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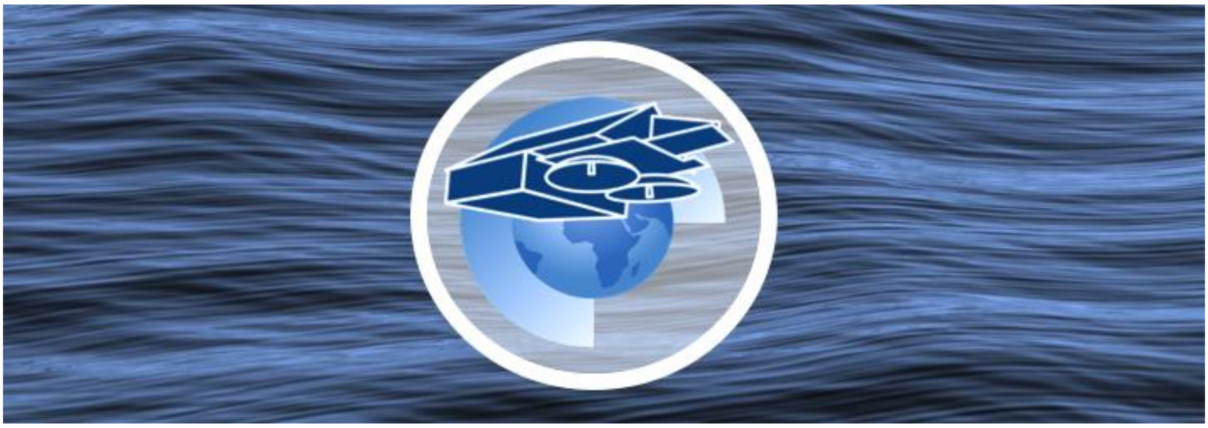
Baseline-D Cryosat Ocean Processor

Ocean Product Handbook



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5.0	20/07/21	Update for Cryosat-2 Ocean Processing Baseline D	S Figerou
5.1	31/05/23	Update for Cryosat-2 Ocean Processing Baseline D, delivery 4.10/4.11	G. D'Apice
5.2	12/03/24	Update for Cryosat-2 Ocean Processing Baseline D, delivery 4.20	G. D'Apice
5.3	26/09/2024	Update for Cryosat-2 Ocean Processing Baseline D, Section 3.5.4 Formula to retrieve the SAR and SARin power echo waveform in Watts the variable echo_scale_factor_20_ku is actually echo_scale_factor_20_hr_ku. In addition, the LRM/PLRM waveform should be divided and not multiplied by the scale factor.	T. Geminale

Index Sheet:	
Context:	
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Distribution:		
Company	Means of distribution	Names

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Exprivia	Electronic Copy	F. Carriero T. Geminale
ESA	Electronic Copy	J. Bouffard A. Di Bella

Applicable documents

AD 1 IPF Cryosat Ocean Products Contract Change Notice
C2-CN-ACS-GS-5309

AD 2 Earth Explorer Ground Segment File Format Standard
PE-TN-ESA-GS-0001

AD 3 IOP & GOP Product Format Specification Products format specification [COP-FMT], CS-RS-ACS-GS-5213 1rev4,
https://earth.esa.int/documents/10174/125273/CryoSat-L1b-L2-Ocean-NetCDF-product-format-specification.pdf

AD 4 CryoSat Ocean NetCDF Product Format Specification (L1b&L2) [PFS-OCE]
CS-RS-ACS-ESL-5266 3rev1

AD 5 CryoSat Baseline D Product Handbook, 2019:
https://earth.esa.int/documents/10174/125272/CryoSat-Baseline-D-Product-Handbook

Reference documents

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(https://www.sciencedirect.com/science/article/pii/S0273117717308542)

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1. INTRODUCTION

1.1. Purpose and scope

The aim of this document is to provide all information needed to describe the CryoSat-2 Near-Real Time (NOP), Intermediate (IOP) and Geophysical (GOP) Ocean Products. This document has been set up by CLS under ESA contract IPF CryoSat-2 Ocean Products Contract Change Notice # 5 [AD 1]. Users can find additional information on these products in [RD 1] and [RD 2].

When using ESA CryoSat ocean products for operational applications, scientific research and/or peer-review publications, please refer to this CryoSat Ocean Product Handbook and/or Bouffard et al, 2017 ([RD 2])

1.2. 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 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.

1.3. Operating modes

CryoSat-2 radar altimetry instrument is called SIRAL. It has been designed with three different operational modes for sea ice, sloping ice sheets and flat ice sheet interiors. The latter mode is also suitable for operation over Open Ocean.

The mode of operation among LRM, SAR and SARin is selected from a mask of geographical zones, updated every two weeks to account for changes in sea ice extent.

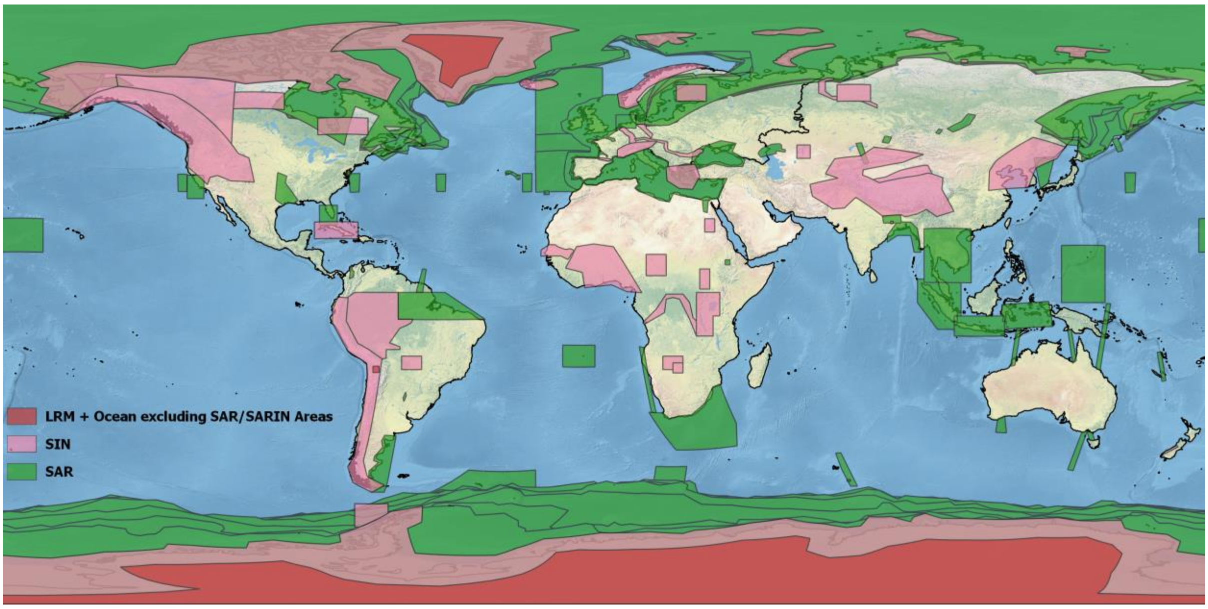

Figure 1: Example of CryoSat-2 mode mask (Mask 4.0)

In Low Resolution Mode (LRM), pulses are sent at intervals of about 500 µs (Pulse Repetition Frequency about 2 kHz) ensuring that the returning echoes are uncorrelated. This mode of measurement is suitable over flat surfaces (ocean and ice-sheet interiors).

In Synthetic Aperture Radar mode (SAR), complex bursts are transmitted to the ground at a Pulse Repetition Frequency about 18 kHz, to allow an on-ground Doppler processing. This mode is used to carry out high-resolution measurements.

In Synthetic Aperture Radar interferometer (SARin) mode, complex bursts from two antennae mounted 1m apart are transmitted to the ground at a Pulse Repetition Frequency about 18 kHz, allowing to retrieve the surface echo location. This mode is generally used around the ice sheet margins and over mountain glaciers.

Within the new COP Baseline-C, ocean geophysical parameters are retrieved both over the LRM, SAR and SARin patches.

For this, the SAR Altimetry MOde Studies and Applications (SAMOSA) retracker algorithm (Cotton et al, 2016; [RD 3]) has been implemented. The SAMOSA retracked SAR and SARIn waveforms are generated using the new COP Baseline C processors, which build on the CryoSat Ice processor heritage but have been correctly reconfigured for ocean applications.

In parallel, a Pseudo LRM processing, consisting of the alignment of these pulses - as performed on-board by the tracker in LRM mode – is still performed, and LRM-like power waveforms are built. These ones are then processed as LRM waveforms. This Pseudo LRM processing allows retrieving estimates of the ocean surface when the altimeter is in SAR and SARin (without using the interferometric phase). The final LRM-like 20Hz estimates may then be used as the usual LRM 20Hz estimates but they are noisier due to the difference in timing and lower number of pulses per unit time. Despite a higher level of noise (especially in SARin), the consistency between LRM and pseudo LRM Sea Level Anomalies is very good (Boy et al., OSTST 2012; [RD 4]).

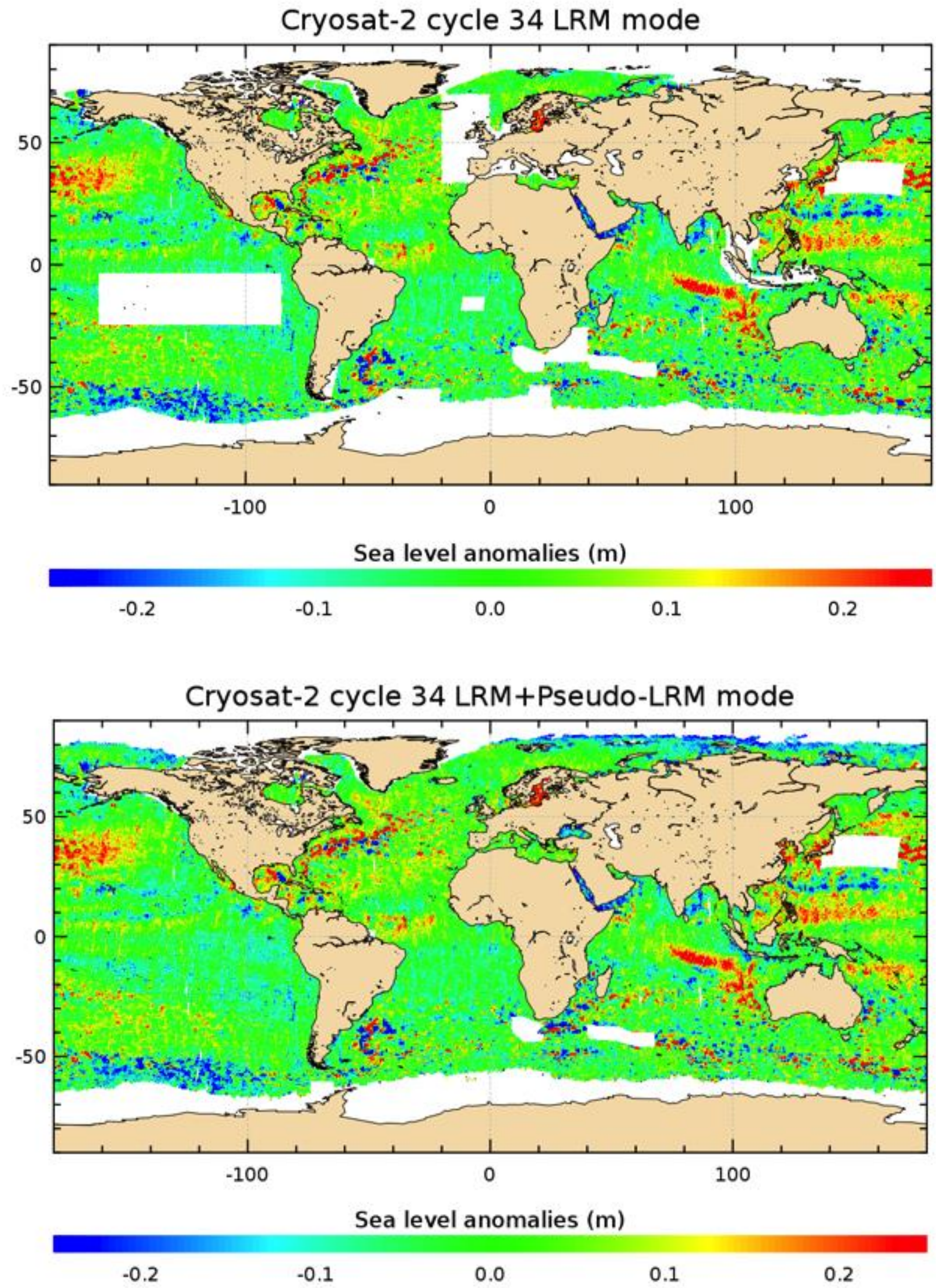

Figure 2: Sea level anomalies for Cryosat-2 cycle 34 with LRM mode only (top) and LRM+pseudo-LRM modes (bottom)

1.4. Distinctions between Low-resolution & high-resolution parameters

The CryoSat-2 Ocean L1B and L2 Products are designed to contain SAR/SARin and LRM/Pseudo-LRM altimeter data together in the same product file. The formats of the L1B and L2 products being the same whatever the operating mode, part of the SAR/SARIN-derived parameters are meaningless in LRM/Pseudo-LRM mode.

1.4.1. In L1B products

In the L1B products, a distinction is made between low-resolution (LRM and Pseudo-LRM) and high resolution (SAR and SARin). Pseudo-LRM and SAR data do not have the same 20-Hz time-tag and therefore many parameters, even not depending on the waveforms, are provided separately for low and high resolution (see section 4.2).

