SENTINEL-3 Products and Algorithms Definition (S3PAD)

Surface Topography Mission (STM) SRAL/MWR L2 Algorithms Definition, Accuracy and Specification [SD-03] [SD-07]

Reference: CLS-DOS-NT-09-119

Nomenclature: S3PAD-RS-CLS-SD03-00017

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CLS 8-10 Rue Hermès - Parc Technologique du Canal - 31520 Ramonville St-Agne - FRANCE Telephone 05 61 39 47 00 Fax 05 61 75 10 14

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Chronology Issues:		
Issue:	Date:	Reason for change:
1rev0	20/04/2009	Draft issue
2rev0	31/07/2009	Adding algorithms specifications. Part of the PDR package
3rev0	10/11/2009	Accounting for the conclusions of the PDR meeting (RIDs 56, 57, 102, 103, 104, 106, 107, 108, 109, 137, 138, 139, 147, 148, 151, 153, 156, 158, 159, 161, 164, 166, 168, 169, 170, 171, 173, 189, 203, 204)
4rev0	31/03/2010	Proposal of routines from public libraries instead of NAG in ALT_RET_OCE_01 algorithm
		Specifications of innovative algorithms selected during PDR (from SD-04).
		Algorithms GEN_ENV_TID_02/04/05 updated.
		Updates for CDR package.
5rev0	30/06/2010	 Correction of the condition for eq. 15 in ALT_MAN_TIM_01 algorithm
		 Ordering the algorithms based on the name convention (CDR RID#138) - all sections
		 Accounting for CDR RID#65 - section 2.5.6
		• Accounting for CDR RID#70 for CLS algorithms - sections 2.20.3.3, 2.20.4.3 and 2.46.4.3Modification of the conditions for post-classification correction (step 5) in GEN_ENV_SUR_02 algorithm
		 Accounting for CDR RID#68 regarding the use of librairies - section 2.32.2
		 Modification of the processing for GEN_ENV_DIS_01 algorithm
		• Accounting for CDR RID#71 - section 2.10
		 Accounting for CDR RID#70 for MSSL algorithms - sections 2.6, 2.10, 2.12, 2.16, 2.17, 2.18, 2.22, 2.23, 2.29, 2.31, 2.39, 2.40
		Accounting for CDR RID#146 - section 2.30
		• Accounting for CDR RID#69 - section 2.23
		• Accounting for CDR RID#139 - section 1.3.1
6rev0	30/09/2010	• Modification of ALT_RET_ICE_02, ALT_PHY_RAN_01

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Chronology Issues:		
lssue:	Date:	Reason for change:
		and GEN_COR_RAN_01 algorithms
		• Clarification of the naming of the output of GEN_COR_RAN_02 algorithm (fluctuations of the sea surface topography)
		 Modification of the output "Number of elementary measurements in the averaged measurement" of ALT_MAN_TIM_01 algorithm
7rev0	12/01/2011	Update for TRR0
		 Correction of algorithm RAD_PHY_GEN_02 (inversion in the neural network inputs) - section 2.55
		 Correction of algorithm ALT_MAN_TIM_01 (equations 35, 36 and 37) - section 2.13
		• Correction of the origin of the ECMWF model coefficients in GEN_COR_RAN_01 algorithm (section 2.35)
8rev0	01/06/2011	Update for QR
		 Correction of algorithm ALT_PHY_GEN_02 (condition on the latitude threshold)) - section 2.19
		 Correction of ALT_PHY_GEN_03 - section 2.20

People involved in this issue:					
Written by (*):		Date + Initials:(visa ou ref)			
	F SOULAT				
	A VERNIER				
	D BROCKLEY (MSSL)				
Checked by (*):	A BLUSSON	Date + Initials:(visa ou ref)			
Approved by (*):	L AMAROUCHE	Date + Initials:(visa ou ref)			
Application authorized by (*) :	P FEMENIAS (ESA) N. PICOT (CNES)	Date + Initials:(visa ou ref)			

*In the opposite box: Last and First name of the person + company if different from CLS

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Applicable documents / reference documents

The issue and date of the AD and RD are provided in the CIDL (AD 4).

- AD 1 : GMES Sentinel-2 and Sentinel-3 Products and Algorithms Definition Statement of Work GMES-DFPR-EOPG-SW-07-0008
- AD 2 : Surface Topography Mission (STM) L0 and L1b Products Specifications [SY-04] S4-IF-CLS-SY-00061
- AD 3 : Guidelines for Sentinel-3 GMES Products Definition GMESPH-DME-TEC-TNO09-E
- AD 4 : Surface Topography Mission (STM) Products and Algorithms Definition Configuration Items Data List [MD-09] S3PAD-CS-CLS-MD09-00006
- AD 5 : Surface Topography Mission (STM) Products and Algorithms Definition Lists of Acronyms and Abbreviations [MD-06] S3PAD-LI-CLS-MD06-00004
- AD 6 : Surface Topography Mission (STM) Products and Algorithms Definition Schedules and Deliverables [MD-03] S3PAD-SC-CLS-MD03-00002
- AD 7 : Surface Topography Mission (STM) L0 and L1b SRAL Algorithms Definition, Accuracy and Specification [SY-24] S3-RS-CLS-SY-00017
- AD 8 : Surface Topography Mission (STM) L2 Mechanisms Specification [SD-07] S3PAD-RS-CLS-SD07-00024
- AD 9 : Surface Topography Mission (STM) SRAL/MWR L2 Input/Output Data Definition [SD-09] S3PAD-RS-CLS-SD09-00018
- AD 10 : Surface Topography Mission (STM) SRAL/MWR L2 Processing Chain Specification [SD-07] S3PAD-RS-CLS-SD07-00022
- AD 11 : Surface Topography Mission (STM) SRAL/MWR L2 Data Management Algorithms Specification [SD-07] S3PAD-RS-CLS-SD07-00023

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- AD 12 : A Quality Assurance Framework for Earth Observation Key Guidelines Version: 2.0 - September 2008
- AD 13: Surface Topography Mission (STM) SRAL/MWR L2 Interface Requirements Definition S3PAD-RS-CLS-SD12-00044
- AD 14: Surface Topography Mission (STM) Algorithms Nomenclature S3PAD-RS-CLS-SD03-00025
- RD 1 : GMES Sentinel-3 Topography Mission Products and Algorithms Definition : Technical Proposal AO/1-5428/07/I-EC, CLS-DOS-PR-07-046
- RD 2 : ENVISAT-Ice Detailed Processing Model Document, Issue 3 Rev. 6 12133/96/NL-GS-DPM
- RD 3 : Definition of the RA-2 Level 2 Ocean and Ice Retracking Algorithms, Issue 1 Rev. 0 PO-NT-RAA-003-CLS
- RD 4 : RA-2 Retracking Comparisons over Ocean Surfaces, Issue 3 Rev. 1 CLS.OC/NT/95.028
- RD 5 : The Art of Scientific Computing in C (Edition 2). William H. Press, Brian P. Flaneery, Saul A. Teukolsky, William T. Vetterling Numerical Recipes
- RD 6 : Algorithm Definition, Accuracy and Specification Bibli_Alti : Altimeter Level 1b Processing SALP-ST-M2-EA-15596-CN
- RD 7 : Algorithms Specifications (Ocean and Ice2 FDGDR Processing), Issue 3 Rev. 5 PO-SP-RAA-0006-CLS
- RD 8 : Algorithm Definition, Accuracy and Specification Bibli_Alti : Altimeter Level 2 Processing SALP-ST-M2-EA-15598-CN
- RD 9 : NAG Fortran Library Manual Mark 18 12133/96/NL-GS-DPM
- RD 10 : Minutes of the CLS Sentinel-3 PAD PM6 Meeting S3PAD-MN-CLS-MD05-00050

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1. Introduction

1.1. Aim

This document is aimed at defining and specifying the "scientific" algorithms used in the Level 2 processing of the Sentinel-3 Surface Topography Mission SRAL and MWR data, which is defined in the L2 Processing Specification document (AD 10).

These definitions and specifications has been carried out in the frame of the definition of Data Products, Level 2 Processing Algorithms and associated Data Processing Prototypes for the ESA Sentinel-3 mission, within the context of Global Monitoring for Environment and Security (GMES), awarded by ESA to a consortium composed of CLS, UCL/MSSL and ACS, led by CLS (see AD 1).

1.2. Definitions

1.2.1. General Terminology

"Scientific" algorithms represent the core of the processing. They are dissociated from "Data management" algorithms (see AD 11), ensuring functions such as data acquisition, data selection and preparation, units conversions, general checks, products generation, processing management, etc., which strongly depend on the format of the input and output data.

The Definition of the altimeter Level 2 scientific algorithms, provided in this document, consists of the identification and the description of their main functions. It will provide the reader with an overview of the procedures and a global understanding of the algorithms.

The Specifications of the altimeter Level 2 scientific algorithms, provided in this document, together with the specifications of the data management algorithms as well as the corresponding interfaces documents, are intended for the team in charge of the software development.

1.2.2. Instrument Data Levels

See AD 9 - Section 1.2.1.

