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Geophysical Correction Application in Level 2 CryoSat Data Products

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TABLE OF CONTENTS

1 INTRODUCTION

1.1 Purpose and Scope

This document provides information on the source and model of each of the geophysical corrections used in the processing of higher level CryoSat data products.

1.2 Referenced Documents

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

RD.1 L1B Product Format Specification CS-RS-ACS-GS-5106

RD.2 L2 Product Format Specification CS-RS-ACS-GS-5123

RD.3 CryoSat Product Handbook

RD.4 Earth Explorer File Format Standards PE-TN-ESA-GS-0001

2 CRYOSAT DATA PROCESSING

2.1 Introduction to Geophysical Corrections

Geophysical corrections are used to correct altimeter measurements from different perturbations due to the environment and ensure the highest precision output data.

The corrections applied to Level 2 CryoSat products, dependant on surface type, are:

- Wet Tropospheric Correction
- Dry Tropospheric Correction
- Inverse Barometric Correction
- Dynamic Atmospheric Correction
- Ionospheric 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 functions are also necessary to identify the surface type and support validation of the above corrections:

- Surface Type Flag
- Mean Sea Surface
- Geoid Height
- Ocean Depth / Land Elevation
- Snow Depth Concentration
- Sea Ice Concentration

2.2 Level 1B Offline Processing

CryoSat Level 1B products are aimed at users who are interested in SIRAL instrument performance and also those interested in algorithm development. The 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. However, geophysical corrections, i.e. atmospheric and tidal corrections, are not applied to the range or time delay in the CryoSat Level 1B products. All corrections are included in the data products and the range can be calculated using these parameters and 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 vacuum).

For further information on the necessary geophysical corrections according to the surface type, please refer to Table 1 in Section 5 of this document.

CryoSat Level 1B Product Format Specification is provided in RD.1 and further detailed information on CryoSat data products is available in RD.3.

2.3 Level 2 Offline Processing

The main CryoSat user products are the Level 2 products, which fulfil the needs of most scientific researchers. Level 2 products contain the time of measurement, the geo-location and the height of the surface above the reference ellipsoid.

The surface height is fully corrected for instrument effects, propagation delays, measurement geometry and additional geophysical effects such as atmospheric and tidal effects.

The surface height field is computed via the following equation:

Surface Height = altitude - (range + all necessary corrections)

Details on all geophysical corrections, which are applied to the Level 2 data products, are provided in Section 4. For further information on the necessary geophysical corrections according to the surface type, please refer to Table 1 of Section 5.

CryoSat Level 2 Product Format Specification is provided in RD.2 and further detailed information on CryoSat data products is available in RD.3.

The value of each geophysical correction provided in the Level 2 products, is the value applied to the corrected Surface Height. If a particular geophysical correction has not been applied, either due to configuration or else due to an error, the correction value is set to zero and the Correction Status Flag is set to invalid (field 27 in L2).

2.4 Near Real Time FDM Processing

Within the Level 2 FDM products, the convention used to flag errors in the values of the geophysical corrections is the use of the maximum value for a short signed integer, 32767.

The various geophysical corrections are all provided in the Level 2 FDM products, derived from forecast auxiliary files. 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 if required.

3 AUXILIARY DATA FILES

3.1 Static Auxiliary Data Files

The table below provides detailed of all static auxiliary data files used in the processing of CryoSat data products.

FileType	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

3.2 Dynamic Auxiliary Data Files

The table below provides detailed of all dynamic auxiliary data files used in the processing of CryoSat data products.

FileType	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_SURFP	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

* Please see Section 3.2.1

3.2.1 Meteo Files

Meteo files are dynamic auxiliary files provided on meteo grids and use a static grid definition file, the Gaussian Altimetric Correction Grid. These dynamic meteo grids cover a time span of 6 hours and two meteo grids, one before and one after the requested date and time for the correction, are required. These grids are interpolated in time and space in order to derive a correction value for each measurement.

