking
int slope_first_trailing_edge_ice2 (time)	
_FillValue	2147483647
long_name	slope of the first part of the trailing edge derived from ICE2_ADVANCED retracking algorithm
units	s^{-1}
scale_factor	1E-4
comment	Slope of the first part of the trailing edge from the \'ice-2\' advanced retracking
int slope_second_trailing_edge_ice2 (time)	
_FillValue	2147483647
long_name	slope of the second part of the trailing edge derived from ICE2_ADVANCED retracking algorithm
units	s^{-1}
scale_factor	1E-4
comment	Slope of the second part of the trailing edge from the \'ice-2\' advanced retracking
int altitude (time)	
_FillValue	2147483647
long_name	altitude of satellite
standard_name	height_above_reference_ellispoid
units	m
add_offset	700000
scale_factor	1E-3
comment	Orbit CNES POE F

byte chirp_band (time) (ENVISAT only)	
_FillValue	127b
long_name	chirp band identifier: 18 Hz Ku band
units	1
flag_values	0b, 1b, 2b
flag_meanings	ku_320, ku_80, ku_20
int epoch_tfmra (time)	
_FillValue	2147483647
long_name	epoch of the retracking derived from TFMRA algorithm for the main frequency band
standard_name	reference epoch
units	m
scale_factor	1E-4
comment	Epoch from TFMRA retracking in main band
int amplitude_tfmra (time)	
_FillValue	2147483647
long_name	amplitude of the retracking derived from \'TFMRA\' algorithm for the main frequency band
units	m
scale_factor	1E-3
comment	Amplitude from TFMRA retracking in main band

3.5 Sea-Ice Thematic Data Products (TDP)

3.5.1 Introduction

There are two main user communities of satellite derived sea ice thicknesses: the modelling community and navigation community. There are recent user requirement studies aiming both user communities: the ESA CCI+ user requirement study [**RD-9**] focusing, but not limited, to modelling community, and the EU H2020 KEPLER user requirements study [**RD-10**] which emphases on navigation users. As the FDR4ALT project produces datasets from historic missions, NRT and time critical applications such as forecast models or tactical navigation support are not relevant here. However, climate change research, reanalysis models and operations planning are.

3.5.2 User requirements

Expert and non-expert users

The CCI+ Sea Ice URD makes a case that there are two different groups of users for the CCI+ CRDP and this stands for the FDR4ALT TDP as well. There are expert users who can be expected to understand that, for example, at times the uncertainty may be larger than the estimated sea ice thickness and take this into account in their application. However, there will also be non-expert users who will not look at the quality information, but most likely just at the variable they are interested in. This boils down to the question should the uncertain sea ice estimates in the product be filtered out or just flagged as uncertain data. We recommend keeping all the data and letting the user apply the filters that seem relevant. Otherwise, the distributions would be biased and the statistical analysis and filtering methods inapplicable. The uncertainty can be already considered as a flag. Adding a new flag may increase confusion.

For sea ice thickness and freeboard, the question is also relevant if the user understands the limitations of auxiliary snow and sea ice type estimates and if they can use histheir own snow product for both propagation speed correction and freeboard to thickness conversion.

The main factor limiting the accuracy of radar altimeter sea ice thickness retrieval is uncertainties in snow and ice density estimates. Neither snow thickness nor densities of snow or ice are derivable from RA or RA-2 measurement. In consequence, the estimates used are auxiliary to the altimeter retrieval. Furthermore, their uncertainty is large, and it is likely that better estimates will emerge later. Thus, the freeboard not corrected for snow propagation must be included in the TDP to allow users to apply their own correction.

Use cases and requirements

The GCOS [**RD-8**] states the requirements for sea ice thickness ECV as a monthly product with 25 km spatial resolution and 10 cm uncertainty. Given the limitations of ERS RA and ENVISAT RA-2 data, this will most likely not be met. Feedback from the climate community is that the users understand the limitations of the altimeter derived sea ice thickness (SIT), and they are happy with *the best possible* SIT estimate, as long as it comes with a realistic uncertainty estimate.

The CCI user requirement document mentions several users using the SIT product to assess the quality of their modelled sea ice thickness. This will most likely be one of the applications for the TDP as well. These users will have SIT estimates in different (model) grids, so they will benefit from an along track SIT product that they will grid to their own grid for the comparison.

A sea ice expert from DNV-GL was interviewed to understand the requirements of sea ice thickness products for the study of ice conditions for a given area to be used in a ship's operations manual. The IMO polar code requires all ships operating in polar areas to assess the past ice conditions but is vague on the details how the assessment should be made. However, the expert pointed out that due to rapid changes in the sea ice cover even ENVISAT era (2002-2012) sea ice observations have only marginal value in operation planning in the current day. 1993-2010 sea ice estimates have value in putting past experience of sea ice into perspective when used today – that is, to make a solid point to users that the sea ice regime has changed. He also made several points valuable for TDP planning:

- There are locations where any information is valuable, and there is a need for sea ice products.
- No strict requirements for the file format as long as the file opens georeferenced in most GIS software.
- Uncertainty information is extremely important! Even estimates with high uncertainty can and will be used.
- Current CMEMS products have been found too complicated to use, much due to complicated user interface on the web page.
- The products should be accompanied by clear license information and preferably also the preferred style how to cite the data.

Auxiliary product maturity

The sea ice thickness product quality depends on the quality of the used auxiliary data – most importantly snow on sea ice estimate and sea ice type from which the ice density is derived. Especially for ERS era, the quality of snow estimates is ambiguous. Widely used Warren 1999 climatology [**RD-11**] is valid for multiyear ice in the central Arctic only. In recent years, it has become commonplace to modify the Warren climatology by using 50% snow thickness from Warren to first-year ice areas. However, this assumption is based on Operation IceBridge flights in the 2010's [**RD-12**], and there is no information on the accuracy of the assumption in 1990's. Furthermore, the Warren climatology gives negative thicknesses in the marginal ice areas during several months due to the nature of the climatology: snow thickness is represented by 2nd

degree polynomials. In consequence, there are areas in the TDP where snow information, and in consequence sea ice thickness, is unreliable.

Thus, the TDP must allow the user to apply his or her own auxiliary data as well as include the auxiliary information used – both as strings in global variables and values for snow (thickness and density), ice type, ice density and mean sea surface height at waveform locations. With these the user can both assess the quality of auxiliary data used in the TDP processing as well as use the FDR4ALT TDP radar freeboard as basis for their own calculation. Furthermore, the process and the equations to derive the sea ice thickness from radar freeboard must be clearly presented in the related documentation.

3.5.3 Metadata

Group	Number of variables	Dimensions
Main	18	time
Expert	9	time

The content of the Main group is meant for all sea ice data users, whereas the content of the Expert group is additional information about the corrections used to retrieve the main sea ice parameters.

3.5.4 Global attributes

Attribute	Value
Conventions	CF-1.8
title	FDR4ALT Thematic Data Product: Sea Ice
institution	ESA
source	FDR4ALT Processing Baseline V1.0
FDR_input	ENVISAT V3.0/ ERS REAPER
history	Creation YYYYMMDDTHHMMSS.mmmmmm
contact	ESA: pierre.femenias@esa.int, LEGOS: sara.fleury@legos.obs-mip.fr
processing_center	CLS core system; CNES CST; LEGOS
reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556
mission_name	[ERS-1/ERS-2/ENVISAT]
altimeter_sensor_name	[RA, RA, RA-2]
cycle_number	Cycle number
pass_number	Pass number in the cycle (relative pass number)
first_meas_time	Date and time of first observation in file (YYYYMMDDTHHMMSS.mmmmmm)
last_meas_time	Date and time of first observation in file (YYYYMMDDTHHMM:SS.mmmmmm)
ellipsoid_ref	WGS84
identifier_product_DOI	10.5270/esa-2eb13ab

identifier_product_DOI_authority	http://dx.doi.org/

3.5.5 Variables definition

Group: main	
Variables in common with other products are described in section 3.1	
int radar_freeboard(time)	
_FillValue	2147483647
long_name	radar altimetric freeboard
units	m
scale_factor	1e-3
comment	Difference between the sea ice height anomaly (ILA) and the sea level anomaly (SLA). If the measurement is over a floe the SLA is interpolated. If the measurement is over a lead the ILA is interpolated. No snow correction.
int sea_ice_freeboard(time)	
_FillValue	2147483647
long_name	sea ice freeboard
standard_name	sea_ice_freeboard
units	m
scale_factor	1e-3
comment	Radar freeboard (radar_freeboard) with applied snow range corrections from [Ulaby, 1986] to take into account the lower speed propagation of the radar waveform in snow.
int sea_ice_thickness(time)	
_FillValue	2147483647
long_name	thickness of the sea ice layer
standard_name	sea_ice_thickness
units	m
scale_factor	1e-3
comment	Sea ice thickness derived from hydrostatic equation using the following parameters: sea ice freeboard, snow depth and densities of ice, snow and water.
int radar_freeboard_uncertainty(time)	
_FillValue	2147483647
long_name	uncertainty of radar freeboard
units	m
scale_factor	1e-3
comment	Uncertainty of [RA/RA2] measured freeboard without snow penetration correction.
int sea_ice_freeboard_uncertainty(time)	
_FillValue	2147483647
long_name	uncertainty of sea ice freeboard
standard_name	sea_ice_freeboard_standard_error
units	m
scale_factor	1e-3
comment	Uncertainty of RA measured freeboard corrected for snow propagation speed.
int sea_ice_thickness_uncertainty(time)	
_FillValue	2147483647
long_name	uncertainty of sea ice thickness
standard_name	sea_ice_thickness_standard_error
units	m
scale_factor	1e-3
comment	Uncertainty of sea ice thickness computed from sea_ice_freeboard_uncertainty variable and the

	following constant density uncertainties (kg/m3): on water=0.5 [Wadhams et al. 1992]; on snow=3.2 [Warren, 1999]; on MYI=23 ; on FYI=35.7 [Alexandrov et al., 2010].

int surface_height(time)	
_FillValue	2147483647
long_name	surface height
units	m
scale_factor	1e-3
comment	Surface height relative to the MSS (DTU15) height = altitude – range – geophysical corrections – MSS DTU15. The geophysical corrections include wet, dry, iono, DAC, tides.
int sea_level_anomaly(time)	
_FillValue	2147483647
long_name	sea level anomaly
standard_name	sea_surface_height_above_mean_sea_level
units	m
scale_factor	1e-3
comment	Sea level anomaly measured over the leads and interpolated between the leads. This SLA is calibrated against SAR altimeter SLA reference (Cryosat-2).
int sea_level_anomaly_uncertainty(time)	
_FillValue	2147483647
long_name	sea level anomaly uncertainty
standard_name	sea_surface_height_above_mean_sea_level standard_error
units	m
scale_factor	1e-3
comment	Uncertainty of sea surface anomaly.
int snow_depth(time)	
_FillValue	2147483647
long_name	snow depth over sea ice
standard_name	surface_snow_thickness
units	m
scale_factor	1e-3
comment	Snow depth over sea ice from auxiliary dataset (a modified [Warren, 1999] solution for NH and snow depth from altrimetry (ASD) for SH [Garnier et al., 2021]).
byte sea_ice_type(time)	
_FillValue	127b
long_name	type of sea ice
standard_name	sea_ice_classification
units	1
flag_values	0b, 1b, 2b
flag_meanings	FYI, ambiguous, MYI
comment	Type of sea ice from auxiliary NSIDC 0611 sea ice age product.
byte surface_type(time)	
_FillValue	127b
long_name	surface type
units	1
flag_values	0b, 1b, 2b, 3b, 4b, 5b
flag_meanings	land, open_ocean, leads, floes, missing_data, ambiguous
comment	Surface type output from classification routine.
byte measurement_status(time)	
_FillValue	127b

long_name	measurement_status
units	1
flag_values	0b, 1b, 2b, 3b, 4b, 6b, 7b, 8b, 11b
flag_meanings	valid, land, masked_waveforms, floes_rejected_from_classification, data_filtered_out_during_sla_computation, offnadir, data_filtered_out_during_ila_computation, unknown_ocean_type, low_bandwidth
comment	Indications on why the value is excluded if it is.
int mean_sea_surface(time)	
_FillValue	2147483647
long_name	mean sea surface
standard_name	sea_surface_height_above_reference_ellipsoid
units	m
scale_factor	1e-3
comment	Mean sea surface height interpolated along track from MSS DTU15 above WGS84 ellipsoid.
int sea_ice_concentration(time)	
_FillValue	2147483647
long_name	sea ice concentration
standard_name	sea_ice_area_fraction
units	percent
comment	Sea ice concentration from the NSIDC 0051 auxiliary product.

Group: expert	
int dry_tropospheric_correction (time)	
_FillValue	2147483647
long_name	dry tropospheric correction
standard_name	altimeter_range_correction_due_to_dry_troposphere
units	m
scale_factor	1e-3
add_offset	0
comment	Computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag. A dry tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for dry tropospheric range delays of the radar pulse.
source	European Centre for Medium Range Weather Forecasting (ECMWF)
int wet_tropospheric_correction (time)	
_FillValue	2147483647
long_name	wet tropospheric correction
standard_name	altimeter_range_correction_due_to_wet_troposphere
units	m
scale_factor	1e-3
add_offset	0
comment	Directly applied at 20hz in the framework of FDR4ALT. Computed at the altimeter time-tag from

	the interpolation of 2 meteorological fields that surround the altimeter time-tag. A wet tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for wet tropospheric range delays of the radar pulse.
source	European Centre for Medium Range Weather Forecasting (ECMWF)
int inverse_barometric_total_correction (time)	
_FillValue	2147483647
long_name	inverse barometric and dynamical atmospheric corrections
standard_name	sea_surface_height_correction_due_to_air_pressure
units	m
scale_factor	1e-3
add_offset	0.
comment	
source	ECMWF
int ionospheric_correction (time)	
_FillValue	2147483647
long_name	model ionospheric correction
standard_name	altimeter_range_correction_due_to_ionosphere
units	m
scale_factor	1e-3
add_offset	0.
comment	Directly applied at 20hz in the framework of FDR4ALT. An ionospheric correction must be added (negative value) to the instrument range to correct this range measurement for ionospheric range delays of the radar pulse.
Source	CNES/CLS v1
int ocean_tide_correction (time)	
_FillValue	2147483647
long_name	elastic ocean tide
units	m
scale_factor	1e-3
add_offset	0.
comment	Directly applied at 20hz in the framework of FDR4ALT. Solution 2 corresponds to FES model. Includes the equilibrium long-period ocean tide height and the short-period part of the corresponding loading tide. The permanent tide (zero frequency) is not included in this parameter because it is included in the geoid and mean sea surface.
source	FES2014b LEGOS/NOVELTIS/CNES/CLS
int ocean_tide_non_equilibrium_correction (time)	
_FillValue	2147483647
long_name	long period non equilibrium ocean tide
standard_name	sea_surface_height_amplitude_due_to_non_equilib rium_ocean_tide

units	m
scale_factor	1e-3
add_offset	0.1
comment	This parameter is computed as a correction to the parameter ocean_tide_eq_01; it contains the long-period ocean tide and the long-period load tide components. This value can be added to ocean_tide_sol2_01, so that the resulting value models the total non equilibrium geocentric ocean tide height.
int solid_earth_tide_correction (time)	
_FillValue	2147483647
long_name	solid earth tide
standard_name	sea_surface_height_amplitude_due_to_earth_tide
units	m
scale_factor	1e-3
add_offset	0.
comment	Directly applied at 20hz in the framework of FDR4ALT. Calculated using Cartwright and Tayler tables and consisting of the second and third degree constituents. The permanent tide (zero frequency) is not included.
Source	[Cartwright and Edden, 1973] Corrected tables of tidal harmonics – J. Geophys. J. R. Astr. Soc., 33, 253-264
int pole_tide_correction (time)	
_FillValue	2147483647
long_name	geocentric polar tide
units	m
scale_factor	1e-3
add_offset	0.
source	[Wahr, 1985] Deformation of the Earth induced by polar motion – J. Geophys. Res. (Solid Earth), 90, 9363-9368.
byte sea_ice_type_rad_alti (time)	
_FillValue	127b
long_name	sea-ice surface type flag
units	1
flag_values	0b, 1b, 2b, 3b, 4b, 5b
flag_meanings	ocean, first-year sea-ice, wet sea-ice, multi-year sea-ice, ambiguous / mixture of type , not evaluated
comment	Surface type flag given as extra information to the users. This flag was not used in the radar freeboard computation process

3.6 Ocean & Coastal Thematic Data Products (TDP)

3.6.1 Introduction

The specific requirements of Ocean & Coastal TDP depend on the applications the end users will use the corresponding products for. A categorical list of these applications can be a starting point to identify the requirements of the different thematic products that can be relevant to create in the framework of this project. Existing Ocean & Coastal processing can then be analysed to see if in their current form they conform to the inferred requirements of the requests. Instead of inferring requirements from a set of historical request data, the users can be asked directly for these requirements – this is indeed valuable (as interests and work methods change through time); this has been done on the first quarter of 2020. These two methods can and should be used in an improvement analysis of current ERS-1/2 and ENVISAT products. The outcome of this analysis is the product requirements definition for Ocean and Coastal TDP in its final form; this version includes results from both the inferred requirements and the results of the user survey.