L1B parameters providing low-resolution altimeter data (LRM and Pseudo-LRM) are identified with the suffix "_ku" whereas parameters aimed at providing high-resolution altimeter data (SAR and SARin) are identified with the suffix "_hr_ku". Parameters without suffix "_ku" or "hr_ku" doesn't rely on the altimeter data resolution.

Example

```
netcdf example {
     short pwr_waveform_20_ku(time_20_ku,ns_20_ku) ;
             pwr_waveform_20_ku:long_name = "waveform samples (scaled): 20 Hz" ;
             pwr_waveform_20_ku:units = "count" ;
             pwr_waveform_20_ku:add_offset = 32768. ;
             pwr_waveform_20_ku:scale_factor = 1. ;
                     pwr_waveform_20_ku:comment = "LRM mode: echo forwarded from
telemetry. SAR mode: echo retrieved by on-ground pseudo-LRM processing. The
echo is corrected from on-board FFT filtering effected, accounting for CAL2
gain profile range window (CAL2). Scaled power echo waveform = real power echo
* echo scale factor (echo_scale_factor_20).The echo is corrected for the
intermediate frequency filter effect." ;

     ushort pwr_waveform_20_hr_ku(time_20_hr_ku, ns_20_hr_ku) ;
             pwr_waveform_20_hr_ku:units = "count" ;
             pwr_waveform_20_hr_ku:long_name = "l1b power waveform scaled 0-65535 from HR
data" ;
             pwr_waveform_20_hr_ku:add_offset = 0us ;
             pwr_waveform_20_hr_ku:scale_factor = 1us ;
             pwr_waveform_20_hr_ku:commment = "The L1b 20Hz power waveform is a fully-
                                 calibrated waveform. For LRM it is a low
                                 resolution pulse limited waveform. For SAR/SARin
                                 it is a high resolution multilooked waveform.
                                 Units are counts scaled to fit in the range 0-
                                 65535." ;
```

Parameters with suffix "hr_ku" are missing or filled with their default values in the LRM mode L1B products.

1.4.2. In L2 and P2P products

In the L2 and P2P products, a distinction is made between optimal processing (LRM, SAR and SARin) and Pseudo-LRM processing. As in the L1B products, Pseudo-LRM and SAR data do not have the same 20-Hz time-tag and therefore many parameters, even not depending on the waveforms, are provided separately for low and high resolution (see section 4.2).

Parameters providing altimeter data from optimal processing are identified with the suffix "_ku". Parameters aimed at providing altimeter data from the Pseudo-LRM processing are identified with the suffix "_plrm_ku". Parameters without suffix "_ku" or "plrm_ku" doesn't rely on the altimeter data resolution.

Example

```
netcdf example {

     short mod_dry_tropo_cor_01(time_01) ;
            mod_dry_tropo_cor_01:_FillValue = -32768s ;
            mod_dry_tropo_cor_01:long_name = "model dry tropospheric
         correction: 1 Hz" ;
            mod_dry_tropo_cor_01:units = "m" ;
            mod_dry_tropo_cor_01:standard_name =
         "altimeter_range_correction_due_to_dry_troposphere" ;
            mod_dry_tropo_cor_01:add_offset = 0. ;
            mod_dry_tropo_cor_01:scale_factor = 0.001 ;
            mod_dry_tropo_cor_01:coordinates = "lon_01 lat_01" ;
            mod_dry_tropo_cor_01:comment = "Computed at the altimeter time-tag
         [time_01] from the interpolation of 2 meteorological fields that
         surround the altimeter time-tag. To be added to range measurement to
         correct for the propagation delay to the radar pulse, caused by the
         dry-gas component of the Earth\'s atmosphere." ;
            mod_dry_tropo_cor_01:source = "European Center for Medium Range
Weather Forecasting" ;
            mod_dry_tropo_cor_01:institution = "ECMWF" ;

     short swh_ocean_01_ku(time_01) ;
            swh_ocean_01_ku:_FillValue = -32768s ;
            swh_ocean_01_ku:long_name = "corrected \'ocean\' significant
         waveheight: 1 Hz ku band" ;
            swh_ocean_01_ku:units = "m" ;
            swh_ocean_01_ku:standard_name =
         "sea_surface_wave_significant_height" ;
            swh_ocean_01_ku:add_offset = 0. ;
            swh_ocean_01_ku:scale_factor = 0.001 ;
            swh_ocean_01_ku:coordinates = "lon_01 lat_01" ;
            swh_ocean_01_ku:source = "LRM: MLE4 retracking, SAR: SAMOSA v2.3
         retracking" ;
            swh_ocean_01_ku:comment = "Instrumental corrections included:
         modeled instrumental errors correction [mod_instr_cor_swh_01_ku] and
         system bias." ;

     short swh_ocean_01_plrm_ku(time_01) ;
            swh_ocean_01_plrm_ku:_FillValue = -32768s ;
            swh_ocean_01_plrm_ku:long_name = "corrected \'ocean\' significant
         waveheight: 1 Hz PLRM ku band" ;
            swh_ocean_01_plrm_ku:units = "m" ;
            swh_ocean_01_plrm_ku:standard_name =
         "sea_surface_wave_significant_height" ;
            swh_ocean_01_plrm_ku:add_offset = 0. ;
            swh_ocean_01_plrm_ku:scale_factor = 0.001 ;
            swh_ocean_01_plrm_ku:coordinates = "lon_01 lat_01" ;
            swh_ocean_01_plrm_ku:source = "MLE4 retracking" ;
            swh_ocean_01_plrm_ku:comment = "Set to FillValue in LRM mode.
         Instrumental corrections included: modeled instrumental errors
         correction [mod_instr_cor_swh_01_plrm_ku] and system bias." ;
```

Parameters with suffix "plrm_ku" are missing or filled with their default values in the LRM mode L2 products.

1.5. Type of products

The CryoSat-2 Ocean Products comes in a family of eight different types of products, distinguished by modes (LRM, SAR, SARin), increasing level, going from Level 1B to Level 2, and increasing latency and accuracy, going from the Near-Real Time Ocean Products (NOP) to the Interim Ocean Products (IOP) and to the Geophysical Ocean Product (GOP).

Figure 3 highlights the applicable CryoSat Ocean Products which are relevant to this document.

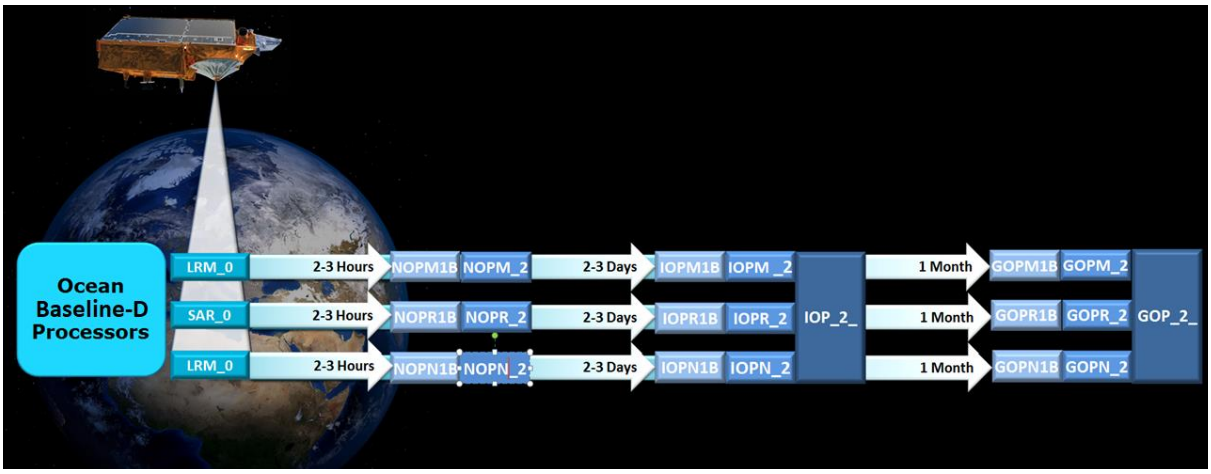

Figure 3: Baseline C COP Products

- **L1b and L2 Near-Real Time (NOP)**: delivered within three hours data sensing acquisition
- **L1b and L2 Intermediate (IOP)**: delivered within 2-3 days after data sensing acquisition, due mainly to the consolidation of some auxiliary or ancillary data (e.g. preliminary restituted orbit data)
- **L2 Intermediate pole-to-pole (IOP P2P)**: delivered with the same latency as IOP and containing LRM, SAR and SARin L2 IOP data covering half an orbit.
- **L1b and L2 Geophysical (GOP)**: delivered within typically 30 days after data sensing acquisition, due mainly to the consolidation of some auxiliary or ancillary data (e.g. precise orbit data).
- **L2 Geophysical pole-to-pole (GOP P2P):** delivered with the same latency as GOP and containing LRM, SAR and SARin L2 GOP data covering half an orbit.

The CryoSat-2 pole-to-pole products (IOP P2P and GOP P2P) are multi-mode L2 products with a half-orbit coverage (from one pole to the other): LRM, SAR and SARin L2 products are concatenated into a single P2P product.

NOP P2P products do not exist because of the three hours latency constraint.

1.6. File Naming Convention

The file names follow the official conventions as for [MASTER-ICD].

MM_CCCC_TTTTTTTTTT_yyyymmdd_hhmmss_YYYYMMDD_HHMMSS_bvvv.nc

MM = CS (Mission Identifier)

CCCC = file class which can be: OFFL (Off Line Processing/Systematic)
RPRO (ReProcessing)
TEST (Testing)

LTA_ (Long Term Archive)

TTTTTTTTTT is the Product Identification (file type) defined in Table 1.

yyyymmdd_hhmmss = validity start time corresponds to the input Level 1 UTC start time

YYYYMMDD_HHMMSS = validity stop time corresponds to the input Level 1 UTC stop time

b = processing baseline identifier

vvv = version number of the file

For example, in case of an operational Intermediate L1B Ocean product of the SIRAL instrument in baseline C and version 1 the name could be:

CS_OPER_SIR_IOPM1B_20170624T075728_20170624T080231_C001.nc

1.7. Product Identification

Table 1 provides the Product Identification for each CryoSat-2 Ocean Product.

Product Identification	Description
SIR_NOPM1B	NRT L1B LRM Ocean Product
SIR_NOPR1B	NRT L1B SAR Ocean Product
SIR_NOPN1B	NRT L1B SARin Ocean Product
SIR_IOPM1B	Interim L1B LRM Ocean Product
SIR_IOPR1B	Interim L1B SAR Ocean Product
SIR_IOPN1B	Interim L1B SARin Ocean Product
SIR_GOPM1B	Geophysical L1B LRM Ocean Product
SIR_GOPR1B	Geophysical L1B SAR Ocean Product
SIR_GOPN1B	Geophysical L1B SARin Ocean Product
SIR_NOPM_2	NRT L2 LRM Ocean Product
SIR_NOPR_2	NRT L2 SAR Ocean Product
SIR_NOPN_2	NRT L2 SARin Ocean Product
SIR_IOPM_2	Interim L2 LRM Ocean Product
SIR_IOPR_2	Interim L2 SAR Ocean Product
SIR_IOPN_2	Interim L2 SARin Ocean Product
SIR_GOPM_2	Geophysical L2 LRM Ocean Product
SIR_GOPR_2	Geophysical L2 SAR Ocean Product
SIR_GOPN_2	Geophysical L2 SARin Ocean Product

SIR_IOP__2	Interim L2 Pole-to-Pole Ocean Product
SIR_GOP__2	Geophysical L2 Pole-to-Pole Ocean Product

Table 1 - CryoSat-2 Ocean Products identification

The CryoSat-2 Level-1b NOP, IOP and GOP products contain all engineering parameters needed to generate the Level-2 product, together with corrections to be applied on range and tidal effects. As the Level-1b products do not include all information required for a correct usage of the altimeter parameters, only Level-2 products are to be considered as user products.

The CryoSat-2 NOP, IOP and GOP Ocean products are generated based on the processing of the CryoSat-2 LRM, SAR and SARin modes data.

1.8. Data access

Access to CryoSat-2 data is controlled by a registration system. To register, or to download data if already registered, visit ESA 'Earthnet Online' Cryosat portal at:

https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/cryosat

After registration the CryoSat-2 Ocean Products are available on the CryoSat-2 dissemination server (ftp://science-pds.cryosat.esa.int).

2 PRODUCT EVOLUTION HISTORY

The current CryoSat-2 Ocean Product version is identified by the Processing Baseline letter "D" in the name of the data products.

2.1 Processing Baseline "D"

2.1.1 Models and standards

The main models and standards that are adopted in this Processing Baseline are listed in Table 2. The ones updated ones towards previous Baseline "C" are written in green. Complementary information on COP processing baselines can be found in [RD 1] and [RD 2].

