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Geophysical Corrections in Level 2 CryoSat Data Products

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GLOSSARY

The following acronyms and abbreviations have been used in this report.

Acronym	Definition
ADF	Auxiliary Data Files
CLS	Collect Localisation Satellites
CNES	Centre National d'Etudes Spatiales
COP	CryoSat Ocean Processor
CPOM	Centre for Polar Observation and Monitoring
DAC	Dynamic Atmospheric Correction
DEM	Digital Elevation Model
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DTM	Digital Terrain Model
DTU	Technical University of Denmark
ECMWF	European Centre for Medium-Range Weather Forecasts
EM	Electromagnetic
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
FDM	Fast Delivery Marine
FES	Finite Element Solution
GFO	Geosat Follow-On
GIM	Global Ionospheric Map
GOP	Geophysical Ocean Products
GOT	Global Ocean Tide
GPS	Global Positioning System
IB	Inverse Barometric
IOP	Intermediate Ocean Products
LRM	Low Rate Mode or Low Resolution Mode
MOG2D	2D Gravity Waves Model
MSS	Mean Sea Surface

MSSL	Mullard Space Science Laboratory
NSIDC	National Snow and Ice Data Center
PCONF	Parameter Configuration File
PDS	Payload Data Segment
SAR	Synthetic Aperture Radar
SARIn	SAR Interferometry
SIRAL	Synthetic Aperture Interferometric Radar Altimeter
SSALTO	Systeme au Sol d'ALTimetrie et d'Orbitographie
SSB	Sea State Bias
T/P	TOPEX/Poseidon
UCL	University College London

1 INTRODUCTION

1.1 Purpose and Scope

This document provides information on the geophysical corrections and ancillary information used in the processing of the Level 2 CryoSat data products. It complements and expands on the information provided in the CryoSat Product Handbook [RD.1] and the CryoSat Level 2 Product Format Specification document [RD.3]. The discussion is largely focused on the Level 2 products, in which the majority of corrections are applied. Two different and independent processors generate those products: The Ice Processor and the Ocean Processor (see Figure 1).

The product types discussed in the following sections are:

- ***Near-Real Time Products from the CryoSat Ice Processor:*** Fast Delivery Marine (FDM) products
- ***Offline Products from the Cryosat Ice Processor:*** Low Resolution Mode (LRM); Synthetic Aperture Radar (SAR) mode; SAR Interferometry (SARIn) mode
- ***Offline Products from the CryoSat Ocean Processor (COP):*** Intermediate Ocean Products (IOP); Geophysical Ocean Products (GOP)

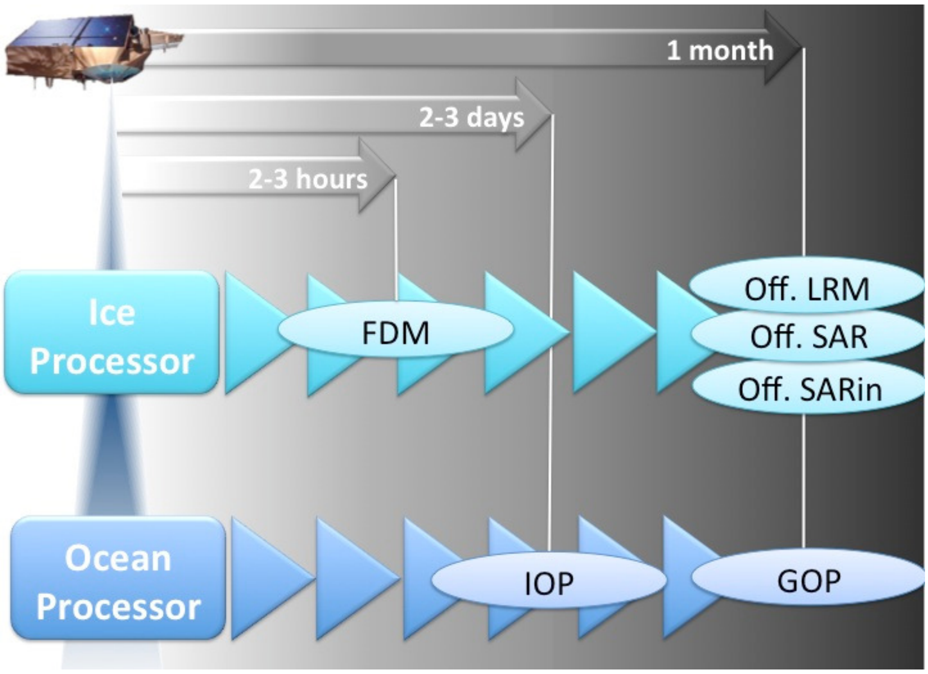

Figure 1: CryoSat product types, associated processor and latency.

At the time of writing this document, all products generated by the Ice Processor are generated with the operational Baseline-C. This new baseline does not impact the Ocean Processor. Currently this document contains references and product field numbers for the Ocean processor products as well as Baseline-C Ice processor products.