3.6.2 User Requirements

Inferring requirements from end-user applications of coastal data

It is not easy to have statistically significant answers in a survey. It is usually observed that a *good* percentage of survey responses is around 10% (and this is indeed what is observed for user satisfaction surveys at the Aviso+ site). Before undertaking a direct survey, we seek to have a better understanding of the altimetry coastal data end users and the applications they envision. To this end, we started to use existing user data such as those that are available at CTOH. As a French national data center («service national d'observation»), the CTOH handles requests for altimetry data since its creation in 1989, and a database centralizing all requests since 2010 is available, particularly for those users requesting the CTOH's coastal product X-TRACK. That means almost 10 years of user requests of coastal data are in the database (from March 2010 to the end of 2018 when the distribution of coastal products was taken over by Aviso+). In this period, more than 550 requests were handled, and for each and every one of them we asked for the scientific purpose of the request. This data has been anonymized and used to categorize the application objectives of coastal altimetry data use. The result of this categorization is shown in Table 3.5 .

Sea level change on coastal areas
climate change
constraints on GIA
coastal waves
sea level and flooding on coastal areas
storm surge study
tide and SLA variability on coast
Coastal Oceanography
coastal currents
inter annual variability of currents
multi sensor approach to coastal hydrology
volume transport from SLA
Altimetry
Tide gauge & altimetry comparison
SWH analysis
wind speed from altimetry
cal/val of future missions
Models
data assimilation
validation regional ocean models
tidal and circulation models

Table 3.5 : Applications of coastal data as given in requests to CTOH 2010-2018

The most frequent request purpose was, not surprisingly, the assessment / validation / control of sea level change on coastal areas, and hence its variability.

Coastal UR: The TDP shall make possible the calculation of sea-level variability.

Of course, the best product for variability should be an L3 product with altimetry data comparable cycle to cycle, reprojected to a reference track and providing timeseries directly. An L3 product being out of the scope of this project, we can only try to mitigate this drawback.

Regarding the coverage of the product, the coastal product should cover the global coastal ocean between -66° South and 66° North. For coherence with a widely used reference coastal product (X-TRACK), we suggest covering the same zones

Coastal UR: The TDP coverage should at least overlap the X-TRACK zones

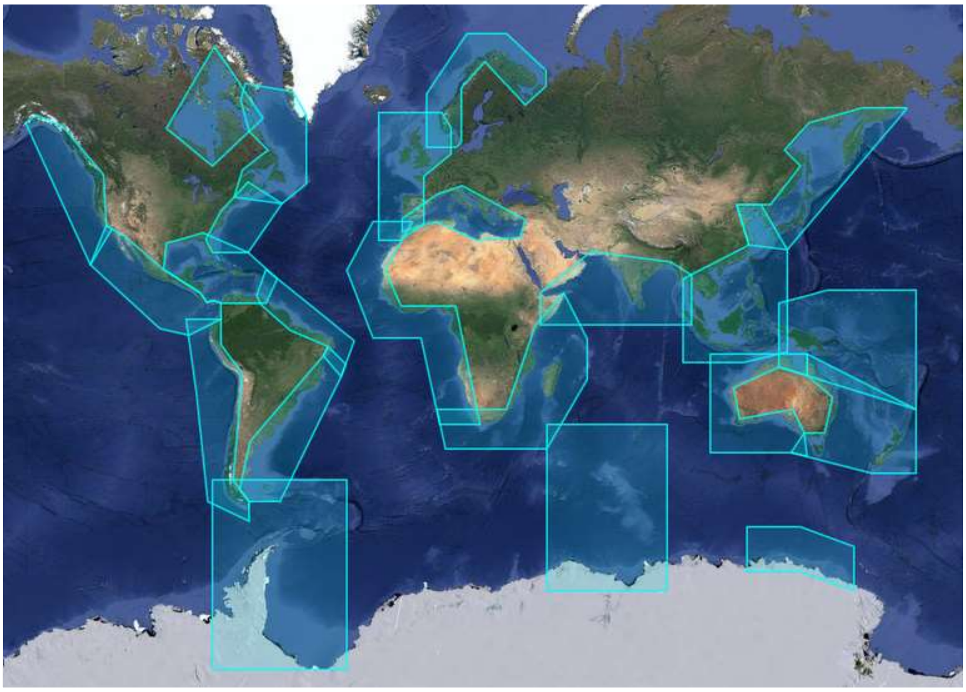


Figure 5 : X-TRACK coastal zones

Several ways of calculating the SLA are indeed possible, depending on the set of altimetric corrections used. Based on our experience as both users and producers of altimetry data, we add the following requirement:

Coastal UR: The TDP should provide a sea level anomaly variable (SLA), but all its constituents shall also be made available in the same product.

This is necessary in the case the user wants to replace, for example, the standard tide model by a specific regional model he has access to.

Regarding each altimetric correction it should be noted the continuity requirement:

Coastal UR: The TDP should provide continuity with ocean TDP products not only at the SLA level but also for every correction used in the SLA calculation.

When dealing with coastal data, knowing what the position of a particular measurement with respect to the coast, is always helpful. Indeed, many coastal publications show analysis of coastal data using distance to coast as abscissa of many graphs. Thus, the following requirement appears:

Coastal UR: The TDP should contain a distance-to-coast parameter.

This can be either the distance to the nearest coastline as given by a database (I.e. GSHHS), or to the nearest coastline pertaining to an object greater than 400 km^2 (Leuliette's distance). When in need of a monotonic parameter, the along track distance to the nearest coast is also relevant.

Concerning the *coastal oceanography* category, a particular need is the multi-sensor approach, which often means mixing model grids with along-track data. In any case, as recent studies and results in CCI projects have shown, we should keep the highest resolution for altimetry products, and particular in the coastal zone where they do provide added value.

Coastal UR: The TDP should provide altimetry data in the highest resolution available.

On the *models* category, altimetry should cater to answer the needs of modelling teams, in such a way that:

Coastal UR: The TDP should provide physical content, resolution and format adequate to the needs of data assimilation in models.

For models in the coastal area, this usually means sub-kilometric resolution and thus high-resolution altimetry.

Additional requirements, part of the TDP philosophy, are the explicit nature of uncertainty in the measurements:

Coastal UR: The TDP should provide uncertainty estimations for the SLA and, if possible, for each component. This information should be provided at a low resolution.

Furthermore, valid and invalid data shall be clearly identified.

Coastal UR: The TDP shall include a binary validity flag for SLA indicating if the measurement is considered usable for coastal applications or not.

User survey of Coastal needs

Can be found in 0

Requirements for end-user applications of ocean data

In order to ease the use of ocean data (global Mean Sea Level studies, …) and ensure continuity with other already available L2P products (from other altimetry missions), it is recommended to deliver a product at low resolution (1Hz). At 20Hz, the continuity with the coastal product should be ensured for distance-to-coast values of more than 20 km.

Ocean UR: The TDP should provide data at 1Hz resolution

Several ways of calculating the SLA are indeed possible, depending on the set of altimetric corrections used. Based on our experience as both users and producers of altimetry data, we add the following requirement:

Ocean UR: The TDP should provide a sea level anomaly variable (SLA), but all its constituents shall also be made available in the same product.

Regarding each altimetric correction it should be noted the continuity requirement:

Ocean UR: The TDP should ensure continuity with coastal TDP solution, not only at the SLA level but also for every correction used in the SLA calculation.

Valid and invalid data shall be clearly identified.

Ocean UR: The TDP shall include a validity flag for SLA indicating if the measurement is considered usable or not.

3.6.3 Metadata

Group	Number of variables	Dimensions
main/data_01	9	time
main/data_20	9	time
expert/data_01	16	time
expert/data_20	16	time

To minimize the storage size and keep adequate numerical precision, some of the parameters are scaled using NetCDF scale_factor and add_offset attributes. This allows to reduce the data size by truncating floats while keeping at least four digits precision.

The Ocean and Coastal TDP files follow the file structure described in section 2.7 with two groups, main and expert. The content of the main group allows to access sea level anomaly information and dedicated validity flag and distance to coast information. The content of the expert group is additional information about the corrections used to retrieve the sea level anomaly, which will allow each user to change sla from one correction and apply its own solution.

Each group includes a data_01 and data_20 sub-group (see Figure 6):

data_01: data at 1Hz rate.
data_20: data at 20Hz rate.

```
netcdf <file name> {

// global attributes:
            [...]

group: main {
  group: data_01 {
    dimensions:
        time = <Number of records at 1Hz> ;
    variables:
            [...]
    data:
            [...]

  group: data_20 {
    dimensions:
        time = <Number of records at 20Hz> ;
    variables:
            [...]
    data:
            [...]
}

group: expert {
  group: data_01 {
    dimensions:
        time = <Number of records at 1Hz> ;
    variables:
            [...]
    data:
            [...]

  group: data_20 {
    dimensions:
        time = <Number of records at 20Hz> ;
    variables:
            [...]
    data:
            [...]
}
```

Figure 6 : Ocean and Coastal TDP NetCDF file structure

3.6.4 Global attributes

Global attributes are given in section 2.8, here we show only the values changed specifically for the TDP Ocean and Coastal.

Attribute	Value
Conventions	CF-1.8
title	FDR4ALT Thematic Data Product: Ocean and Coastal
institution	ESA
source	FDR4ALT Processing baseline V1.0 – Coastal V1.0 – Ocean V1.0
FDR_input	FDR ALT V1.0
history	Creation YYYY-MM-DDTHH:MM:SS
contact	ESA pierre.femenias@esa.int CLS: hroinard@groupcls.com; LEGOS: fernando.nino@ird.fr
processing center	CLS core system; CNES CST
reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556
mission_name	[ERS-1/ERS-2/ENVISAT]
altimeter_sensor_name	[RA/RA/RA-2]

radiometer_sensor_name	[ATSR-MW/ATSR-MW/MWR]
cycle_number	Relative cycle number
pass_number	Pass number in the cycle (relative pass number)
first_meas_time	date and time of the first observation in file (YYYYMMDDTHHMMSS.mmmmmm)
last_meas_time	date and time of the last observation in file (YYYYMMDDTHHMMSS.mmmmmm)
ellipsoid_ref	WGS84
large_scale_uncertainty	<specific to each file value>
identifier_product_DOI	10.5270/ESA-7c37033
identifier_product_DOI_authority	http://dx.doi.org/

3.6.5 Variables definition

In the case of ocean tide height correction, a unique composite solution is presented hereafter: it should be built from the best algorithm against regional area, with continuity from coastal zone to open ocean. Coastal TDP products will contain only the data_20 component.

	main		expert	
	data_01	data_20	data_01	data_20
time	X	X		
latitude	X	X		
longitude	X	X		
sea_level_anomaly	X	X		
inter_mission_bias	X	X		
validation_flag	X	X		
distance_to_coast	X	X		
meso_scale_uncertainty	X	X		
short_scale_uncertainty	X	X		
surface_type			X	X
altitude			X	X
range			X	X
sea_state_bias			X	X
ionospheric_correction			X	X
high_frequency_adjustment				X
range_ssb_hfa			X	
wet_tropospheric_correction			X	X
dry_tropospheric_correction			X	X
dynamic_atmospheric_correction			X	X
ocean_tide_height			X	X
ocean_tide_height_model_type			X	X
internal_tide			X	X
pole_tide			X	X
solid_earth_tide			X	X
mean_dynamic_topography			X	X

mean_sea_surface			X	X
Total number of variables	*9*	*9*	*16*	*16*

Table 3.6 : Ocean and Coastal TDP variables content

The following table concerns all data given in the Ocean and Coastal TDP. If not specified, the following variables will be both available at a 20 Hz rate (data_20) and at a 1Hz rate (data_01). Coastal TDP will have only 20 Hz rate data. Some are available only at 1Hz or 20Hz following the user interest or variable availability for each rate (see also Table 3.6).