Description	Model
Product format	
L1B NOP, IOP, GOP	NetCDF-4
L2 NOP, IOP, GOP	NetCDF-4
Orbit	
NOP	DORIS Navigator
IOP	DORIS Preliminary Orbit: POE-E up to 27 April 2019 POE-F from 27 April 2019 onwards
GOP	DORIS Precise Orbit: POE-E up to 27 April 2019 POE-F from 27 April 2019 onwards
Altimeter retracking	
LRM & PLRM	"Ocean MLE4" retracking MLE4 fit from 2nd order Brown analytical model: MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: • Epoch (tracker range offset) ⇒ altimeter range • Composite Sigma ⇒ SWH • Amplitude ⇒ Sigma0 • Square of mispointing angle "Ice OCOG" retracking

	Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: Epoch (tracker range offset) ⇒ altimeter range Amplitude ⇒ Sigma0
SAR	"SAMOSA DPM 2.5" retracking Fit from a theoretical multi-looked waveform model using the Levenberg-Marquardt method
SARin	"SAMOSA DPM 2.5" retracking Fit from a theoretical multi-looked waveform model using the Levenberg-Marquardt method
Geophysical models	
Mean Sea Surface (solution 1)	CNES-CLS22
Mean Sea Surface (solution 2)	DTU21
Geoid	EGM 2008
Mean Dynamic Topography (solution 1)	CNES/CLS22
Mean Dynamic Topography (solution 2)	DTU22
Bathymetry	ACE-2
Ocean & Loading Tide Heigth (Solution 1)	GOT 4.10c
Ocean & Loading Tide Heigth (Solution 2)	FES2014b
Non Equilibrium Ocean Tide	FES2014b
Solid Earth Tide	Cartwright & Eden
Polar tide model	DESAI 2015/ coefficients 2017
Internal Tide	Zaron 2019
Surface Slope Correction	Sandwell Smith 2014
Environmental models	
Dry Troposphere Range Correction	From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides
Wet Troposphere Range Correction from model	From ECMWF
Wet Troposphere Range Correction	From UoP, combination of DComb and GNss-derived path delay

from GPD+	
Inverse Barometer Correction	Computed from ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Non-tidal High-frequency Dealiasing Correction	Mog2D High Resolution Ocean model on IOP and GOP. None for NOP. Ocean model forced by ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Wind speed from model	From ECMWF
Altimeter wind speed (LRM, Pseudo-LRM, SAR and SARin)	Abdalla 2007 (with an adjustment of the backscatter coefficient to the Abdalla model)
SSB & Instrumental corrections	
SSB LRM, Pseudo-LRM	Empirical solution from Cryosat-2 Ocean Baseline-D data in LRM model
SSB SAR	Empirical solution from Cryosat-2 Ocean Baseline-D data in SAR model
SSB SARin	Empirical solution from Cryosat-2 Ocean Baseline-C data in LRM model
Instrumental corrections LRM	LRM Cryosat-2 Ocean
Instrumental corrections Pseudo-LRM	Pseudo-LRM Cryosat-2 Ocean
Instrumental corrections SAR	Currently set to 0
Instrumental corrections SARin	Currently set to 0

Table 2 - Models and standards (CryoSat-2 Ocean Baseline “D”)

2.1.2 Orbit models

Cryosat-2 orbit standards is currently POE-F.

Those are summarized in Table 5, where the previous standard (POE-E) is also recalled:

	POE-E	POE-F
Time span	Up to 27 April 2019	From 27 April 2019 onwards
Gravity model	EIGEN-GRGS.RL03-v2.MEAN-FIELD Non-tidal TVG: one annual, one semi-annual, one bias and one drift terms for each year up to deg/ord 80; C21/S21 modeled according to IERS2010 conventions Solid Earth tides: from IERS2003 conventions Ocean tides: FES2012 Oceanic/atmospheric gravity: 6hr NCEP pressure fields (70x70) + tides from Biancale-Bode model Pole tide: solid Earth and ocean from IERS2010 conventions Third bodies: Sun, Moon, Venus, Mars and Jupiter	**EIGEN-GRGS.RL04-v1.MEAN-FIELD** Non-tidal TVG: one annual, one semi-annual, one bias and one drift terms for each year **up to deg/ord 90; C21/S21 non modified** Unchanged Ocean tides: **FES2014** Oceanic/atmospheric gravity: **3hr dealiasing products from GFZ AOD1B RL06** Unchanged Unchanged
Surface forces	Radiation pressure model: calibrated semi-empirical solar radiation pressure model Earth radiation: Knocke-Ries albedo and IR satellite model Atmospheric density model: DTM-13 for Jason satellites, HY-2A, and MSIS-86 for other satellites	Unchanged Unchanged Atmospheric density model: DTM-13 for Jason satellites, HY-2A, and **MSIS-00 for other satellites**
Estimated dynamical parameters	Stochastic solutions	Unchanged
Satellite reference	Mass and center of gravity: post-launch values + variations generated by Control Center	Unchanged

	Attitude model: For Jason satellites: quaternions and solar panel orientation from control center, completed by nominal yaw steering law when necessary Other satellites: nominal attitude law	**Refined nominal attitude laws**
Displacement of reference points	Earth tides: IERS2003 conventions Ocean loading: FES2012 Pole tide: solid earth pole tides and ocean pole tides (Desai, 2002), cubic+linear mean pole model from IERS2010 S1-S2 atmospheric pressure loading, implementation of Ray & Ponte (2003) by van Dam Reference GPS constellation: JPL solution - fully consistent with IGS08	Unchanged Ocean loading: **FES2014** Pole tide: solid earth pole tides and ocean pole tides (Desai, 2002), **new linear mean pole model** Unchanged Reference GPS constellation: **GRG solution – fully consistent with IGS14**
Geocenter variations	Tidal: ocean loading and S1-S2 atmospheric pressure loading Non-tidal: seasonal model from J. Ries, applied to DORIS/SLR stations	Unchanged Non-tidal: **full non-tidal model (semi-annual, annual, inter-annual) derived from DORIS data and the OSTM/Jason-2 satellite, applied to DORIS/SLR stations and GPS satellites**
Terrestrial Reference Frame	Extended ITRF2008 (SLRF/ITRF2008, DPOD2008, IGS08)	**Extended ITRF2014 (SLRF/ITRF2014, DPOD2014, IGS14)**
Earth orientation	Consistent with IERS2010 conventions and ITRF2008	Consistent with IERS2010 conventions and **ITRF2014**
Propagations delays	SLR troposphere correction: Mendes-Pavlis SLR range correction: constant 5.0 cm range correction for Envisat, elevation dependent range correction for Jason DORIS troposphere correction: GPT/GMF model DORIS beacons phase center correction GPS PCO/PCV (emitter and receiver)	Unchanged SLR range correction: **geometrical models for all satellites** DORIS troposphere correction: **GPT2/VMF1 model** Unchanged GPS PCO/PCV (emitter and receiver) consistent with constellation orbits and

	consistent with constellation orbits and clocks (IGS08 ANTEX), pre-launch GPS receiver phase map GPS: phase wind-up correction	clocks **(IGS14 ANTEX), in-flight adjusted GPS receiver phase map** Unchanged
Estimated measurement parameters	DORIS: one frequency bias per pass, one troposphere zenith bias per pass SLR: Reference used to evaluate orbit precision and stability GPS: floating ambiguity per pass, receiver clock adjusted per epoch	DORIS: one frequency bias **and drift (for "SAA stations")** per pass, one troposphere zenith bias per pass, **horizontal tropospheric gradients per arc** Unchanged GPS: **fixed ambiguity (when possible)** per pass, receiver clock adjusted per epoch
Tracking Data corrections	Jason-1 Doris data: updated South Atlantic Anomaly model (J.-M. Lemoine et al.) applied before and after DORIS instrument change DORIS time-tagging bias for Envisat and Jason aligned with SLR before and after instrument change	Unchanged Unchanged
Doris Weight	1.5 mm/s (1.5 cm over 10 sec) For Jason-1, SAA DORIS beacons weight is divided by 10 before DORIS instrument change	**Process data down to as low elevation angles as possible (from 10° to 5° elevation cut-off angle) with a consistent down-weighting law** Unchanged
SLR Weight	15 cm Reference used to evaluate orbit precision and stability	Unchanged
GPS Weight	2 cm (phase) / 2 m (code)	Unchanged

Table 3 – Orbit Models

2.2 Processing Baseline “C”

2.2.1 Models and standards

The main models and standards that are adopted in this Processing Baseline are listed in Table 2. The ones updated ones towards previous Baseline “b” are written in green. Complementary information on COP processing baselines can be found in [RD 1] and [RD 2].

Description	Model
Product format	
L1B NOP, IOP, GOP	NetCDF-4
L2 NOP, IOP, GOP	NetCDF-4
Orbit	
NOP	DORIS Navigator
IOP	DORIS Preliminary Orbit: POE-E up to 27 April 2019 POE-F from 27 April 2019 onwards
GOP	DORIS Precise Orbit: POE-E up to 27 April 2019 POE-F from 27 April 2019 onwards
Altimeter retracking	
LRM & PLRM	“Ocean MLE4” retracking MLE4 fit from 2nd order Brown analytical model : MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: • Epoch (tracker range offset) ⇒ altimeter range • Composite Sigma ⇒ SWH • Amplitude ⇒ Sigma0 • Square of mispointing angle “Ice OCOG” retracking Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: Epoch (tracker range offset) ⇒ altimeter range Amplitude ⇒ Sigma0
SAR	“SAMOSA DPM 2.3” retracking

	Fit from a theoretical multi-looked waveform model using the Levenberg-Marquardt method
SARin	"SAMOSA DPM 2.3" retracking Fit from a theoretical multi-looked waveform model using the Levenberg-Marquardt method
Geophysical models	
Mean Sea Surface (solution 1)	CNES-CLS15
Mean Sea Surface (solution 2)	DTU15
Geoid	EGM 2008
Mean Dynamic Topography (solution 1)	CNES/CLS13
Mean Dynamic Topography (solution 2)	DTU15
Bathymetry	ACE-2
Ocean & Loading Tide Heigth (Solution 1)	GOT 4.10c
Ocean & Loading Tide Heigth (Solution 2)	FES2014b
Non Equilibrium Ocean Tide	FES2014b
Solid Earth Tide	Cartwright & Eden
Environmental models	
Dry Troposphere Range Correction	From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides
Wet Troposphere Range Correction from model	From ECMWF
Wet Troposphere Range Correction from GPD+	From UoP, combination of DComb and GNss-derived path delay
Inverse Barometer Correction	Computed from ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Non-tidal High-frequency Dealiasing Correction	Mog2D High Resolution ocean model on IOP and GOP. None for NOP. Ocean model forced by ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Wind speed from model	From ECMWF
Altimeter wind speed (LRM, Pseudo-LRM, SAR and SARin)	Abdalla 2007 (with an adjustment of the backscatter coefficient to the Abdalla model)

SSB & Instrumental corrections	
SSB LRM, Pseudo-LRM	Empirical solution from Cryosat-2 Ocean Baseline-B data in LRM mode
SSB SAR	Empirical solution from Cryosat-2 Ocean Baseline-B data in LRM mode
SSB SARin	Empirical solution from Cryosat-2 Ocean Baseline-B data in LRM mode
Instrumental corrections LRM	LRM Cryosat-2 Ocean
Instrumental corrections Pseudo-LRM	Pseudo-LRM Cryosat-2 Ocean
Instrumental corrections SAR	Currently set to 0
Instrumental corrections SARin	Currently set to 0

Table 4 - Models and standards (CryoSat-2 Ocean Baseline "c")

2.2.2 Orbit models

Cryosat-2 orbit standards is currently POE-F.

Those are summarized in Table 5, where the previous standard (POE-E) is also recalled:

	POE-E	POE-F
Time span	Up to 27 April 2019	From 27 April 2019 onwards
Gravity model	EIGEN-GRGS.RL03-v2.MEAN-FIELD Non-tidal TVG: one annual, one semi-annual, one bias and one drift terms for each year up to deg/ord 80; C21/S21 modeled according to IERS2010 conventions Solid Earth tides: from IERS2003 conventions Ocean tides: FES2012 Oceanic/atmospheric gravity: 6hr NCEP pressure fields (70x70) + tides from Biancale-Bode model Pole tide: solid Earth and ocean from IERS2010 conventions Third bodies: Sun, Moon, Venus, Mars and Jupiter	**EIGEN-GRGS.RL04-v1.MEAN-FIELD** Non-tidal TVG: one annual, one semi-annual, one bias and one drift terms for each year **up to deg/ord 90; C21/S21 non modified** Unchanged Ocean tides: **FES2014** Oceanic/atmospheric gravity: **3hr dealiasing products from GFZ AOD1B RL06** Unchanged Unchanged
Surface forces	Radiation pressure model: calibrated semi-empirical solar radiation pressure model Earth radiation: Knocke-Ries albedo and IR satellite model Atmospheric density model: DTM-13 for Jason satellites, HY-2A, and MSIS-86 for other satellites	Unchanged Unchanged Atmospheric density model: DTM-13 for Jason satellites, HY-2A, and **MSIS-00 for other satellites**
Estimated dynamical parameters	Stochastic solutions	Unchanged
Satellite reference	Mass and center of gravity: post-launch values + variations generated by Control Center	Unchanged