1.2 Referenced Documents

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

RD.1 CryoSat Product Handbook
https://earth.esa.int/documents/10174/125272/CryoSat_Product_Handbook

RD.2 Level 1B Product Format Specification for Baseline-C (CS-RS-ACS-GS-5106)
https://earth.esa.int/documents/10174/125273/CryoSat_L1_Products_Format_Specification

RD.3 Level 2 Product Format Specification for Baseline-C (CS-RS-ACS-GS-5123)
https://earth.esa.int/documents/10174/125273/CryoSat_L2_Products_Format_Specification

RD.4 CryoSat IOP and GOP Product Format Specification CS-RS-ACS-ESL-5213
https://earth.esa.int/web/guest/document-library/browse-document-library/-/article/cryosat-iop-and-gop-product-format-specification

RD.5 Earth Explorer Ground Segment File Format Standards PE-TN-ESA-GS-0001
https://earth.esa.int/web/guest/-/earth-explorer-ground-segment-file-format-standard-7476

RD.6 Carrère, L. and Lyard, F. (2003). Modeling the barotropic response of the global ocean to atmospheric wind and pressure forcing - comparisons with observations, Geophys. Res. Lett., 30, 1275, doi:10.1029/2002GL016473.

RD.7 Hausman, J. and Zlotnicki, V. (2010). Sea State Bias in Radar Altimetry Revisited. Marine Geodesy 33 (S1) : 336-347, doi : 10.1080/01490419.2010.487804.

RD.8 Lyard, F. et al. (2006). Modelling the Global Ocean Tides : Modern Insights from FES2004. Ocean Dynamics 56 : 394-415, doi :10.1007/s10236-006-0086.

RD.9 Ray, R. (1999). A Global Ocean Tide Model from TOPEX/POSEIDON Altimetry : GOT99.2. NASA/TM-1999-209478. Greenbelt, MD, Goddard Space Flight Center/NASA: 58.

RD.10 Wunsch, C. (1967). The long-period tides. Rev. Geophys. 5 475, doi: 10.1029/RG005i004p00447

RD.11 Cartwright, D. and Edden, A. (1973). Corrected Tables of Tidal Harmonics. Geophysical Journal of the Royal Astronomical Society 33 : 253-264.

RD.12 Lemoine, F. et al. (1998). The Development of the Joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96.

RD.13 Earth Gravitational Model 2008 (EGM2008). *http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/*

RD.14 Schaeffer, P. et al. (2012). The CNES_CLS11 Global Mean Sea Surface Computer from 16 Years of Satellite Altimeter Data. Marine Geodesy, 35 (S1) : 3-19, doi: 10.1080/01490419.2012.718231.

RD.15 The DTU10 Global Mean Sea Surface Model. *http://www.space.dtu.dk/english/Research/Scientific_data_and_models/Global_Mean_sea_surface*.

RD.16 Defrenne D. and Benveniste J. A Global Land Elevation and Ocean Bathymetry Model from Radar Altimetry", QWG meeting minutes, March 2004.

RD.17 Smith W. H. F. and Sandwell D.T. (1997). Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings. Science, 277 : 1957-1962.

RD.18 Abdalla, S. (2012). Ku-Band Radar Altimeter Surface Wind Speed Algorithm. Marine Geodesy 35 : 276-298, doi:10.1080/01490419.2012.718676.

RD.19 Mean Dynamic Topography CNES-CLS09 Model. *http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/mdt.html*

2 CRYOSAT DATA PROCESSING

2.1 Introduction to Geophysical Corrections

Altimetry measures the *range*, which is the distance between the satellite and the sampled surface. This distance minus the satellite position (*altitud*e) gives the *Surface Height* above the reference ellipsoid. Geophysical corrections are used to correct altimeter measurements from different perturbations due to the environment and ensure the highest precision output data.

The geophysical corrections applied to Level 2 CryoSat products are listed below. Which particular corrections are applied depends on product type and surface type (see Table 1, Section 3 for full details):

- Wet Tropospheric Correction
- Dry Tropospheric Correction
- Ionospheric Correction
- Inverse Barometric Correction
- Dynamic Atmospheric Correction
- Sea State Bias Correction
- Ocean Tide Correction
- Long Period Equilibrium Tide Correction
- Solid Earth Tide Correction
- Tidal Loading Correction
- Geocentric Polar Tide Correction

Furthermore, a number of ancillary parameters are also necessary in order to identify the surface type (which determines the corrections to be applied) and to generate higher-level products for scientific and operational applications:

- Surface Type Flag
- Geoid Height
- Mean Sea Surface
- Ocean Depth / Land Elevation
- Mean Dynamic Topography

- Sea Ice Concentration
- Snow Depth
- Snow Density
- Wind Speed

2.2 Level 1B Processing

CryoSat Level 1B products are aimed at users who are interested in the SIRAL instrument performance and users who are interested in developing their own Level 2 data processing. These products contain time and geo-location information as well as SIRAL measurements in engineering units. Calibration corrections are included and have been applied to the window delay computations. Geophysical corrections are computed from Auxiliary Data Files (ADFs). In Offline products, geophysical corrections are computed from Analysis ADFs, whereas in FDM products corrections are computed for Forecast ADFs. More information on ADFs can be found in Annex 1. In Level 1B products the geophysical corrections are not applied to the range or time delay. All corrections are included in the data products and therefore the range can be calculated by taking into account the surface type.