Variables in common with other products (time, latitude, longitude) are described in section 3.1

group : main/data_01 and main/data_20

short sea_level_anomaly(time)	
_FillValue	32767s
long_name	sea level anomaly
standard_name	sea_surface_height_above_sea_level
quality_flag	/main/data_20/validation_flag or /main/data_01/validation_flag
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment (data_20 only)	= altitude of satellite (/expert/data_20/altitude) – Ku band corrected ocean altimeter range (/expert/data_20/range) – sea state bias correction in Ku band (/expert/data_20/sea_state_bias) – high frequency adjustment (/expert/data_20/high_frequency_adjustment) – altimeter ionospheric correction on Ku band (/expert/data_20/ionospheric_correction) – radiometer wet tropospheric correction (/expert/data_20/wet_tropospheric_correction) – model dry tropospheric correction (/expert/data_20/dry_tropospheric_correction) – dynamic atmospheric correction (/expert/data_20/dynamic_atmospheric_correction) – geocentric ocean tide height (/expert/data_20/ocean_tide_height) – internal tide (/expert/data_20/internal_tide) – geocentric pole tide height (/expert/data_20/pole_tide) – solid earth tide height (/expert/data_20/solid_earth_tide)– mean sea surface (/expert/data_20/mean_sea_surface) – inter mission bias (/expert/data_20/inter_mission_bias).
comment (data_01 only)	= altitude of satellite (/expert/data_01/altitude) – Ku band corrected with ssb and hfa ocean altimeter range (/expert/data_01/range_ssb_hfa) – altimeter ionospheric correction on Ku band (/expert/data_01/ionospheric_correction) – radiometer wet tropospheric correction (/expert/data_01/wet_tropospheric_correction) – model dry tropospheric correction (/expert/data_01/dry_tropospheric_correction) – dynamic atmospheric correction (/expert/data_01/ dynamic_atmospheric_correction) – geocentric ocean tide height (/expert/data_01/ocean_tide_height) – internal tide (/expert/data_01/internal_tide) – geocentric pole tide height (/expert/data_01/pole_tide) – solid earth tide height (/expert/data_01/

	solid_earth_tide)– mean sea surface (/expert/data_01/mean_sea_surface) – inter mission bias (/expert/data_01/inter_mission_bias).

short inter_mission_bias(time)	
_FillValue	32767s
long_name	bias correction to have consistent time series since ERS1
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude

byte validation_flag (time)	
_FillValue	127b
long_name	validation flag
standard_name	status_flag
flag_meanings	0_rejected 1_valid_data_over_ocean 2_valid_data_on_coastal
flag_values	0b, 1b, 2b
valid_min	0b
valid_max	2b
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude

int distance_to_coast (time)	
_FillValue	2147483647
long_name	distance to the coast
units	m
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude

short meso_scale_uncertainty (time)	
_FillValue	32767s
long_name	uncertainty at meso scale
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude

short short_scale_uncertainty (time)	
_FillValue	32767s
long_name	uncertainty at short scale
units	m
scale_factor	1e-4

coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude

group : expert/data_01 and expert/data_20

byte surface_type (time)	
_FillValue	127b
long_name	surface type from GSHHG
flag_values	0b, 1b, 2b, 3b, 4b
flag_meanings	ocean land lake island_in_lake pond_in_island
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	GSHHG data version 2.3.7
valid_min	0b
valid_max	4b

int altitude(time)	
_FillValue	2147483647
long_name	altitude of satellite
standard_name	height_above_reference_ellipsoid
institution	CNES for ENVISAT / ESA for ERS1/2
source	POE-F for ENVISAT / DEOS for ERS1/2
units	m
add_offset	700000
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	Altitude of satellite above the reference ellipsoid WGS84.

int range(time)	
_FillValue	2147483647
long_name	corrected altimeter range in main altimeter frequency band
standard_name	altimeter_range
units	m
add_offset	700000.
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	All instrumental corrections included, except high frequency adjustement»

short sea_state_bias(time)	
_FillValue	32767s
long_name	«sea surface height bias due to sea surface roughness on main altimeter frequency band»

standard_name	«sea_surface_height_bias_due_to_sea_surface_roughness»
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	A sea state bias correction must be added (negative value) to the instrument range to correct this range measurement for sea state delays of the radar pulse.

short ionospheric_correction(time)	
_FillValue	32767s
long_name	ionospheric correction on Ku band
standard_name	altimeter_range_correction_due_to_ionosphere
source	GIM for ENVISAT, ERS2 and ERS1 from cycle 106 onwards. NIC09 for ERS1 until cycle 105 included.
institution	NASA/JPL (for GIM) or Altimetrics for NIC09
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	An ionospheric correction must be added (negative value) to the instrument range to correct this range measurement for ionospheric range delays of the radar pulse.

short high_frequency_adjustment (time) data_20 ONLY	
_FillValue	32767s
long_name	high frequency adjustment
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude
comment	high frequency adjustment for 20 Hz altimeter sea level data

int range_ssb_hfa (time) data_01 ONLY	
_FillValue	2147483647
long_name	corrected altimeter range in main altimeter frequency band
standard_name	altimeter_range
units	m
add_offset	700000
scale_factor	1e-4
coordinates	/main/data_01/longitude /main/data_01/latitude
comment	All instrumental corrections included. Corrected by high_frequency_adjustment and sea_state_bias before compression from 20Hz to 1Hz

short wet_tropospheric_correction (time)

_FillValue	32767s
long_name	radiometer wet tropospheric correction
standard_name	altimeter_range_correction_due_to_wet_troposphere
source	FDR4ALT: TDP ATM
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	A wet tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for wet tropospheric range delays of the radar pulse. This correction is computed from the data of the onboard radiometer.

short dry_tropospheric_correction (time)	
_FillValue	32767s
long_name	model dry tropospheric correction at zero altitude
standard_name	altimeter_range_correction_due_to_dry_troposphere
institution	ECMWF
source	ERA5
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	Computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag. A dry tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for dry tropospheric range delays of the radar pulse.

short dynamic_atmospheric_correction (time)	
_FillValue	32767s
long_name	dynamic atmospheric correction
institution	LEGOS/CLS/CNES
source	TUGO ERA5 or MOD2d (in case of ERS-1 before cycle 64)
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment (ERS-1)	TUGO or MOG2d high resolution forced with operational ECMWF or ERA5 pressure and wind fields plus inverse barometer. This correction is computed by adding the high frequency fluctuations of the sea surface topography and the inverted barometer height correction computed from rectangular grids. Sum of the high frequency fluctuations correction and of the low frequency inverted barometer correction
comment (ERS-2 and ENVISAT)	TUGO high resolution forced with ECMWF ERA5 pressure and wind fields plus inverse barometer. This correction is computed by adding the high frequency fluctuations of the sea surface topography and the inverted barometer height correction computed from rectangular grids. Sum of the

	high frequency fluctuations correction and of the low frequency inverted barometer correction

int ocean_tide_height (time)	
_FillValue	2147483647
long_name	geocentric ocean tide height
standard_name	sea_surface_height_amplitude_due_to_geocentric_ocean_tide
institution	LEGOS/NOVELTIS/CNES/CLS
source	FES14B/regional model , see ocean_tide_height_model_type for data_20 FES14B for data_01
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	Includes the corresponding loading tide and equilibrium long-period ocean tide height. The permanent tide (zero frequency) is not included in this parameter because it is included in the geoid and mean sea surface. See ocean_tide_height_model_type to see if the global or the regional solution is used

byte ocean_tide_height_model_type(time)	
_FillValue	127b
long_name	Global tide solution (value = 0) or regional tide solution (value = 1) given in variable ocean_tide_height.
flag_meanings	0: global with FES2014B, 1: regional
flag_values	0b, 1b
valid_min	0b
valid_max	1b
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude

short internal_tide(time)	
_FillValue	32767s
long_name	internal tide height
source	E. D. Zaron. Baroclinic tidal sea level from exact-repeat mission altimetry. Journal of Physical Oceanography, 49(1):193-210, 2019.
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	Includes the M2, K1, S2, O1 contributions

short pole_tide(time)	
_FillValue	32767s
long_name	geocentric pole tide height
standard_name	sea_surface_height_amplitude_due_to_pole_tide

source	Desai, Wahr, and Beckley [2015], Revisiting the pole tide for and from satellite altimetry – J. Geodesy, 89 (12). 1233-1243.
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	Adopts Ries and Desai [2017] model for mean pole location. Xp = 55.0 + 1.677*DT, Yp = 320.5 + 3.460*DT in milliarcseconds with DT = years since 2000.0.

short solid_earth_tide(time)	
_FillValue	32767s
long_name	solid earth tide height
standard_name	sea_surface_height_amplitude_due_to_earth_tide
source	Cartwright and Edden [1973] Corrected tables of tidal harmonics – J. Geophys. J. R. Astr. Soc., 33, 253-264.
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	Calculated using Cartwright and Tayler tables and consisting of the second and third degrees constituents. The permanent tide (zero frequency) is not included.

int mean_dynamic_topography (time)	
_FillValue	2147483647
long_name	mean dynamic topography above geoid
source	MDT_CNES_CLS-2018
institution	CLS/CNES
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude

int mean_sea_surface(time)	
_FillValue	2147483647
long_name	mean sea surface height above reference ellipsoid
institution	CNES/CLS/DTU/SIO
source	Combined SIO/CNES_CLS2015/DTU15
units	m
scale_factor	1e-4
coordinates	/main/data_20/longitude /main/data_20/latitude or /main/data_01/longitude /main/data_01/latitude
comment	The Mean Sea Surface Combined SIO/CNES_CLS2015/DTU15 model (DOI: 10.24400/527896/a01- 2021.004) was produced by SSALTO/DUACS and distributed by AVISO+

	(https://www.aviso.altimetry.fr/) with support from CNES, in collaboration with SIO and DTU

3.7 Ocean Waves Thematic Data Product (TDP)

3.7.1 Introduction

The FDR4ALT Ocean Waves TDP is an innovative product made available for the wave community. It was designed to become a demonstration product for the Wave-TAC CMEMS.

For this, we chose to make it compliant with the current format of "L2P wave product" distributed for CMEMS to build their L3 product.

3.7.2 User Requirements

In 2021, the Wave-TAC user service at Mercator published a survey whose results asked for future evolutions:

- Higher resolution products for coastal studies and high variability areas.
- Uncertainty values

CMEMS have decided that the future baseline production will be 5Hz data. The FDR4ALT project can help to demonstrate the quality of such product and ENVISAT will become one of the pioneer missions to be tested by CMEMS internal users (jointly with CFOSAT and Jason-3).

This product intends to fulfil the needs of end users such as the ones already identified in the Wave-TAC of CMEMS project. Therefore, its format should be in line with what is expected as inputs of the usual formats expected and described in https://catalogue.marine.copernicus.eu/documents/PUM/CMEMS-WAV-PUM-014-005-006-007.pdf.

Such product needs to contain valid, selected, and calibrated data. It will be given at 5Hz to maximize the improvement of signal to noise ratio provided by the adaptive (with HFA, TBC in phase 2) processing.

3.7.3 Metadata

The Ocean Waves TDP does not use the grouping strategy. Indeed, it was not considered relevant for this TDP to add an expert group with additional fields. Note that it is the only FDR4ALT product with only one group.

Group	Number of variables	Dimensions
/	7	time

3.7.4 Global Attributes

Global attributes are given in section 2.8, here we show only the values changed specifically for the Ocean Waves TDP.

Attribute	Value
conventions	CF-1.8
title	FDR4ALT Thematic Data Product: Ocean Waves
institution	ESA

source	FDR4ALT Processing Baseline V1.0 –
FDR_input	FDR ALT V1.0
history	Creation YYYYMMDDTHHMMSS
contact	ESA pierre.femenias@esa.int CLS: aollivier@groupcls.com;
reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556
processing_center	CLS core system ; CNES CST
mission_name	[ERS-1/ERS-2/ENVISAT]
altimeter_sensor	[RA/RA/RA-2]
cycle_number	Relative cycle number
pass_number	Relative pass number
first_time_meas	Date and time of the first observation in file (YYYYMMDDTHHMMSS.mmmmmm)
last_time_meas	Date and time of the last observation in file (YYYYMMDDTHHMMSS.mmmmmm)
ellipsoid_ref	"WGS84"
large_scale_uncertainty	[0.35/0.35/0.05]
identifier_product_DOI	10.5270/esa-4427c33
identifier_product_DOI_authority	http://dx.doi.org/

3.7.5 Variables definition

The format is L2P like and contains, in addition to the global attributes described in 2.8 and to the time, latitude and longitudes variables, described in 3.1 :

variables in common with other products are described in section 3.1	
short swh_adjusted(time)	
_FillValue	32767s
long_name	Sea surface wave significant height adjusted
units	m
scale_factor	1e-3
add_offset	0.0
valid_min	0s
valid_max	32767s
coordinates	longitude latitude
short swh_adjusted_filtered(time)	
_FillValue	32767s
long_name	Sea surface wave significant height filtered with EMD
units	m
scale_factor	1e-3
add_offset	0.0
valid_min	0s
valid_max	32767s
coordinates	longitude latitude

short swh_bias_adjusted(time)	
_FillValue	32767s
long_name	'Global bias of Significant Wave Height with respect to Envisat data.'
units	m
scale_factor	1e-3
add_offset	0.0
valid_min	-32767s
valid_max	32767s
coordinates	longitude latitude
comment	Adding this value to swh allows to recover the original L2 swh value
short swh_uncertainty(time)	
_FillValue	32767s
long_name	Uncertainty on top-of-Significant Wave Height
units	m
scale_factor	1e-3
add_offset	0.0
valid_min	0s
valid_max	32767s
coordinates	longitude latitude
comment	This uncertainty is based on residual between the filtered and the non-filtered signal.

3.8 Inland Water Thematic Data Products (TDP)

3.8.1 User requirements

The Inland Water Thematic Data Products have been preliminarily defined thanks to the survey of potential users identified from the space hydrology and hydrology communities.

Two different surveys were performed:

- one addressing the space hydrology community (and in particular L3 producers), which are direct users of these products. The questions were specific on the content and format of the products. At this time, 12/2019, 7 users answered.
- one addressing the hydrology community, which are indirect users of these products, to understand their needs in terms of L3 / L4 products, which will have repercussions on our choices for the TDP products. At this time, 12/2019, 24 users answered.

Based on the user responses, described in following sections, the final product contains two groups. The main group that includes higher level data on water surface height, its quality indicator and the associated uncertainty as well as some auxiliary data. This group aims to meet the needs of the hydrological community. The second group, with lower-level data, is dedicated to users with expert knowledge of altimetry. It contains the different components and corrections used in the estimation of the water surface height.

3.8.2 Survey addressed to space hydrology users

This questionnaire was addressed to the space hydrology community (complete results in 0) with main objective to understand the surface of interest and the most appropriate contents and file format according to the users. Most of them are interested in rivers and lakes (including reservoirs) on a global spatial coverage

Users generally agree with the variables proposed in the survey. It can be noted that most users want several retracking solutions and recommend:

- «Retracking algorithms similar to SARAL plus additional for testing (including ALES, SARvatore, and any adaptive retracker output, etc)»
- «If possible, a persistent retracker. I.e., the Multiple persistent narrow primary peak. As it find persistent reflections.»
- «ice1, ice3 (CLS), any new/robust physical retracker»

Besides, few users want the detail of instrumental corrections, it could thus be included in range directly, and Electromagnetic Bias corrections. The interest for Electromagnetic Bias correction could be investigated further on lakes in the frame of the Round-Robin exercise as it could be of interest for some lakes.

There is a strong interest for along-track information on the surface type (land/water mask, water occurrence, etc).

3.8.3 Survey addressed to the hydrology community

The questionnaire was distributed to different universities, private and public companies and research organizations mainly related to the hydrology field, also including climate, limnology, ecology and flood disaster fields (see 0). The questionnaire had the objectives to understand:

1. to what inland water surface the users would be interested.
2. the requirements associated to the products released by the project (temporal resolution, river width and accuracy);
3. the data format and the preferred way to disseminate the products.
4. if the end users use or have used altimetry data in their activities and if they will use them.

Their answers will be used to understand whether the scientific objectives are in line with the user needs and whether the final products are mature enough to reach the user requirements.

In the following we report and discuss the questions and the user's answers.