1.2.3. Anciliary/Auxiliary and Dynamic/Static Data*

See AD 9 - Section 1.2.3.

1.2.4. Altimeter Terminology

See AD 9 - Section 1.2.4.

1.3. General rules

1.3.1. Algorithms Description

Each scientific algorithm is described, using the following items:

- Name and identifier of the algorithm (see AD 14)
- Heritage (mission for which the algorithm is used or derived)
- Function
- Algorithm Definition:

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- Input data
- Output data
- Mathematical statement

As previously mentioned, only the scientific core of each algorithm is specified in this document. For each algorithm, the input data (1) identified in the "Algorithm definition" section corresponds to the input data required for the global processing (Data Management and Scientific Core), while the input data (2) identified in the "Algorithm specification" section corresponds to the data requested for the scientific core only.



Figure 1 - Data Management and scientific core of the algorithms

The general information necessary for a global understanding of the algorithm within the overall processing is provided in the "Algorithm definition" sections.

1.3.2. Basic rules

The following basic rules are applied to the specification of the algorithms:

- Elementary functions that are common to several algorithms (also called "mechanisms") are specified in the L2 Mechanisms Specification document.
- The input and output data are always identified by a precise description, an explicit name (that could be used in the coding phase), a unit and, if necessary, a reference system
- Regarding the errors that may occur during the processing functions (for example, negative argument for logarithmic or square root functions), the algorithms systematically output an execution status. The building and the management of this information will be defined during the architectural design of the software.
- Regarding the representation of tables, the following conventions are used in the following:
 - $X[N_1:N_2]$ represents a one-dimension table whose elements are X(i) (or X_i) with $i \in [N_1, N_2]$
 - $X[N_1:N_2][M_1:M_2]$ represents a two-dimension table whose elements are X(i,j) (or X_{ij}) with $i \in [N_1,N_2]$ and $j \in [M_1,M_2]$
 - And so on
- Regarding the representation of complex signals, two conventions are used in the following:
 - Either distinct real and imaginary parts ("I" and "Q")
 - Or complex signal "IQ" corresponding to I+jQ

1.4. Correspondence with SD documents

The correspondence between this document and the SD documents is described in AD 4 and AD 5.

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2. Algorithms Definition and Specification

2.1. ALT_COR_BAC_01 - To compute the corrected retracked backscatter coefficients

2.1.1. Heritage

Jason-1, Jason-2

2.1.2. Function

To compute the corrected retracked backscatter coefficients (main and auxiliary bands).

2.1.3. Algorithm Definition

2.1.3.1. Input data

- Altimeter configuration data
- Backscatter coefficient:
 - Retracked backscatter coefficient and associated validity flag
- Instrumental correction:
 - Backscatter modeled instrumental coefficient correction
 - AGC instrumental errors correction
 - Internal calibration correction
- Processing parameters (SAD):
 - Backscatter coefficient system bias

2.1.3.2. Output data

- Corrected retracked backscatter coefficients
- Net instrumental correction

2.1.3.3. Mathematical statement

The estimates of the retracked backscatter coefficients are already corrected through the scaling factors for Sigma0 evaluation, for the AGC errors and the internal calibration (see AD 7). The two following corrections are added:

- the modeled instrumental correction
- the system bias

⁽¹⁾ 2 states: "valid" or "invalid"

⁽²⁾ Value to be selected according to the processed band (altimeter configuration data)

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2.2. ALT_COR_GEN_01 - To compute the modeled instrumental corrections on the retracked parameters (Ku-band)

2.2.1. Heritage

TOPEX/POSEIDON, Jason-1, Jason-2

2.2.2. Function

To compute the modeled corrections of the instrumental errors on the altimetric estimates (altimeter range, altimeter range rate, significant waveheight, backscatter coefficient and square of the mispointing angle - (main band), using correction tables depending on significant waveheight and signal to noise ratio.

2.2.3. Algorithm Definition

2.2.3.1. Input data

- Altimeter configuration data
- Signal to noise ratio:
 - Signal to noise ratio and associated validity flag
- Significant waveheight:
 - Significant waveheight and associated validity flag
- Instrumental correction tables (SAD) ⁽¹⁾:
 - Main band altimeter range correction table
 - Main band significant waveheight correction table
 - Main band backscatter coefficient correction table
 - Main band squared mispointing angle correction table
- Processing parameters (SAD):
 - Default value for the inputs of the correction tables

2.2.3.2. Output data

- Main band altimeter range modeled instrumental correction
- Main band significant waveheight modeled instrumental correction
- Main band backscatter modeled instrumental coefficient correction
- Main band squared mispointing modeled instrumental coefficient correction

2.2.3.3. Mathematical statement

Principle

The imperfections of the altimeter components lead to errors on the altimetric estimates. To provide accurate measurements, a complete knowledge of these errors (source and quantization of their effects) is required.

⁽¹⁾ Including features such as lower bound, upper bound and step for each input

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The following errors are accounted for:

- errors of the on-board software
- errors due to the low-pass filtering
- errors due to the leakage spikes
- errors due to the on-board FFT
- errors due to the PTR

Nevertheless, the linearity of these errors is not obvious at all, and a separate correction for each effect is probably not consistent with the instrument behavior. An integrated modeling of these errors is thus necessary.

All these effects are accounted for in a simulator (including the ocean retracking), which provides correction tables depending on significant waveheight and signal to noise ratio. The correction $\Delta(x,y)$ corresponding to a given significant waveheight x and a given signal to noise ratio y, will be computed by bilinear interpolation of the corresponding correction table, i.e. by:

$$\Delta(\mathbf{x}, \mathbf{y}) = \frac{(\mathbf{x}_{n} - \mathbf{x})(\mathbf{y}_{n} - \mathbf{y})}{\mathbf{s}_{\mathbf{x}} \cdot \mathbf{s}_{\mathbf{y}}} \cdot \Delta(\mathbf{x}_{p}, \mathbf{y}_{p}) + \frac{(\mathbf{x}_{n} - \mathbf{x})(\mathbf{y} - \mathbf{y}_{p})}{\mathbf{s}_{\mathbf{x}} \cdot \mathbf{s}_{\mathbf{y}}} \cdot \Delta(\mathbf{x}_{p}, \mathbf{y}_{n}) + \frac{(\mathbf{x} - \mathbf{x}_{p})(\mathbf{y}_{n} - \mathbf{y})}{\mathbf{s}_{\mathbf{x}} \cdot \mathbf{s}_{\mathbf{y}}} \cdot \Delta(\mathbf{x}_{n}, \mathbf{y}_{p}) + \frac{(\mathbf{x} - \mathbf{x}_{p})(\mathbf{y} - \mathbf{y}_{p})}{\mathbf{s}_{\mathbf{x}} \cdot \mathbf{s}_{\mathbf{y}}} \cdot \Delta(\mathbf{x}_{n}, \mathbf{y}_{n})$$
(1)

where:

- x_p and x_n are the abscissa just before and just after x, and s_x is the corresponding step $(x_n x_p)$
- y_p and y_n are the abscissa just before and just after y, and s_y is the corresponding step $(y_n y_p)$

Be aware that the errors due to the low-pass filtering are not accounted for in the simulator aimed at building the correction tables, because the waveforms from which the altimetric parameters are derived in the retracking processing have already been corrected for these effects. Moreover, no mispointing correction on the backscatter coefficient is accounted for (because mispointing is managed through the retracking algorithm).

Computation of the corrections

The processing consists of a bilinear interpolation of the corresponding input correction tables versus the significant waveheight and the signal to noise ratio. If the significant waveheight or the signal to noise ratio values are out of range, then these values will be set to the appropriate minimum or maximum authorized value.

⁽¹⁾ main band or auxiliary band parameter according to the band of the processed parameter (X)

⁽²⁾ The auxiliary band correction tables will be selected according to the emitted bandwidth in C band (configuration data)

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2.3. ALT_COR_GEN_02 - To compute the modeled instrumental corrections on the retracked parameters (C-band)

2.3.1. Heritage

TOPEX/POSEIDON, Jason-1, Jason-2

2.3.2. Function

To compute the modeled corrections of the instrumental errors on the altimetric estimates (altimeter range, altimeter range rate, significant waveheight and backscatter coefficient - (auxiliary band), using correction tables depending on significant waveheight and signal to noise ratio.

2.3.3. Algorithm Definition

2.3.3.1. Input data

- Altimeter configuration data
- Signal to noise ratio:
 - Signal to noise ratio and associated validity flag
- Significant waveheight:
 - Significant waveheight and associated validity flag
- Instrumental correction tables (SAD) ⁽¹⁾:
 - Auxiliary band altimeter range correction tables
 - Auxiliary band significant waveheight correction tables
 - Auxiliary band backscatter coefficient correction tables
- Processing parameters (SAD):
 - Default value for the inputs of the correction tables

2.3.3.2. Output data

- Auxiliary band altimeter range modeled instrumental correction
- Auxiliary band significant waveheight modeled instrumental correction
- Auxiliary band backscatter modeled instrumental coefficient correction

2.3.3.3. Mathematical statement

Principle

The imperfections of the altimeter components lead to errors on the altimetric estimates. To provide accurate measurements, a complete knowledge of these errors (source and quantization of their effects) is required.