In order to calculate the Range, the following equation is applicable:

Range = (0.5 * c * window delay) + retracking correction + surface-dependent geo-corrections

Where c = 299792458.0 m/s (the speed of light in a vacuum).

The ***retracking correction*** is the offset between the retracking point and centre of the range window.

Information on the necessary geophysical corrections according to the surface type is provided in Table 1 in Section 3. For further detailed information on both the FDM and Offline Level 1B products please refer to the CryoSat Level 1B Product Format Specification [RD.2] and the Cryosat Product Handbook [RD.1].

2.3 Level 2 Processing

The main CryoSat user products are the Level 2 products generated from the CryoSat Ice Processor (see Figure 1), even though the products also contain oceanic parameters. The Offline Level 2 LRM, SAR and SARIn products are generated 30 days after data acquisition and are principally dedicated to scientific users working on sea-ice and land-ice areas. The Level 2 FDM products are near-real time ocean products, generated 2-3 hours after data acquisition, and fulfill the needs of some operational services.

Level 2 products contain the time of measurement, the geo-location and the height of the surface. In order to be exploitable, the surface height must be fully corrected for instrumental effects, propagation delays, measurement geometry and additional geophysical effects such as atmospheric and tidal effects.

The surface height field is computed via the following equations:

Surface Height = altitude – Corrected_range

Where: ***Corrected_range = range + all necessary corrections***

In the Offline Level 2 products, the value of each geophysical correction provided is the value applied to the corrected Surface Height. If a particular geophysical correction has not been applied, either due to configuration or due to an error, the correction value is set to zero and the Correction Status Flag is set to invalid.

In the FDM Level 2 products the geophysical corrections are computed from Forecast ADFs instead of the Analysis ADFs used in Offline processing. However, these corrections are not applied to the range as the oceanographic convention is followed for FDM processing, which allows the data users to apply the corrections as required. Within the FDM Level 2 products, the convention used to flag errors in the geophysical correction values is the use of the maximum value, which for a short-signed integer is 32767.

Section 4 describes in detail all the geophysical corrections applied to the Level 2 data products. Information on the necessary geophysical corrections according to the surface type is provided in Table 1 of Section 3. More information on ADFs can be found in Annex 1. For further detailed information on both the FDM and Offline Level 2 products please refer to the CryoSat Level 2 Product Format Specification [RD.3] and the Cryosat Product Handbook [RD.1].

2.4 **Ocean Products**

IOP and GOP are outputs of the CryoSat Ocean Processor (COP, see Figure 1). These products are dedicated to the study of ocean surfaces, and provided specifically for the needs of the oceanographic community (complimentary to the FDM products which are outputs of the Ice processor).

The two product types differ in the orbit files used and therefore the latency of their generation. IOP are generated 2-3 days after data sensing acquisition and use the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) Preliminary Orbit. GOP are typically generated 30 days after data sensing acquisition and use the DORIS Precise Orbit. With regards to the geophysical corrections included and applied to the data, the same applies to both product types.

The Level 1 IOP and GOP contain all engineering parameters needed to generate the Level 2 products, together with the corrections to be applied to the range and tidal effects.

The Level 2 IOP and GOP contain all the information necessary for the correct usage of the altimeter parameters over ocean surfaces, and therefore are considered to be more suitable for users. Geophysical corrections provided in the Level 2 IOP and GOP products are computed from the Analysis ADFs (as with the Offline products from the CryoSat Ice Processor), however following the oceanographic convention the corrections are not applied to the range. The corrections are provided in the products to allow the user to apply them as required.

3 GEOPHYSICAL CORRECTIONS BY SURFACE TYPE

The geophysical corrections included and applied in the Level 2 products depend on the product and surface type. Table 1 below lists the main Level 2 product characteristics and the necessary geophysical corrections over each surface type in order to retrieve corrected elevations.

Please note that for Level 2 FDM, IOP and GOP products, according to the oceanographic convention the corrections are not applied to the range, but are simply included in the products. For Offline Level 2 products from the CryoSat Ice Processor, the relevant corrections are applied to the range.

Processor	*Products Mode*	*Distribution latency*	*Surface type*	*Corrections applied to the range?*	*Ocean surface corrections*	*Tidal corrections*	*Atmospheric propagation corrections*
CryoSat Ocean Processor	**IOP** (LRM & SAR)	1-3 days	**Ocean**	No	DAC Sea State Bias	Ocean Tide (Solution 1 & 2) Long Period Equilibrium Tide Non-Equilibrium Long Period Ocean Tide Ocean Loading Tide (Solution 1 & 2) Solid Earth Tide Geocentric Polar Tide	Dry Tropospheric Wet Tropospheric Ionospheric
	GOP (LRM & SAR)	30 days					
CryoSat Ice Processor	**FDM** (LRM)	2-3 hours		No	IB Sea State Bias	Ocean Tide Long Period Equilibrium Tide Ocean Loading Tide Solid Earth Tide Geocentric Polar Tide	
	Offline LRM	30 days		Yes	DAC Sea State Bias		
	Offline LRM		Interior Land Ice		Not applied	Ocean Loading Tide Solid Earth Tide Geocentric Polar Tide	
	Offline SARIn		Margin Land Ice		Not applied		
	Offline SAR		Sea Ice		IB	Ocean Tide Long Period Equilibrium Tide Ocean Loading Tide Solid Earth Tide Geocentric Polar Tide	

***Table 1**: Geophysical Corrections applied to Level 2 products over each surface type*

4 GEOPHYSICAL CORRECTIONS APPLIED IN LEVEL 2 PROCESSING

4.1 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 a number of propagation corrections.

