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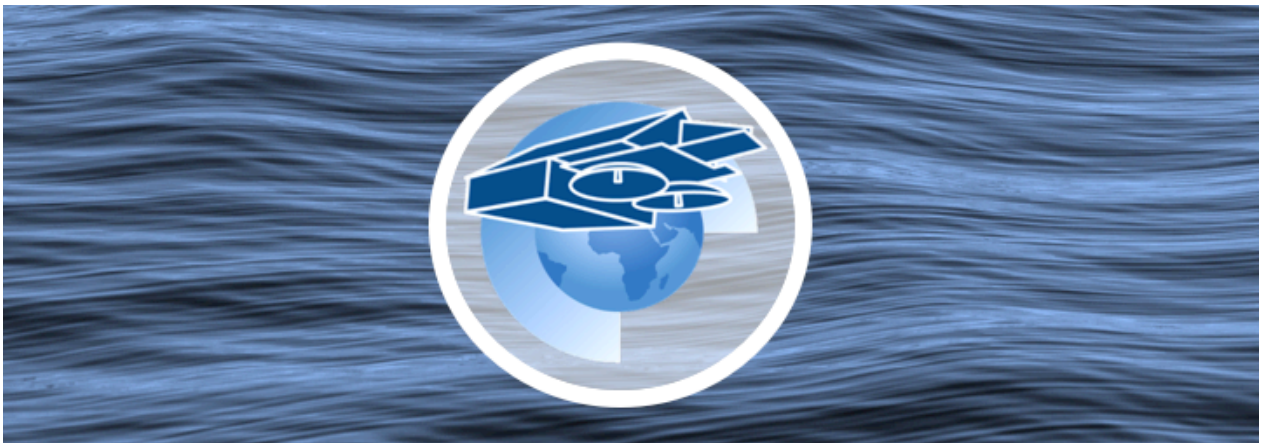
Baseline-C Cryosat Ocean Processor

Main evolutions and Data Quality Status Summary



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1 INTRODUCTION

1.1 Purpose and Scope

This document provides a high-level overview of the CryoSat Ocean Product evolutions associated to CryoSat Ocean Processor (COP) Baseline-C as well as details on known anomalies which are being tracked, and that could affect the quality of the CryoSat Ocean Level 1 and Level 2 data products operationally generated by the COP and distributed by ESA.

This list of anomalies is complete and up to date as of 06 November 2017. An updated version of this document will be released on a quarterly basis in additional anomalies are identified with respect to the previous version.

1.2 Applicable and Referenced Documents

The following list contains documents with a direct bearing on the content of this report. Where referenced in the text, these are identified as AD.n or RD.n, where 'n' is the number in the list below:

AD.1 CryoSat Ocean NetCDF Produc Format Specification (L1 & L2), C2-RS-ACS-ESL-5266, v3.1, https://earth.esa.int/documents/10174/125273/CryoSat-L1b-L2-Ocean-NetCDF-product-format-specification.pdf

AD.2 CryoSat Ocean Product Handbook, CLS-DOS-NT-13-111_COP-PH Version 4.

RD.1 Bouffard, J., M. Naeije, E. Schrama, C. J. Banks, F. M. Calafat, P. Cipollini, H. M. Snaith, E. Webb, A. Hall, R. Mannan, P. Féménias and T. Parrinello, (2017). CryoSat Ocean: Product Quality Status and future Evolution. *Advances in Space Research*, ISSN 0273-1177, **https://doi.org/10.1016/j.asr.2017.11.043**

RD.2 Cotton, P. D., O. B. Andersen, L. Stenseng, F. Boy, M. Cancet, P. Cipollini, C. Gommenginger, S. Dinardo, A. Egido, M.J. Fernandes, P. Nilo-Garcia, T. Moreau, M. Naeije, R. Scharroo, B. Lucas, and Benveniste J. (2016). Improved Oceanographic Measurements with CryoSat SAR Altimetry: Results and Roadmap from ESA CryoSat Plus for Oceans Project. In *Proceeding of the ESA Living Planet Symposium*, 9-13 May 2016, Prague, Czech Republic, ESA Special Publication SP-740 (CD-ROM). http://www.satoc.eu/projects/CP4O/docs/0519cotton%20_CP4Oroadmap.pdf

When using ESA CryoSat ocean products for operational applications, scientific research and/or peer-review publications, please refer to [AD.2] and [RD.1].