	Attitude model: For Jason satellites: quaternions and solar panel orientation from control center, completed by nominal yaw steering law when necessary Other satellites: nominal attitude law	**Refined nominal attitude laws**
Displacement of reference points	Earth tides: IERS2003 conventions Ocean loading: FES2012 Pole tide: solid earth pole tides and ocean pole tides (Desai, 2002), cubic+linear mean pole model from IERS2010 S1-S2 atmospheric pressure loading, implementation of Ray & Ponte (2003) by van Dam Reference GPS constellation: JPL solution - fully consistent with IGS08	Unchanged Ocean loading: **FES2014** Pole tide: solid earth pole tides and ocean pole tides (Desai, 2002), **new linear mean pole model** Unchanged Reference GPS constellation: **GRG solution – fully consistent with IGS14**
Geocenter variations	Tidal: ocean loading and S1-S2 atmospheric pressure loading Non-tidal: seasonal model from J. Ries, applied to DORIS/SLR stations	Unchanged Non-tidal: **full non-tidal model (semi-annual, annual, inter-annual) derived from DORIS data and the OSTM/Jason-2 satellite, applied to DORIS/SLR stations and GPS satellites**
Terrestrial Reference Frame	Extended ITRF2008 (SLRF/ITRF2008, DPOD2008, IGS08)	**Extended ITRF2014 (SLRF/ITRF2014, DPOD2014, IGS14)**
Earth orientation	Consistent with IERS2010 conventions and ITRF2008	Consistent with IERS2010 conventions and **ITRF2014**
Propagations delays	SLR troposphere correction: Mendes-Pavlis SLR range correction: constant 5.0 cm range correction for Envisat, elevation dependent range correction for Jason DORIS troposphere correction: GPT/GMF model DORIS beacons phase center correction GPS PCO/PCV (emitter and receiver)	Unchanged SLR range correction: **geometrical models for all satellites** DORIS troposphere correction: **GPT2/VMF1 model** Unchanged GPS PCO/PCV (emitter and receiver) consistent with constellation orbits and

	consistent with constellation orbits and clocks (IGS08 ANTEX), pre-launch GPS receiver phase map GPS: phase wind-up correction	clocks **(IGS14 ANTEX), in-flight adjusted GPS receiver phase map** Unchanged
Estimated measurement parameters	DORIS: one frequency bias per pass, one troposphere zenith bias per pass SLR: Reference used to evaluate orbit precision and stability GPS: floating ambiguity per pass, receiver clock adjusted per epoch	DORIS: one frequency bias **and drift (for "SAA stations")** per pass, one troposphere zenith bias per pass, **horizontal tropospheric gradients per arc** Unchanged GPS: **fixed ambiguity (when possible)** per pass, receiver clock adjusted per epoch
Tracking Data corrections	Jason-1 Doris data: updated South Atlantic Anomaly model (J.-M. Lemoine et al.) applied before and after DORIS instrument change DORIS time-tagging bias for Envisat and Jason aligned with SLR before and after instrument change	Unchanged Unchanged
Doris Weight	1.5 mm/s (1.5 cm over 10 sec) For Jason-1, SAA DORIS beacons weight is divided by 10 before DORIS instrument change	**Process data down to as low elevation angles as possible (from 10° to 5° elevation cut-off angle) with a consistent down-weighting law** Unchanged
SLR Weight	15 cm Reference used to evaluate orbit precision and stability	Unchanged
GPS Weight	2 cm (phase) / 2 m (code)	Unchanged

Table 5 – Orbit Models

2.3 Processing Baseline "B"

The main models and standards that are adopted in this Processing Baseline are listed in Table 6. The ones updated ones towards previous Baseline "a" are written in green.

Description	Model
Product format	
L1B IOP, GOP (no NOP)	Earth Explorer Format
L2 IOP, GOP (no NOP)	Earth Explorer Format
Orbit	
NOP	/
IOP	DORIS Preliminary Orbit - GDR-E
GOP	DORIS Precise Orbit - GDR-E
Altimeter retracking	
LRM & PLRM	"Ocean MLE4" retracking MLE4 fit from 2nd order Brown analytical model : MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: • Epoch (tracker range offset) ⇒ altimeter range • Composite Sigma ⇒ SWH • Amplitude ⇒ Sigma0 • Square of mispointing angle "Ice OCOG" retracking Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: Epoch (tracker range offset) ⇒ altimeter range Amplitude ⇒ Sigma0
SAR	/
SARin	/
Geophysical models	
Mean Sea Surface (solution 1)	CNES-CLS11
Mean Sea Surface (solution 2)	DTU10
Geoid	EGM 2008

Mean Dynamic Topography (solution 1)	CNES/CLS09
Mean Dynamic Topography (solution 2)	/
Bathymetry	MACESS
Ocean & Loading Tide Heigth (Solution 1)	GOT 4.8
Ocean & Loading Tide Heigth (Solution 2)	FES2004
Non Equilibrium Ocean Tide	FES2004
Solid Earth Tide	Cartwright & Eden
Environmental models	
Dry Troposphere Range Correction	From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides
Wet Troposphere Range Correction from model	From ECMWF
Wet Troposphere Range Correction from GPD+	/
Inverse Barometer Correction	Computed from ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Non-tidal High-frequency Dealiasing Correction	Mog2D High Resolution ocean model. Ocean model forced by ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Wind speed from model	From ECMWF
Altimeter wind speed (LRM, Pseudo-LRM, SAR and SARin)	Abdalla 2007
SSB & Instrumental corrections	
SSB (LRM, Pseudo-LRM, SAR and SARin)	Empirical solution from Jason-2 GDR-C MLE-4 data
Instrumental corrections LRM	LRM Cryosat-2 Ocean
Instrumental corrections Pseudo-LRM	Pseudo-LRM Cryosat-2 Ocean
Instrumental corrections SAR	/
Instrumental corrections SARin	/

Table 6 - Models and standards (CryoSat-2 Ocean Baseline "b")

2.4 Processing Baseline "A"

The main models and standards that are adopted in this Processing Baseline are listed in Table 7.

Description	Model
Product format	
L1B IOP, GOP (no NOP)	Earth Explorer Format
L2 IOP, GOP (no NOP)	Earth Explorer Format
Orbit	
NOP	/
IOP	DORIS Preliminary Orbit - GDR-D
GOP	DORIS Precise Orbit - GDR-D
Altimeter retracking	
LRM & PLRM	"Ocean MLE4" retracking MLE4 fit from 2nd order Brown analytical model : MLE4 simultaneously retrieves the 4 parameters that can be inverted from the altimeter waveforms: • Epoch (tracker range offset) ⇒ altimeter range • Composite Sigma ⇒ SWH • Amplitude ⇒ Sigma0 • Square of mispointing angle "Ice OCOG" retracking Geometrical analysis of the altimeter waveforms, which retrieves the following parameters: Epoch (tracker range offset) ⇒ altimeter range Amplitude ⇒ Sigma0
SAR	/
SARin	/
Geophysical models	
Mean Sea Surface (solution 1)	CNES-CLS11
Mean Sea Surface (solution 2)	DTU10

Geoid	EGM 2008
Mean Dynamic Topography (solution 1)	CNES/CLS09
Mean Dynamic Topography (solution 2)	/
Bathymetry	MACESS
Ocean & Loading Tide Heigth (Solution 1)	GOT 4.8
Ocean & Loading Tide Heigth (Solution 2)	FES2004
Non Equilibrium Ocean Tide	FES2004
Solid Earth Tide	Cartwright & Eden
Environmental models	
Dry Troposphere Range Correction	From ECMWF atmospheric pressures and model for S1 and S2 atmospheric tides
Wet Troposphere Range Correction from model	From ECMWF
Wet Troposphere Range Correction from GPD+	/
Inverse Barometer Correction	Computed from ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Non-tidal High-frequency Dealiasing Correction	Mog2D High Resolution ocean model. Ocean model forced by ECMWF atmospheric pressures after removing S1 and S2 atmospheric tides
Wind speed from model	From ECMWF
Altimeter wind speed (LRM, Pseudo-LRM, SAR and SARin)	Abdalla 2007
SSB & Instrumental corrections	
SSB (LRM, Pseudo-LRM, SAR and SARin)	Empirical solution from Jason-2 GDR-C MLE-4 data
Instrumental corrections LRM	Jason-2
Instrumental corrections Pseudo-LRM	Jason-2
Instrumental corrections SAR	/

Instrumental corrections SARin	/

Table 7 - Models and standards (CryoSat-2 Ocean Baseline “a”)

3 PRODUCT CONTENT

Users will find in this section a detailed description on the parameters provided in the L1b and L2 products.

The table including all parameter names is available in section 5 (p.39). This table indicates in which product is provided each field (Level 1B or Level 2) and points to the following sub-sections where detailed information can be found.

3.1 Operating modes

The mode of operation among LRM, SAR and SARin is available in the Level 1b and Level 2 CryoSat-2 products (see parameters flag_instr_op_mode_01, flag_instr_op_mode_20_ku, flag_instr_op_mode_20_hr_ku, flag_instr_op_mode_20_plrm_ku).

3.2 Spacecraft Orbit and Orientation

3.2.1 Drifting orbit and long repeat cycle

Same as in [**AD 5**].

3.2.2 Orbit processing

For the NOP products the orbit is derived from DORIS Navigator Orbit. For the IOP products the orbit is derived from DORIS Preliminary Orbit (MOE). For the GOP products the orbit is derived from DORIS Precise Orbit (POE).

3.2.3 Reference frame processing

Same as in [**AD 5**].

3.2.4 Mispointing

The mispointing angle is the angle between the antenna pointing and the nadir direction.

In LRM and PLRM modes, the square of the mispointing estimation is computed from the ocean retracking algorithm (see parameters off_nadir_angle_wf_ocean_01_ku and off_nadir_angle_wf_ocean_01_plrm_ku).

In SAR and SARin mode, the pointing information is issued from the star tracker (see parameters off_nadir_roll_angle_str_20_ku, off_nadir_pitch_angle_str_20_ku and off_nadir_yaw_angle_str_20_ku). Detailed information can be found in [AD 5] ("Reference Frame Processing" section).

3.2.5 Centre of Mass

CryoSat-2's centre of mass (CoM) is collocated with its centre of gravity (CoG), which is not always the case for a satellite. CryoSat-2 has been designed so that the centre of mass corresponds to the centre of the single, spherical fuel tank. The fuel is gaseous nitrogen, which uniformly fills the tank. CryoSat-2 has no moving part. Consequently, the centre of mass will not move during the satellite lifetime. All information is given in ftp://ftp.ids-doris.org/pub/ids/satellites/DORISSatelliteModels.pdf.

3.2.6 Distance Antenna-Center of Mass

The tracker and altimeter ranges provided in CryoSat-2 Ocean Products are corrected for the nadir distance between the antenna reference and the Centre of Mass/Gravity of the satellite (called "antenna-COG distance") corresponding currently to a nominal nadir antenna pointing. The correction considers the Center Of Mass position provided in the instrument characterization data file, but not potential mispointing effects.

3.3 Spacecraft Time and Location

Conventional ground-based mapping is usually referenced to the geoid, I.E. the equipotential surface at the sea level without any motion. However, satellite height measurements are references to an ellipsoid, a simple mathematic figure that describes the geoid as a rough approximation.

3.3.1 Reference Ellipsoid

The reference ellipsoid is WGS84, defined by the National Geospatial Intelligence Agency of the USA.

3.3.2 Timestamps

The averaged (so-called 1-Hz) measurements time-tags are built from the reference time (01-01-2000 0h) and a duration (Δt, processing parameter close to 1 second) as shown in the figure below. This strategy is used to guarantee a single definition of the 1-Hz measurements, independent of the existing elementary (so-called 20-Hz) measurements, avoiding thus a change of 1-Hz datation in case of reprocessing.

The 20-Hz measurements (time tags t_i) belonging to a given 1-Hz measurement (time-tag T) are the measurements such as: $T - \frac{\Delta t}{2} \leq t_i < T + \frac{\Delta t}{2}$.

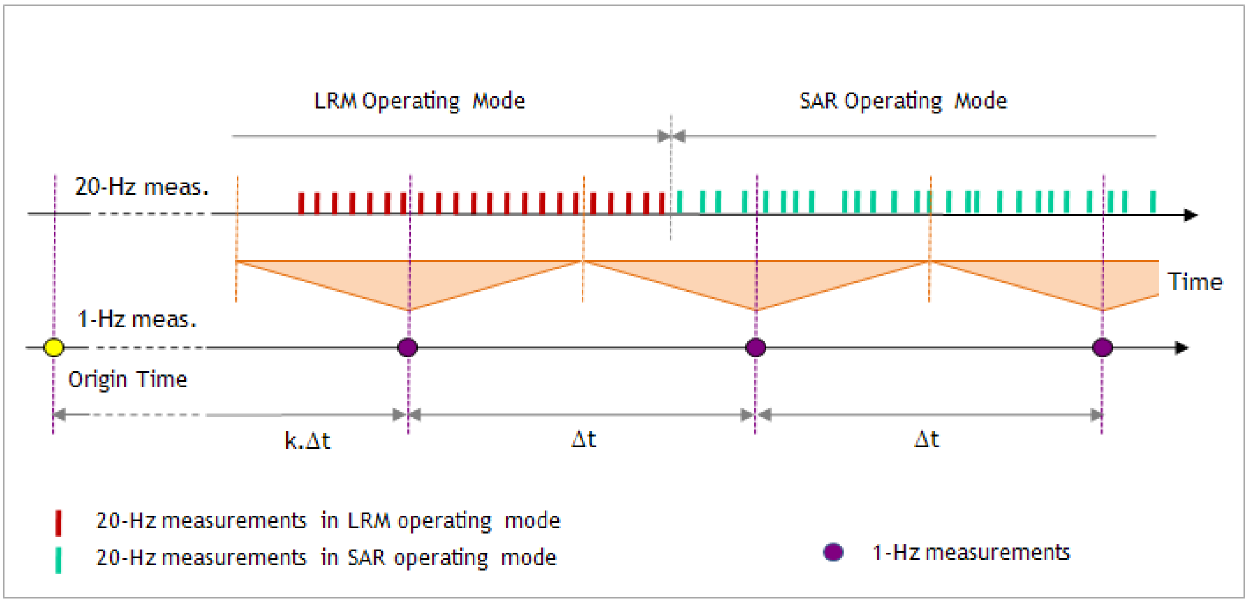

Figure 4: 1-Hz Timestamps determination

Excepted in pole-to-pole products, data flows to be processed at Level 2 are organized by operating mode within the ground segment, avoiding thus the presence of both LRM and SAR mode data within a same 1-Hz measurement.