The following errors are accounted for:

• errors of the on-board software

⁽¹⁾ Including features such as lower bound, upper bound and step for each input

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- errors due to the low-pass filtering
- errors due to the leakage spikes
- errors due to the on-board FFT
- errors due to the PTR

Nevertheless, the linearity of these errors is not obvious at all, and a separate correction for each effect is probably not consistent with the instrument behavior. An integrated modeling of these errors is thus necessary.

All these effects are accounted for in a simulator (including the ocean retracking), which provides correction tables depending on significant waveheight and signal to noise ratio. The correction $\Delta(x,y)$ corresponding to a given significant waveheight x and a given signal to noise ratio y, will be computed by bilinear interpolation of the corresponding correction table, i.e. by:

$$\Delta(\mathbf{x}, \mathbf{y}) = \frac{(\mathbf{x}_{n} - \mathbf{x})(\mathbf{y}_{n} - \mathbf{y})}{\mathbf{s}_{x} \cdot \mathbf{s}_{y}} \cdot \Delta(\mathbf{x}_{p}, \mathbf{y}_{p}) + \frac{(\mathbf{x}_{n} - \mathbf{x})(\mathbf{y} - \mathbf{y}_{p})}{\mathbf{s}_{x} \cdot \mathbf{s}_{y}} \cdot \Delta(\mathbf{x}_{p}, \mathbf{y}_{n}) + \frac{(\mathbf{x} - \mathbf{x}_{p})(\mathbf{y}_{n} - \mathbf{y})}{\mathbf{s}_{x} \cdot \mathbf{s}_{y}} \cdot \Delta(\mathbf{x}_{n}, \mathbf{y}_{p}) + \frac{(\mathbf{x} - \mathbf{x}_{p})(\mathbf{y} - \mathbf{y}_{p})}{\mathbf{s}_{x} \cdot \mathbf{s}_{y}} \cdot \Delta(\mathbf{x}_{n}, \mathbf{y}_{n})$$
(1)

where:

- x_p and x_n are the abscissa just before and just after x, and s_x is the corresponding step $(x_n x_p)$
- y_p and y_n are the abscissa just before and just after y, and s_y is the corresponding step $(y_n y_p)$

Be aware that the errors due to the low-pass filtering are not accounted for in the simulator aimed at building the correction tables, because the waveforms from which the altimetric parameters are derived in the retracking processing have already been corrected for these effects. Moreover, no mispointing correction on the backscatter coefficient is accounted for (because mispointing is managed through the retracking algorithm).

Computation of the corrections

The processing consists of a bilinear interpolation of the corresponding input correction tables versus the significant waveheight and the signal to noise ratio. If the significant waveheight or the signal to noise ratio values are out of range, then these values will be set to the appropriate minimum or maximum authorized value.

⁽¹⁾ main band or auxiliary band parameter according to the band of the processed parameter (X)

⁽²⁾ The auxiliary band correction tables will be selected according to the emitted bandwidth in C band (configuration data)

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2.4. ALT_COR_MIS_01 - To compute the corrected squared mispointing angle

2.4.1. Heritage

Jason-1, Jason-2

2.4.2. Function

To compute the corrected squared mispointing angle (main band).

2.4.3. Algorithm Definition

2.4.3.1. Input data

- Altimeter configuration data
- Squared mispointing angle:
 - Retracked squared mispointing angle and associated validity flag
- Instrumental correction:
 - Squared mispointing modeled instrumental correction (main band)
- Processing parameters (SAD):
 - Squared mispointing system bias

2.4.3.2. Output data

• Corrected retracked square of the mispointing angle

2.4.3.3. Mathematical statement

The modeled instrumental correction and system bias are added to the input squared mispointing angle.

⁽¹⁾ 2 states: "valid" or "invalid"

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2.5. ALT_COR_RAN_01 - To compute the Doppler correction

2.5.1. Heritage

Jason-1 (Poseidon-2), Jason-2, ENVISAT

2.5.2. Function

To compute the Doppler corrections on the altimeter range.

2.5.3. Algorithm Definition

2.5.3.1. Input data

- Orbit:
 - Orbital altitude rate
- Altimeter configuration data
- Altimeter instrumental characterization data, i.e. for each band (Ku, C):
 - Emitted frequency
 - Pulse duration
 - Emitted bandwidth
 - Sign of the slope of the transmitted chirp

2.5.3.2. Output data

- Ku-band Doppler correction
- C-band Doppler correction

2.5.3.3. Mathematical statement

For each band, the Doppler correction to be added to the altimeter range is computed by:

$$\Delta h_{\text{Doppler}} = -\varepsilon \cdot \frac{f.T}{B} \cdot h'$$
(1)

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where:

- h' is the altitude rate
- f is the emitted frequency
- T is the pulse duration
- B is the emitted bandwidth
- $\varepsilon = \pm 1$ is the sign of the slope of the transmitted chirp

⁽¹⁾ Value to be selected according to the processed band

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2.6. ALT_COR_RAN_02 - To compute the General Doppler Correction (all)

2.6.1. Heritage

Envisat, Cryosat2

2.6.2. Function

This algorithm determines the generalised Doppler correction to range, due to the effects of the spacecraft orbit and due to line of sight variations arising over sloping surfaces. This is known as the generalised-Doppler range correction.

2.6.3. Algorithm Definition

2.6.3.1. Input data

- Slope corrected latitude: θ'
- Slope corrected longitude: λ'
- Slope corrected height: h'
- Orbit (DAD)
 - Values extracted via the CFI [CFI-S-01]; see reference for methods.
 - Position of the satellite in the ITER frame: ${f \ddot P}$
 - Velocity of the satellite in the ITER frame: \vec{v}
- Geophysical constants
 - Speed of light: c
- Altimeter instrumental characterization data
 - Wavelength: λ_c
 - Chirp slope: S_c

2.6.3.2. Output data

• General Doppler correction: D^{general}

2.6.3.3. Mathematical statement

- Calculate the line of sight vector from the spacecraft to the echoing point
- Using the CFI supplied functions, convert the echoing point coordinates from geodetic to Cartesian ITER reference frames
- Form the line of sight unit vector: \vec{I}
- Calculate the component of the spacecraft velocity in the line of sight vector

 $v_s = \vec{v} \cdot \vec{l}$

• Calculate the generalised Doppler correction:

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 $D^{general} = \frac{cv_s}{\lambda_c S_c}$

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2.7. ALT_COR_RAN_03 - To compute the corrected retracked altimeter ranges

2.7.1. Heritage

Jason-1, Jason-2

2.7.2. Function

To compute the corrected retracked altimeter ranges (main and auxiliary bands).

2.7.3. Algorithm Definition

2.7.3.1. Input data

- Altimeter configuration data
- Altimeter range:
 - Retracked altimeter range and associated validity flag

- Instrumental corrections:
 - Doppler corrections on the altimeter range (computed at L1b and L2 levels)
 - Modeled instrumental correction on the retracked altimeter range
 - USO drift correction
 - Internal path correction
- Platform data:
 - Distance antenna COG
- Processing parameters (SAD):
 - Altimeter range system bias

2.7.3.2. Output data

- Corrected retracked altimeter range
- Net instrumental correction

2.7.3.3. Mathematical statement

The L1b estimates of the retracked altimeter range are already corrected through the tracker range estimates, for the USO frequency drift and the internal path correction (see AD 7). The three following corrections are added:

- the modeled instrumental correction
- the system bias
- the distance antenna COG

In addition for both LRM and SAR modes, the Doppler correction corresponding to the L1b processing at the measurement location is first removed from the altimeter range and the Doppler correction estimated during the L2 processing (cf.ALT_COR_RAN_01 - To compute the Doppler correction) is then applied.

⁽¹⁾ 2 states: "valid" or "invalid"

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2.8. ALT_COR_RAN_04 - To compute the sea state biases

2.8.1. Heritage

TOPEX/Poseidon, ERS-1, ERS-2, Jason-1, Jason-2, ENVISAT

2.8.2. Function

To compute the sea state bias in the main and in the auxiliary frequency bands. The sea state bias is the difference between the apparent sea level as "seen" by an altimeter and the actual mean sea level.

2.8.3. Algorithm Definition

2.8.3.1. Input data

- Significant waveheight:
 - Significant waveheight (main band)
 - Associated validity flag
- Wind speed:
 - Wind speed corrected for atmospheric attenuation (W)
- Sea state bias table (SAD)

2.8.3.2. Output data

• Sea state bias in main and in auxiliary bands

2.8.3.3. Mathematical statement

The SSB is bilinearly interpolated from a SAD table that is provided as a function of significant waveheight (main band) and of wind speed, with same values for the main and the auxiliary bands.