1.3 Acronyms and Abbreviations

ADF	Auxiliary Data File
AR	Anomaly Report
CAL	Calibration
COP	CryoSat Ocean Processor
CONFORM	CryOsat Netcdf FORmat
DEM	Digital Elevation Model
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DSD	Data Set Descriptors
EE	Earth Explorer
ESA	European Space Agency
FBR	Full Bit Rate
FDM	Fast Delivery Marine
GOP	Geophysical Ocean Product
HR	High Rate
IDEAS	Instrument Data quality Evaluation and Analysis Service
IOP	Intermediate Ocean Product
IPF	Instrument Processing Facility
L0/L1B/L2	Level 0/Level 1B/Level 2
LRM	Low Resolution Mode
NetCDF	Network Common Data Form
NOP	NRT Ocean Product
NRT	Near Real Time
P2P	Pole-to-Pole
PCONF	Parameter Configuration File
PDS	Payload Data System
PLRM	Pseudo LRM
PSAR	Pseudo SAR
RMS	Root Mean Square
SAR	Synthetic Aperture Radar
SARIn	SAR Interferometric
SID	SARIn Degraded
SIRAL	SAR Interferometric Radar Altimeter
SPR	Software Problem Report
SW	Software
XREF	Reference DSDs

2 OVERVIEW

2.1 CryoSat Mission

ESA's Earth Explorer CryoSat mission, launched on 8 April 2010, is dedicated to precise monitoring of the changes in the thickness of marine ice floating in the polar oceans and variations in the thickness of the vast ice sheets that overlie Greenland and Antarctica.

CryoSat is an advanced radar altimeter specifically designed to monitor the most dynamic sections of Earth's cryosphere. It borrows synthetic aperture radar and interferometry techniques from standard imaging radar missions to sharpen its accuracy over rugged ice sheet margins and sea ice in polar waters. The primary payload is the SAR Interferometric Radar Altimeter (SIRAL) which has extended capabilities to meet the measurement requirements for ice-sheet elevation and sea-ice freeboard.

Going beyond its primary mission objective to observe the cryosphere, CryoSat is also a valuable source of data for the oceanographic community. The satellite's radar altimeter can measure high-resolution geophysical parameters from the open ocean to the coast; its measurements over the ocean are of great value to the oceanographic and climate research communities. Consequently, ESA has developed and implemented its own CryoSat Ocean Processor (COP), to generate CryoSat products specifically designed for oceanographers. The COP includes up-to-date and ocean-oriented algorithms and corrections in order to bridge the gap between previous and future ocean missions as well as to contribute to a better knowledge of polar circulation.

In order to do this it is imperative that the quality of the CryoSat Ocean data products meet the highest standards of performance. This is achieved through constant improvement of the Instrument Processing Facilities (IPFs), based on both external and internal inputs from the scientific community and various validation campaigns.

2.2 Introduction to Ocean Processing Baseline-C

All remaining sections of this document address the CryoSat Ocean Products processed with the latest version of the CryoSat Ocean IPFs; Baseline-C.

Baseline-C is a major update to the CryoSat Ocean Processors, which implements significant improvements to the existing Ocean products as well as introducing a new format specification based on NetCDF, NRT ocean processing and new Pole-to-Pole (P2P) products. In terms of product content the main changes concern the addition of native SAR/SARIN data over the relevant regions in the Geographical Mode Mask, and a number of new parameters including updated geophysical corrections.