The timestamp is provided in UTC, together with the difference TAI-UTC.

Pseudo-LRM and SAR data do not have the same 20-Hz time-tag and therefore are provided separately (see section 1.4).

3.3.3 Latitude, Longitude and Altitude

The latitude, longitude and altitude measurements are those interpolated from the orbit at the exact time recorded in the timestamp. All of them are measured from the reference ellipsoid at nadir to the satellite centre of gravity.

3.3.4 Link between 1-Hz and 20-Hz variables

The following indexes are provided in the CryoSat-2 Ocean Products to ease the association between 1-Hz and 20-Hz variables:

Indices			
Name	Description	L1b	L2
ind_first_meas_20hz_01	Index of the first 20Hz measurement of the 1Hz packet	x	x
ind_first_meas_20hz_01_plrm_ku	Index of the first 20Hz PLRM measurement of the 1Hz packet		x

ind_meas_1hz_20_ku	Index of the 1Hz measurement to which belongs the 20Hz measurement	x	x
ind_meas_1hz_20_plrm_ku	Index of the 1Hz measurement to which belongs the 20Hz PLRM measurement		x

Table 8 – Link between 1-Hz and 20-Hz variables

Index zero refers to the first measurement of a CryoSat-2 NOP, IOP or GOP product.

Users are advised not using these indices within the pole-to-pole CryoSat-2 Ocean Products. Please use the "UTC time of the 1Hz measurement: 20 Hz ku band" parameter instead (see time_1hz_20_ku parameter).

3.3.5 DORIS Ultra Stable Oscillator

The DORIS USO drift is required to accurately convert the SIRAL altimeter time and range counts into UTC time tag and range delay measurements. SIRAL derives all its radar frequencies from the DORIS Ultra Stable Oscillator whose frequency, in terms of deviations from nominal value (one measurement every 24 hours), is made available in a DORIS Level 1b product, which is an incremental file.

In LRM and PLRM modes, the LR USO drift correction is provided in distance. It is already applied on the tracker range (L1B products) and altimeter ranges (L2 products).

In SAR and SARin mode, the HR USO drift correction is provided as a factor which must be applied on the window delay (see uso_cor_20_hr_ku parameter). It is already applied on the altimeter ranges in the L2 products.

3.3.6 Satellite Velocity Vector

The satellite velocity vector is given in the international Terrestrial Reference frame (ITRF), which is defined and maintained by the international Earth Rotation Service (IERS). All information is given in https://www.iers.org/IERS/EN/Science/science.html

3.4 Instrument Corrections and Noise

3.4.1 Automatic Gain Control

Corrections due to the AGC loop control are applied to the AGC. For the CryoSat-2 Ocean Products, these corrections are issued from the instrument characterization data file, whose the name is identified in the global attributes of the products.

3.4.2 Signal Phase Corrections

Same as in [**AD 5**]

3.4.3 Phase Slope Correction

Same as in [**AD 5**].

3.4.4 Hamming Weighting Function for SAR Azimuth FFT

Unlike in the Cryosat-2 Ice processor, no hamming weighting function is applied in the Cryosat-2 Ocean processor.

3.4.5 Noise

Same as in [**AD 5**].

3.4.6 Echo Saturation

Same as in [**AD 5**].

3.4.7 Doppler Correction

The Doppler effect on the altimeter range is due to the variation of the radar altimeter frequency because of the radial variation of distance between the altimeter antenna and the overflown surface. This correction is computed assuming that the measurement is performed at nadir. It is thus convenient for ocean surfaces but should not be considered for other surfaces.

The tracker range (see section 3.5.1), which may be used by the user to recompute estimates of the altimeter range over any type of surface does not account for this Doppler Correction. Only the ocean altimeter range (see section 3.5.6.1) includes this correction.

3.5 Parameters retrieved from the waveform analysis

3.5.1 Tracker range and window Delay

The tracker range is the distance from the satellite to the Earth's surface corrected for instrumental corrections.

In LRM and PLRM modes, this information is expressed in distance (parameter tracker_range_20_ku). It is corrected for the USO drift, the internal path delay (parameter int_path_cor_01, derived from the internal calibration) and the antenna-COG distance (parameter cog_cor_01). It is not corrected for Doppler correction.

In SAR and SARin modes, this information is expressed in time and called window delay (parameter window_del_20_hr_ku). It is corrected for the internal path delay (derived from the internal calibration) and the antenna-COG distance. It is not corrected for USO drift and for Doppler correction.

3.5.2 Reception Period

Same as in [**AD 5**]

3.5.3 Range window sampling

Same as in [AD 5] excepted that PLRM waveforms generated by SAR/SARin PLRM processing are not averaged over 1 second

3.5.4 Echo Positioning and Scaling

In the data products the position of the echo within the range window depends on the SIRAL mode. The instrument dynamically sets the range window. In LRM the window position is not changed by the data processing. In SAR and SARin mode, echoes are averaged during the data processing on the ground and the position of the window is then selected to better accommodate the resulting waveform.

To retain as much information as possible, the individual samples of each echo waveform are scaled to fit between 0 and 65535. A scaling factor provided in the product shall be applied by the users to retrieve the real power waveform.

In LRM and PLRM modes, power echo waveform expressed in FFT power unit can be retrieved using the formula:

pwr_waveform_20_ku = pwr_waveform_20_ku/echo_scale_20_ku

In SAR and SARin modes, power echo waveform expressed in Watts can be retrieved using the formula:

*waveform_20_hr_ku = pwr_waveform_20_hr_ku/echo_scale_factor_20_hr_ku*2^echo_scale_pwr_20_hr_ku*

3.5.5 Waveform Retracking

3.5.5.1 LRM and Pseudo-LRM

In LRM and in Pseudo-LRM (SAR or SARin) modes, two retracking methods are used to process low-resolution geophysical parameters: Ocean MLE-4 and Ice OCOG.

The aim of the MLE-4 retracking algorithm ([RD 6]) is to make the measured waveform fit with an analytic return power model, according to weighted Least Square Estimators derived from Maximum Likelihood Estimators, and to estimate the 4 following parameters:

- Epoch (linked to the position of the waveform in the analysis window), from which the altimeter range is derived, accounting for the tracker range
- Composite Sigma (linked to the width of the waveform leading edge), from which the significant wave height (SWH) is derived, accounting for the width of the Point Target Response
- Amplitude of the waveform, from which the backscatter coefficient - and then the wind speed - is derived, accounting for the radar equation
- Square of the off-nadir angle (linked to the slope of the waveform trailing edge)

The OCOG retracker ([RD 7]) complements the ocean MLE3/MLE4 to provide elementary elevation and backscatter coefficient over any kind of surfaces, and in particular where ranges vary rapidly and for overflown reflecting surfaces exhibiting high heterogeneities.

3.5.5.2 SAR and SARIN Mode

In SAR and SARin modes, one additional retracking is used to process high-resolution geophysical parameters: SAMOSA DPM 2.3 ([RD 10]).

The SAMOSA retracking algorithm is based on the analytical expression of the theoretical model for Delay Doppler Altimeter waveforms developed by Starlab in SAMOSA Project. Version 2.3.x is based on the formulation of the SAM3 model presented in [RD 8] and [RD 9]. It estimates the 3 following parameters:

- Epoch (linked to the position of the waveform in the analysis window), from which the altimeter range is derived, accounting for the tracker range.
- Significant wave height (SWH)
- Amplitude of the waveform, from which the backscatter coefficient - and then the wind speed - is derived, accounting for the radar equation.

3.5.6 From Range to the Corrected Sea Level Anomaly

3.5.6.1 Range

An altimeter operates by sending out a short pulse of radiation and measuring the time required for the pulse to return from the sea surface. This measurement, known as the altimeter range, gives the distance between the instrument (antenna reference) and the sea surface, provided that the velocity of the propagation of the pulse and the precise arrival time are known.

In the CryoSat-2 Ocean L1B Products:

- LRM and PLRM modes: the LR window delay is converted into distance (tracker_range_20_ku). It is corrected for the USO drift, the internal path delay (derived from the internal calibration) and the antenna-COG distance. It is not corrected for Doppler correction.
- SAR and SARin modes: the HR window delay is expressed in time (parameter window_del_20_hr_ku). It is corrected for the internal path delay (derived from the internal calibration) and the antenna-COG distance. It is not corrected for Doppler correction.

In the Level 2 CryoSat-2 Ocean Products, this tracker range is corrected for the epoch (tracker range offset computed by ocean or ice retracking algorithm) and for modelled instrumental correction tables (for MLE-4 retracking only), doppler correction, and system bias, leading thus to the altimeter range corrected for all instrumental effects. For LRM/PLRM, the range is then retrieved from OCOG and MLE4 algorithms (see section 3.5.5.1). For SAR/SARin, the range is retrieved from SAMOSA algorithms (see section 3.5.5.2)

To account for environmental effects, the given range must be corrected by the user for path delay in the atmosphere. The corrected range is therefore given by:

Corrected Range = Range + Wet Tropospheric Correction + Dry Tropospheric Correction + GIM Ionospheric Correction

Wet Tropospheric Correction : See section 3.6.1

Dry Tropospheric Correction : See section 3.5.2

GIM Ionospheric Correction : See section 3.6.3

3.5.6.2 Sea Surface Height and Sea Surface Height Anomaly

Sea surface height (SSH) is the height of the sea surface above the reference ellipsoid (see section 3.2.1). It can be calculated by subtracting the corrected range (accounting for instrumental effects and environmental corrections, as defined above) from the Altitude:

Sea Surface Height = Altitude – Corrected Range - Solid Earth Tide Height - Geocentric Ocean Tide Height - Pole Tide Height - Dynamic Atmospheric Correction - Sea State Bias - Surface Slope Correction (in LRM/PLRM) - Internal tide Height - Non-equilibrium Oceanic Tide Height

The Sea Surface Height Anomaly (SSHA), also called Sea Level Anomaly (SLA), is defined as the Sea Surface Height minus the Mean Sea Surface (MSS).
It is given by:

Sea Surface Height Anomaly = Sea Surface Height - Mean Sea Surface

Altitude : See section 3.3.3

Corrected Range : See previously in this section

Solid Earth Tide Height : See section 3.7.7

Geocentric Ocean Tide Height : See section 3.7.4.2

Pole Tide Height : See section 3.7.8

Dynamic Atmospheric Correction : See section 3.7.3
(If the Dynamic Atmospheric Correction is missing, the **Inverted Barometer correction** shall be used instead, See section 3.7.2)

Sea State Bias : See section 3.7.1

Mean Sea Surface : See section 3.8.2

Surface Slope (POCA) Correction : See section 3.8.3

The users can compute their own SSHA based on the previous equations listed parameters/corrections, or use the one already included in the CryoSat-2 Ocean Products.

The SSHA provided in the CryoSat-2 Ocean Products is computed by including solution 2 mean sea surface (CNES-CLS-22) and solution 1 ocean tide (FES2014b).

Regarding the wet troposphere Correction, the ECMWF model is used for NOP and IOP processing and the GDP+ is used for GOP processing (see section 3.6.2).

Regarding the Dynamic Atmospheric Correction (See section 3.7.3), the high frequency fluctuations from the MOG2D model [RD.15] are used when available for the IOP and GOP processing. As MOG2D model output are not available at time of NOP computation, the inverted Barometer Correction is used (See section 3.7.2)

3.5.6.3 Suggested editing criteria

The following editing criteria are recommended to compute corrected sea surface height anomaly. (The users are encouraged to review these criteria and potentially refine them in function of their study areas or domains of application)

First, retain only ocean data and remove any bad, missing, or flagged data:

Parameter	Value	Meaning
Surface type	0	Open oceans or semi-enclosed seas
Sea surface height anomaly quality flag	0	Good

Table 9 - Recommended editing criteria

Then, edit data to retain only relevant values when computing the corrected Sea Surface Height Anomaly:

Parameter	Minimum value	Maximum value
Sea surface height anomaly	-3 m	3 m
Standard deviation of range	0 m	0.2 m
Dry tropospheric correction	-2.5 m	-1.9 m
Wet tropospheric correction	-0.5 m	-0.001 m
Ionospheric correction	-0.4 m	0.04 m
Sea state bias	-0.5 m	0 m
Backscatter coefficient	7 dB	30 dB

Standard deviation of backscatter coefficient	0 dB	0.23 dB

Table 10 - Recommended filtering criteria

To restrict studies to deep water, apply a limit, e.g., water depth of 1000m or greater, using the bathymetry parameter (ocean depth in meters.)

3.5.7 Backscattering

The radar backscattering coefficient (sigma-0) provides information about the observed surface. It is a function of the radar frequency, polarization and incidence angle and the target surface roughness, geometric shape and dielectric properties.

The backscatter coefficient is corrected for AGC correction (see agc_cor_01 parameter), internal calibration correction (see internal_cor_sig0_01 parameter), modeled instrumental correction (see mod_instr_cor_sig0_01_ku, mod_instr_cor_sig0_01_plrm_ku parameters) and for a system bias insuring the consistency with the sigma0 to wind speed model. It is not corrected for atmospheric attenuation (see atm_cor_sig0_01 parameter). The latter might be wrongly detailed in the Level-2 variables of the backscattering coefficient.