⁽²⁾ Value to be selected according to the processed band and the emitted bandwidth (altimeter configuration data)

⁽¹⁾ Two states : "valid", or "invalid"

 $^{^{(1)}}$ I = 0 for the main band, I = 1 for the auxiliary band

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2.9. ALT_COR_RAN_05 - To compute the dual-frequency ionospheric corrections

2.9.1. Heritage

Jason 1, Jason 2, ENVISAT

2.9.2. Function

To combine the altimeter ranges in the main and auxiliary frequency bands, so as to derive the main band ionospheric correction and the auxiliary band ionospheric correction. The altimeter ranges are first corrected for sea state bias before being combined.

2.9.3. Algorithm Definition

2.9.3.1. Input data

- Altimeter range:
 - Corrected altimeter range (main and auxiliary bands)
 - Associated validity flag (main and auxiliary bands)
- Sea state bias:
 - Sea state bias correction (main and auxiliary bands)
- Altimeter instrumental characterization data:
 - Main and auxiliary band emitted frequencies

2.9.3.2. Output data

• Ionospheric correction (main and auxiliary bands)

2.9.3.3. Mathematical statement

The following formulae assume input parameters in mm.

The main band and auxiliary band sea state bias corrections are first added to the input main band and auxiliary band altimeter ranges to correct them, because these corrections may be different for the two frequencies. Let R_{Main} and R_{Aux} be the corresponding corrected values.

The range R corrected for ionospheric delay is given for the two frequencies by the following equations:

$$R = R_{Main} + Iono_Alt_Main$$
(1)

$$R = R_{Aux} + Iono_Alt_Aux$$

where the ionospheric corrections lono_alt_Main and lono_alt_Aux are obtained (in mm) by using the first order expansion of the refraction index:

$$lono Alt Aux = -40300. \frac{\text{TEC}}{f_Main^2} \quad (\text{Main band}) \tag{2}$$

$$f_Aux^2$$
 (Advice y band)
 f_Aux^2

where f_Main and f_Aux are the emitted frequencies (in Hz), and where TEC is the columnar total electron content of the ionosphere, expressed in electrons/ m^2 .

Combining equations (1) and (2) leads to:

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$$lono_Alt_Main = \delta f_{Ku}.(R_{Main} - R_{Aux}) \\ lono_Alt_Aux = \delta f_{Aux}.(R_{Main} - R_{Aux})$$
(3)
with:

$$\delta f_{Main} = \frac{f_Aux^2}{f_Main^2 - f_Aux^2}$$
(4)

$$\delta f_{Aux} = \frac{f_Main^2}{f_Main^2 - f_Aux^2}$$

For LRM mode, the algorithm is run from 20-Hz Ku- and C- band altimeter estimates.

For SAR mode, it is run from 20-Hz Ku-band altimeter estimates and 20-Hz C-band filtered estimates (computed by linear regression of 1-Hz related estimates, at the Ku-band time tag).

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⁽¹⁾ Two states : "valid", or "invalid"

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2.10. ALT_COR_RAN_06 - To calculate the applicable set of corrections (LRM Ice; SAR Sea-Ice, Margin)

2.10.1. Heritage

Cryosat2

2.10.2. Function

A single corrections value is created by summing all of the applicable meteorological and geophysical corrections.

2.10.3. Algorithm Definition

2.10.3.1. Input data

- Corrections
 - GIM Ionospheric Correction (IONO)
 - Inverse Barometric (IB)
 - Ocean Tide (OT)
 - Loading Tide (OLT)
 - Solid Earth Tide (SET)
 - Polar Tide (PT)
 - Model Wet Tropospheric (WET)
 - Model Dry Tropospheric (DRY)
- Corrections status flags
- Application flags and model choices
- Surface type

2.10.3.2. Output data

• Corrections: C

2.10.3.3. Mathematical statement

- Select an ocean tide model (GOT or FES) based on PCONF flag
- Form the summed correction as
 - Ocean or Sea-Ice : DRY + WET + IB + IONO + OT + OLT + SET + PT
 - Land : DRY + WET + IONO + OLT + SET + PT Extract snow depth and sea-ice concentration from aux files with bilinear interpolation

Note that the Mog2d is not appropriate over these surfaces and the radiometer wet correction is not available.

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2.11. ALT_COR_SWH_01 - To compute the corrected retracked significant waveheights

2.11.1. Heritage

Jason-1, Jason-2

2.11.2. Function

To compute the corrected retracked significant waveheights (main and auxiliary bands).

2.11.3. Algorithm Definition

2.11.3.1. Input data

- Altimeter configuration data
 - Significant waveheight:
 - Retracked significant waveheight and associated validity flag
- Instrumental correction:
 - Significant waveheight modeled instrumental correction
- Processing parameters (SAD):
 - Significant waveheight system bias

2.11.3.2. Output data

- Corrected retracked significant waveheight
- Net instrumental correction

2.11.3.3. Mathematical statement

The two following corrections are added to the input significant waveheights:

- the modeled instrumental correction
- the system bias

⁽¹⁾ 2 states: "valid" or "invalid"

⁽²⁾ Value to be selected according to the processed band and the emitted bandwidth (altimeter configuration data)

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2.12. ALT_MAN_INT_01 - To perform short-arc along-track interpolation

2.12.1. Heritage

Cryosat2

2.12.2. Function

An estimation of the height of the sea surface that would be present in the absence of sea ice is performed.

This algorithm needs continuous data i.e. from across the Arctic. Therefore as an input to this processor we need data that is either not partitioned at the pole or multiple datasets to provide continuity.

2.12.3. Algorithm Definition

2.12.3.1. Input data

- For all records
 - Sea surface height anomaly: h_{sha}
 - Surface type: d_{surf}
- Processing parameters:
 - Maximum interpolation time delta from current time: r_i

2.12.3.2. Output data

• Interpolated sea-surface height anomaly: h'sha

2.12.3.3. Mathematical statement

- For each record, select those records that are of ocean type and which have a timestamp within the interpolation delta of the timestamp of the current record, and form arrays:
 - $h_{sha}[0:N_i-1]$ surface height anomaly
 - t_{sha} [0 : N_i 1] timestamp

where N_i is the count of records found and skipping the current record if this value is too small.

• Perform a linear fit to the selected records

$$- \overline{t}_{sha} = \frac{1}{N_i} \sum_{i} t_{sha} [i]$$

$$- \overline{h}_{sha} = \frac{1}{N_i} \sum_{i} h_{sha} [i]$$

$$- b_1 = \frac{\sum_{i} (t_{sha}[i] - N_i \overline{t}_{sha} \overline{h}_{sha})}{\sum_{i} (t_{sha}^2 [i] + N_i \overline{t}^2)}$$

$$- b_0 = \overline{h}_{sha} - b_1 \overline{t}_{sha}$$

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- Sample the fitted function at the current location and assign the result as the sea-surface height anomaly at this location.
 - $\quad h_{sha}'(t) = b_0 b_1 t$

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2.13. ALT_MAN_TIM_01 - To compute 1-Hz time tags

2.13.1. Heritage

None

2.13.2. Function

To build the averaged measurements from sets of continuous elementary measurements and to compute their time-tags.

2.13.3. Algorithm Definition

2.13.3.1. Input data

- For each elementary measurement (LRM mode, SAR mode Ku-band, SAR mode C-band):
 - Time tag $\{t_i\}$
- Processing parameter (SAD):
 - Duration of the averaged measurement (Δt)

2.13.3.2. Output data

- For each averaged measurement:
 - Time tag
 - Operating mode (LRM, SAR, LRM and SAR)
 - Number of elementary measurements in the averaged measurement (for each frequency band)
- For each elementary measurement:
 - Index of the associated averaged measurement

2.13.3.3. Mathematical statement

The averaged (so-called 1-Hz) measurements time-tags are built from the reference time (01-01-2000 0h) an a duration (Δ t, 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 (e.g. NRT processing from a given data set vs STC processing with additional measurements , ...).

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

The number of 20-Hz measurements per 1-Hz measurement is computed, and an operating mode (LRM, SAR or both modes) is associated to each 1-Hz measurement.

The possible gaps of elementary measurements within the data set, leading to empty 1-Hz measurements are managed.



¹ Seconds elapsed sine 01-01-2000 0h

² "LRM" or "SAR" or "LRM and SAR"

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2.14. ALT_MAN_WAV_02 - To discriminate waveforms

2.14.1. Heritage

Cryosat2

2.14.2. Function

Records must be assigned a surface type classification based upon the record contents. This enables surface type specific processing to occur later in the algorithm chain.

2.14.3. Algorithm Definition

2.14.3.1. Input data

- Power waveform: P[1:N_{bins}]
- Beam behaviour parameters: $\Theta[1:N_{bb}]$
- Processing parameters
 - Min/max bounds for each classification metric for each surface type: M_{min}[1:N_{metrics}][1:N_{surf}], M_{max}[1:N_{metrics}][1:N_{surf}]
- Sea-ice concentration for the current location and time (SAD/DAD)
 - This is used as one of the classification metrics for the current location. The dataset is indexed for the current location via a CFI call.