All the surfaces proposed are of interest to the participants, even if the rivers, collecting the maximum value of answers, seem to play a dominant role compared to lakes, reservoirs, and wetlands. Global and regional scales are more interesting than local analyses that have obtained half of the answers. Whereas the information on single hydrographic basin or water body (river, or lake or wetlands) are preferred to climatic ecoregion or water bodies. Both surveys underline that the interest of the hydrological community is mainly focus on specific river basin, with regional analysis rather than local investigations related to specific environment. Moreover, the global studies are more related to the identification of patterns and characteristics in rivers and lakes, more useful for hydroclimate change and its consequences in water resources.

About the requirements of the data products, inland water products would be particularly interesting if provided for narrow – medium rivers, characterized by a width ranging from 10-300 m, rather than large rivers (width greater than 500 m). Similarly, lakes with areas of 100 km2 are preferred to bigger ones. The reduced size of the water body targets has a central role, and of course represents a big challenge for the past and current state of the satellite missions.

Concerning the temporal resolution, the answers show that daily resolution is the desired frequency for monitoring and forecasting activities, while for climate change studies and water management activities, weekly and monthly scales are probably preferred. The state of the current satellite missions cannot guarantee potential retrieval of water surface elevation with daily temporal resolution, but a multi-mission approach is potentially able to provide information every 3-4 days.

In terms of errors, specific values are clearly described by the hydrology users and in particular, a Root Mean Square Error of about 20-30 cm is considered acceptable for rivers and lakes. These values are smaller than what it was investigated in literature so far, but they can be considered an evaluable target to be achievable.

About the data format the NetCDF is preferred along with the FTP to download inland water products. These questions aim to investigate if the participants have familiarity with satellite altimetry products and for what applications they are interested to use them. Most of the participants have already used the satellite altimetry products for different applications related to hydrological/hydraulic modelling, also aimed to data assimilation techniques, the estimation of water level, river discharge and water volume up to the investigation of climate change and river/lake characterization. Based on these replies, the interest of the community seems quite large and it is reflected also in the possible use of the FDR4ALT products. A further question deepens the possible combination of the radar altimetry with other satellite products. The answers focus mainly on the optical and SAR images with interest also for GRACE, and other satellite altimetry missions.

As optional question, we asked for any other needs to be complied by the FDR4ALT Inland water products and we got three answers:

altimeter waveforms

metadata information on retracker used

gridded vertical precision, and hydrologically corrected versions

These answers underline the interest of space hydrology to understand the processing of the altimetry raw data and the accuracy of the final product.

3.8.4 Global attributes

Attribute	Value
Conventions	CF-1.8
title	FDR4ALT Thematic Data Product: Inland Waters
institution	ESA
Source	FDR4ALT Processing baseline V1.0
FDR_input	FDR ALT V1.0
History	Creation YYYYMMDDTHHMMSS.mmmmmm
Contact	ESA pierre.femenias@esa.int, CLS: bcalmettes@groupcls.com
reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556
processing_center	CLS core system ; CNES CST
mission_name	[ERS-1/ERS-2/ENVISAT]
altimeter_sensor_name	[RA, RA, RA-2]
cycle_number	Relative cycle number

pass_number	Relative pass number
first_meas_time	Date and time of the first observation in file (YYYYMMDDTHHMMSS.mmmmmm)
last_meas_time	Date and time of the last observation in file (YYYYMMDDTHHMMSS.mmmmmm)
ellipsoid_ref	WGS84
identifier_product_DOI	10.5270/ESA-e3e68ff
identifier_product_DOI_authority	http://dx.doi.org/

3.8.5 Metadata

The Inland water variables are separated in two groups. The variables in the main group are adequate for the majority of users and allow easier access to the most important variables, including the water surface height obtained with the retracking more adapted to inland waters in a general way. The second group contains additional data, allowing expert users to evaluate the water surface height from other retrackers for specific targets, or have access to data allowing the use of different geophysical corrections for example.

The “time” variable is strictly identical for both groups, therefore it is the only variable that is outside the groups.

Group	Number of variables	Dimensions
Main	8	time
Expert	17	time

3.8.6 Variables definition

The tables below, describe the content of the variable for the three missions (ERS1, ERS2 and ENVISAT) for each group.

Group: main	
variables in common with other products (time, latitude, longitude) are described in section 3.1	
float wsh_above_ellipsoid(time)	
_FillValue	9.969209968386869e+36
long_name	Water surface height above ellipsoid WGS84
Units	m
valid_min	-250
valid_max	5000
Comment	The water surface heigh (wsh) is estimated as the satellite altitude – range (ICE1 retracking) - geophysical corrections based on models (Dry tropospheric correction, Wet tropospheric correction, Ionospheric correction, Earth and Polar tides).
byte wsh_quality_flag(time)	
_FillValue	127b
long_name	Water surface height quality flag
flag_meanings	good_quality medium_quality bad_quality no_data
flag_values	0b, 1b, 2b, 3b
Comment	These are quality indicators and are important for the correct use of data.
int wsh_uncertainty(time)	

_FillValue	2147483647
long_name	Water surface height uncertainty
Units	cm
scale_factor	1e-2
valid_min	0
valid_max	20000
Comment	The uncertainty is given by the quadratic sum of the uncertainties from each component of water surface height. It includes the geophysical uncertainties for inland waters as well as the range uncertainty
int geoid (time)	
_FillValue	2147483647
long_name	Geoid height above reference ellipsoid
Units	m
scale_factor	1e-4
valid_min	-1000000
valid_max	1000000
comment	Earth Gravitational Model EGM 2008
byte land_water_occurrence (time)	
_FillValue	127b
long_name	Statistical Water Occurrence based on GSWE
units	percent
valid_min	1
valid_max	100
comment	Statistical water occurrence is based on Global Surface Water Explorer (1984-2015). Only values with occurrence bigger than 0 are included in this dataset
byte surface_type (time)	
_FillValue	127b
long_name	Surface type based on GLWD3
units	1
flag_values	1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, 10b, 11b, 12b
flag_meanings	lake reservoir river floodplain swamp_forest_and_flooded_forest coastal_wetland pan_brackish_saline_wetland bog_fen_mire_peatland intermitant_wetetland_lake 50_100_wetland 25_50_wetland 0_25_wetland_compex
comment	Global Lakes and Wetlands Database classification (https://www.worldwildlife.org/pages/global-lakes-and-wetlands-database)

Group: expert	
byte waveform_class (time)	
_FillValue	127b
long_name	20Hz Ku-band waveform main class
units	1
valid_min	1
valid_max	20
flag_values	1b,2b,3b,4b,5b,6b,7b,8b,9b,10b,11b,12b,13b,14b,15b,16b,17b,18b,19b,20b
flag_meanings	brown_ocean peaky noisy strong_peak brown_peak_trailing_edge brown_peak_leading_edge brown_flat_trailing_edge peak_end unknown brown_noise two_leading_edges shifted_brown, altered_leading_edge

	distorted_brown linear_rise_noise shifted_brown2 breakage_leading_edge linear_decrease_noise step_leading_edge peak_and_brown
comment	Waveform main class derived from the ALT FDR L1 neural network classification. ENVISAT non applicable classes :17, 18, 19, 20. ERS-1/ERS-2 non applicable classes : 8, 12, 14, 19, 20.
int altitude (time)	
_FillValue	2147483647
long_name	Altitude of CoM above reference ellipsoid WGS84
units	m
scale_factor	1e-3
comment	Altitude of satellite center of mass above the reference ellipsoid
int sigma0_[rtk-algorithm*](time)	
_FillValue	2147483647
long_name	Backscatter coefficient with **[rtk-algorithm*]** retracking algorithm
units	dB
scale_factor	1e-2
comment	Values below the following thresholds, depending on the retracking, are edited (Detailed processing model [D-2-01]). MLE4: 7dB ICE1: 5 dB ICE3: 40 dB TFMRA: 8dB ADAPTIVE: 10dB
int range_[rtk-algorithm*](time)	
_FillValue	2147483647
long_name	Range with [rtk algorithm*]
units	m
scale_factor	1e-3
add_ofsset	0
comment	Range estimation in main altimeter frequency band with **[rtk-algorithm*]** retracking algorithm
int dry_tropospheric_correction (time)	
_FillValue	2147483647
long_name	Model dry tropospheric correction.
units	m
scale_factor	1e-4
comments	Computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag, from 3D meteorological reanalysis at measurement altitude. A dry tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for dry tropospheric range delays of the radar pulse. Dry tropospheric correction from ERA Interim model is provided courtesy of ECMWF.
int wet_tropospheric_correction (time)	
_FillValue	2147483647
long_name	Model correction due to wet troposphere from ERA interim model

units	m
scale_factor	1e-3
comments	Computed at the altimeter time-tag from the interpolation of 2 meteorological fields that surround the altimeter time-tag, from 3D meteorological reanalysis at measurement altitude. A wet tropospheric correction must be added (negative value) to the instrument range to correct this range measurement for wet tropospheric range delays of the radar pulse. Wet tropospheric correction from ERA Interim model is provided courtesy of ECMWF.
int ionospheric_correction (time)	
_FillValue	2147483647
long_name	Altimeter range correction due to ionosphere
units	m
scale_factor	1e-3
comments	An ionospheric correction must be added (negative value) to the instrument range to correct this range measurement for ionospheric range delays of the radar pulse. GIM (Global Ionosphere Map) is provided for ENVISAT and ERS2 missions. For ERS1 mission, NIC09 (NOAA Ionosphere Climatology) is provided before 01/01/1994 followed by GIM
source	Iijima, B.A.; Harris, I.L.; Ho, C.M.; Lindqwister, U.J.; Mannucci, A.J.; Pi, X.; Reyes, M.J.; Sparks, L.C.; Wilson, B.D. Automated daily process for global ionospheric total electron content maps and satellite ocean altimeter ionospheric calibration based on Global Positioning System data. J. Atmos. Sol.: Terr. Phys. 1999, 61, 1205–1218 Scharroo, R.; Smith, W.H.F. A global positioning system-based climatology for the total electron content in the ionosphere. J. Geophys. Res.: Space Phys. 2010, doi:10.1029/2009JA014719.
int pole_tide_correction (time)	
_FillValue	2147483647
long_name	Water Surface height Amplitude due to pole tide
units	m
scale_factor	1e-3
comments	Desai, Wahr, and Beckley [2015], Revisiting the pole tide for and from satellite altimetry – J. Geodesy, 89 (12). 1233-1243.The polar tide correction must be added (negative value) to the instrument range to correct this range measurement for ionospheric range delays of the radar pulse
int solid_earth_tide_correction (time)	
_FillValue	2147483647
long_name	Water Surface height amplitude due to elastic response to tidal potential
units	m
scale_factor	1e-3
comments	Cartwright and Edden [1973] Corrected tables of tidal harmonics - J. Geophys. J. R. Astr. Soc., 33, 253-264. Solid earth tide must be added to the range to remove the effect of local tidal distortion in the crust of the Earth.

*where rtk-algorithm is one of ice1, ice3, tfmra, adaptive or mle4

3.9 Atmosphere Thematic Data Products (TDP)

3.9.1 Introduction

The Atmospheric TDP produced in the context of the FDR4ALT project comprise *Total Column Water Vapour* (TCWV), *Cloud Liquid Water Path* (LWP), atmospheric attenuation of the altimeter backscattering coefficient (AtmAtt) and *Wet Tropospheric Correction* (WTC), retrieved from Microwave Radiometer (MWR) observations on-board ENVISAT, ERS-1, and ERS-2, using either 1D-VAR or neural network solutions.

3.9.2 User Requirements

Long-term observations of trends in total column water vapour and sea surface height (SSH) are essential for understanding impacts and risks of Climate Change. The Global Climate Observing System (GCOS) has thus identified at an early stage both TCWV and SSH as atmosphere and ocean essential climate variables (ECVs) and has provided requirements on measurement uncertainty and stability as well as spatial resolution and observation frequency. More recently, the cloud water path (liquid and ice) has also been defined as another Atmospheric ECV, providing requirements that can also be applied to the FDR4ALT product LWP (see Table 3.*7*).

The largest source of uncertainty for SSH estimates from radar altimetry is caused by the path delay of the radar signal due to the highly variable atmospheric humidity. In fact, the spatial and temporal variability of water vapour is such that an instantaneous estimation and correction of its impact on altimeter measurements is needed, the so-called wet tropospheric correction (WTC). Due to the paramount importance of WTC on the accuracy of SSH, the GCOS requirements on SSH can also be applied as minimum requirements to WTC.

ECV	Spatial resolution	Temporal resolution	Accuracy	Stability
Global mean sea level (SSH)	10 – 100 km	Weekly to monthly	2-4 mm (global mean), 1 cm over a grid mesh	< 0.3 mm/year (global mean)
Regional sea level (SSH)	10 km	Hourly to weekly	1 cm (over grid mesh of 50-100 km)	< 1.0 mm/year (over grid mesh of 50-100 km)
Total Column Water Vapor (TCWV)	25 km	4 hours	2 %	0.3 % per decade
Cloud water path (liquid and ice)	50 km	3 hours	25 %	5 % per decade

Table 3.7 : GCOS requirements [GCOS-200, 2016] of relevance to FDR4ALT's Atmospheric TDP.

3.9.3 Metadata

The Atmosphere Thematic Data Product is composed of two groups. The variables in the group "main" provide the atmosphere processing results of the solution chosen after the phase 1 round robins (neural network retrieval). The "Expert" group gives additional access to the results of the 1DVAR retrieval.