The tuning of the Sigma0 in SARin has been performed using a limited set of data (3 months) and therefore may be still improved. A longer GOP dataset is required for further refinement and will be done after the GOP reprocessing campaign.

3.5.8 Peakiness

Peakiness is a measure of how sharply peaked an echo is. It is essentially the ratio of the highest bin value to the mean value of all bins above the retracking point. High peakiness indicates a very specular reflection, such as that from leads in sea ice.

By construction, the peakiness parameter computed for CryoSat-2 Ocean Products is greater by a factor 128/(128-47) with respect to the one provided in the ENVISAT products. For ENVISAT, users frequently exploit the peakiness values for data editing purpose. The corresponding thresholds must account for the above-mentioned factor to be applicable to CryoSat-2 Ocean Products.

3.5.9 Significant Wave Height

Significant wave height (SWH) is the average wave height, trough to crest, of the one-third largest waves in a particular geographical location. SWH can be derived from inspection of the echo waveform using retracking methods (see section 3.5.5).

In LRM and PLRM modes only, the SWH is corrected for the modeled instrument correction (see mod_instr_cor_swh_01_ku, mod_instr_cor_swh_01_plrm_ku parameters).

3.5.10 Wind Speed

The model functions developed to date for altimeter wind speed have all been purely empirical. A wind speed is computed from a linear interpolation of a table of Ku-band backscatter coefficient, based on empirical fits ([RD 11]).

Finally, a 10-meter (above surface) wind vector (in east-west and north-south directions) is also provided (see wind_speed_mod_u_01, wind_speed_mod_v_01 parameters). This wind speed vector is determined from an interpolation of the ECMWF model.

3.6 Atmospheric Propagation Corrections

An altimeter pulse slows down as it passes through the Earth's atmospheric layers due to the refractive properties of the ionosphere and troposphere. When the time delay is converted to range, using the speed of light in a vacuum, this small additional delay must be accounted for via several propagation corrections.

3.6.1 Dry Tropospheric Corrections

The Dry Tropospheric Correction (DTC) is the correction for refraction due to the dry gas component of the atmosphere, which generates a path delay in the radar return signal. This effect can be measured or modeled as discussed below.

The propagation velocity of a radio pulse is slowed by the "dry" gases and the quantity of water vapor in the Earth's troposphere. The gases in the troposphere contribute to the index of refraction. In detail, the refractive index depends on pressure and temperature. When hydrostatic equilibrium and the ideal gas law are assumed, the vertically integrated range delay is a function only of the surface pressure, see Chelton et al. [2001]. The dry meteorological tropospheric range correction is principally equal to the surface pressure multiplied by -2.277mm/mbar, with a small adjustment also necessary to reflect a small latitude dependence.

*mod_dry_tropo_cor_01 = -2.277 * Patm * [1 + 0.0026 * cos(2 * phi)]*

where Patm is surface atmospheric pressure in mbar, phi is latitude, and mod_dry_tropo_cor_01 is the dry troposphere correction in mm. There is no straightforward way of measuring the nadir surface pressure from a satellite, so it is determined from the European Center for Medium Range Weather Forecasting (ECMWF) numerical weather prediction model using the surface pressure fields.

The ECMWF meteorological fields Psurf are interpolated to provide the model dry troposphere correction at the time and location of the altimeter measurement (see mod_dry_tropo_cor_01).

For NOP processing, predicted ECMWF Psurf fields are used and for IOP and GOP processing analyzed fields are used.

3.6.2 Wet Tropospheric Correction

The Wet Tropospheric Correction (WTC) is the correction for the path delay in the altimetric return signal due to water vapor in the atmosphere.

The water vapor in the troposphere is quite variable and produces a altimetric height calculation error of -6 cm to -40 cm. The amount of water vapor present along the path length contributes to the index of refraction of the Earth's atmosphere. Its contribution to the delay of the radio pulse is called the wet tropospheric delay.

The ECMWF numerical weather prediction model provides a value for the wet tropospheric delay. The ECMWF meteorological fields are interpolated to provide the model wet tropospheric corrections at the time and location of the altimeter measurement and included in the CryoSat-2 Ocean Products. (see mod_wet_tropo_cor_01). For NOP processing, predicted ECMWF wet tropospheric delay fields are used and for IOP and GOP processing analyzed fields are used.

In addition to ECMWF-derived WTC correction, the GOP baseline C products now include GPD Plus (GPD+) Wet Tropospheric Corrections (see parameter gpd_wet_tropo_cor_01). The GPD+ WTC method is the merged of two WTC retrieval methods called DComb (Data Combination) and GPD (GNss-derived Path Delay) ([RD 14]). Since CryoSat-2 does not carry an on-board microwave radiometer (MWR), the algorithm combines, by space-time objective analysis (OA) the following set of external wet path delay data sources:

- ✓ Total Column Water vapour (TCWV) products from scanning microwave imaging radiometers (SI-MWR) on board remote sensing satellites (NOAA-15, -16, -17, -18, -19; MetOp-A, MetOp-B; AMSR-E from Aqua; AMSR-2 from GCOM-W; SSMI/S from F16, F17; Windsat from Coriolis; TMI from TRMM (with a few months delay); TMI swath data (NRT)).
- ✓ Zenith Total Delays (ZTD) from GNSS island and coastal stations (>700).
- ✓ ECMWF operational model-at its highest spatial resolution (1/8º) 6-h interval, to be used as first guess in the OA and as adopted WTC value in the absence of observations. This model is also used in the processing of GNSS-derived ZTD to compute the zenith wet delays (ZWD), WTC equivalent.

To ensure consistency and the long-term stability of the WTC, the large set of radiometers used in the GPD+ estimations have been inter-calibrated, using the set of Special Sensor Microwave Imager (SSM/I) and SSMI/I Sounder (SSM/IS) on-board the Defense Meteorological Satellite Program satellite series (F10, F11, F13, F14, F16 and F17) as reference, due to their well-known stability and independent calibration. Thus, with respect to previous WTC versions, the GPD+ WTC for CryoSat-2 is calibrated with respect to F16 and F17, instead of the Advanced Microwave Radiometer (AMR) on board Jason-2.

In spite of the sparseness of the GNSS data compared with the SI-MWR, these improve the WTC in the coastal regions, where CryoSat-2 is mostly operating in the increased along-track resolution SAR mode, therefore being of major importance.

3.6.3 Ionospheric Correction

The ionospheric correction compensates from the free electrons in the Earth's ionosphere slowing the radar pulse. For the CryoSat-2 Ocean Products, external ancillary data are used to compute ionosphere correction, in the form of TEC grids computed from GPS-based observations and ionosphere model (the JPL Global Ionosphere Maps – GIM – model). Other auxiliary data such as solar activity coefficients (within swh95) are used to correct the satellite altitude. GIM model has been validated through comparisons with T/P, Jason-1, Jason-2 and ENVISAT dual frequency ionosphere corrections.

3.7 Ocean surface corrections

These corrections are necessary to account for the ocean's response to atmospheric and tidal forcing and are removed from the sea surface height.

3.7.1 Sea State Bias

The, sea-state effects are an intrinsic property of the large footprint radar measurements. The surface scattering elements do not contribute equally to the radar return; troughs of waves tend to reflect altimeter pulses better than do crests. Thus the centroid of the mean reflecting surface is shifted away from mean sea level towards the troughs of the waves. The shift, referred to as the electromagnetic (EM) bias, causes the altimeter to overestimate the range ([RD 12]). In addition, a skewness bias also exists from the assumption in the onboard algorithms that the probability density function of heights is symmetric, while in reality it is skewed. Finally, there is a tracker bias, which is a purely instrumental effect. The sum of EM bias, skewness bias, and tracker bias is called 'sea state bias' (SSB).

The accuracy of the SSB models remains limited and continues to be a topic of research. The current most accurate estimates are obtained using empirical models derived from analyses of the altimeter data. The sea state bias is computed from a bilinear interpolation of a table of sea state biases versus significant wave height and wind speed, based on empirical fits ([RD 13]). the same model is currently used in LRM, PLRM, SAR and SARin modes.

3.7.2 Inverse Barometric Correction

The Inverse Barometric Correction is the correction for variations in the sea surface height due to atmospheric pressure variations (atmospheric loading). The correction is calculated using dynamic surface pressure files sourced from Meteo-France via SSALTO based on ECMWF outputs, as well as static S1 and S2 tide grids of monthly means of global amplitude and phase.

3.7.3 Dynamic Atmospheric Correction

The Dynamic Atmospheric Correction (DAC) is needed to correct for the depression of the ocean surface caused by the local barometric pressure and wind effects.

The correction is a combination of the high frequency, high resolution 2D Gravity Waves Model (MOG2D, [RD.15]), an ocean model forced by ECMWF atmospheric parameters after removing S1 and S2 atmospheric tides, and the low frequency Inverse Barometric (IB) Correction (see 3.6.2). The DAC correction is provided by grids taken from the barotropic MOG2D model and is sourced from CNES via SSALTO.

N.B. The DAC correction is not available in the NOP because the Forecast MOG2D ADFs necessary for this correction are not available at the time of NOP processing. As a result, the default value is provided for the DAC correction in NOP products.

3.7.4 Ocean Tide

For CryoSat-2 Ocean Products, 2 solutions are proposed:

3.7.4.1 Solution 1: GOT 4.10c

Solution GOT4.10c ([RD 16]), is the last version of GOT models developed by R. Ray.

This model is different from previous version GOT4.8 as it is now based on Jason-1 and Jason-2 data, ERS-1 and ERS-2 and GFO.

None T/P data has been used in this solution.

The solution consists of independent near-global estimates of 10 constituents (K1, K2, M2, M4, N2, O1, P1, Q1, S1, S2). An a priori model was used that consisted of the hydrodynamic model FES 2004 ([RD 18]) and several other local hydrodynamic models.

Note that GOT4.10c model uses the new tidal geocenter correction proposed by Shailen and Ray ([RD 17]). Moreover, the dry-tropospheric correction for the Jason satellites never had the S2 air-tide error that the original T/P data had.

GOT4.10c solution does not use the Cg correction, as it is a T/P correction.

3.7.4.2 Solution 2: FES2014b

FES2014 is the last version of the FES (Finite Element Solution) tide model developed in 2014-2016. It is an improved version of the FES2012 model, which was fully revised version of the global hydrodynamic tide solutions initiated by the works of Christian Le Provost in the early nineties. This new FES2014 model has been developed, implemented and validated by the LEGOS, NOVELTIS and CLS, within a CNES funded project.

FES2014 takes advantage of longer altimeter time series and better altimeter standards, improved modelling and data assimilation techniques, a more accurate ocean bathymetry and a refined mesh in most of shallow water regions. Special efforts have been dedicated to address the major non-linear tides issue and to the determination of accurate tidal currents.

FES2014 is based on the resolution of the tidal barotropic equations (T-UGO model) in a spectral configuration.

A new global finite element grid (~2.9 million nodes, 50% more than FES2012) is used and model physic has been improved, leading to a nearly twice more accurate 'free' solution (independent of in situ and remote-sensing data) than the previous FES2012 version. Then the accuracy of this 'free' solution was improved by assimilating long-term altimetry data (Topex/ Poseidon, Jason-1, Jason-2, TPN-J1N, and ERS-1, ERS-2, ENVISAT) and tidal gauges through an improved representer assimilation method.

A preliminary version, noted FES2014a, has been produced in 2015 based on GOT4v8ac loading tide. Then new tide loading effects have been computed using FES2014a oceanic tide (J.P. Boy, Univ. Strasbourg). These FES2014a tide loading effects have been used to produce the final model version noted FES2014b, which is used for the CryoSat-2 Ocean Products:

FES2014b geocentric (elastic) tide = FES2014b oceanic tide + FES2014a loading tide.

Final FES2014b solution shows strong improvement compared to FES2012 and GOT4V10, particularly in coastal and shelf regions and also in some deep ocean areas and in the Arctic region.

34 tidal constituents have been computed: N2, EPS2, J1, K1, K2, L2, La2, M2, M3, M4, M6, M8, Mf, MKS2, Mm, MN4, MS4, MSf, MSqm, Mtm, Mu2, N2, N4, Nu2, O1, P1, Q1, R2, S1, S2, S4, Sa, Ssa, T2.

See http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes.html

The Oceanic tide contains the Long Period Tide height and Ocean Loading Tide. It does not contain Non-equilibrium long period Ocean tide height which is also provided.

The permanent tide (zero frequency) is not included in the Oceanic tide parameters because it is included in the geoid and mean sea surface.

3.7.5 Ocean Loading Tide

For CryoSat-2 Ocean Products, 2 solutions are proposed:

- Solution 1: GOT 4.10c (See section 3.7.4.1)
- Solution 2: FES2014b (See section 3.7.4.2)

FES2014b tidal loading contains the total load tide height (short-period and long-period) for the geocentric ocean tide (solution 2). This value has already been added to the corresponding ocean tide height value recorded in the product [ocean_tide_sol2_01].

To get only the pure ocean tide height (solution 2), do:

[ocean_tide_sol2_01] + [ocean_tide_non_eq_01] - [load_tide_sol2_01].

3.7.6 Non-equilibrium oceanic tide height

This parameter is computed as a correction to the equilibrium long period ocean tide (see ocean_tide_eq_01, ocean_tide_non_eq_01 parameters). It contains the long-period ocean tide and the long period load tide components.

This parameter can be added to [ocean_tide_eq_01] (or [ocean_tide_sol1_01], [ocean_tide_sol2_01]) so that the resulting value models the total non-equilibrium ocean tide height.