4.1.1 Dry Tropospheric Correction

The Dry Tropospheric Correction is the correction for refraction due to the dry gas component of the atmosphere, which generates a path delay in the radar return signal.

For CryoSat, this correction is not received via a direct ADF input. Instead this correction is computed by the CryoSat processors using dynamic mean surface pressure Meteo grids sourced from Meteo-France via the Systeme au Sol d'ALTimetrie et d'Orbitographie (SSALTO) based on the European Centre for Medium-Range Weather Forecasts (ECMWF) model, as well as static S1 and S2 tide grids of monthly means of global amplitude and phase. These static tide grids for amplitude and phase have latitude coverage from -90 to +90 degrees and a step in latitude/longitude of 1.125 degrees.

For the Dry Tropospheric Correction over water (open water, semi-enclosed seas or enclosed seas and lakes), the surface pressure is equal to the mean pressure minus the climatology (computed with the pressure grids). Over land, the surface pressure is equal to the mean pressure so the Dry Tropospheric Correction over land is computed from the mean pressure alone.

Field 24 in L2 FDM Products [RD.3]

Field 11 (Baseline-C) in L2 Offline Products [RD.3]

Field 36 in L2 IOP/ GOP Products [RD.4]

4.1.2 Wet Tropospheric Correction

The Wet Tropospheric Correction is the correction for the path delay in the altimetric return signal due to liquid water in the atmosphere.

For CryoSat, this correction is provided by Meteo grids, sourced from Meteo-France via SSALTO and is based on the ECMWF model. The Wet Tropospheric Correction is received as a direct ADF input from ECMWF analysed grids and is then formatted to the CryoSat Payload Data Segment (PDS) file standard before being used by the CryoSat processor [RD.5].

Field 25 in L2 FDM Products [RD.3]

Field 12 (Baseline-C) in L2 Offline Products [RD.3]

Field 37 in L2 IOP/GOP Products [RD.4]

4.1.3 Ionospheric Correction

The Ionospheric Correction takes into account the path delay in the radar return signal due to the free electron content of the ionosphere.

There are two sources currently used to derive this correction for CryoSat; the Global Ionospheric Map (GIM) and the Bent model.

Computation of the GIM correction requires Global Positioning System (GPS) ionospheric data computed every second along the satellite tracks. This is sourced from Centre National d'Etudes Spatiales (CNES) via SSALTO as a dynamic daily ADF.

The Bent Model correction is derived using two static files, the Bent Ionospheric Coefficients file and the Bent Modified Dip Map, provided by Collect Localisation Satellites (CLS). In addition, the Bent Model Ionospheric Correction also requires the Solar Activity Index, provided as monthly files by CNES. It should be noted that the Bent Model is not available for latitudes greater than ±82 degrees.

Level 1B FDM and Offline products currently contain the Ionospheric Correction values derived from both the GIM and Bent Models. At Level 2, only the Ionospheric Correction value which is applied to the range is provided. Following a recent IPF Processor update to implement changes to the Task Tables, the use of the Ionospheric GPS Grid is now mandatory for all Offline production, and is used to compute the GIM Ionospheric correction in all cases.

In Level 2 IOP/GOP products, only the GIM Ionospheric Correction is provided, and not the Bent Model.

Field 28 in L2 FDM Products [RD.3]

Field 13 (Baseline-C) in L2 Offline Products [RD.3]

Field 40 in L2 IOP/GOP Products [RD.4]

4.2 **Ocean Surface Corrections**

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

4.2.1 Sea State Bias

The Sea State Bias (SSB) or Electromagnetic (EM) Bias is the correction for bias in the measurements introduced by varying reflectivity of the crests and troughs of the sea surface. Wave troughs are better reflectors of energy than wave crests due to their different distributions of specularly-reflecting facets, thus the centroid of the mean reflecting surface is shifted away from the mean sea surface towards the troughs of the waves. This shift causes the altimeter to over-estimate the height of the satellite above the sea surface. The SSB correction (EM bias correction) given in the Level 2 data is an empirical correction proportional to the significant wave height which compensates for the asymmetric shape of ocean waves, and is derived from a model provided by CLS to ESA [RD.7].

In Level 2 IOP/GOP products the SSB correction provided is currently the same as for Jason-2.

Field 29 in L2 FDM Products [RD.3]

Field 16 (Baseline-C) in L2 Offline Products [RD.3]

Field 41 in L2 IOP/GOP Products [RD.4].