4 GEOPHYSICAL CORRECTIONS APPLIED IN LEVEL 2 PROCESSING

4.1 Atmospheric Corrections

An altimeter pulse slows down as it passes through the Earth's troposphere due to the refractive index of the atmosphere. The conversion of the time delay to range, using the speed of light in a vacuum, therefore has to be corrected for this small additional delay.

4.1.1 Wet Tropospheric Correction

The Wet Tropospheric Correction is the correction for the path delay in the radar 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 data from ECMWF. The Wet Tropospheric Correction is received as a direct auxiliary file input directly from ECMWF analysed grids and is then formatted to the CryoSat PDS file standard [RD.4] before being directly used by the CryoSat processor.

Field 9 in L2 Products [RD.2]

4.1.2 Dry Tropospheric Correction

The Dry Tropospheric Correction is the correction for the dry gas component of the atmosphere refraction and takes into account the path delay in the radar return signal due to the atmosphere.

For CryoSat, this correction is not received via a direct auxiliary file input; this correction is computed by the CryoSat processors using dynamic mean surface pressure grids sourced from Meteo-France via SSALTO based on data from ECMWF, 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 accounted for is the mean pressure so the Dry Tropospheric Correction over land is computed with this sole mean pressure.

Field 8 in L2 Products [RD.2]

4.1.3 Dynamic Atmospheric Correction

The Dynamic Atmosphere Correction is the correction which is needed to correct for the depression of the ocean surface caused by the local barometric pressure.

For CryoSat this correction is used over ocean only where there is no sea-ice cover, in LRM, SARIn and FDM modes when the surface type is “Open Ocean”.

The correction is provided by meteo grids taken from the barotropic MOG2D model and is sourced from CNES via SSALTO.

Field 11 in L2 Products [RD.2]

4.1.4 Inverse Barometric Correction

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

For CryoSat this correction is used only in SAR mode, over sea ice and when the surface type is “Open Ocean”.

The correction is computed using the Dry Tropospheric Correction, which in turn is calculated using dynamic surface pressure files sourced from Meteo-France via SSALTO based on data from ECMWF, as well as static S1 and S2 tide grids of monthly means of global amplitude and phase (section 4.1.2).

Field 10 in L2 Products [RD.2]

4.1.5 Ionospheric Correction

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

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 GPS ionospheric data computed every second along the satellite tracks. This is sourced from CNES via SSALTO as a dynamic daily auxiliary file.

The Bent Model correction is derived using two static files, the Bent Ionospheric Coefficients file and the Bent Modified Dip Map, provided by CLS. In addition, the Bent Model Ionospheric Correction also requires the Solar Activity Index, provided as monthly files by CNES.

CryoSat Level 1B products currently contain the Ionospheric Correction values derived from both the GIM and Bent Models. At Level 2, only the Ionospheric Correction value applied to the range is provided. This is nominally derived using the GIM by default, however when this is unavailable the Bent model is used as an alternative.

It should be noted that the Bent Model is not available for latitudes greater than ±82 degrees.

Field 12 in L2 Products [RD.2]

4.2 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 of land surface, or tide-free sea surface.

4.2.1 Ocean Tide and Long-Period Equilibrium Tide

The Ocean Tide correction removes the effects of local tides (i.e. those caused by the moon). In addition, the Long Period Equilibrium Ocean Tide correction removes tidal effects due to the Sun.

The corrections are computed using a static file; the tide model used to compute these corrections is the FES2004 model, which has latitude coverage from -90 to +90 degrees and a step in latitude/longitude of 0.125 degrees.

Fields 14 and 15 in L2 Products [RD.2]

4.2.2 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.

The correction is computed using a static file; the tide model used to compute these corrections is the FES2004 model, which has latitude coverage from -90 to +90 degrees and a step in latitude/longitude of 0.25 degrees

Field 16 in L2 Products [RD.2]

4.2.3 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 Earths body.