The new Ocean IPFs are operational since November 2017 .

Further information on historic processor versions and the dates these were first used in operational CryoSat data production is available on the CryoSat IPF Baseline webpage and in [RD. 1].

2.3 COP Baseline-C Products

The CryoSat Ocean IPFs process SIRAL Level 0 LRM, SAR and SARIn products to generate Level 1B (L1B) and Level 2 (L2) Ocean Products by applying processing algorithms specified for the ocean surface. These products are dedicated to the study of ocean surfaces, and are provided specifically for the needs of the oceanographic community.

The Ocean processors provide three classes of products, which vary according to their delivery latency:

- Near-Real Time Ocean Products (NOP)
- Intermediate Ocean Products (IOP)
- Geophysical Ocean Products (GOP)

Figure 1 highlights the applicable CryoSat Ocean Products which are relevant to this document. Further information on the products is also provided below.

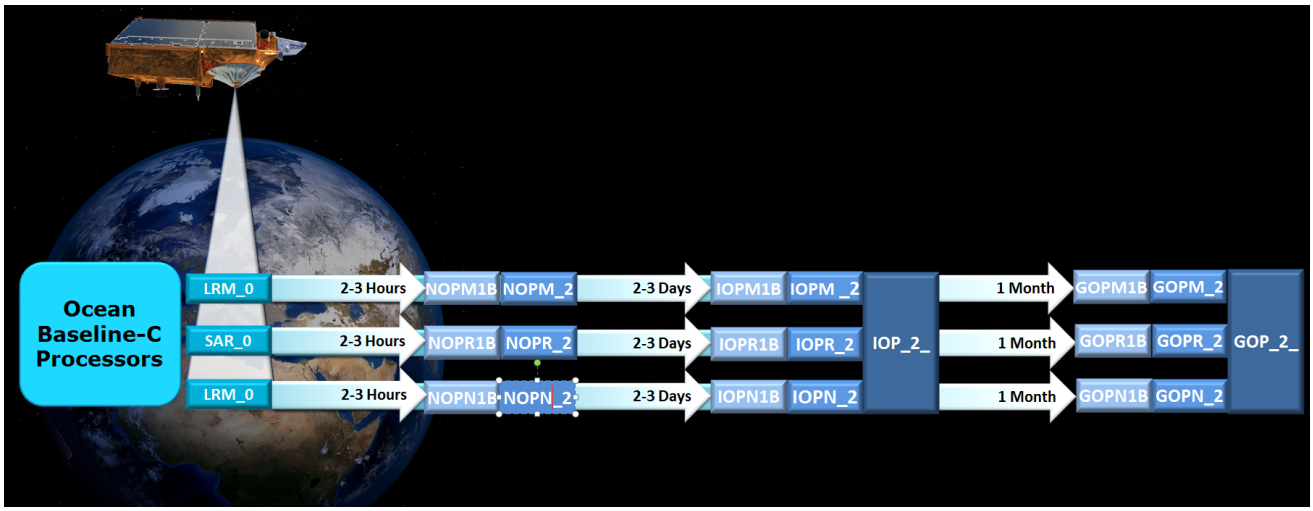

Figure 1 – Baseline C CryoSat Ocean Products

CryoSat NOP, IOP and GOP are classified according to the processing level (L1B and L2) and the acquisition mode; the data products are generated based on the processing of input Level 0 LRM, SAR and SARIn mode data.

The processing applied to generate the NOP, IOP and GOP is the same in all three cases, with the only difference being the type of input auxiliary files used for the processing. This refers to the corrections included and applied, and also the orbit files used; the longer the latency, the more accurate the orbit file used for the data generation.

L1B and L2 NOP are delivered within 3-hours of sensing and are generated using the DORIS Navigator Orbit. This NRT processing is a new feature of the Baseline-C IPF and further information is provided in Section 3.6. This product will replace FDM before the end of 2018.