4.2.2 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.

For the CryoSat Ice processor, this correction is used over ocean only where there is no sea-ice cover, i.e. for LRM and in a very few cases for SARIn mode when the surface type is “Open Ocean”. It should not be used over land, enclosed seas or lakes.

The correction is a combination of the high frequency, high resolution 2D Gravity Waves Model (MOG2D), an ocean model forced by ECMWF atmospheric parameters after removing S1 and S2 atmospheric tides, and the low frequency Inverse Barometric (IB) Correction. The DAC correction is provided by Meteo grids taken from the barotropic MOG2D model [RD. 6] and is sourced from CNES via SSALTO.

N.B. The DAC correction is not available in the FDM products because the Forecast MOG2D ADFs necessary for this correction are not available at the time of FDM processing. As a result the default error value of 32767 is provided for the DAC correction in FDM products.

Field 27 in L2 FDM Products [RD.3]

Field 14 (Baseline-C) in L2 Offline Products [RD.3]

Field 39 in L2 IOP/GOP Products [RD.4]

4.2.3 Inverse Barometric Correction

The IB Correction is the correction for variations in the sea surface height due to atmospheric pressure variations (atmospheric loading).

For the CryoSat Ice processor, this correction is used only in FDM and in SAR mode over sea ice and when the surface type is “Open Ocean”. It should not be used over land, enclosed seas or lakes.

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.

Field 26 in L2 FDM Products [RD.3]

Field 15 (Baseline-C) in L2 Offline Products [RD.3]

Field 38 in L2 IOP/GOP Products [RD.4]

4.3 Tidal Corrections

Tidal corrections are also applied to the Level 2 products in order to adjust the range to appear as if it originates from the mean ice or land surface, or tide-free sea surface.

4.3.1 Ocean Tide

In Level 2 Offline products (from the CryoSat Ice Processor) the Ocean correction is computed using a static file, derived from the Finite Element Solution 2004 (FES2004) tide model [RD.8] (Solution 2 below), which has latitude coverage from -90 to +90 degrees and a step in latitude/longitude of 0.125 degrees. In these products the Ocean Tide does not include the Ocean Loading Tide or the Long-Period Equilibrium Tide, and these are provided separately (see below).

In Level 2 FDM products the Total Geocentric Ocean Tide is provided (field 57). This is not the same as the Ocean Tide given in Offline Products, but instead combines both the Ocean Loading Tide and Long-Period Equilibrium Tide. This follows the same convention of other ocean-oriented altimetry products (e.g. Envisat, Jason-2 and Sentinel-3).

In Level 2 IOP/GOP products the Total Geocentric Ocean Tide includes the Ocean Loading Tide and the Long-Period Equilibrium Tide, therefore these two corrections should not be added to the range together with the Ocean Tide. In Level 2 IOP/GOP products two solutions are provided for the Total Geocentric Ocean Tide:

Solution 1: the Global Ocean Tide (GOT) 4.8 Model developed by R. Ray [RD.9], and is identical to all constituents of version 4.7 except for S2. GOT4.7 used data from TOPEX/Poseidon (T/P) (364 cycles), T/P on the interlaced orbit (114 cycles), European Remote-Sensing Satellite 1 (ERS1) and ERS2 (117 cycles), and Geosat Follow On (GFO) (126 cycles). No Jason data was used in this solution, and it consists of independent near-global estimates of 10 constituents (named K1, K2, M2, M4, N2, O1, P1, Q1, S1, S2). An a-priori model was used that consisted of the hydrodynamic model FES2004 [RD.8], and several other local hydrodynamic models. GOT4.8 implements the fixed dry tropospheric correction for T/P which mostly affects S2, and also has a TP Cg correction.

Solution 2: the FES2004 Ocean Tide Model [RD.8] is a global hydrodynamic tide model initiated by the works of Christian Le Provost in the early nineties. It is based on the resolution of the tidal barometric equations on a global finite element grid (~1 million nodes), which leads to solutions independent of the in situ and remote-sensing data (no open boundary condition and no assimilation data). A new original high-resolution bathymetry was used and ice in Polar Regions was taken into account. The accuracy of these 'free' solutions was improved by assimilating tide gauge and altimetry data (T/P and ERS-2) through a revised representer assimilation method (*http://www.aviso.oceanobs.com/index.php?id=1279*).

Fields 57 in L2 FDM Products [RD.3]

Field 17 (Baseline-C) in L2 Offline Products [RD.3]

Fields 78 and 79 in L2 IOP/GOP Products [RD.4]

4.3.2 Long-Period Equilibrium Tide

The Long-Period Equilibrium Tide correction removes the effects of low frequency local tides caused by the gravitational attraction effects. The long-period tides, with a period greater than 2 weeks, have amplitudes of less than 1 cm and on theoretical grounds have generally been thought to approximate to static equilibrium in the ocean [RD.10].

In the Level 2 Offline products (from the CryoSat Ice Processor) the correction is computed using a static file, derived from the FES2004 tide model [RD.8], which has latitude coverage from -90 to +90 degrees and a step in latitude/longitude of 0.125 degrees.