Group	Number of variables	Dimensions
Main	14	time

Expert	16	time

3.9.4 Global attributes

Attribute name	Description
conventions	CF-1.8
title	FDR4ALT Thematic Data Product: Atmosphere
institution	ESA
source	FDR4ALT Processing Baseline V1.0
FDR_input	FDR MWR V1.0
history	Creation YYYYMMDDTHHMMSS.mmmmmm
contact	«Informus / Fluctus: fell@informus.de, CLS: fpiras@groupcls.com, ESA: pierre.femenias@esa.int»
processing_center	Informus / Fluctus
reference_document	FDR4ALT Products Requirements and Format Specification, CLS-ENV-SP-19-0556CLS-ENV-SP-19-0556
mission_name	[ERS-1/ERS-2/ENVISAT]
altimeter_sensor_name	[RA/RA/RA-2]
radiometer_sensor_name	[ATSR-MW/ATSR-MW/MWR]
cycle_number	Cycle number
pass_number	Pass number in the cycle (relative pass number)
first_meas_time	Date and time of the first observation in file (YYYYMMDDTHH:MMSS.mmmmmm)
last_meas_time	Date and time of the last observation in file (YYYYMMDDTHHMMSS.mmmmmm)
ellipsoid_ref	WGS84
identifier_product_DOI	10.5270/ESA-2d07033
identifier_product_DOI_authority	http://dx.doi.org/

3.9.5 Variables definition

Group : main	
time variable is common with other products and described in section 3.1	
latitude variable is common with other products and described in section 3.1	
longitude variable is common with other products and described in section 3.1	
int rad_water_vapor (time)	
_FillValue	2147483647
long_name	Total column water vapour (TCWV)
standard_name	atmosphere_mass_content_of_water_vapor
units	kg/m^2
scale_factor	1e-4
valid_min	0
valid_max	1e6
quality_flag	rad_retrieval_quality_flag
coordinates	longitude latitude
comment	TCWV derived from radiometer measurements

short rad_water_vapor_uncertainty (time)	
_FillValue	32767s
long_name	Uncertainty on Total Column Water Vapor (TCWV)
standard_name	atmosphere_mass_content_of_water_vapor standard_error
units	kg/m^2
comment	A posteriori uncertainty of TCWV retrieval.
scale_factor	1.e-2
valid_min	0
valid_max	100
coordinates	longitude latitude
int rad_liquid_water (time)	
_FillValue	2147483647
long_name	Cloud liquid water path (LWP)
standard_name	atmosphere_mass_content_of_cloud_liquid_water
units	kg/m^2
scale_factor	1e-4
valid_min	0
valid_max	100000
quality_flag	rad_retrieval_quality_flag
coordinates	longitude latitude
comment	LWP derived from radiometer measurements.
short rad_liquid_water_uncertainty (time)	
_FillValue	32767s
long_name	Uncertainty on Cloud Liquid Water Path (LWP)
standard_name	atmosphere_mass_content_of_cloud_liquid_water standard_error
units	kg/m^2
comment	A posteriori uncertainty of LWP retrieval.
scale_factor	1.e-2
valid_min	0
valid_max	1000.0
coordinates	longitude latitude
int rad_wet_tropo_corr (time)	
_FillValue	2147483647
long_name	Wet troposphere correction (WTC
standard_name	altimeter_range_correction_due_to_wet_troposphere
units	m
comment	Wet tropospheric correction retrieved from radiometer measurements for concomitantly acquired altimeter observations. To be added to the altimeter range.
scale_factor	1e-4
valid_min	-1e4
valid_max	0
quality_flag	rad_retrieval_quality_flag
coordinates	longitude latitude
short rad_wet_tropo_corr_uncertainty (time)	
_FillValue	32767s
long_name	Uncertainty on Wet Tropospheric Correction (WTC)
standard_name	altimeter_range_correction_due_to_wet_troposphere standard_error
units	m
scale_factor	1.e-2
valid_min	0
valid_max	100
coordinates	longitude latitude
short rad_attenuation_ku (time)	
_FillValue	32767s
long_name	Atmospheric attenuation on Ku band altimeter backscatter coefficient (ATT Ku)

units	dB
comment	Ku-band attenuation retrieved from radiometer measurements to correct the altimeter sigma_0 for the atmospheric impact
scale_factor	1.e-2
valid_min	0
valid_max	10000
quality_flag	rad_retrieval_quality_flag
coordinates	longitude latitude
short rad_attenuation_ku_uncertainty (time)	
_FillValue	32767s
long_name	Uncertainty on atmospheric attenuation on Ku band altimeter backscatter coefficient (ATT Ku)
units	dB
comment	A posteriori uncertainty of ATT Ku retrieval.
scale_factor	1.e-2
valid_min	0
valid_max	100
coordinates	longitude latitude
byte rad_retrieval_quality_flag (time)	
_FillValue	127b
long_name	Flag indicating retrieval quality
standard_name	quality_flag
units	1
flag_values	0b, 1b, 2b,3b
valid_min	0
valid_max	3
flag_meanings	good degraded_tb degraded_sig0 degraded_both
coordinates	longitude latitude
int solar_zenith_angle (time)	
_FillValue	2147483647
long_name	Solar zenith angle
standard_name	solar_zenith_angle
units	degree
comment	Zenith angle takes values greater than 90° if the sun is below the horizon
scale_factor	1e-2
valid_min	0
valid_max	18000
coordinates	longitude latitude
byte day_night_flag (time)	
_FillValue	127b
long_name	Light level indicator flag
standard_name	quality_flag
units	1
flag_values	0b, 1b, 2b
flag_meanings	day night twilight
valid_min	0
valid_max	2
coordinates	longitude latitude

Group : expert	
Variables in common with other products are described in section 3.1	
int rad_water_vapor_1DVAR (time)	
_FillValue	2147483647
long_name	Total column water vapour (TCWV) – 1DVAR
standard_name	atmosphere_mass_content_of_water_vapour
units	kg/m^2
quality_flag	rad_retrieval_quality_flag_1DVAR
comment	Vertically integrated atmospheric water vapour content. Only to be used over the ice-free ocean.
scale_factor	1e-4
valid_min	0
valid_max	1000000
coordinates	longitude latitude
short rad_water_vapor_uncertainty_1DVAR (time)	
_FillValue	32767s
long_name	Uncertainty on Total Column Water Vapour (TCWV) – 1DVAR
standard_name	atmosphere_mass_content_of_water_vapour: uncertainty
units	kg/m^2
comment	A posteriori uncertainty of 1DVAR TCWV retrieval.
scale_factor	1e-2
valid_min	0s
valid_max	10000s
coordinates	longitude latitude
int rad_liquid_water_1DVAR (time)	
_FillValue	2147483647
long_name	Cloud liquid water path (LWP) – 1DVAR
standard_name	atmosphere_mass_content_of_cloud_liquid_water
units	kg/m^2
quality_flag	rad_retrieval_quality_flag_1DVAR
comment	Vertically integrated cloud liquid water content. Only to be used over the ice-free ocean.
scale_factor	1e-4
valid_min	-100000
valid_max	100000
coordinates	longitude latitude
short rad_liquid_water_uncertainty_1DVAR (time)	
_FillValue	32767s
long_name	Uncertainty on Cloud Liquid Water Path (LWP) – 1DVAR
standard_name	atmosphere_mass_content_of_cloud_liquid_water: uncertainty
units	kg/m^2
comment	A posteriori uncertainty of 1DVAR LWP retrieval.
scale_factor	1e-2
valid_min	0s
valid_max	1000s
coordinates	longitude latitude
int rad_wet_tropo_corr_1DVAR (time)	
_FillValue	2147483647
long_name	Wet troposphere correction (WTC) – 1DVAR

standard_name	altimeter_range_correction_due_to_wet_troposphere
units	m
quality_flag	rad_retrieval_quality_flag_1DVAR
comment	Wet tropospheric correction for concomitantly acquired altimeter observations. Negative value to be added to the altimeter range. Only to be used over the ice-free ocean.
scale_factor	1e-4
valid_min	-10000
valid_max	0
coordinates	longitude latitude
short rad_wet_tropo_corr_uncertainty_1DVAR (time)	
_FillValue	32767s
long_name	Uncertainty on Wet Tropospheric Correction (WTC) – 1DVAR
standard_name	altimeter_range_correction_due_to_wet_troposphere: uncertainty
units	m
comment	A posteriori uncertainty of 1DVAR WTC retrieval.
scale_factor	1e-4
valid_min	-10000s
valid_max	0s
coordinates	longitude latitude
short rad_attenuation_ku_1DVAR (time)	
_FillValue	32767s
long_name	Atmospheric attenuation on Ku band altimeter backscatter coefficient (ATT Ku) – 1DVAR
standard_name	atmosphere_attenuation_in_ku_band
units	dB
quality_flag	rad_retrieval_quality_flag_1DVAR
comment	Ku-band attenuation calculated from retrieved TCWV [Lillibridge et al., 2014] to correct the altimeter sigma_0 for the atmospheric impact. Only to be used over the ice-free ocean.
scale_factor	1e-2
valid_min	0s
valid_max	1000s
coordinates	longitude latitude
short rad_attenuation_ku_uncertainty_1DVAR (time)	
_FillValue	32767s
long_name	Uncertainty on atmospheric attenuation on Ku band altimeter backscatter coefficient (ATT Ku) – 1DVAR
standard_name	atmosphere_attenuation_in_ku_band: uncertainty
units	dB
comment	A posteriori uncertainty of 1DVAR ATT Ku retrieval.
scale_factor	1e-2
valid_min	0s
valid_max	1000s
coordinates	longitude latitude
byte rad_retrieval_quality_flag_1DVAR (time)	
_FillValue	127b
long_name	Flag indicating retrieval quality – 1DVAR
standard_name	quality_flag
units	1
comment	Retrieval success indicator. Helpful for product evaluation.

flag_values	0b, 98b, 99b
flag_meanings	retrieval successful, retrieval failed, retrieval not attempted (e.g., over land)
coordinates	longitude latitude
byte day_night_flag_1DVAR (time)	
_FillValue	127b
long_name	Light level indicator flag – 1DVAR
standard_name	quality_flag
units	1
comment	Light level indicator. Helpful for product evaluation.
flag_values	0b, 1b, 2b
flag_meanings	day, night, twilight
coordinates	longitude latitude
int rad_water_vapor_prior_1DVAR (time)	
_FillValue	2147483647
long_name	A priori value of Total Column Water Vapour (TCWV) – 1DVAR
standard_name	atmosphere_mass_content_of_water_vapour_prior
units	kg/m^2
comment	A priori value used for 1DVAR total column water vapour retrieval.
scale_factor	1e-2
valid_min	0
valid_max	10000
coordinates	longitude latitude
short rad_cost_1DVAR (time)	
_FillValue	32767s
long_name	Cost function – 1DVAR
units	1
comment	1DVAR retrieval cost function. Helpful for product evaluation.
scale_factor	1e-2
valid_min	0s
valid_max	10000s
coordinates	longitude latitude

4 Auxiliary data files

4.1 Cycle and pass definition for ERS-2

As explained in section 2.6, a new ORF file for ERS-2 has been defined to ensure an optimal completeness of the products. It will be delivered as an auxiliary file in the frame of this project.

This file is named **FDR4ALT_ERS2_CycleAndPassDefinition.txt.**

It is an ASCII file with a header and 4 columns:

Header	Cycle number	Pass number	Start date	End date
Format	Int	Int	YYYY-MM-DD THH:MM:SS.mmmmmm	YYYY-MM-DD THH:MM:SS.mmmmmm

Results from the hydrology community survey

A1.1 Results of the survey addressed to the Hydrology community about the Inland Water TDP

What is the surface of interest for your applications?

Figure A.1 - Pie chart indicating the surface of interest

What is the geographical area of interest for your applications?

Figure A.2 - Pie chart indicating the scale of application

For your application, how do you prefer data to be spatially aggregated?

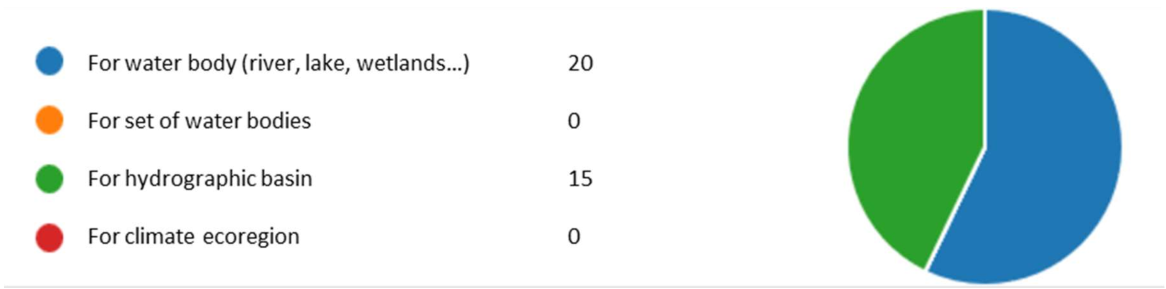


Figure A.3 - Pie chart indicating the spatially aggregated data

What is, approximately, the minimum and the maximum width of the surface of interest?

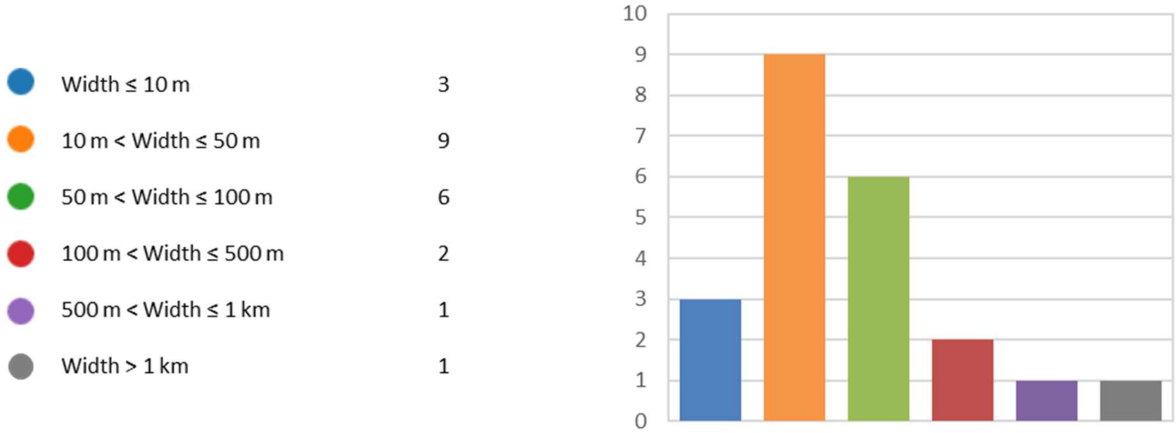


Figure A.4 - Bar chart indicating the minimum width of the surface of interest

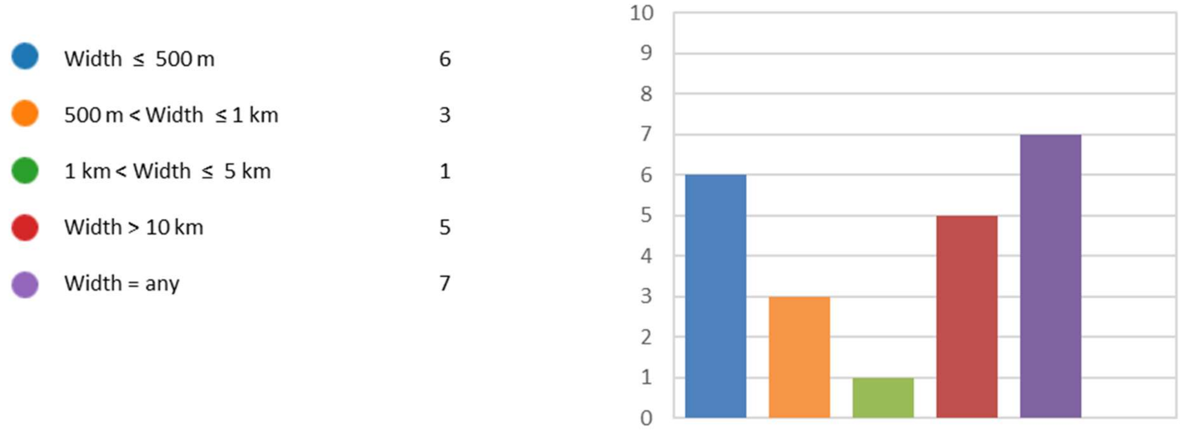


Figure A.5 - Bar chart indicating the maximum width of the surface of interest

In terms of root mean square error, which error range would you consider acceptable for the surface of interest?