IOP are generated 2-3 days after data sensing for medium-range ocean forecasting and use preliminary orbits (CNES Medium Orbit Ephemeris) with geophysical corrections computed from Forecast metrological Auxiliary Data Files (ADFs) and, when possible, the Analysis metrological ADFs.

GOP are typically generated 30-days after data sensing using consolidated orbits (CNES Precise Orbit Ephemeris) The GOP are always processed with geophysical corrections computed from the Analysis metrological ADFs.

The CryoSat L1B IOP and GOP contain all engineering parameters needed to generate the Level 2 products, together with corrections to be applied for range and tidal effects.

Also new to the Baseline-C IPFs are the Pole-to-Pole products; these are delivered with the same latency as IOP and GOP. Further information on the new P2P products is provided in Section 3.5.

3 MAIN PRODUCT EVOLUTIONS

3.1 Upgrade to NetCDF

The new Baseline-C IPF introduces a migration from the Earth Explorer format (used for the Baseline-B Ocean products) to the more flexible, user-friendly and up-to-date **NetCDF format** for all CryoSat Ocean products intended for distribution to the user community. This new format is aimed at ensuring homogeneity with other altimetry missions and also maximising the uptake and use of CryoSat Ocean data by scientific users.

This new format is called CONFORM (CryOsat Netcdf FORMat) and is applicable to all NOP, IOP and GOP Baseline-C products. The version of the NetCDF libraries used for the CryoSat Ocean products is NetCDF-4 CF compliant (http://cfconventions.org), with data stored in a way to allow efficient sub-setting. Interfaces to NetCDF are based on the C library and are available in numerous languages (e.g. Matlab, IDL, Python, Octave), therefore enabling a wide range of software applications to read NetCDF files. NetCDF files can be easily read using third-party-software like *Panoply*.

Further details on the new NetCDF Ocean products can be found in the Ocean Product Handbook [AD.2] and the updated Ocean Product Format Specification [AD.1].

The same format change, to NetCDF, is also planned for the next update of the CryoSat Ice products.

3.2 Mode-Dependent Processing

The new Baseline-C Ocean IPFs will generate ocean products for all data acquisition modes (LRM, SAR and SARIn), therefore providing complete data coverage for ocean users. By comparison, the previous Baseline-B Ocean IPFs used as input only the LRM and SAR data (geophysical parameters processed in Pseudo-LRM (PLRM)).

As shown in Figure 1, there are now a total of 20 CryoSat Ocean product types; 9 L1B products, 9 L2 products and 2 Pole-to-Pole products.

The different processing levels, modes and associated product types are summarised in Table 1. Further information on the full ocean Delay-Doppler processing is provided in Section 3.3.

Processing Level	Mode	Product Types	Description
L1B	LRM	NOP**M**1B; IOP**M**1B; GOP**M**1B	Contains LRM measurements and data using as input the L0 LRM data.
L1B	SAR	NOP**R**1B; IOP**R**1B; GOP**R**1B	Contains Pseudo-LRM (PLRM) (data acquired in SAR mode and reduced to a sequence of LRM-like echoes) and SAR parameters (retrieved from a delay-Doppler processing) using as input the L0 SAR data.
L1B	SARIn	NOP**N**1B; IOP**N**1B; GOP**N**1B	Contains PLRM (data acquired in SAR mode and reduced to a sequence of LRM-like echoes) and SARIn parameters (retrieved from a delay-Doppler processing) using as input the L0 SARIn data.

L2	LRM	NOP**M**_2; IOP**M**_2; GOP**M**_2	Contains LRM measurements and data using as input the L1B LRM data.
L2	SAR	NOP**R**_2; IOP**R**_2; GOP**R**_2	Contains PLRM and SAR measurements and data using as input the L1B SAR data.
L2	SARIn	NOP**N**_2; IOP**N**_2; GOP**N**_2	Contains PLRM and Pseudo-SAR (PSAR) (i.e. the two SARIn channels data averaged in the L1B processing and retracked as SAR data in the L2 processing) measurements and data, using as input the L1B SARIn data.