3.7.7 Solid Earth Tide

The solid Earth tide correction removes the deformation of the Earth due to tidal forces from the Sun and Moon acting on the Earth's body. Typically, this correction ranges from -30cm to +30cm. The Cartwright model is used for this correction.

3.7.8 Geocentric Polar Tide

The geocentric polar tide correction removes a long-period distortion of the Earth's crust caused by variations in centrifugal force as the Earth's rotational axis moves its geographical location. Typically, this correction ranges from -2cm to +2cm. It is derived from the pole location files. The Desai model from 2015 with 2017 coefficient is used for this correction.

3.7.9 Internal Tide

Internal tides are baroclinic tides generated by the arrival of a barotropic tide flow on an underwater sharp topography pattern (seamount or shelfbreak region); they can reach amplitudes of several 10th of meters at the thermocline level and they have a signature of several cm at the surface with wavelengths about 50-250 km for the first mode and shorter wavelengths for higher modes.

The global ocean tide models described in previous sections are barotropic tide models, so by essence they do not correct from the internal tides signature at the surface.

The level 2 CryoSat-2 Ocean Products provides one internal tide value, computed from Zaron (2019) model. It models the internal tides surface signatures which remain coherent with the four main barotropic tide frequencies.

3.8 Reference Surfaces

3.8.1 Geoid

The Geoid provided in level 2 CryoSat-2 Ocean Products comes from the model EGM2008. All information is given in:

http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/egm08_wgs84.html

3.8.2 Mean Sea Surface

There are two fields of Mean Sea Surface (MSS) for level 2 CryoSat-2 Ocean Products provided by the following models:

Solution 1: CNES-CLS22 MSS. The description is given in:

https://www.aviso.altimetry.fr/fr/donnees/produits/produits-auxiliaires/mss/description-mss-cnes-cls2022.html

Solution 2: DTU21 MSS. The description is given in:

https://ftp.space.dtu.dk/pub/DTU21/

3.8.3 POCA (Point of closes approach) correction

The slope correction model improves the accuracy of mean sea surface topography models. The correction is greatest above ocean trenches and large seamounts where higher slopes are present. In extreme cases, the correction to the mean sea surface height is 40 mm. The correction needs to be considered for LRM and PLRM mode.

The correction is defined only between -80°<latitude<80°. For latitude outside this range, the correction is Not a Number and not included in the SSHA calculation.

3.8.4 Mean Dynamic Topography

There are two fields of Mean Dynamic Topography (MDT) for level 2 CryoSat-2 Ocean Products provided by the following models:

Solution 1: CNES-CLS22 MDT. All information is given in:

https://www.aviso.altimetry.fr/fr/donnees/produits/produits-auxiliaires/mdt.html

Solution 2: DTU22 MDT. All information is given in:

https://ftp.space.dtu.dk/pub/DTU22/MDT/

3.8.5 Ocean depth/land elevation model

The ocean depth/land elevation model in level 2 CryoSat-2 Ocean Products is ACE-2 (Altimeter Corrected Elevation 2). All information is given in:
http://tethys.eaprs.cse.dmu.ac.uk/ACE2/

3.8.6 Effects of Terrain

The CryoSat-2 Ocean Products provide a parameter that gives the ocean depth or land elevation of the data point. Ocean depths have negative values, and land elevations have positive values (see odle_01 parameter). To restrict studies to deep water, users can apply editing criteria on this parameter, e.g., water depth of 1000m or greater (ocean depth in meters.)

4 PRODUCT DESCRIPTION

4.1 NetCdf format and CF convention

The version of the NetCDF libraries used for the CryoSat-2 production is **NetCDF-4 CF compliant** and consists of the following elements:

- **DIMENSIONS:**

A dimension is used to represent a real physical dimension (for example, time, latitude, longitude, and height) or to index other quantities (for example number of records or waveforms or samples). A dimension can also be used to index other quantities (waveforms index for example).

A NetCDF dimension has both a name and a length and can be limited or unlimited (i.e. a dimension that can be appended to).

- **VARIABLES:**

Variables are used to store the bulk of the data in a NetCDF dataset. 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, which may be added, deleted or changed after the variable is created.

- **COORDINATE VARIABLES:**

A variable can have the same name as a dimension and in this case the variable is called a coordinate variable. It typically defines a physical coordinate corresponding to that dimension. If a dimension has a corresponding coordinate variable, then this provides an alternative, and often more convenient, means of specifying position along it. Current application packages that make use of coordinate variables commonly assume they are numeric vectors and strictly monotonic (all values are different and either increasing or decreasing).

- **ATTRIBUTES:**

Attributes are used to store information about the data (ancillary data or metadata). Most attributes provide information about a specific variable. These are identified by the name (or ID) of that variable, together with the name of the attribute.

- **GLOBAL ATTRIBUTES:**

Some attributes provide information about the whole dataset and are called global attributes. In particular, the global attributes used in the CryoSat-2 products contains the information that were present in the EE header (see [COP-FMT], [AD.3])

4.2 CryoSat-2 NetCDF variable name conventions

The names of the CryoSat-2 NetCDF variables are as much as possible self-explaining and a specific effort has been done to align them to the same kind of variables used in other current and future altimetric missions (e.g. Sentinel 3 and Sentinel 6/Jason-CS).

Moreover, the following template has been used for the ***L1b variables*** names:

variable_name_F1_F2_F3

where:

- Variable_name is a self-explaining name for the variable. This lowercase name can contain underscores and numbers (e.g. *cor2_applied*) and it is mandatory
- F1: this field can be **01** or **20** to state whether the variable is a 1-Hz or a 20-Hz variable (e.g. *cor2_applied_20*) and it is mandatory
- F2: this field can only hold **hr** (i.e. high resolution) and it is used for the variables computed by processing native SAR or SARin waveforms. This suffix is not used for variable computed with PLRM waveforms and it is therefore optional. Example: *cor2_applied_20* or *cor2_applied_20_hr*
- F3: this field can only hold **ku** and it is used flag variable computed with data coming from the satellite (Ku-band) and therefore it is optional. Example: *cor2_applied_20_ku* or *cor2_applied_20_hr_ku* but *wind_speed_mod_v_01*

The conventions used for ***L2 variables*** names are alike but not exactly the same. In this case the convention is:

variable_name_F1_F4_F3

where:

- Variable_name is a self-explaining name for the variable. This lowercase name can contain underscores and numbers (e.g. *lon*) and it is mandatory
- F1: this field can be **01** or **20** to state whether the variable is a 1-Hz or a 20-Hz variable (e.g. *lon_20*) and it is mandatory
- F4: this field can only hold **plrm** and it is used for the variables computed by processing PLRM L1 data. This suffix is not used for variable computed with high resolution (SAR/SARin) L1b variables and it is therefore optional. Example: *lon_20* or *lon_20_plrm*
- F3: this field can only hold **ku** and it is used flag variable computed with data coming from the satellite (Ku-band) and therefore it is optional. Example: *lon_20 _ku* or *lon_20_plrm_ku* but *wind_speed_mod_v_01*

4.3 The NetCDF Data Model

A NetCDF file contains **dimensions**, **variables**, and **attributes**, which all have both a name by which they are identified. These components can be used together to capture the meaning of data and relations among data fields in an array-oriented data set.

4.4 Dimensions

A dimension may be used to represent a real physical dimension, for example, time, latitude, longitude, or height. A dimension might also be used to index other quantities (waveforms index for example).

The following dimensions are used in the CryoSat-2 L1b product files:

Dimension Name	Value
time_01	Number of 1 Hz measurements in the product file
time_20_hr_ku	Number of 20 Hz HR measurements in the product file
time_20_ku	Number of 20 Hz measurements in the product file
ns_20_hr_ku	Number of samples in one HR waveform
ns_20_ku	Number of samples in one waveform
space_3d	3 (3 dimensions of space (x,y,z))

Table 11 - Dimensions used in the CryoSat-2 L1b products

The following dimensions are used in the CryoSat-2 L2 product files:

Dimension Name	Value
time_01	Number of 1 Hz measurements in the product file
time_20_ku	Number of 20 Hz measurements in the product file
time_20_plrm_ku	Number of 20 Hz PLRM measurements in the product file

Table 12 - Dimensions used in the CryoSat-2 L2 products

4.5 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, which may be added, deleted or changed after the variable is created.

The following types are used in the CryoSat-2 Ocean Products:

Variable type	Description
byte	8-bit data signed
short	16-bit signed integer
int	32-bit signed integer
double	IEEE double precision floating point

	(64 bits)

Table 13 - NetCDF variable type

4.6 Coordinate variables and auxiliary coordinate variables

A variable with the same name as a dimension is called a **coordinate variable**. It typically defines a physical coordinate corresponding to that dimension. In accordance with the Climate and Forecast conventions, we must declare a coordinate variable for each dimension. What's more, missing values are not allowed in coordinate variables and they must be strictly monotonic.

An **auxiliary coordinate variable** is a NetCDF variable that contains coordinates data but is not a coordinate variable as defined above. Unlike coordinate variables, there is no relationship between the name of an auxiliary coordinate variable and the name(s) of its dimension(s).

4.7 Attributes

NetCDF attributes are used to store data 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** - similar to the header of the CryoSat-2 products in EE format.

The following table shows the variable attributes used in the CryoSat-2 product. There are no mandatory attributes.

Attributes	
Name	Description
add_offset	If present, this number is to be added to the date after it is read by an application. If both *scale_factor* and *add_offset* attributes are present, the date 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
_FillValue	A value used to represent missing or undefined data add_offset If present, this number is to be added to the date
flag_meanings	Use in conjunction with flag_values to provide descriptive words or phrase for each flag value.
flag_values	Provide a list of the flag values. Use in conjunction with *flag_meanings*.
flag_mask	Provide a list of number of independent Boolean conditions using bit field notation. Use in conjunction

	with *flag_meanings*.
institution	Institution which provides 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.
tai_utc_difference	Difference between TAI and UTC reference time
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.

Table 14 - Variable's attributes

Global attributes (the equivalent of header parameters for CryoSat-2 EE products) may be displayed from a CryoSat-2 product file using **"ncdump –h"** command.

4.8 Software

This section lists some software that may be used to browse and use data from CryoSat-2 Ocean Products.

4.8.1 Software provided with NetCDF : "ncdump"

« ncdump » converts NetCDF files to ASCII form (CDL)

See http://www.unidata.ucar.edu/software/netcdf/docs/ncdump-man-1.html

The main options are the following:

- -h Show only the header information in the output, that is the declarations of dimensions, variables, and attributes but no data values for any variables
- -c Show the values of coordinate variables (variables that are also dimensions) as well as the declarations of all dimensions, variables, and attribute values
- **-v** *var1,...,varn* The output will include data values for the specified variables, in addition to the declarations of all dimensions, variables, and attributes
- **-x** *var1,...,varn* Output XML (NcML) instead of CDL. The NcML does not include data values

4.8.2 Additional general software

- **ncbrowse**

"ncBrowse" is a Java application that provides flexible, interactive graphical displays of data and attributes from a wide range of NetCDF data file conventions.

See http://www.epic.noaa.gov/java/ncBrowse/

- **NetCDF Operator (NCO)**

The NetCDF Operators, or "NCO", are a suite of programs known as **operators**. Each operator is a standalone, command line program which is executed at the UNIX shell-level, like, e.g., ls or mkdir. The operators take NetCDF files as input, then perform a set of operations (e.g., deriving new data, averaging, hyperslabbing, or metadata manipulation) and produce a NetCDF file as output. The operators are primarily designed to aid manipulation and analysis of gridded scientific data. The single command style of NCO allows users to manipulate and analyze files interactively and with simple scripts, avoiding the overhead (and some of the power) of a higher level programming environment.

See http://nco.sourceforge.net/

4.8.3 Basic Radar Altimetry Toolbox: "BRAT"

The "Basic Radar Altimetry Toolbox" is a collection of tools and tutorial documents designed to facilitate the use of radar altimetry data. It is able to read most distributed radar altimetry data from all the satellites, to do some processing, data editing and statistic over them, and to visualise the results. The Basic Radar Altimetry Toolbox is able to read ERS-1 and 2, TOPEX/Poseidon, GEOSAT Follow-on, Jason-1, Jason-2, ENVISAT, SARAL/AltiKa and CRYOSAT-2 missions altimetry data from official data centers (ESA, NASA/JPL, CNES/AVISO, NOAA, ISRO), and this for different processing levels, from level 1B (Sensor Geophysical Data Record) to level 3/4 (gridded merged data).

See http://www.altimetry.info/toolbox.

5 PRODUCTS VARIABLES

The table below make the link between the products variables and the product content described in section 3. Moreover, it indicates in which product (L1b, L2), for which mode (LRM, SAR, SARin), and when needed for which latency (NOP, IOP and GOP) each variable is provided.