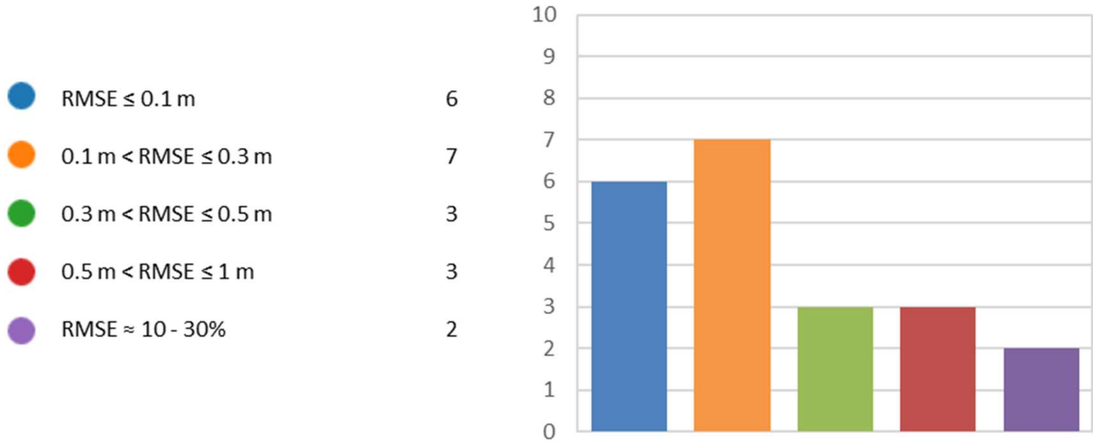


Figure A.6 - Bar chart indicating the errors in terms of Root Mean Square Error, RMSE considered acceptable for the surface of interest

What temporal resolution is required for your applications?

Figure A.7 - Pie chart indicating the temporal resolution of data product

Which dissemination format for the products would you like?

FigureA.8 - Pie chart indicating the preferred dissemination format

How do you prefer to download the FDR4ALT Inland water products?

FigureA.9 - Pie chart indicating the preferred way to download product

About the data format the NetCDF is preferred along with the FTP to download inland water products.

Have you ever used altimetry satellite data for your research/applications?

If yes, please specify the research/application:

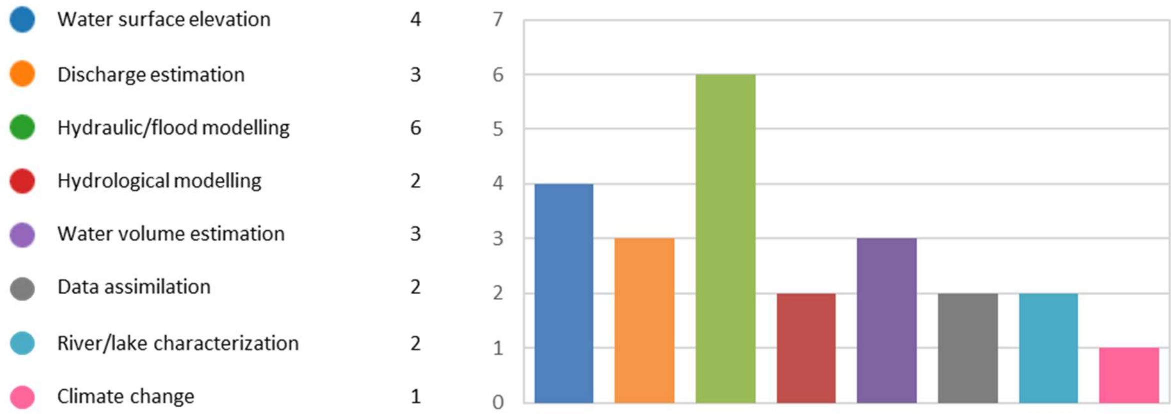


Figure A.10 – Pie chart and bar charts indicating if the participants have ever used the satellite altimetry and for which specific application

How would you use FDR4ALT inland water product?

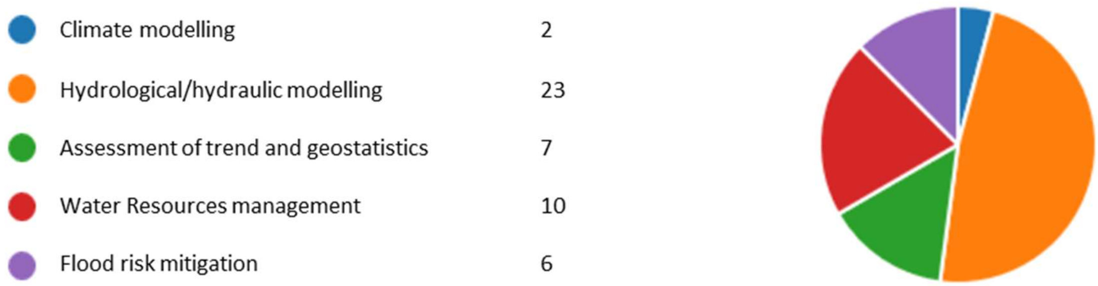


Figure A.11 - Pie chart indicating for which application they would use the FDR4ALT products

Will you combine altimetry products with other satellite data?

If yes, please specify the research/application:

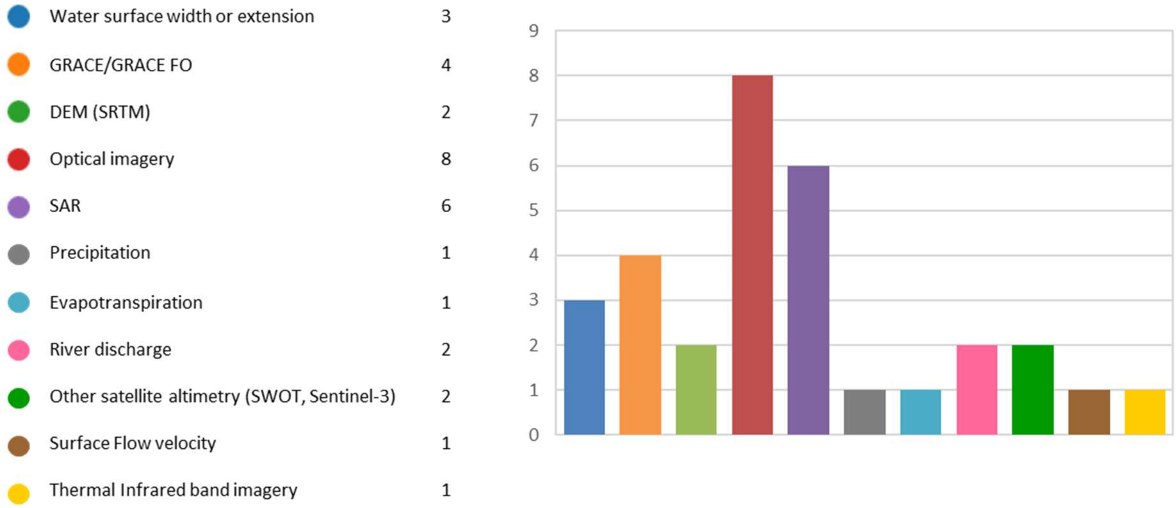


Figure A.12 – Pie chart and bar charts indicating if the participants would combine the altimetry products with other satellite data and which one

Results of the space hydrology users

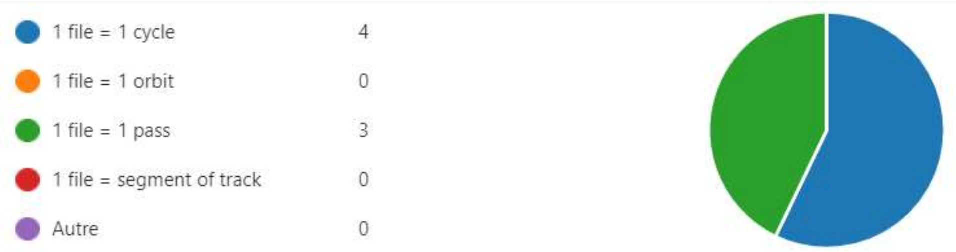
All the inland water surfaces are of interest for the users with a clear preference for rivers, lakes and reservoirs

Spatial Coverage: The Inland Water Thematic Data Product is a high-resolution along-track product extracted from the Global Fundamental Data record. What should be the spatial coverage of this product?

The spatial coverage should be global, including all land surfaces and preferably with a buffer zone on coastal regions.

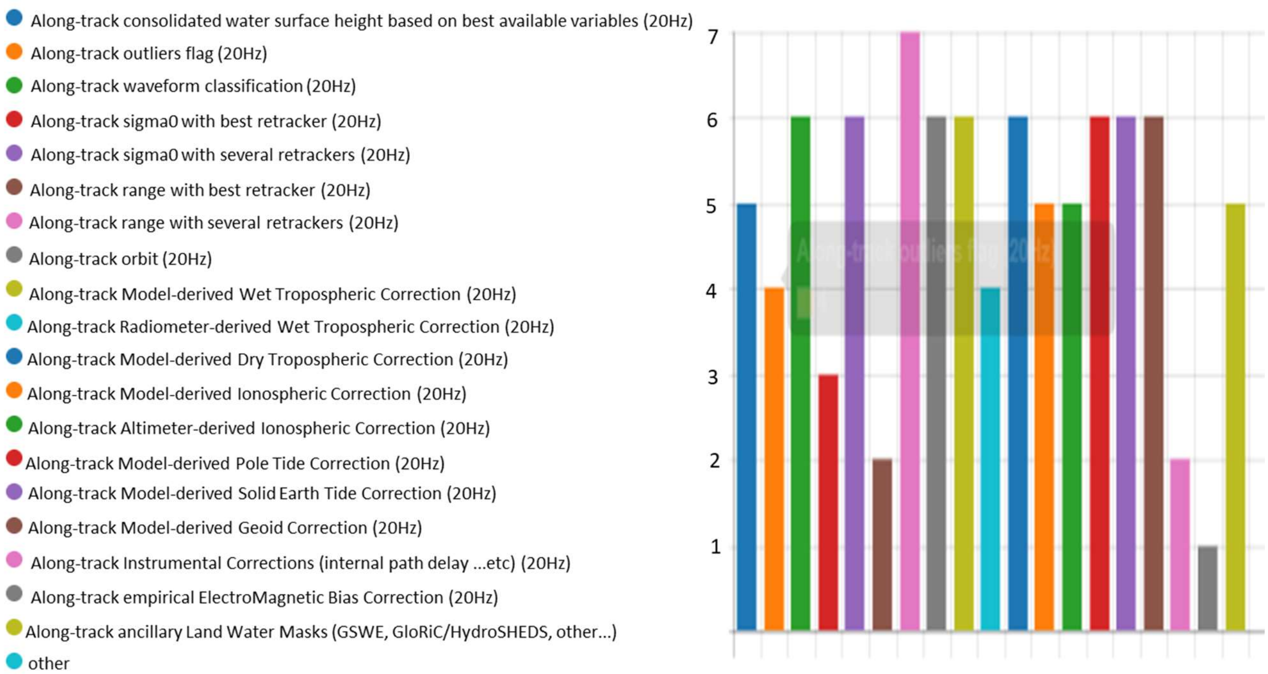
File Format: Which dissemination format for the products would you like?

File Granularity: Which time coverage for each individual file would you like?



Depending on the size of each individual file, the granularity should be 1 pass or 1 cycle

Variables: Which variables would you like to see in the products for your application? Keep in mind that too many variables will result in larger files.



Results from the coastal needs survey

A specific user survey of coastal needs was made at the beginning of 2020. Its website is found at: **http://tinyurl.com/coastal-survey**. Two announcements were made to the community: (1) through email, to the OSTST list and to CTOH users and (2) to coastal users present at the 12th Coastal Altimetry Workshop that took place in Frascati between the 4 and 7 february 2020.

Figure C.1 - Text publicizing the survey and presentation of the Coastal Workshop

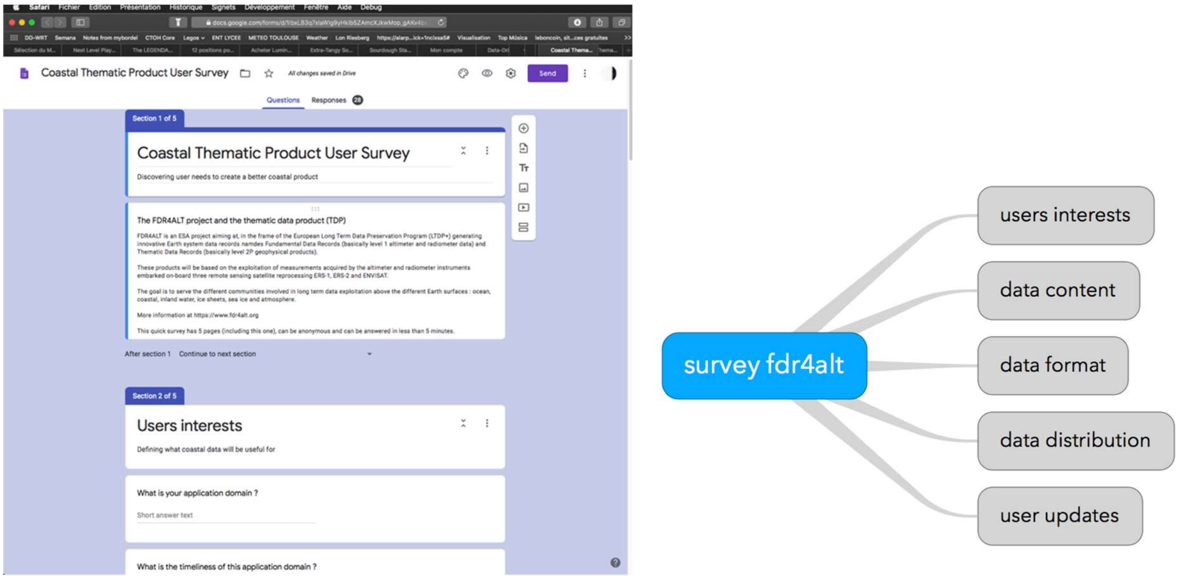


Figure C.2 - First page of the user survey and sections presented

The user survey was presented in a web form of 5 sections, which could be completed in less than 5 minutes. We had 28 answers which is quite significant, given the specific group targeted.

User interests

Regarding user interests, about half of them were on oceanography, about à quarter on coastal dynamics and the last quarter climate & sea level, altimetry and hydrology. A detailed decomposition is given in Figure C.3.

Most of users are concerned only by delayed time scientific applications, a third of them are interested in European areas (cf. Figures C.4 and C.5), and most of them are in interested in local scales of the order of 50km, with time scales spread almost evenly between day, season, year and decade (Figure C.6).

The preferred level data is L3: along-track data reprojected on a reference track.