In Level 2 IOP/GOP products, the Non-Equilibrium Long-Period Ocean Tide is also provided, which is a correction to the Equilibrium Long-Period Ocean Tide.

Field 58 in L2 FDM Products [RD.3]

Field 18 (Baseline-C) in L2 Offline Products [RD.3]

Fields 80 and 81 in L2 IOP/GOP Products [RD.4]

4.3.3 Ocean Loading Tide

The Ocean Loading Tide correction removes the deformation of the Earth’s crust due to the weight of the overlying ocean tides.

In the Level 2 Offline products (from the CryoSat Ice Processor) the correction is computed using a static file, derived from the FES2004 tide model [RD.8], which has latitude coverage from -90 to +90 degrees and a step in latitude/longitude of 0.25 degrees.

As described above for the Ocean Tide, the Level 2 IOP/GOP products include two solutions for the Ocean Loading Tide, one from the GOT4.8 model and one from the FES2004 model.

Field 59 in L2 FDM Products [RD.3]

Field 19 (Baseline-C) in L2 Offline Products [RD.3]

Field 82 and 83 in L2 IOP/GOP Products [RD.4]

4.3.4 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.

The correction is computed using a static file, derived from the Cartwright tide model [RD.11].

Field 60 in L2 FDM Products [RD.3]

Field 20 (Baseline-C) in L2 Offline Products [RD.3]

Field 84 in L2 IOP/GOP Products [RD.4]

4.3.5 Geocentric Polar Tide

The Geocentric Polar Tide correction accounts for the ocean's response to the long-period distortion of the Earth's crust caused by variations in the centrifugal force during perturbations in the Earth's rotational axis.

The correction is derived using dynamic Instantaneous Polar Location files, which comprise the historical pole positions and are provided as daily dynamic files sourced from CNES via SSALTO.

Field 61 in L2 FDM Products [RD.3]

Field 21 (Baseline-C) in L2 Offline Products [RD.3]

Field 85 in L2 IOP/GOP Products [RD.4]

4.4 **Additional Ancillary Functions**

In addition to the geophysical corrections, the CryoSat Level 2 products also contain a number of ancillary parameters, which are used to identify the surface type and support the validation of the corrections which are computed.

4.4.1 Surface Identification

The Level 2 products contain a flag word, provided at 1 Hz resolution, to classify the surface type at nadir. This classification is derived using a four state surface identification grid, computed from a static Digital Terrain Model 2000 (DTM2000) file.

The grid provides four states of the flag: 0 = open oceans or semi-enclosed seas; 1 = enclosed seas or lakes; 2 = continental ice; 3 = land.

Field 67 in L2 FDM Products [RD.3]

Field 23 (Baseline-C) in L2 Offline Products [RD.3]

Field 90 in L2 IOP/GOP Products [RD.4]

4.4.2 Geoid Height

Over land, when the Surface Type is set to 2 (continental ice) or 3 (land), the Level 2 products include a field for the geoid height.

In both the Level 2 FDM and Offline products (from the CryoSat Ice Processor), the geoid height is derived from a static file based on the EGM96 model, a spherical harmonic model of the Earth's gravitational potential [RD.12]. In Level 2 FDM products, the geoid value is set to 2147483647 in case of error.

In the Level 2 IOP/GOP products the geoid height is derived from the EGM2008 model [RD.13].

Field 55 in L2 FDM Products [RD.3]

Field 24 (Baseline-C) in L2 Offline Products [RD.3]

Field 74 in L2 IOP/GOP Products [RD.4]

4.4.3 Mean Sea Surface Height

Over ocean, when the Surface Type is set to 0 (open ocean) or 1 (closed sea), the Level 2 products include a field for the surface height with respect to the mission ellipsoid, derived from the Mean Sea Surface (MSS) model.

In the Level 2 FDM and Offline products (from the CryoSat Ice Processor), the MSS is provided from the University College London 04 (UCL04) model, a hybrid global model covering latitudes from -80 to +89 degrees and with a step in latitude/longitude of 0.0625 degrees. This UCL04 model is a combination of 3 separate models, which use the following:

a) *A geoid and dynamic topography model, compiled from the Arctic Gravity Project Geoid and PIPS Mean Dynamic Topography (81.5N and above)*

b) *A MSS derived using 4 years of ERS-2 data (60N – 81.5N)* *c) The CLS01 MSS model (80S – 82N)*

1) Merge of (a + b):

From 60N to 81.45N, only data from the ERS-2 model is used.

Between 81.45N and 82N, the ERS-2 model (b) is blended in with the geoid and dynamic topography model (a).

2) Merge of (c) with merged model (1) created above:

From 80S to 60N only data from the CLS model (c) is used.

From 70N to 89N the merged model (1) is used.

Between 60N and 70N the CLS model (c) is blended with the merge model (1).

3) Resampling

The complete merged model is then resampled from a sampling of lat=0.025, lon=0.125 to lat=0.0625, lon=0.0625.

In Level 2 FDM products, the MSS value is set to 2147483647 in case of error.