Table 1 – Summary of CryoSat Ocean Products by processing level, mode and product type

For further information regarding the processing of PLRM (SAR or SARIn modes) and the associated references please refer to the Ocean Product Handbook [AD.2] and Bouffard et al 2017 [AD.1].

3.3 Full Ocean Delay Doppler Processing

Within the new Baseline-C L2 IPF ESA's SAR Altimetry MOde Studies and Applications (SAMOSA) retracker algorithm (Cotton et al, 2016; [RD.2]) has been tested and implemented. For this, the SAMOSA retracked SAR and SARIn waveforms are generated using the new processors, which build on the CryoSat Ice processor heritage but have been correctly reconfigured for ocean applications. The SAMOSA retracker computes the 20 Hz epoch, amplitude, SWH and wind speed for SAR and SARIn (without using phase information). Within the new Baseline-C IPFs 1 Hz altimeter range, SWH and backscatter coefficients are also computed, simply by averaging the 20 Hz parameters. The SAMOSA derived 1 Hz and 20 Hz parameters are generated together with the PLRM parameters using the MLE-4 ocean retracker not only for SAR (as in the previous COP Baseline-B) but also for SARIn regions. Therefore, the format of the new Baseline-C L2 NOP, IOP and GOP have been updated to include all these new fields.

3.4 New and Updated Geophysical Corrections

The Baseline-C Ocean Products include several new geophysical corrections such as improved Ocean and Loading Tidal Corrections, as well as an updated Mean Sea Surface (MSS) and Mean Dynamic Topography.

As the satellite does not carry an on-board microwave radiometer, one of the major upgrades implemented within Baseline-C also concerns the inclusion of an improved Wet Tropospheric Correction (GPD+). The algorithm has been developed by the University of Porto (UoP), within the scope of the ESA CryoSat Plus for Ocean (CP4O) project, and combines external wet path delay data from multiple sources by space-time objective analysis. Users should note that the Wet Tropospheric Correction from the ECMWF Model is also still available and is used for both NOP and IOP processing, whilst the new GDP+ is used only for GOP processing.

Table 1 summaries the main models and standards, which have been updated in Baseline-C with respect to the Baseline-B. For further information concerning all models and standards, which are used in the products, please refer to [AD.2] and Bouffard et al. 2017 [RD.1].

Description	In Baseline-B	Updated in Baseline-C
Altimeter Retracking: SAR	N/A	"SAMOSA DPM 2.3" retracking Fit from a theoretical multi-looked waveform model using the Levenberg-Marquardt method
Altimeter Retracking: SARIn	N/A	"SAMOSA DPM 2.3" retracking Fit from a theoretical multi-looked waveform model using the Levenberg-Marquardt metho
MSS (solution 1)	CNES-CLS11	CNES-CLS15
MSS (solution 1)	DTU10	DTU15
Mean Dynamic Topography (solution 1)	CNES/CLS09	CNES-CLS15
Mean Dynamic Topography (solution 2)	N/A	DTU15
Bathymetry	MACESS	ACE-2
Ocean & Loading Tide Height (Solution 1)	GOT 4.8	GOT 4.10c
Ocean & Loading Tide Height (Solution 2)	FES2004	FES2014b
Non Equilibrium Ocean Tide	FES2004	FES2014b
Wet Troposphere Range Correction from GPD+	N/A	From UoP, combination of DComb and GNss-derived path delay
Altimeter wind speed (LRM, PLRM, SAR/SARin)	Abdalla 2007	Abdalla 2007 (now with an adjustment of the backscatter coefficient to the Abdalla model)
SSB LRM, Pseudo-LRM	Empirical solution from Jason-2 GDR-C MLE-4 data	Empirical solution from CryoSat Ocean Baseline-B data in LRM
SSB SAR	Empirical solution from Jason-2 GDR-C MLE-4 data	Empirical solution from CryoSat Ocean Baseline-B data in LRM
SSB SARIn	N/A	Empirical solution from CryoSat Ocean Baseline-B data in LRM

Table 2 – The main models and standards, which have been updated in Baseline-C with respect to the previous Baseline-B.