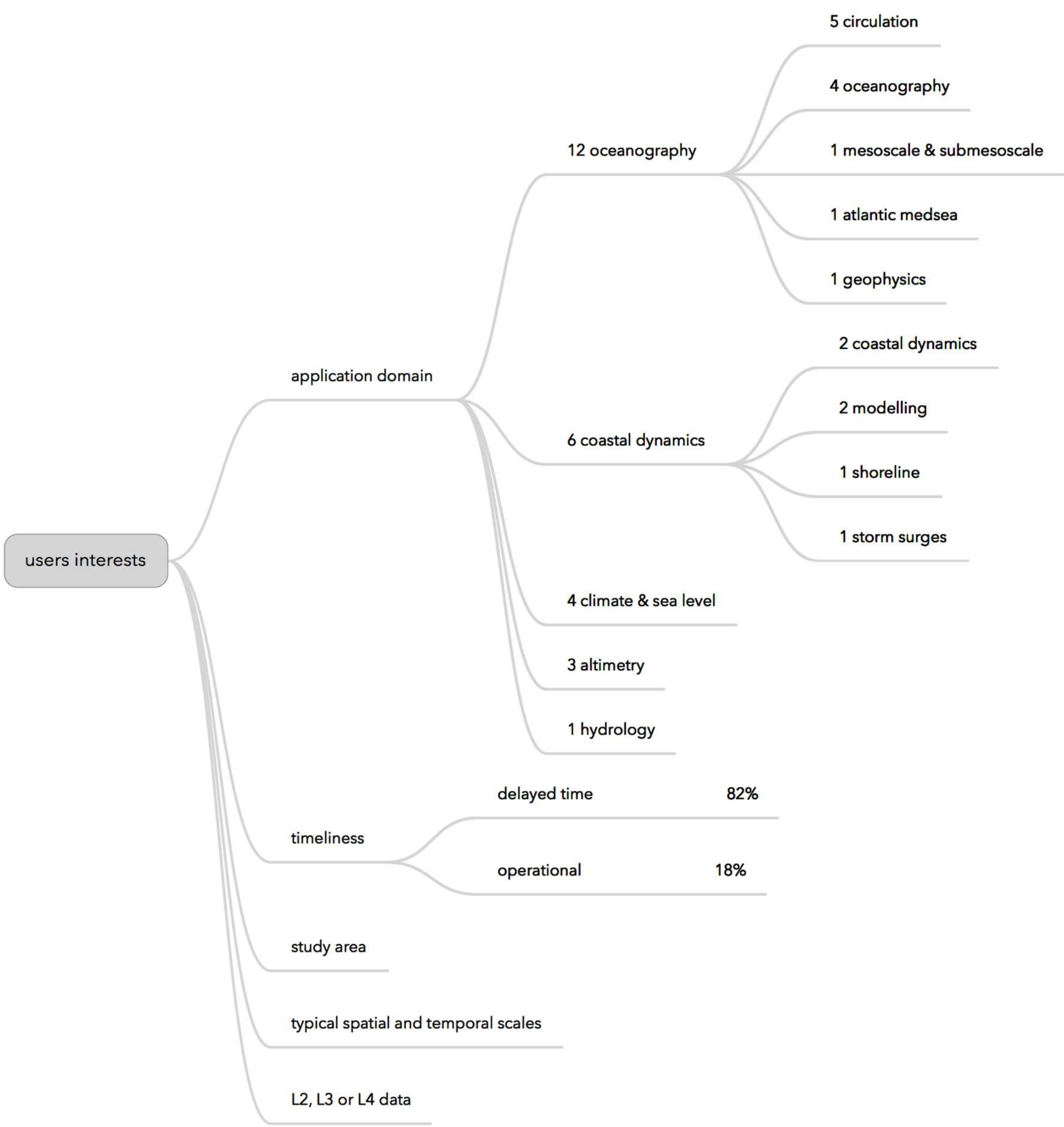


Figure C.3 - Users interests answers categorized

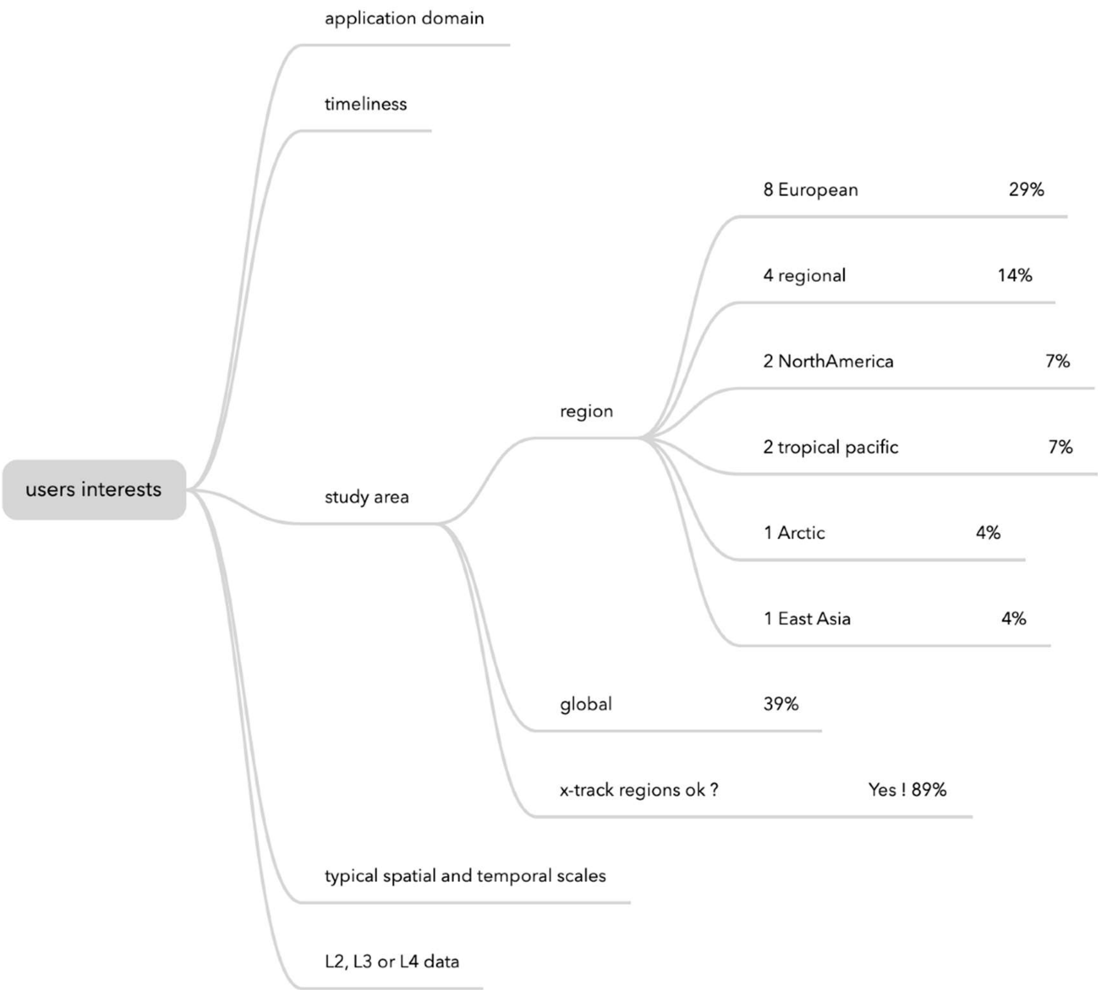


Figure C.4 - Users interests, area, scales and data level

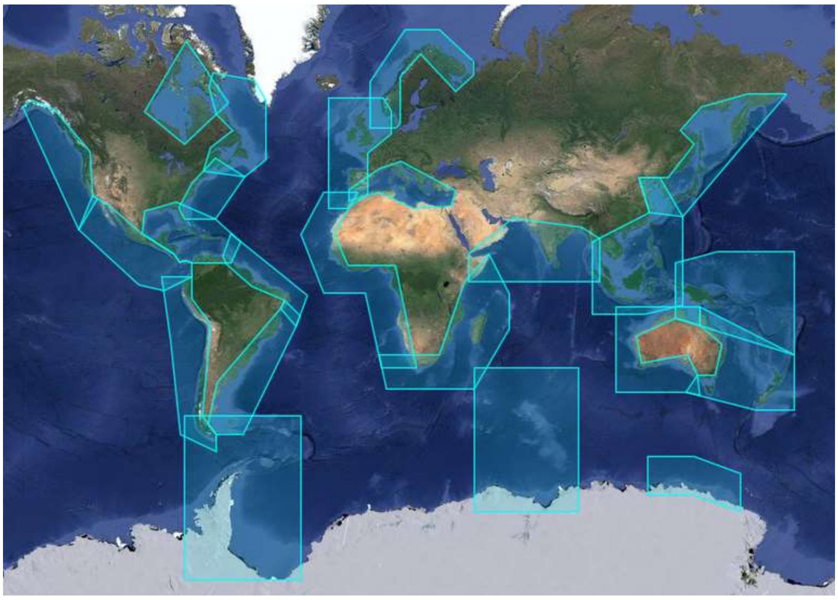


Figure C.5 - X-track regions

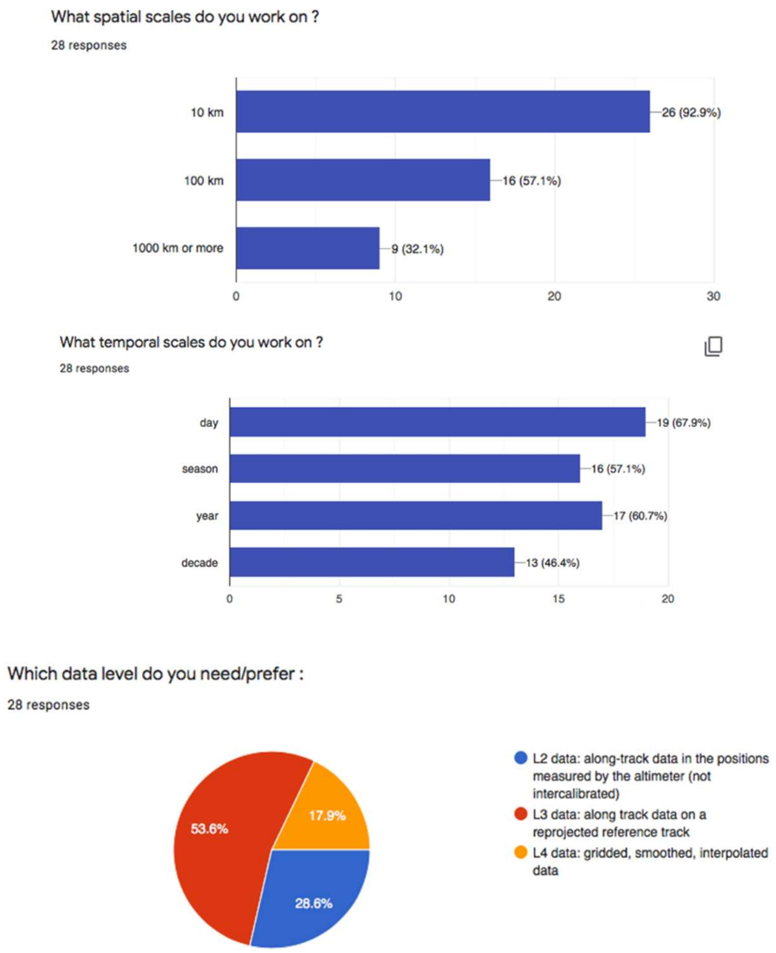
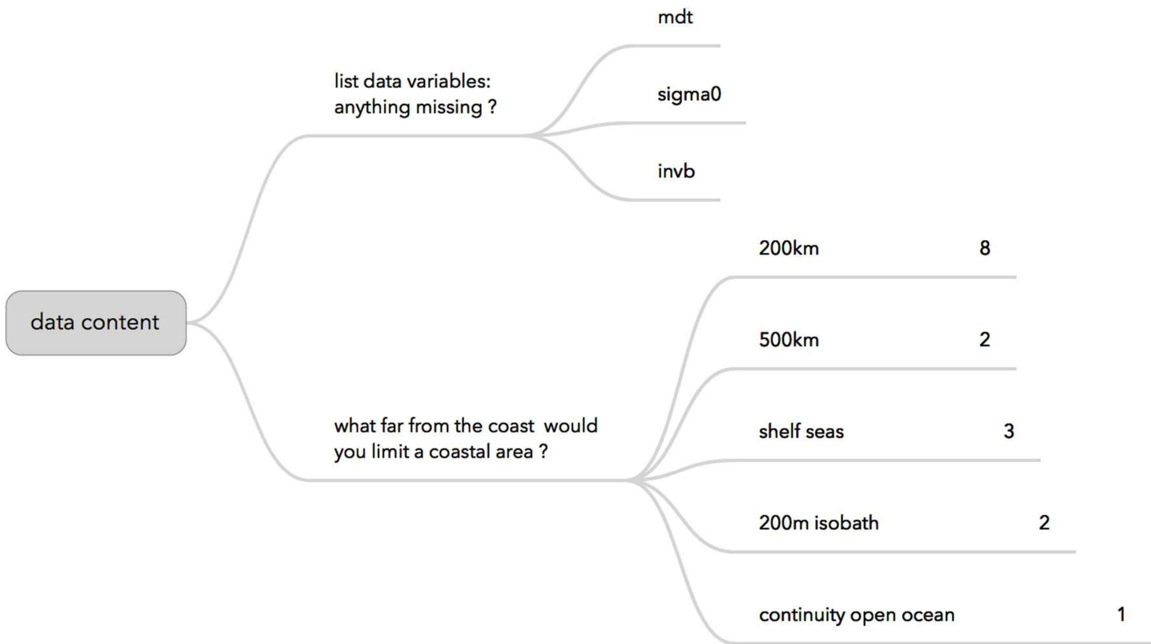
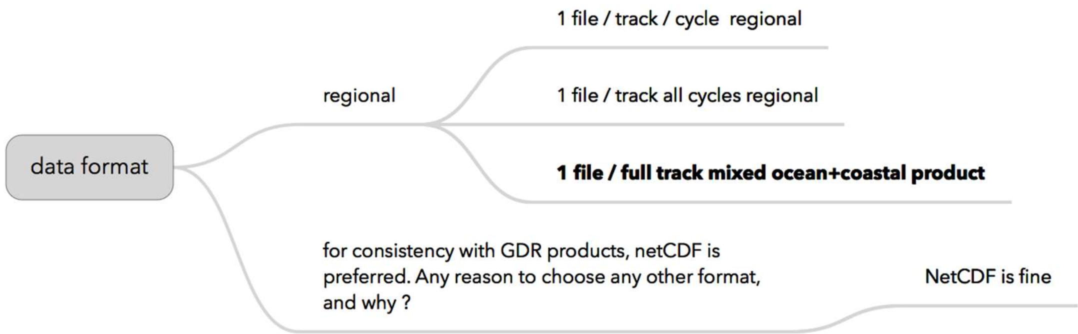
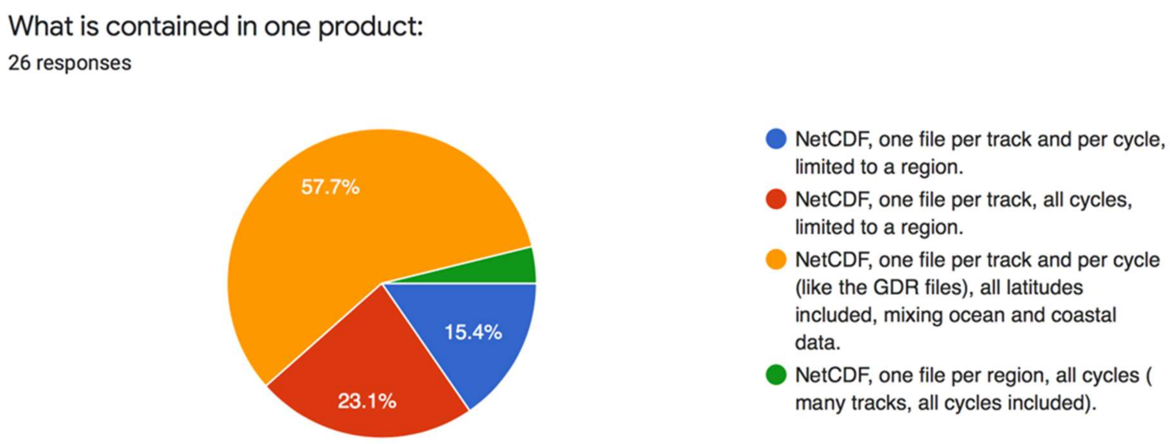