2.14.3.2. Output data

- Surface type classification: d_{surf}
 - Open ocean
 - Sea-ice
 - Lead
 - Unclassified

2.14.3.3. Mathematical statement

- Form a classification vector of classification metrics M[1:N_{metrics}] from the results of applying a set of classification functions to the values within the record and the values from auxiliary datasets.
 - Current metrics are:
 - * Waveform peakiness (from power waveform)
 - * Sea-ice concentration
 - The list of metrics is to be updated following Cryosat2 commissioning.
- Determine whether this classification vector falls within one of a set of N_{surf} non-overlapping regions within an $N_{metrics}$ -dimensional classification space
 - If it does, assign the surface type represented by that region to the record
 - If it does not, assign the 'unclassified' type to that record

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- The regions are defined as boxes with their minimum and maximum extent in each dimension found from $M_{min}[1:N_{metrics}][1:N_{surf}], M_{max}[1:N_{metrics}][1:N_{surf}]$

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2.15. ALT_PHY_BAC_01 - To compute the retracked backscatter coefficients

2.15.1. Heritage

Jason-1, ENVISAT, Jason-2

2.15.2. Function

For each elementary measurement, to compute the retracked estimates of the backscatter coefficient (main and auxiliary bands).

2.15.3. Algorithm Definition

2.15.3.1. Input data

- Scaling factor:
 - Scaling factor for sigma0 evaluation (corrected in level 1b processing)
- Retracking outputs (amplitude):
 - Amplitude
 - Execution flag (valid / invalid)

2.15.3.2. Output data

• Backscatter coefficient and associated validity flag

2.15.3.3. Mathematical statement

For each elementary measurement in both bands, the backscatter coefficient is computed using (1), where P_u represents the amplitude estimate output by the retracking algorithm and where K_{cal} is the scaling factor for Sigma0 evaluation.

$$\sigma_{0} = K_{cal} + 10.\log_{10}(P_{u})$$
(1)

The validity of the retracked backscatter coefficients is determined from the retracking execution flags. Default values are provided in case of invalidity of the retracked backscatter coefficient estimates.

⁽¹⁾ 2 states: "valid" and "invalid"

⁽³⁾ Must be set to "valid" for the ice-1 and sea-ice parameters

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2.16. ALT_PHY_BAC_02 - To compute the backscatter coefficient (SAR, Sea-Ice, Margin)

2.16.1. Heritage

Cryosat2

2.16.2. Function

To calculate the backscatter value for the surface, σ^0 .

We start with the baseline for this algorithm as described below. However, a new study about to start with ESA for Cryosat2 will produce a new method for this algorithm that we intend to use later.

2.16.3. Algorithm Definition

2.16.3.1. Input data

- Retracked waveform power estimate: P_{fit}
- Scaling factor from L1b: Kcal
- Processing parameters:
 - Linear bias: b_{ref}
 - Multiplicative bias: a_{ref}

2.16.3.2. Output data

• Backscatter: σ^0

2.16.3.3. Mathematical statement

• Backscatter is $\sigma^0 = 10 \log_{10} (P_{fit}/a_{ref}) - b_{ref} + Kcal$
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2.17. ALT_PHY_BAC_03 - To compute the backscatter coefficient (LRM, Ice)

2.17.1. Heritage

Cryosat2

2.17.2. Function

To calculate the backscatter value for the surface σ^0 .

2.17.3. Algorithm Definition

2.17.3.1. Input data

- Retracked waveform power estimate: P_{fit}
- Scaling factor from L1b: Kcal
- Processing parameters:
 - Linear bias: b_{ref}
 - Multiplicative bias: a_{ref}

2.17.3.2. Output data

• Backscatter: σ^0

2.17.3.3. Mathematical statement

• Backscatter is $\sigma^0 = 10 \log_{10}(P_{fit}/a_{ref}) - b_{ref} + K_{cal}$

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2.18. ALT_PHY_GEN_01 - To compute the elevation and location of echoing points (LRM, Ice ; SAR, Margin)

2.18.1. Heritage

Envisat, Cryosat2.

2.18.2. Function

The corrected echo direction and range are used to compute the height, latitude and longitude of the actual echoing point.

2.18.3. Algorithm Definition

2.18.3.1. Input data

- Uncorrected latitude: θ_0
- Uncorrected longitude: λ_0
- Range estimate from retracker: R
- Echo position altitude (η) and azimuth (ϕ)
- Meridional radius of curvature of the ellipsoid ρ_{θ_n}
- Radius of parallel circle at geodetic latitude $\rho_{\lambda 0}$

2.18.3.2. Output data

- Slope corrected latitude: θ'
- Slope corrected longitude: λ'
- Slope corrected height: h'

2.18.3.3. Mathematical statement

$$\theta' = \theta_0 + \frac{R \sin \eta \cos \phi}{\rho_{\theta_0}}$$
$$\lambda' = \lambda_0 + \frac{R \sin \eta \sin \phi}{\rho_{\lambda_0}}$$
(R sin n

$$h' = h_e - R\cos\eta + \frac{(R\sin\eta)^2}{2\rho}$$

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2.19. ALT_PHY_GEN_02 - To compute the rain flag

2.19.1. Heritage

ENVISAT

2.19.2. Function

To compute a 6-states rain flag ("no rain", "rain", "high rain probability from altimeter", "high probability of no rain from altimeter", " ambiguous situation (possibility of ice)" or "evaluation not possible") from main and auxiliary bands altimeter backscatter coefficients.

2.19.3. Algorithm definition

2.19.3.1. Input data

- Location:
 - Latitude of the altimeter measurement
- Backscatter coefficient:
 - Corrected backscatter coefficient (main and auxiliary bands)
 - Associated validity flag (main and auxiliary bands)
- Integrated liquid water content
- Altimeter surface type
- Radiometer interpolation quality flag
- Table providing, for an input value of auxiliary band backscatter coefficient, the expected main band backscatter coefficient with its associated uncertainty (SAD)
- Processing parameters (SAD)

2.19.3.2. Output data

- Rain flag
- Rain attenuation

2.19.3.3. Mathematical statement

The rain flag, initialized to "evaluation not possible", is updated if both altimeter and radiometer data are available, if both main and auxiliary bands backscatter coefficients are valid and positive, and if the altimeter surface type is set to "open ocean or semi-enclosed seas" or to "enclosed seas or lakes".

This update is determined from the expected main band backscatter coefficient and its associated uncertainty which are computed by linear interpolation in the input table, as function of the auxiliary band backscatter coefficient:

- If the interpolation of radiometer data to the altimeter measurement failed, then:
 - If the rain attenuation i.e. the difference between the expected main band backscatter coefficient and the measured main band backscatter coefficient exceeds a threshold (which depends on the uncertainty in the expected main band backscatter coefficient), then the rain flag is set to "high rain probability from altimeter"
 - Else, the rain flag is set to to "high probability of no rain from altimeter"

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- Else if the rain attenuation exceeds the above-mentionned threshold and if the integrated liquid water content from the radiometer exceeds some given threshold, then:
 - If the latitude exceeds a given threshold, then the rain flag is set to "ambiguous situation"
 - Else, the rain flag is set to "rain"
- Else, the rain flag is set to "no rain"

The input main and auxiliary bands backscatter coefficients to be used are not corrected for atmospheric attenuation.

⁽¹⁾ Set to "SRAL" or "SRAL+MWR"

⁽²⁾ 4 states ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", "land").

⁽³⁾ Two states : "valid", or "invalid"

⁽⁴⁾ 4 states: "good", "interpolation with gap", "extrapolation", or "fail"

⁽⁵⁾ Six states : "no rain", "rain", "high rain probability from altimeter", "high probability of no rain from altimeter", " ambiguous situation (possibility of ice)" or "evaluation not possible"

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2.20. ALT_PHY_GEN_03 - To compute the rain rate

2.20.1. Heritage

None

2.20.2. Function

To compute the rain rate.

2.20.3. Algorithm definition

2.20.3.1. Input data

- Datation:
 - Altimeter time-tag (1 Hz)
- Location:
 - Latitude of the altimeter measurement (1 Hz)
 - Longitude of the altimeter measurement (1 Hz)
- Rain flag
- Rain attenuation
- Brightness temperatures (interpolated at altimeter time tags):
 - 23.8 GHz brightness temperature (1 Hz)
 - 36.5 GHz brightness temperature (1 Hz)
- Radiometer interpolation quality flag
- Processing parameters (SAD)

2.20.3.2. Output data

• Rain rate

2.20.3.3. Mathematical statement

For each sample indicated as rainy by the rain flag, the freezing level (FL) is inferred by the inversion of the radiometer brightness temperatures or from seasonal maps of FL, if the inversion process fails. The rain rate is then computed from the FL and attenuation using the Marshal-Palmer relation [1948]:

$$RR = (\Delta \sigma_0 / 2 FL a)^{1/b}$$

(1)

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a and *b* are frequency-dependent coefficients and whose values are $a = 0.02038 \text{ dB.km}^{-1}$ and b = 1.203 [Quartly et al, 1999]. Comparison of Topex, Jason-1 and Envisat dual-frequency rain rate estimates by [Tournadre 2006] showed that Envisat overestimated low rain rates. Therefore, the rain rate value is corrected with an inter-calibration relation with Jason-1 rain rate estimates that significantly reduces the differences between the mean annual rain rate computed from Envisat and those from both Topex and Jason-1 missions.