In the Level 2 IOP/ GOP products two values are provided for the MSS, solution 1 from the CNES-CLS11 MSS model [RD.14] and solution 2 from the Technical University of Denmark 10 (DTU10) MSS model [RD.15].

Following implementation of Baseline-C the Level 2 SAR products will use a new Arctic MSS, the UCL13 MSS. This has been created by combining existing models to provide full coverage over the Arctic region of interest. The UCL13 MSS merges the CLS2011 model with CryoSat Arctic data and is interpolated via the Geo CFI library.

Field 54 in L2 FDM Products [RD.3]

Field 24 (Baseline-C) in L2 Offline Products [RD.3]

Fields 72 and 73 in L2 IOP/GOP Products [RD.4]

4.4.4 Ocean Depth/Land Elevation

The Level 2 products contain a value for the ocean depth or land elevation, depending on surface type.

In all product types (FDM, Offline, IOP and GOP) the values are derived from a static ADF which is based on the ESA developed MACESS Global Digital Elevation Model [RD.16]. This is a Global Digital Elevation Model (DEM) developed by merging the ACE land elevation data and the Smith and Sandwell ocean bathymetry data [RD.17].

In Level 2 FDM products, the Ocean Depth/Land Elevation is set to 2147483647 in case of error.

Following implementation of Baseline-C the Level 2 SARIn products will use a new DEM over Antarctica and Greenland. This was developed by the Centre for Polar Observation and Monitoring (CPOM) at Leeds University and evaluated by MSSL.

Field 56 in L2 FDM Products [RD.3]

Field 25 (Baseline-C) in L2 Offline Products [RD.3]

Field 75 in L2 IOP/GOP Products [RD.4]

4.4.5 Sea Ice Concentration

The Sea Ice Concentration is nominally obtained from a dynamic ADF provided by UCL and is based on the sea ice concentration data from National Snow and Ice Data Center (NSIDC).

If the dynamic data is unavailable, the Sea Ice Concentration values are extracted from static climatology files, based on the UCL04 model, provided for each month of the year. This static file has latitude coverage from -90 to +90 degrees and a step in latitude/longitude of 0.0625 degrees.

Field 26 (Baseline-C) in L2 Offline Products [RD.3]

Field not included in L2 FDM or IOP/GOP Products

4.4.6 Snow Depth

CryoSat Level 2 data includes a snow depth value for each 1 Hz record. The snow depth values are extracted from a static climatology model, UCL04, and can be used to adjust the freeboard estimate to account for snow-loading.

There is a separate climatology file for each month of the year, which provides snow depth values for the Arctic Region only, for latitude coverage from 0 to +90 degrees and a step in latitude/longitude of 0.0625 degrees. A climate model for the Antarctic Region is not available for use in CryoSat processing.

Field 27 (Baseline-C) in L2 Offline Products [RD.3]

Field not included in L2 FDM or IOP/GOP Products

4.4.7 Snow Density

CryoSat Level 2 data also includes a value for snow density for each 1 Hz record. The snow density value is a constant value which is extracted by the processor from a Parameter Configuration File (PCONF) and this value can be used to adjust the freeboard estimate to account for snow-loading.

The current snow density value used in the CryoSat Level 2 products is 400 kg/m^3.

Field 28 (Baseline-C) in L2 Offline Products [RD.3]

Field not included in L2 FDM or IOP/GOP Products

4.4.8 Wind Speed

CryoSat Level 2 data includes wind speed, which is calculated from the radar backscattering coefficient using the Abdalla 2007 model [RD.18]. In Level 2 FDM, IOP and GOP products, U-Wind and V-Wind components are also provided from the ECMWF model.

Fields 62, 63 and 64 in L2 FDM Products [RD.3]

Field 32 (Baseline-C) in L2 Offline Products [RD.3]

Fields 87, 88 and 89 in L2 IOP/GOP Products [RD.4]

4.4.9 Mean Dynamic Topography

The Mean Dynamic Topography refers to the sea surface elevation relative to the permanent mean global ocean circulation. This corresponds to the time average of the ocean surface topography relative to the Earth's geoid, i.e. the elevation after the static component due to the geoid has been removed.

CryoSat L2 IOP and GOP products include the Mean Dynamic Topography, which is provided from the CNES-CLS09 model [RD.19]. This model is an estimate of the ocean mean dynamic topography for the period 1993-1999, based on 4.5 years of GRACE data and 15 years of altimetry and in-situ data.

Field 76 in L2 IOP/GOP Products [RD.4]

ANNEX 1.

1 AUXILIARY DATA FILES

Auxiliary Data Files (ADFs) are the input data files used to compute geophysical corrections. A range of both static and dynamic data files are used, which are derived from model data.

1.1 Static Auxiliary Data Files

The table below provides details of all static auxiliary data files used in the processing of CryoSat data products. These files are referred to as static because they have fixed “start” and “stop” times which cover the entire mission duration. During processing space and time interpolation is performed along the CryoSat track location. The “grid” type files have data distributed on a geographical grid, whereas the “data” type files are non-geographical.