The correction is computed using a static file; the tide model used to compute these corrections is the Cartwright model.

Field 17 in L2 Products [RD.2]

4.2.4 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 geographic location.

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 18 in L2 Products [RD.2]

4.3 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.

4.3.1 Geoid Height

Over land, when the Surface Type (field 20) is set to 2 or 3, the Level 2 products include a field for the geoid height.

This height is derived from a static file based on the EGM96 model, a spherical harmonic model of the Earth's gravitational potential.

Field 21 in L2 Products [RD.2]

4.3.2 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 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 20 in L2 Products [RD.2]

4.3.3 Mean Sea Surface Height

Over Ocean, when the Surface Type (field 20) is set to 0 or 1, the Level 2 products include a field for the surface height with respect to the mission ellipsoid, derived from the Mean Sea Surface model.

The UCL04 model, a hybrid global model used to provide the MSS in CryoSat Level 2 products, has latitude coverage from -80 to +89 degrees and a step in latitude/longitude of 0.0625 degrees. This UCL04 model is actually a merge 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 (60N – 89N)*

b) *A MSS derived using 4 years of ERS-2 data (60N – 81.45N)*

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 merge 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.

Field 21 in L2 Products [RD.2]

4.3.4 Ocean Depth/Land Elevation

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

The values are derived from a static file which is based on the ESA developed MACESS model. This is a Global Digital Elevation Model developed by merging the ACE land elevation data and the Smith and Sandwell ocean bathymetry data.

Field 22 in L2 Products [RD.2]

4.3.5 Snow Depth Concentration

CryoSat Level 2 data includes a snow depth value for each 1Hz 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 24 in L2 Products [RD.2]

4.3.6 Sea Ice Concentration

The Sea Ice Concentration is nominally obtained from a dynamic auxiliary file provided by UCL and is based on the sea ice concentration data from 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 23 in L2 Products [RD.2]

4.3.7 Snow Density

CryoSat Level 2 data also includes a value for snow density for each 1Hz 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 25 in L2 Products [RD.2]

5 GEOPHYSICAL CORRECTIONS BY SURFACE TYPE

The geophysical corrections applied in the Level 2 products depend on the surface type. The table below lists all the different geophysical corrections necessary over each surface type:

Surface Type	Atmospheric Corrections	Tidal Corrections
Ocean	Dry Tropospheric Correction Wet Tropospheric Correction Dynamic Atmospheric Correction	Ocean Tide Long Period Equilibrium Ocean Tide Ocean Loading Tide Solid Earth Tide Geocentric Polar Tide
Sea Ice	Dry Tropospheric Correction Wet Tropospheric Correction Ionospheric Correction Inverse Barometric Correction	Ocean Tide Long Period Equilibrium Ocean Tide Ocean Loading Tide Solid Earth Tide Geocentric Polar Tide
Land / Land Ice	Dry Tropospheric Correction Wet Tropospheric Correction Ionospheric Correction	Ocean Loading Tide Solid Earth Tide Geocentric Polar Tide

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

6 GLOSSARY

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

Term	Definition
CLS	Collecte Localisation Satellite
CNES	Centre National d'Etudes Spatiales
DEM	Digital Elevation Model
DTM	Digital Terrain Model
ECMWF	European Centre for Medium-Range Weather Forecasts
ESA	European Space Agency
FDM	Fast Delivery Marine
GIM	Global Ionospheric Map
LRM	Low Rate Mode
MOG2D	2D Gravity Waves Model
MSS	Mean Sea Surface
MSSL	Mullard Space Science Laboratory
NSIDC	National Snow and Ice Data Centre
NRT	Near Real Time
PDS	Payload Data Segment
SAR	Synthetic Aperture Radar
SARIn	SAR Interferometry
SSALTO	Systeme au Sol d'ALTimetrie et d'Orbitographie.
UCL	University College London