⁽¹⁾ Set to "RA2" or "RA2+MWR"

⁽²⁾ Seconds elapsed since 01-01-2000 0h

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2.21. ALT_PHY_RAN_01 - To compute the retracked altimeter ranges

2.21.1. Heritage

Jason-1, Jason-2, ENVISAT

2.21.2. Function

For each elementary measurement, to compute the retracked estimates of the altimeter range (main and auxiliary bands).

2.21.3. Algorithm Definition

2.21.3.1. Input data

- Tracker range:
 - Tracker range (corrected in the level 1b processing)

- Retracking outputs:
 - Epoch
 - Execution flag (valid / invalid)
- Universal constants (SAD):
 - Light velocity

2.21.3.2. Output data

• Altimeter range and associated validity flag

2.21.3.3. Mathematical statement

For each elementary measurement in main and auxiliary bands, the altimeter range is computed using (1), where h_t represents the input tracker range and where τ is the epoch estimate output by the retracking algorithm.

$$\mathbf{h} = \mathbf{h}_{\mathrm{t}} + \tau \tag{1}$$

The validity of the retracked altimeter ranges is determined from the retracking execution flags. Default values are provided in case of invalidity of the retracked altimeter range estimates.

```
<sup>(4)</sup> 4 states: "good", "interpolation with gap", "extrapolation", or "fail"
```

⁽³⁾ Six states : "no rain", "rain", "high rain probability from altimeter", "high probability of no rain from altimeter", " ambiguous situation (possibility of ice)" or "evaluation not possible"

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2.22. ALT_PHY_RAN_02 - To compute the surface height anomaly (SAR, Sea-Ice)

2.22.1. Heritage

Cryosat2

2.22.2. Function

Provide a surface height anomaly relative to the mean sea surface and corrected for retracker height error and other effects.

2.22.3. Algorithm Definition

2.22.3.1. Input data

- Platform altitude: h_e
- Range corrected for fitting retracker: R_{fit}
- Mean sea surface: h_{MSS}

2.22.3.2. Output data

- Surface height: h
- Sea surface height anomaly: h_{sha}

2.22.3.3. Mathematical statement

- The surface height is calculated as $h = h_e R_{fit}$
- This gives the surface height anomaly $h_{sha} = h h_{MSS}$

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2.23. ALT_PHY_RAN_03 - To compute the freeboard

2.23.1. Heritage

Cryosat2

2.23.2. Function

For records identified as containing sea-ice, the difference between the calculated height and estimated sea-surface is taken and used to estimate the freeboard.

2.23.3. Algorithm Definition

2.23.3.1. Input data

- Surface height: h
- Interpolated sea-surface height anomaly: h'sha
- Discriminated surface type: d_{surf}

2.23.3.2. Output data

- Ice freeboard: h_{freb}
- In the case where freeboard is not computed, it will be set to the appropriate fill value in the L2 product.

2.23.3.3. Mathematical statement

For records discriminated as sea-ice, calculate freeboard $h_{freb} = h - h'_{sha}$ i.e. the difference between the measured surface height and the expected sea-surface height at this location.

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2.24. ALT_PHY_SNR_01 - To compute the SNR from the estimates of the amplitude and of the thermal noise level of the waveforms

2.24.1. Heritage

TOPEX/POSEIDON, Jason-1, Jason-2

2.24.2. Function

To compute the signal to noise ratio (main and auxiliary bands) from the estimates of the amplitude and of the thermal noise level of the waveforms.

2.24.3. Algorithm Definition

2.24.3.1. Input data

- Altimeter configuration data
- AGC:
 - Corrected AGC: AGC_c
- Retracking outputs (power):
 - Amplitude of the waveforms (P_u) and associated validity flag
 - Thermal noise level of the waveforms (P_n) and associated validity flag
- Processing parameters (SAD):
 - Minimum value of AGC requested to set SNR to AGC in case of null thermal noise: AGC_{min}
 - Bias between SNR and AGC: Bias

2.24.3.2. Output data

• Signal to noise ratio

2.24.3.3. Mathematical statement

For each band, the signal to noise ratio is computed by:

$$SNR = 10.\log_{10}\left(\frac{P_u}{P_n}\right)$$
(1)

The input validity flags are managed. Moreover, if the thermal noise level is set to 0, the signal to noise ratio is set to AGC_c + Bias (if AGC_c exceeds a threshold, AGC_{min}), or otherwise to P_u (in dB) (i.e. that P_n is set to the amplitude resolution of the analysis window).

⁽¹⁾ 2 states: "valid" or "invalid"

⁽²⁾ Value to be selected according to the processed band and the emitted bandwidth (altimeter configuration data)

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2.25. ALT_PHY_SWH_01 - To compute SWH from the retracked composite Sigma

2.25.1. Heritage

Jason-1, ENVISAT, Jason-2

2.25.2. Function

For each elementary measurement, to derive the estimates of the significant waveheight (main and auxiliary bands) from the retracked estimates of the composite Sigma.

2.25.3. Algorithm Definition

2.25.3.1. Input data

- Altimeter configuration data
- Retracking outputs (composite Sigma):
 - Composite Sigma
 - Execution flag (valid / invalid)
- Altimeter instrumental characterization data:
 - Sampling interval of the analysis window
 - Ratio between the PTR width and the sampling interval of the analysis window
- Universal constants (SAD):
 - Light velocity

2.25.3.2. Output data

• Significant waveheight and associated validity flag

2.25.3.3. Mathematical statement

For each elementary measurement in main and auxiliary bands, the significant waveheight SWH is computed as follows:

$$SWH = 2c.\sqrt{\sigma_c^2 - \sigma_p^2}$$
(1)

where: σ_c is the composite Sigma (expressed in time units) σ_p is the PTR width (expressed in time units)

c is the light velocity

The validity of the significant waveheights is determined from the retracking execution flags.

⁽¹⁾ 2 states: "valid" or "invalid"

⁽²⁾ Value to be selected according to the processed band and the emitted bandwidth (altimeter configuration data)

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2.26. ALT_PHY_WIN_01 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed

2.26.1. Heritage

GEOSAT, TOPEX/POSEIDON, ERS-1, ERS-2, ENVISAT

2.26.2. Function

To correct the backscatter coefficients for atmospheric attenuation and to compute the altimeter wind speed from the corrected Ku-band backscatter coefficient and the Ku-band significant waveheight.

2.26.3. Algorithm Definition

2.26.3.1. Input data

- Backscatter coefficient:
 - Ku-band ocean backscatter coefficient
 - C-band ocean backscatter coefficient
 - Ku-band ocean backscatter coefficient validity flag
 - C-band ocean backscatter coefficient validity flag
- Atmospheric attenuation:
 - Ku-band backscatter coefficient atmospheric attenuation
 - C-band backscatter coefficient atmospheric attenuation
- Backscatter coefficient to wind speed conversion (SAD, look-up table)

2.26.3.2. Output data

- Backscatter coefficients (both bands) corrected for atmospheric attenuation
- Wind speed corrected for atmospheric attenuation

2.26.3.3. Mathematical statement

First, atmospheric attenuation is added to the backscatter coefficient to correct it (in both bands). Then the wind speed is computed (in m/s) from a model depending on the Ku-band corrected backscatter coefficient.

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2.27. ALT_RET_ICE_01 - To perform the ice-1 (OCOG) retracking (SAR sea-ice, margin ; LRM ice)

2.27.1. Heritage

Envisat, Cryosat2.

2.27.2. Function

A standard OCOG retracking is performed on the power waveform.

The OCOG retracking method is the same for all forms of this algorithm, however the processing parameters may be tuned independently. This tuning is performed by loading a set of processing parameters that are appropriate to the mode and surface type.

2.27.3. Algorithm Definition

2.27.3.1. Input data

- Power waveform: $P[0:N_s-1]$
- R_{tr} tracker range from L1b
- CoG correction d_{CoG}
- Applicable geophysical and meteorological corrections C
- Processing parameters
 - d_{bin} size of a range window bin in metres
 - i_{TP} nominal tracking point

2.27.3.2. Output data

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- OCOG Retracker range correction : δR_{OCOG}
- OCOG Retracker range estimate : R_{OCOG}
- OCOG Retracker power estimate : P_{OCOG}

2.27.3.3. Mathematical statement

Calculate OCOG amplitude as
$$P_{OCOG} = \sqrt{\frac{\sum_{i=0}^{N_s-1} P^4[i]}{\sum_{i=0}^{N_s-1} P^2[i]}}$$

- Search the power waveform array to locate the index of first bin containing more power than $P_{OCOG} \mbox{ as } i_0$
- Calculate OCOG retrack bin $i_{OCOG} = (i_0 1) + \frac{P_{OCOG} P[i_0 1]}{P[i_0] P[i_0 1]}$

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- The OCOG range correction is $\delta R_{OCOG} = (i_{OCOG} i_{TP})d_{bin}$ •
- Calculate the OCOG corrected range as $R_{OCOG} = R_{tr} + \delta R_{OCOG} + C + d_{CoG}$ •
- •

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2.28. ALT_RET_ICE_02 - To perform the ice-2 retracking (LRM)

2.28.1. Heritage

ENVISAT, Jason-2

2.28.2. Function

To perform the ice-2 retracking (the so-called ice_erf algorithm) on the waveforms.