3.5 Pole-to-Pole Products (P2P)

The Baseline-C Ocean IPF will also generate a new set of L2 products known as Pole-to-Pole (P2P) products. These are multi-mode L2 products with half-orbit coverage (from one pole to the other). As a result there will be two P2P products generated per orbit, combining successive LRM, SAR and SARIn L2 products spanning between the North and South poles into concatenated products.

L2 Intermediate Pole-to-Pole (IOP P2P) products will be delivered with the same latency as IOP (2-3 days) and will contain LRM, SAR and SARIn L2 IOP covering half an orbit. L2 Geophysical Pole-to-Pole (GOP P2P) products will be delivered with the same latency as GOP (~30 days) and will contain LRM, SAR and SARIn L2 GOP covering half an orbit. These new products will be available for users to access on the CryoSat Science Server.

User should note that NOP P2P products do not exist due to the 3-hour latency constraint.

3.6 Near Real Time Ocean Products (NOP)

The Baseline-C Ocean IPF will generate NRT Ocean Products (NOP) with an approximate latency of 2-3 hours from data sensing. Numerous evolutions have been implemented to significantly improve the quality of the new NOP products with respect to the current FDM products generated by the CryoSat Ice processor; this includes the integration of full SAR Delay-Doppler processing (see Section 3.3) and the addition of new ad-hoc corrections (see Section 3.4).

These new products will utilize the DORIS Navigator Orbit and the Forecast metrological ADFs, and will be made available in early 2018 for registered users on the CryoSat Science Server.

Users should note that the NOP are intended to replace the existing FDM products, which will no longer be generated from mid-2018.

4 QUALITY STATUS

4.1 Validation of Ocean Baseline-C IPFs

Prior to being transferred into operational use the CryoSat Baseline-C IPFs have undergone a thorough validation process by the ESA/ESRIN Sensor Performance, Products and Algorithms (SPPA) office with the support from the Instrument Data quality Evaluation and Analysis Service (IDEAS+), and also the UK National Oceanography Centre (NOC).

During these validation activities, several issues and data anomalies were opened and then resolved in the final version of the ESA processing chains used to generate the operational data (see Section 0). Details of minor pending issues, which due to be closed in a future update of the IPFs, are provided in Section 4.2.

4.2 Summary Table of Open Anomalies

Table 3 below lists all the minor anomalies, which have been tracked for operational CryoSat Ocean Baseline-C products and shall be fixed in an upcoming processing baseline.

The table also summaries, which specific data processor and product level is affected by each open anomaly. Further details on each anomaly can be found in Section 4.2.1 of this document.

It should be noted that none of these issues were considered as blocking for the transfer to operations of the new Baseline-C IPFs as they do not affect the quality of the Ocean products in terms of scientific content and exploitation.

Anomaly ID	Processing Level Affected						
	Level 1B			Level 2			
	NOP	IOP	GOP	NOP	IOP	GOP	P2P
CRYO-COP-1	No	No	No	No	No	No	Yes
CRYO-COP-3	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CRYO-COP-4	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CRYO-COP-8	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 3 - Summary of Open Anomalies on the Baseline-C Ocean IPFs