Variable Name	L1b LRM	L1b SAR / SARin	L2 LRM	L2 SAR / SARin	Section
agc_01_ku	x	x	x	x	**3.4.1**
agc_20_ku	x	x			**3.4.1**
agc_ch1_20_hr_ku		x			**3.4.1**
agc_ch2_20_hr_ku		x			**3.4.1**
agc_cor_01	x	x	x	x	**3.4.1**
alt_01	x	x	x	x	**3.3.3**
alt_20_ku	x	x	x	x	**3.3.3**
alt_20_hr_ku		x			**3.3.3**
alt_20_plrm_ku				x	**3.3.3**
atm_cor_sig0_01			x	x	**3.5.7**
beam_dir_vec_20_hr_ku		x			**3.2.3**
cog_cor_01	x	x	x	x	**3.2.5**
coherence_waveform_20_hr_ku		**SARin**			/
cor2_applied_20_ku	x	x			**3.5.2**
cor2_applied_20_hr_ku		x			**3.5.2**
dop_angle_start_20_hr_ku		x			/
dop_angle_stop_20_hr_ku		x			/
dop_cor_01_ku	x	x	x	x	**3.4.7**
dop_cor_20_ku	x	x			**3.4.7**
dop_cor_20_hr_ku		x			**3.4.7**
echo_numval_20_ku	x	x			/
echo_numval_20_hr_ku		x			/
echo_scale_20_ku	x	x			**3.5.4**
echo_scale_20_hr_ku		x			**3.5.4**
echo_scale_pwr_20_hr_ku		x			**3.5.4**
flag_cor_err_01	x	x			/
flag_cor_status_01	x	x			/
flag_echo_20_hr_ku		x			/
flag_instr_conf_rx_bwdt_20_ku	x	x			/
flag_instr_conf_rx_bwdt_20_hr_ku		x			/

Variable Name	L1b LRM	L1b SAR / SARin	L2 LRM	L2 SAR / SARin	Section
flag_instr_conf_rx_flags_20_ku	x	x			/
flag_instr_conf_rx_flags_20_hr_ku		x			/
flag_instr_conf_rx_in_use_20_ku	x	x			/
flag_instr_conf_rx_in_use_20_hr_ku		x			/
flag_instr_conf_rx_str_in_use_20_hr_ku		x			/
flag_instr_conf_rx_trk_mode_20_ku	x	x			/
flag_instr_conf_rx_trk_mode_20_hr_ku		x			/
flag_instr_mode_att_ctrl_20_hr_ku		x			/
flag_instr_mode_flags_20_hr_ku		x			/
flag_instr_op_mode_20_plrm_ku				x	3.1
flag_instr_op_mode_01			x	x	3.1
flag_instr_op_mode_20_hr_ku		x			3.1
flag_instr_op_mode_20_ku	x	x	x	x	3.1
flag_mcd_20_ku	x	x	x	x	/
flag_mcd_20_hr_ku		x			/
flag_trk_cycle_20_ku	x	x			/
flag_trk_cycle_20_hr_ku		x			/
geoid_01			x	x	3.8.1
gpd_wet_tropo_cor_01			GOP	GOP	3.6.2
gpd_wet_tropo_cor_qual_01			GOP	GOP	3.6.2
h0_applied_20_ku	x	x			3.5.2
h0_applied_20_hr_ku		x			3.5.2
h0_fai_word_20_ku	x	x			3.5.2
h0_fai_word_20_hr_ku		x			3.5.2
h0_lai_word_20_ku	x	x			3.5.2
h0_lai_word_20_hr_ku		x			3.5.2
hf_fluct_cor_01	x	x	IOP/GOP	IOP/GOP	3.7.3
ind_first_meas_20hz_01	x	x	x	x	3.3.4
ind_first_meas_20hz_01_plrm_ku				x	3.3.4
ind_meas_1hz_20_ku	x	x	x	x	3.3.4
ind_meas_1hz_20_plrm_ku				x	3.3.4
instr_cor_gain_rx_20_hr_ku		x			3.4
instr_cor_gain_tx_rx_20_hr_ku		x			3.4
instr_cor_range_rx_20_hr_ku		x			3.4

Variable Name	L1b LRM	L1b SAR / SARin	L2 LRM	L2 SAR / SARin	Section
instr_cor_range_tx_rx_20_hr_ku		x			3.4
instr_ext_ph_cor_20_hr_ku		SARin			3.4.2
instr_int_ph_cor_20_hr_ku		SARin			3.4.2
int_path_cor_01	x	x	x	x	3.5.1
inter_base_vec_20_hr_ku		x			3.2.3
internal_cor_sig0_01	x	x	x	x	3.5.7
internal_tide_01	x		x	x	3.7.9
inv_bar_cor_01	x	x	x	x	3.7.2
iono_cor_gim_01	x	x	x	x	3.6.3
lat_01	x	x	x	x	3.3.3
lat_20_ku	x	x	x	x	3.3.3
lat_20_hr_ku		x			3.3.3
lat_20_plrm_ku				x	3.3.3
load_tide_sol1_01	x	x	x	x	3.7.5
load_tide_sol2_01	x	x	x	x	3.7.5
lon_01	x	x	x	x	3.3.3
lon_20_ku	x	x	x	x	3.3.3
lon_20_hr_ku		x			3.3.3
lon_20_plrm_ku				x	3.3.3
look_angle_start_20_hr_ku		x			/
look_angle_stop_20_hr_ku		x			/
mean_dyn_topo_sol1_01			x	x	3.8.4
mean_dyn_topo_sol2_01			x	x	3.8.4
mean_sea_surf_sol1_01			x	x	3.8.2
mean_sea_surf_sol2_01			x	x	3.8.2
mod_dry_tropo_cor_01	x	x	x	x	3.6.1
mod_instr_cor_range_01_ku			x	x	3.5.6.1
mod_instr_cor_range_01_plrm_ku				x	3.5.6.1
mod_instr_cor_sig0_01_ku			x	x	3.5.7
mod_instr_cor_sig0_01_plrm_ku				x	3.5.7
mod_instr_cor_swh_01_ku			x	x	3.5.9
mod_instr_cor_swh_01_plrm_ku				x	3.5.9
mod_wet_tropo_cor_01	x	x	x	x	3.6.2
mqe_ocean_20_ku			x	x	/
mqe_ocean_20_plrm_ku				x	/

Variable Name	L1b LRM	L1b SAR / SARin	L2 LRM	L2 SAR / SARin	Section
noise_power_20_ku	x	x			/
noise_power_20_hr_ku		x			/
ns_20_ku	x	x			/
num_meas_20hz_01	x	x	x	x	**3.3.4**
num_meas_20hz_01_plrm_ku				x	**3.3.4**
ocean_tide_eq_01	x	x	x	x	**3.7.6**
ocean_tide_non_eq_01	x	x	x	x	**3.7.6**
ocean_tide_sol1_01	x	x	x	x	**3.7.4**
ocean_tide_sol2_01	x	x	x	x	**3.7.4**
odle_01			x	x	**3.8.6**
off_nadir_angle_wf_ocean_01_ku			x	x	**3.2.4**
off_nadir_angle_wf_ocean_01_plrm_ku				x	**3.2.4**
off_nadir_pitch_angle_str_20_ku				x	**3.2.4**
off_nadir_pitch_angle_str_20_hr_ku		x			**3.2.4**
off_nadir_roll_angle_str_20_ku				x	**3.2.4**
off_nadir_roll_angle_str_20_hr_ku		x			**3.2.4**
off_nadir_yaw_angle_str_20_ku				x	**3.2.4**
off_nadir_yaw_angle_str_20_hr_ku		x			**3.2.4**
orb_alt_rate_01	x	x	x	x	**3.3.3**
orb_alt_rate_20_ku	x	x			**3.3.3**
orb_alt_rate_20_hr_ku		x			**3.3.3**
peakiness_01_ku			x	x	**3.5.8**
peakiness_01_plrm_ku				x	**3.5.8**
peakiness_20_ku			x	x	**3.5.8**
peakiness_20_plrm_ku				x	**3.5.8**
ph_diff_waveform_20_hr_ku		**SARin**			/
ph_slope_cor_20_hr_ku		**SARin**			**3.4.3**
pole_tide_01	x	x	x	x	**3.7.8**
pwr_waveform_20_ku	x	x			**3.5.4**
pwr_waveform_20_hr_ku		x			**3.5.4**
qual_ssha_01_ku			x	x	**3.5.6**
qual_ssha_01_plrm_ku				x	**3.5.6**
qual_ssha_20_ku			x	x	**3.5.6**
qual_ssha_20_plrm_ku				x	**3.5.6**
range_ocean_01_ku			x	x	**3.5.6**

Variable Name	L1b LRM	L1b SAR / SARin	L2 LRM	L2 SAR / SARin	Section
range_ocean_01_plrm_ku				x	3.5.6
range_ocean_20_ku			x	x	3.5.6
range_ocean_20_plrm_ku				x	3.5.6
range_ocean_numval_01_ku			x	x	3.5.6
range_ocean_numval_01_plrm_ku				x	3.5.6
range_ocean_qual_20__ku			x	x	3.5.6
range_ocean_qual_20_plrm_ku				x	3.5.6
range_ocean_rms_01_ku			x	x	3.5.6
range_ocean_rms_01_plrm_ku				x	3.5.6
range_ocog_01_ku			x		3.5.6
range_ocog_01_plrm_ku				x	3.5.6
range_ocog_20_ku			x		3.5.6
range_ocog_20_plrm_ku				x	3.5.6
range_ocog_numval_01			x		3.5.6
range_ocog_numval_01_plrm_ku				x	3.5.6
range_ocog_qual_20_ku			x		3.5.6
range_ocog_qual_20_plrm_ku				x	3.5.6
range_ocog_rms_01			x		3.5.6
range_ocog_rms_01_plrm_ku				x	3.5.6
rec_count_20_ku	x	x			/
rec_count_20_hr_ku		x			/
retracking_ocean_qual_20_ku			x	x	3.5.5
retracking_ocean_qual_20_plrm_ku				x	3.5.5
sat_vel_vec_20_hr_ku		x			3.3.6
scale_factor_20_ku	x	x	x	x	3.5.7
scale_factor_20_plrm_ku				x	3.5.7
sea_state_bias_01_ku			x	x	3.7.1
sea_state_bias_01_plrm_ku				x	3.7.1
seq_count_01			x	x	/
seq_count_20_ku	x	x			/
seq_count_20_hr_ku		x			/
sig0_ocean_01_ku			x	x	3.5.7
sig0_ocean_01_plrm_ku				x	3.5.7
sig0_ocean_20_ku			x	x	3.5.7
sig0_ocean_20_plrm_ku				x	3.5.7

Variable Name	L1b LRM	L1b SAR / SARin	L2 LRM	L2 SAR / SARin	Section
sig0_ocean_numval_01_ku			x	x	3.5.7
sig0_ocean_numval_01_plrm_ku				x	3.5.7
sig0_ocean_qual_20_ku			x	x	3.5.7
sig0_ocean_qual_20_plrm_ku				x	3.5.7
sig0_ocean_rms_01_ku			x	x	3.5.7
sig0_ocean_rms_01_plrm_ku				x	3.5.7
sig0_ocog_01_ku			x		3.5.7
sig0_ocog_01_plrm_ku				x	3.5.7
sig0_ocog_20_ku			x		3.5.7
sig0_ocog_20_plrm_ku				x	3.5.7
sig0_ocog_numval_01_ku			x		3.5.7
sig0_ocog_numval_01_plrm_ku				x	3.5.7
sig0_ocog_qual_20_ku			x		3.5.7
sig0_ocog_qual_20_plrm_ku				x	3.5.7
sig0_ocog_rms_01_ku			x		3.5.7
sig0_ocog_rms_01_plrm_ku				x	3.5.7
solid_earth_tide_01	x	x	x	x	3.7.7
square_swh_ocean_01_ku			x	x	3.5.9
square_swh_ocean_01_plrm_ku				x	3.5.9
ssha_01_ku			x	x	3.5.6
ssha_01_plrm_ku				x	3.5.6
stack_centre_20_hr_ku		x			/
stack_centre_angle_20_hr_ku		x			/
stack_kurtosis_20_hr_ku		x			/
stack_number_after_weighting_20_hr_ku		x			/
stack_number_before_weighting_20_hr_ku		x			/
stack_scaled_amplitude_20_hr_ku		x			/
stack_skewness_20_hr_ku		x			/
stack_std_20_hr_ku		x			/
stack_std_angle_20_hr_ku		x			/
surf_type_01	x	x	x	x	/
Surface_slope_cor_01			x	x	
swh_ocean_01_ku			x	x	3.5.9
swh_ocean_01_plrm_ku				x	3.5.9

Variable Name	L1b LRM	L1b SAR / SARin	L2 LRM	L2 SAR / SARin	Section
swh_ocean_20_ku			x	x	**3.5.9**
swh_ocean_20_plrm_ku				x	**3.5.9**
swh_ocean_numval_01_ku			x	x	**3.5.9**
swh_ocean_numval_01_plrm_ku				x	**3.5.9**
swh_ocean_qual_20_ku			x	x	**3.5.9**
swh_ocean_qual_20_plrm_ku				x	**3.5.9**
swh_ocean_rms_01_ku			x	x	**3.5.9**
swh_ocean_rms_01_plrm_ku				x	**3.5.9**
time_01	x	x	x	x	**3.3.2**
time_1hz_20_ku			x	x	**3.3.4**
time_20_ku	x	x	x	x	**3.3.2**
time_20_hr_ku		x			**3.3.2**
time_20_plrm_ku				x	**3.3.2**
tot_gain_ch1_20_hr_ku		x			**3.4.1**
tot_gain_ch2_20_hr_ku		x			**3.4.1**
tracker_range_20_ku	x	x			**3.5.1**
transmit_pwr_20_hr_ku		x			**/**
uso_cor_01_ku	x	x	x	x	**3.3.5**
uso_cor_20_ku	x	x			**3.3.5**
uso_cor_20_hr_ku		x			**3.3.5**
wind_speed_alt_01_ku			x	x	**3.5.10**
wind_speed_alt_01_plrm_ku				x	**3.5.10**
wind_speed_mod_u_01	x	x	x	x	**3.5.10**
wind_speed_mod_v_01	x	x	x	x	**3.5.10**
window_del_20_hr_ku		x			**3.5.1**