2.28.3. Algorithm Definition

2.28.3.1. Input data

- Altimeter configuration data and quality information
- Waveform:
 - Waveform (128 FFT samples for Ku and C bands)
- Altimeter instrumental characterization data:
 - Altimeter instrumental characterization data for the preparation of data for the ice-2 retracking
 - Sampling interval of the analysis window
- Processing parameters (SAD)
- Universal constants (SAD):
 - Light velocity

2.28.3.2. Output data

For each band, the following 20-Hz parameters:

- Epoch or "range offset": τ
- Width of the leading edge: σ_L
- Amplitude: P_u
- Mean amplitude: P_t
- Thermal noise level: P_n
- Slope of the first part of the logarithm of the trailing edge: s_{T1}
- Slope of the second part of the logarithm of the trailing edge: sT2
- Slope of the first part of the logarithm of the trailing edge for mispointing estimation: $s_{\rm T1m}$ (Ku band only)
- Thermal noise level: P_n
- Mean quadratic error between the normalized waveform and its model
- Quality information, such as an execution flag (valid / invalid)

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2.28.3.3. Mathematical statement

The ice-2 retracking algorithm is performed on the Ku and on the C band waveforms. The only difference in the retracking of Ku and C waveforms is the processed data (waveform, processing and instrumental parameters). A single description is thus given below.

Background

The ice-2 retracking algorithm is based on the ENVISAT RA-2 ice-2 retracking. The aim of the ice-2 retracking algorithm is to make the measured waveform coincide with a return power model, according to Least Square estimators.

The expression of the return power as a function of time is given Brown (Brown, 1977):

$$Vm(t) = \frac{P_u}{2} \left[1 + erf\left(\frac{t-\tau}{\sigma_L}\right) \right] exp[s_T (t-\tau)] + P_n \quad \text{(with: } erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \text{)}$$
(1)

where the parameters to be estimated are:

- τ : the epoch
- σ_L : the width of the leading edge
- P_u : the amplitude
- s_T : the slope of the logarithm of the trailing edge
- P_n : the thermal noise level (to be removed from the waveform samples)

Basic principle and main steps of the processing (see RD 3)

The basic principle and the main steps of the processing are defined hereafter.

• Identification of the waveform validity:

The validity of the waveform is determined from the input waveform quality information. The retracking is then performed only if the input waveform is valid.

• Waveform normalization and leading edge identification:

Depending on the option for thermal noise determination (processing parameter), the thermal noise level (P_n) is either the input noise power measurement (NPM), or it is computed from an arithmetic average of samples of the first plateau, or it is a default value (processing parameter).

 P_n is removed from the waveform samples which is then normalized (i.e. divided by an estimate of the maximum amplitude of the useful signal). Finally, the beginning and the end of the leading edge are identified from an analysis of the shape of the waveform (accounting in particular for the frequent case of a trailing edge with a positive slope), and an estimation window is built around the detected leading edge.

• Coarse estimation stage (τ, σ_L) :

A coarse estimation of the epoch (τ) of the waveform in the estimation window and of the width of the leading edge (σ_L) , is then derived from Least Square estimators by fitting the processed waveform to a mean return power model with a flat trailing edge. This fit is performed in the estimation window i.e. around the leading edge of the waveform. These estimates are the values which minimize the residual in the estimation window, between the normalized waveform and the corresponding model. For each possible value of τ (corresponding to a position varying between the beginning and the end of the estimation window, with a predefined step) and of σ_L (varying between two thresholds, with a predefined step):

- The normalized model (V_{mn}) is computed in the estimation window

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- The amplitude P_u of the normalized waveform is estimated by minimizing the mean quadratic error between the normalized waveform (V_n) and the weighted normalized model (P_u . V_{mn}) in the estimation window (linear regression between the waveform and the normalized model)
- The residual R between V_n and P_u . V_{mn} is computed in the estimation window
- The estimates are updated if R is smaller than the previous minimum value
- Fine estimation stage (τ , σ_{L} , P_{u}):

A fine estimation of τ , σ_L and P_u (amplitude) is finally derived. The coarse and fine estimation stages are very similar. The particularities of the fine estimation process are the following:

the simulated values of τ and σ_L correspond to a position and a width, centered on the coarse estimates, with left and right deviations equal to the half of the coarse resolutions, and with predefined steps (smaller than those used in the coarse estimation process).

The estimated amplitude is provided in output.

• Estimation of the slope of the logarithm of the trailing edge (s_{T1}, s_{T2}) :

The estimation of the slope of the logarithm of the trailing edge is intentionally fully decorrelated from the estimation of the other parameters (τ , σ_L , P_u), because slopes variations may be very important from a waveform to another, and because the uncertainty on its estimate is very important due to speckle effects. Indeed, over ice surfaces, the slope of the trailing edge depends on several parameters among which the slope and the curvature of the overflown surface, the signal due to the penetration of the radar wave in the snow pack (Legresy and Remy, 1997), and of course instrumental features (e.g. antenna). The slope is estimated by linear regression of the logarithm of the normalized waveform samples in two windows part of the trailing edge: the first one (s_{T1}) just after the end of the leading edge with a predefined width, and the second one (s_{T2}) in a contiguous window with a predefined width. The first estimation is aimed at pointing out a possible volume signal existing at the end of the leading edge.

For Ku band, a third slope (s_{T1m}) is estimated as s_{T1} , with an other predefined width aimed at pointing out a mispointing angle over ocean surfaces.

• Estimation of the mean amplitude (P_t):

The mean amplitude of the waveform is estimated by an arithmetic average of the waveform samples (thermal noise level removed) in a window limited by the beginning of the leading edge and the end of the first window used in the slope estimation.

Finally, outputs are converted (the epoch τ is referred to the analysis window, the amplitude P_u is denormalized, etc.)

⁽¹⁾ Value to be selected according to the processed band, the emitted bandwidth and the operating RF subsystem (Ku bandwidth and RF subsystem identifiers)

⁽²⁾ Values to be selected according to the processed band and the emitted bandwidth (Ku bandwidth identifier)

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2.29. ALT_RET_ICE_03 - To perform the "function fit" retracking (SAR, Sea-Ice)

2.29.1. Heritage

Cryosat2

2.29.2. Function

The power waveform is retracked by fitting a function that models the expected power return to the waveform.

The retracking method is the same for both the sea-ice and ice-sheet forms of this algorithm, however the processing parameters may be tuned independently.

2.29.3. Algorithm Definition

2.29.3.1. Input data

- Power waveform: P[0:N_s 1]
- R_{tr} tracker range from L1b
- CoG correction d_{CoG}
- Applicable geophysical and meteorological corrections C
- Processing parameters
 - d_{bin} size of a range window bin in metres
 - i_{TP} nominal tracking point
 - Initialisation values for function parameters (may be static from configuration files or dynamic from prior waveform QA or OCOG retracking): $\alpha [0:N_{\alpha} 1]$
 - * Amplitude $a_0 = \alpha[0]$
 - * Tracking point $t_0 = \alpha[1]$ (i_{fit} when expressed in bins)
 - * Sigma of Gaussian $\sigma = \alpha[2]$
 - * Exponential $k = \alpha[3]$
 - N_{iter} maximum number of iterations to perform
 - $-\chi^2_{finish}$ stop iterating if the fit converges to this level
 - r_{iter} stop iterating if the improvement in the fit is less that this ratio
 - N_{stuck} stop iterating if the fit does not improve for this many consecutive iterations

2.29.3.2. Output data

- Final (fitted) value of function parameters: $\alpha'[0:N_{\alpha}-1]$
- Retracker waveform power estimate: P_{fit}
- Retracker range correction: δR_{fit}

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- Retracker range estimate: R_{fit}
- Retracker quality measurement: χ^2_{fit}

2.29.3.3. Mathematical statement

• Fit $P(t) = f(t, \underline{\alpha'})$ by non-linear least-squares method (Levenberg-Marquard).