File Type	Description	Type	Parameters
AUX_CARTWR	Cartwright and Edden tables	Data	N/A
AUX_DEMMSL	MSSL high resolution Slope models of Greenland and Antarctica	Grid	Cartesian grids covering Antarctica, grid step = 5km, and Greenland, grid step = 2.5km
AUX_DIPMAP	Bent Modified Dip Map file	Grid	Latitude coverage: [-88,88] degrees Step in latitude: 2 degrees Step in longitude: 2 degrees
AUX_GEOID	EGM96 Geoid values	Grid	Latitude coverage: [-88,88] degrees Step in latitude: 0.25 degrees Step in longitude: 0.25 degrees
AUX_LS_MAP	Four state static Surface Identification grid from DTM2000	Grid	Latitude coverage: [-90,90 -1/30] Step in latitude: 1/30 degrees Step in longitude: 1/30 degrees
AUX_MICOEF	Bent Ionospheric Coefficients File	Data	N/A
AUX_MSSURF	Mean Sea Surface from UCL04 model	Grid	Latitude coverage: [-88,88] degrees Step in latitude: 0.0625 degrees Step in longitude: 0.0625 degrees

AUX_OCTIDE	FES2004 Ocean Tide Model	Grid	Latitude coverage: [-90,90] degrees Step in latitude: 0.125 degrees Step in longitude: 0.125 degrees
AUX_ODLE	MACESS Ocean Depth / Land Elevation	Grid	Latitude coverage: [-90,90 -1/30] Step in Latitude: 1/30 degrees Step in longitude: 1/30 degrees
AUX_PRSS00 AUX_PRSS06 AUX_PRSS12 AUX_PRSS18	Climatology pressure grids, four per day, for 0h, 6h 12h and 18h. Each grid point contains 12 values of climatological pressure, one for each month of the year	Grid	Latitude coverage: [-90,90] degrees Step in latitude: 0.5 degrees Step in longitude: 0.5 degrees
AUX_S1AMPL AUX_S2AMPL	The S1 and S2 tide grids of monthly means of global amplitude. Each grid point contains 12 values of amplitude, one for each month of the year	Grid	Latitude coverage: [-90,90] degrees Step in latitude: 1.125 degrees Step in longitude: 1.125 degrees
AUX_S1PHAS AUX_S2PHAS	The S1 and S2 tide grids of monthly means of global phase. Each grid point contains 12 values of amplitude, one for each month of the year	Grid	Latitude coverage: [-90,90] degrees Step in latitude: 1.125 degrees Step in longitude: 1.125 degrees
AUX_SDC_xx	UCL04 Snow Depth Climatology model (nn= month number)	Grid	Latitude coverage: [0,90] degrees Step in latitude: 0.0625 degrees Step in longitude: 0.0625 degrees
AUX_TDLOAD	FES2004 Tidal Loading Model	Grid	Latitude coverage: [-90,90] degrees Step in latitude: 0.25 degrees Step in longitude: 0.25 degrees
AUX_WNDCHE	Abdalla2007 Wind Speed Table	Data	Sigma0 coverage: [5,19.6] Step in Sigma0: 0.2

Table A1: *Static ADFs used in the processing of CryoSat data products.*

1.2 Dynamic Auxiliary Data Files

The table below provides details of all the dynamic auxiliary data files used in the processing of CryoSat data products. These files have shorter validity periods compared to the static ADFs and variable “start” and “stop” times. Their “start” and “stop” times increase in fixed increments, i.e. daily, weekly, monthly; and appropriate files are selected to cover the processing validity.

File Type	Description
AUX_SUNACT	Monthly incremented Solar Activity Index files
AUX_ALTGRD	Gaussian Altimetric Grid used for the computation of all meteo corrections. This is updated only when the horizontal spatial resolution of the ECMWF model is updated
AUX_IONGIM †	Daily dynamic files of the GPS Ionospheric Map
AUX_POLLOC	Daily incremental files of the Instantaneous Polar Location
AUX_WETTRP †	Daily dynamic meteo files of Wet Tropospheric Correction *
AUX_U_WIND †	Daily dynamic meteo files of WE Wind component *
AUX_V_WIND †	Daily dynamic meteo files of SN Wind component *
AUX_SURFPS †	Daily dynamic meteo files Surface Pressure *
AUX_SEAMPS †	Daily dynamic meteo files of Mean Ocean Pressure *
AUX_MOG_2D †	Daily dynamic meteo files of Dynamic Atmospheric Correction *
AUX_SEA_IC	Dynamic sea-ice concentration files

***Table A2**: Dynamic ADFs used in the processing of CryoSat data products.*

† Also available as Forecast ADFs.

A number of Forecast ADFs are used to provide corrections in the FDM products, since the Analysis ADFs are not available at the time of FDM production. These files are computed from forecast model data, and are identified by “AUXI” in the filename.

* Meteo Files.

Meteo files are dynamic ADFs provided on Meteo grids, and use a grid definition file; the Gaussian Altimetric Correction Grid. Each dynamic Meteo grid covers a 6-hour period. Two Meteo grids are required for the computation of a correction: one before and one after the product validity time. These grids are interpolated in time and space in order to derive a correction value for each measurement.