Figure C.6 - spatio-temporal scales and data level answers

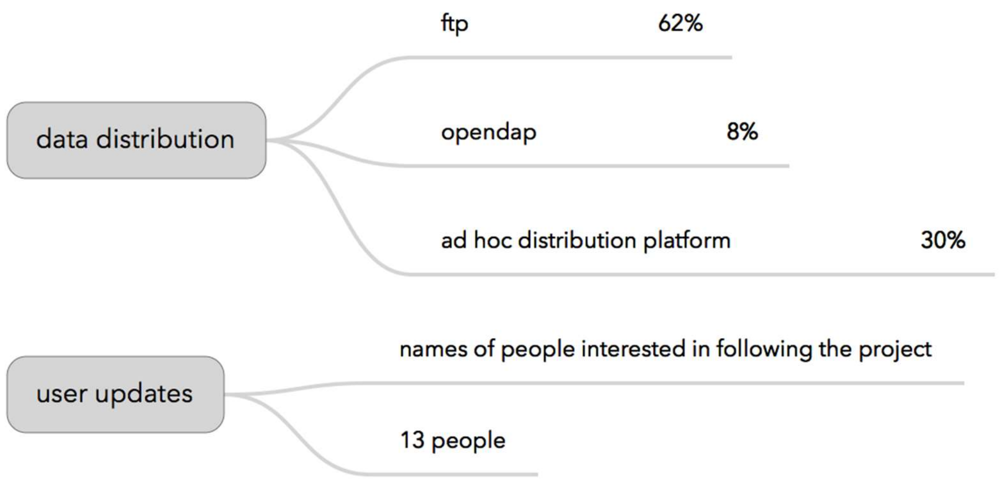
1.1.1.1. Data content and data format

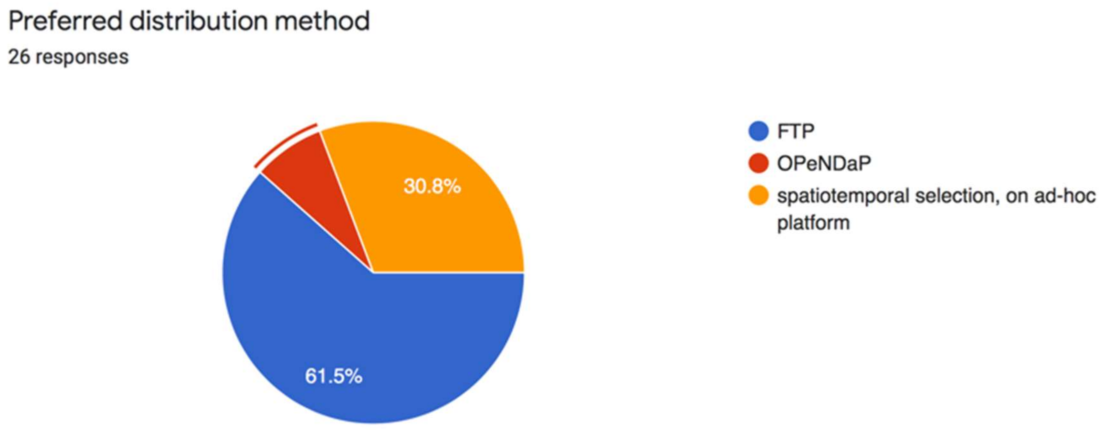






1.1.1.2. Data distribution and user updates





1.1.1.3. Conclusions of the survey

- We need an GDR-like product providing both open ocean and coastal data, seamlessly.
- Should MDT, invb and sigma0 be added ?
- Distribution by FTP should be privileged.
- Interest for news from project
- List of 13 ß-testers for the product

Main parameters:

- time, latitude, longitude
- altimeter range
- wet tropospheric correction

- wet tropospheric correction (model)
- dry tropospheric correction (model)
- dynamic atmospheric correction
- ocean tide height
- internal tide
- pole tide
- solid earth tide
- sea state bias
- ionospheric correction
- ionospheric correction (model)
- mean sea surface
- sea level anomaly
- sea wave height
- inter-mission bias
- distance to coast
- ocean basin or region identifier
- validation flags ocean
- validation flags coastal

FDR4ALT deliverables

The table below lists all FDR4ALT deliverables with their respective ID number and confidentiality level.

Document	ID	Confidentiality Level
Products Requirements & Format Specifications Document	[D-1-01] [D-2-02]	Public
Roadmap & Product Summary Document	[D-1-02]	Project Internal
Data Requirements Document	[D-1-03]	Project Internal
System Maturity Matrix	[D-1-04]	Project Internal
Examples of products	[D-1-05]	Project Internal
Review Procedure Document	[D-1-06]	Project Internal
Review Data Package	[D-1-07]	Project Internal
Phase 1 Review Report Document	[D-1-08]	Project Internal
Detailed Processing Model Document	[D-2-01]	Public
Round Robin Assessment Report Document	[D-2-03]	Public
Data Production Status Report	[D-3-01]	Project Internal
Final Output Dataset	[D-3-01]	Public
Product Validation Plan	[D-4-01]	Project Internal
Product Validation Report : FDR	[D-4-02a]	Public
Product Validation Report : Sea-Ice TDP	[D-4-02b]	Public
Product Validation Report: Land-Ice TDP	[D-4-02c]	Public
Product Validation Report : Ocean Waves TDP	[D-4-02d]	Public
Product Validation Report : Ocean & Coastal TDP	[D-4-02e]	Public
Product Validation Report: Inland Waters TDP	[D-4-02f]	Public
Product Validation Report: Atmosphere TDP	[D-4-02g]	Public
Uncertainty Characterization Definition Document	[D-5-01]	Project Internal
Uncertainty Characterization Report	[D-5-02]	Public
Product User Guide	[D-5-03]	Public
Completeness Report ALT	[D-7-01]	Public
Completeness Report MWR	[D-7-02]	Public

Table 4.1 : List of FDR4ALT deliverables

Reference Documents

RD-1	Copernicus Polar and Snow Cover Applications User Requirements Workshop, http://www.copernicus.eu/polar-snow-workshop
RD-2	PEG-1 Report, User Requirements for a Copernicus Polar Mission, Step 1 Report, Polar Expert Group, Issue: 12th June 2017
RD-3	PEG-2 Report, Polar Expert Group, Phase 2 Report on Users Requirements, Issue: 31st July 2017
RD-4	2015 Update of Actions in The Response of the Committee on Earth Observation Satellites (CEOS) to the Global Climate Observing System Implementation Plan 2010 (GCOS IP-10), 10th May 2015, http://ceos.org/document_management/Working_Groups/WGClimate/WGClimate_The-CEOS-CGMS-Response-to-the-GCOS-2010-IP_Jun2015.pdf
RD-5	CMEMS requirements for the evolution of the Copernicus Satellite Component, Mercator Ocean and CMEMS partners, February 21, 2017, http://marine.copernicus.eu/wp-content/uploads/2019/01/CMEMS-requirements-satellites.pdf
RD-6	User Requirements Document (URD) for the Antarctic_Ice_Sheet_cci project of ESA's Climate Change Initiative, version 3.0, 01 November 2017. Available from: http://www.esa-icesheets-antarctica-cci.org/.
RD-7	User Requirements Document for the Ice_Sheets_cci project of ESA's Climate Change Initiative, version 1.5, 03 Aug 2012. Available from: http://www.esa-icesheets-cci.org/.
RD-8	GCOS Satellite Supplement 2011, Systematic observation requirements for satellite-based data products for climate. Supplemental details to the satellite-based component of the»Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)», December 2011. Available online at http://www.wmo.int/pages/prog/gcos/index.php.
RD-9	User Requirement Document of ESA's Climate Change Initiative CCI+ Phase 1, version 1.0, 21 June 2019. Available from: https://www.climate.esa.int/media/documents/Sea_Ice_User_Requirements_Document_1.0.pdf
RD-10	Overall Assessment of Stakeholder Needs for the EU H2020 KEPLER project, 03 November 2020. Available from: https://kepler380449468.files.wordpress.com/2021/06/kepler-deliverable-report-1.4-rev.-nov.-2020.pdf
RD-11	Warren, S. G., Rigor, I. G., Untersteiner, N., Radionov, V. F., Bryazgin, N. N., Aleksandrov, Y. I., and Colony, R.: Snow depth on Arctic sea ice, J. Climate, 12, 1814–1829, 1999.
RD-12	Kurtz, N. T. and Farrell, S. L.: Large-scale surveys of snow depth on Arctic sea ice from operation IceBridge, Geophys. Res. Lett., 38, L20505, https://doi.org/10.1029/2011GL049216, 2011.
RD-13	Wooliams et al, 2016
RD-14	Ulaby, F. T., R. K. Moore, and A. K. Fung, Microwave Remote Sensing, Vol. 3, From Theory to Applications, Artech House, 1986.
RD-15	Wadhams, P., Tucker III, W. B., Krabill, W. B., Swift, R. N., Comiso, J. C., and Davis, R. N.: Relationship between sea ice free board and draft in the Arctic Basin, and implication for ice thickness monitoring. J. Geophys. Res., 97(C12), 20325–20334, 1992.
RD-16	Alexandrov, V., Sandven, S., Wahlin, J., and Johannessen, O. M.: The relation between sea ice thickness and freeboard in the Arctic, The Cryosphere, 4, 373–380, https://doi.org/10.5194/tc-4-373-2010, 2010.
RD-17	Cartwright, D.E., & Edden, A.C. Corrected Tables of Tidal Harmonics. Geophysical Journal International, 33, 253-264, 1973.

RD-18	Wahr J. M., Deformation induced by polar motion, J. Geophys. Res., 90(B11): 9363 – 9368, 1985.
RD-19	J. Poisson, G. D. Quartly, A. A. Kurekin, P. Thibaut, D. Hoang and F. Nencioli, "Development of an ENVISAT Altimetry Processor Providing Sea Level Continuity Between Open Ocean and Arctic Leads," in IEEE Transactions on Geoscience and Remote Sensing, vol. 56, no. 9, pp. 5299-5319, Sept. 2018, doi: 10.1109/TGRS.2018.2813061.
RD-20	RA L1b IODD from REAPER project. Ref REA-DD-IODD-L1b-6002.
RD-21	RA-2 ALGORITHMS SPECIFICATION FOR LEVEL 1B SOFTWARE PROTOTYPING, ISARD_ESA_L1B_ESL_DPM_022
RD-22	R Peacock, N. R., and S. W. Laxon (2004), Sea surface height determination in the Arctic Ocean from ERS altimetry, J. Geophys. Res., 109, C07001, doi:10.1029/2001JC001026

List of acronyms

AD	Applicable Documents
ALES	Adaptive Leading Edge Subwaveform
AGC	Automatic Gain Control
ATT	Atmospheric Attenuation
CCI	Climate Change Initiative
CDL	Common Data Language
CEOS	Committee on Earth Observation Satellite
CFOSAT	Chinese-French Oceanic SATellite
CMEMS	Copernicus Marine Service
CMUG	Climate Modelling User Group
CF	Climate and Forecast
CLS	Collecte Localisation Satellite
CNES	Centre National des Etudes Spatiales
CSC	Copernicus Space Component
CST	Centre Spatial de Toulouse
CTOH	Centre of Topography of the Oceans and the Hydrosphere
COG	Center Of Gravity
DFT	Discrete Fourier Transform
DNV-GL	Det Norske Veritas-Germanischer Lloyd
DOI	Digital Object Identifier
DORIS	Doppler Orbitography by Radiopositioning Integrated on Satellite
DUACS	Data Unification and Altimeter Combination System
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ENVISAT	ENVIronment SATellite
EO	Earth Observation
EGM	Earth Gravitational Model
ERA	ECMWF Re-Analysis
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
ESRIN	European Space Research Institute
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FDR	Fundamental Data Record

FES	Finite Element Solution
FIDUCEO	Fidelity and uncertainty in climate data records from Earth Observations
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
GCOS	Global Climate Observing System
GDR	Geophysical Data Record
GIM	Global Ionosphere Map
GRACE	Gravity Recovery and Climate Experiment
GSHHG	Global Self-consistent, Hierarchical, High-resolution Geography Database
GSWE	Global Surface Water Explorer
HFA	High-Frequency Adjustment
HTL	Height Tracking Loop
ICSU	International Council for Science
IF	Intermediate Frequency
IOC	Intergovernmental Oceanographic Commission
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KEPLER	KEY ENVIRONMENTAL MONITORING FOR POLAR LATITUDES AND EUROPEAN READINESS
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LPF	Low Pass Filter
LTDP	Long Term Data Preservation
LWP	Liquid Water Path
MCD	Measurement Confidence Data
MSS	Mean Sea Surface
MWR	Microwave Radiometer
NIC	NOAA Ionosphere Climatology
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
OBDH	On-board data handling
OLC	Open Loop Calibration
OSTST	Oceanography Surface Topography Science Team
PEG	Polar Experts Group
PID	Persistent Identifier
POCA	Point Of Closest Approach

POE	Precise Orbit Ephemerides
PTR	Point Target Response
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
RA	Radar Altimeter
RD	Reference Documents
REAPER	REprocessing of Altimeter Products for ERS
REMA	Reference Elevation Model of Antarctica
RMSE	Root Mean Square
SAR	Synthetic Aperture Radar
SARAL	Satellite with Argos and Altika
SBC	Satellite Binary Clock
SIT	Sea Ice Thickness
SLA	Sea Level Anomaly
SPTR	Scanning Point Target Response
SSALTO	Segment Sol multimissions d'ALTimétrie, d'Orbitographie et de localisation précise
SSH	Sea Surface Height
SSHA	Sea Surface Height Anomaly
STL	Slope Tracking Loop
TAC	Thematic Assembly Center
TBC	To be confirmed
TBD	To be defined
TCWV	Total column water vapour
TDP	Thematic Data Product
TFMRA	Threshold First-Maximum Retracker Algorithm
TUGO	Toulouse Unstructured Grid Ocean
UNESCO	United Nations Educational Scientific and Cultural Organization
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
URD	United Nations Environment Programme
USO	Ultra Stable Oscillator
UTC	Coordinated Universal Time
WGCV	Working Group on Calibration & Validation
WMO	World Meteorological Organization
WTC	Wet Tropospheric Correction