4.2.1 Level 1 & Level 2 Data minor anomalies

AR ID	CRYO-COP-1	AR Title	20Hz times set to Default Value
Affected Products		P2P Products	
Description	The 20Hz / 1Hz indexes variables ind_first_meas_20hz_01 (L1B and L2 products) and ind_first_meas_20hz_01_plrm_ku (L2 products) need to be stored into 4-Byte integer (int) instead of 2-Bytes integer (short). The storage on 2-Bytes does not allow the proper management of long data flow covering more than 32767 2Hz measurements. Therefore the content of the product is not properly filled for the measurements after 32677th, which generates an error during the L2 post-processing. As a result the corresponding L2 products are not generated by the post-processing which leads to many missing products. This issue was fixed for the L2 mode-dependant products; however it later became apparent that this issue also affected P2P production. Whilst a fix has now also been provided for P2P, users should be aware that it will not likely fix all the possible occurrences, leaving a residual probability of less than 1% P2P production failures A full patch for the P2P processor, which address the remaining <1% failure cases, will be deferred to a second stage and implemented in a future COP update.		
AR Status	Open		

AR ID	CRYO-COP-3	AR Title	Meteo fields set to default over Land & Continental Ice
Affected Products		All L1B and L2 Products	
Description	The Dry Tropospheric Correction (DTC), Wet Tropospheric Correction (WTC), Inverse Barometric (IB) correction and the U- and V-components of the model wind vector from the ECMWF models show nominal values over Ocean and Closed Sea surface-types, however valid values for these corrections are not provided over areas flagged as Land and Continental Ice by the surface-type model. In the latest version of the IPFs (Baseline-C), the issue has been fixed for Land surfaces, now showing valid values for each of the corrections. However the issue is still open for marginal continental ice surfaces where CryoSat operates in SARIn. It should be noted that this issue does not affect the GPD+ WTC values from UoP.		
AR Status	Open		

AR ID	CRYO-COP-4	AR Title	Missing and Duplicated DSDs in L1B/L2 Products
Affected Products	All L1B and L2 Products		
Description	Analysis of the product Header files revealed a number of inconsistencies between different modes and types of products. There are a number of Data Set Descriptors (DSDs) missing, some duplicates and some mistakes. This minor issue affects all product types (GOP, IOP & NOP) to varying degrees.		
AR Status	Open		

AR ID	CRYO-COP-8	AR Title	Naming Discrepancies in Global Attributes & Product Variables
Affected Products	All L1B and L2 Products		
Description	Discrepancies have been observed in the naming/presence of fields in the products (.DBL file) compared to the latest Product Format Specification document [AD.1]. These fields contain information that was previously present in the header files of the EEF products and should be comparable in terms of field names and their contents. This issue can be broken down into two groups: ○ Discrepancies in the Variables and their attributes. This includes missing attributes, typos, incorrect information and inconsistencies in the text. ○ Discrepancies in the "global attributes" section, primarily, but not entirely, between the XREFS (reference DSDs) in the global attributes section of the L1B and L2 products and those expected according to the latest Product Format Specification document (RD.1). This includes, differences in variable names, field contents, missing XREFS (some missing in the products, others missing in [AD.1]). This minor issue affects all product types (GOP, IOP & NOP) to varying degrees.		
AR Status	Open		

4.3 Anomalies Closed with the Latest Processing Baseline

Table 4 lists all of the anomalies that have been recently closed with the operational Baseline-C COP and have been verified by quality assessment validations performed by IDEAS+ and NOC (see Section 4.1).

Anomaly ID	Anomaly Title	Status	Implemented in Release
CRYO-COP-2	Adjustment of Sigma0 bias in SARIn mode (More details in section 3.5.7 of [AD.2])	Resolved	Baseline-C
CRYO-COP-5	Surface Type Statistics in L2: wrong percentage computed	Resolved	Baseline-C
CRYO-COP-6	Missing hr global attributes in L1B	Resolved	Baseline-C
CRYO-COP-7	P2P IOP missing inputs	Resolved	Baseline-C
CRYO-COP-9	Star Tracker Usage	Resolved	Baseline-C
CRYO-COP-10	P2P production failures due to time_01 outside processing window	Resolved	Baseline-C
CRYO-COP-11	P2P production failure due to AUX_ORBDOP border case	Resolved	Baseline-C

Table 4 – Summary of all closed anomalies with the latest processing Baseline update