The fitted function $f(t, \underline{\alpha}')$ is a three-part piecewise function:

- Leading edge
$$f_1(t, \alpha) = a_0 e^{-\left\lfloor \frac{t-t_0}{\sigma} \right\rfloor}$$

- Linking function
$$f_2(t, \alpha) = a_0 e^{-\left[-\frac{(3k\sigma-2c)}{2\sigma t_b^2 c}(t-t_0)^3 - \frac{(-5k\sigma+4c)}{2\sigma t_b c}(t-t_0)^2 + \frac{1}{\sigma}(t-t_0)\right]^2}$$
, where

*
$$t_b = k\sigma^2$$

- * $c = \sqrt{kt_b}$
- Trailing edge $f_3(t, \alpha) = a_0 e^{-k(t-t_0)}$

 $P(t) = \begin{cases} P_1(t) & \text{for} & t < t_0 \\ P_2(t) & \text{for} & t_0 < t < t_b \\ P_3(t) & \text{for} & t_b < t \end{cases} \text{ (note that } {}^{t_0} \text{ and } {}^{t_b} \text{ are defined above)}$

- The range correction for the fitted retracker is $\delta R_{fit} = (i_{fit} i_{TP})d_{bin}$
- The range corrected for the fitted retracker is $R_{fit} = R_{tr} + \delta R_{fit} + C + d_{CoG}$

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2.30. ALT_RET_ICE_04 - To merge MLE4 results into the ice chain (LRM Ice)

2.30.1. Heritage

2.30.2. NoneFunction

Usage of the CryoSat retracker CFI has been removed as the software is no longer supported. The functionality will be replaced by using the results of the MLE4 retracker (which are read from the input L2 file). This algorithm now simply maps the MLE4 results onto the variables previously filled by the CFI retracker.

The processing is described below.

2.30.2.1. Input data

- R_{tr} tracker range from L1b
- CoG correction d_{CoG}
- Applicable geophysical and meteorological corrections C
- MLE4 retracking 'epoch': δR_{MLE4}
- MLE4 power estimate: P_{MLE4}

2.30.2.2. Output data

- MLE4 Retracker range estimate: R_{CFI}
- MLE4 power estimate: P_{CFI}

2.30.2.3. Mathematical statement

• Calculate the MLE4 corrected range as $R_{CFI} = R_{tr} + \delta R_{MLE4} + C + d_{CoG}$

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2.31. ALT_RET_ICE_05 - To perform the SAR ice-margin WW retracking (SAR ice margin)

2.31.1. Heritage

Cryosat2.

2.31.2. Function

A model of the SAR mode waveform is fitted to the received power. The amplitude and retracking offset are derived from analysis of the fitted waveform. The method is that used for waveforms received in the SARin degraded case for CryoSat where the phase and coherence information is unavailable.

2.31.3. Algorithm Definition

2.31.3.1. Input data

- Power waveform: $P[0:N_s-1]$
- R_{tr} tracker range from L1b
- CoG correction d_{CoG}
- Applicable geophysical and meteorological corrections C
- Processing parameters
 - d_{bin} size of a range window bin in metres
 - i_{TP} nominal tracking point

2.31.3.2. Output data

- WW Retracker range correction: δR_{WW}
- WW Retracker range estimate: R_{WW}
- WW Retracker power estimate: P_{WW}

2.31.3.3. Mathematical statement

The retracking algorithm has been designed to exploit least squares fitting of a semi-analytical model of the echo. The echo model is a modified gaussian of the form:

$$P(t) = ae^{-f(t)}$$

where f is a 5-part piecewise continuous function whose form addresses different regions of the echo thus:

$$\begin{split} f_1(t) &= g(t-t_0) + \left(m - g(t_0 - n\sigma)\right) & \text{where} \quad t < t_0 + n\sigma \\ f_2(t) &= b_0 + b_1(t-t_0 - t_1) + b_2(t-t_0 - t_1)^2 + b_3(t-t_0 - t_1)^3 & \text{where} \quad t + n\sigma < t < t_0 + t_2 \\ f_3(t) &= \frac{1}{\sigma(t-t_0 - t_1)} & \text{where} \quad t_0 + t_2 < t < t_0 - t_1 \end{split}$$

$$\begin{aligned} \text{CLS-DOS-NT-09-119 Iss : 8.0 - date: 01/06/11 - Nomenclature : S3PAD-RS-CLS-SD03-00017} & 46 \\ f_4(t) &= \frac{1}{\sigma} (t - t_0 - t_1) + a_2 (t - t_0 - t_1)^2 + a_3 (t - t_0 - t_1)^3 & \text{where} \quad t_0 - t_1 < t < t_0 - t_3 \end{aligned}$$

$$f_5(t) &= \left(-\log \left[\frac{c e^{-\alpha (t - t_0)}}{a \sqrt{t - t_0}} \right] \right)^{1/2} & \text{where} \quad t > t_0 + t_3 \end{aligned}$$

A Levenberg-Marqhart non-linear least-squares fit is performed to derived the parameters $a, \alpha, \sigma, n, c, t$. Then:

 $\textbf{P}_{WW} = \textbf{a} \times max(\textbf{P})$

 $\delta R_{WW} = d_{bin} \big(t - i_{TP} \big)$

 $R_{WW} = R_{tr} + \delta R_{WW} + C + d_{CoG}$

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2.32. ALT_RET_OCE_01 - To perform the ocean retracking (LRM)

2.32.1. Heritage

Jason-2

2.32.2. Function

To perform the ocean retracking (hereafter called "ocean-3" retracking from Jason heritage) on the waveforms (main and auxiliary bands), i.e. to estimate the altimetric parameters (epoch, composite Sigma, amplitude, square of the mispointing angle).

In this algorithm, the resolution of the set of m linear equations is based on a least-square method and utilizes the standard routine "F04AMF" of the NAG library, simulated by the routines "dgeqrf" and "dormqr" from the public LAPACK library (<u>www.netlib.org/lapack</u>) and the routines "dtrsm", "dgemv" and "dnrm2" from the BLAS library (<u>www.netlib.org/blas</u>). Thus, a wrapper (provided by CLS) will be used to call these routines with the interfaces expected from the "F04AMF" routine of the NAG library.

2.32.3. Algorithm Definition

2.32.3.1. Input data

- Altimeter configuration data
- Waveform:
 - Waveform
 - Waveform validity flag
- Off-nadir angle:
 - Off-nadir angle (square value)
- Orbit:
 - Orbit altitude (20-Hz)
- Altimeter instrumental characterization data:
 - Altimeter instrumental characterization data for the preparation of data for the ocean retracking
 - Abscissa of the reference sample for tracking
 - Sampling interval of the analysis window
 - Antenna beamwidth
 - Ratio between the PTR width and the sampling interval of the analysis window
- Processing parameters (SAD)
- Universal constants (SAD):
 - Light velocity
 - Earth radius

2.32.3.2. Output data

For each band, the following 20-Hz parameters:

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- Epoch: *τ*
- Composite Sigma: σ_c
- Amplitude: P_u
- Thermal noise level: P_n
- Square of the mispointing angle: ξ^2 (relevant for Ku-band only)
- Mean quadratic error between the normalized waveform and its model
- Number of iterations
- Quality information, such as an execution flag (valid / invalid)

2.32.3.3. Mathematical statement

The ocean-3 retracking algorithm is performed on the Ku-band and on the C-band waveforms. For each 20-Hz measurement, the Ku-band waveform must be processed first, because the Ku-band estimate of the square of the mispointing angle is requested on input of the processing of the C-band waveform.

Background

The aim of the ocean-3 retracking algorithm is to make the measured waveform coincide with a return power model, according to weighted Least Square Estimators derived from Maximum Likelihood Estimators. Regarding mispointing, the return power model accounts for the second order terms. Moreover, within the Ku-band ocean-3 retracking, the square of the off-nadir angle is estimated together with the three standard altimetric parameters (epoch, composite Sigma and amplitude).

The expression of the return power as a function of time is given by Amarouche (Amarouche, 2003). Accounting for a skewness coefficient (λ_s : processing parameter), and assuming a Gaussian Point Target Response, it is given by:

$$Vm(t) = AP_{u} \exp(-v_{1}) \left\{ \left[1 + erf(u_{1}) \right] + \frac{\lambda_{s}}{6} \left(\frac{\sigma_{s}}{\sigma_{c}} \right)^{3} \left\{ \left[1 + erf(u_{1}) \right] \alpha_{1}^{3} \sigma_{c}^{3} - \frac{\sqrt{2}}{\sqrt{\pi}} w_{1} \exp(-u_{1}^{2}) \right\} \right\} - A \frac{P_{u}}{2} \exp(-v_{2}) \left\{ \left[1 + erf(u_{2}) \right] + \frac{\lambda_{s}}{6} \left(\frac{\sigma_{s}}{\sigma_{c}} \right)^{3} \left\{ \left[1 + erf(u_{2}) \right] \alpha_{2}^{3} \sigma_{c}^{3} - \frac{\sqrt{2}}{\sqrt{\pi}} w_{2} \exp(-u_{2}^{2}) \right\} \right\} + P_{n} \right\}$$
(1)

with: $\operatorname{erf}(x) = \frac{2}{\sqrt{2}} \int_{0}^{x} e^{-t^{2}} dt$

$$A = \exp\left(\frac{-4\sin^2 \xi}{\gamma}\right), \ \gamma = \frac{2}{\log_e(2)} \cdot \sin^2(\frac{\theta_0}{2}), \ \theta_0 = \text{antenna beamwidth}$$
$$\beta = \frac{4}{\gamma} \cdot \sqrt{\frac{c}{h\left(1 + \frac{h}{R_e}\right)}} \cdot \sin(2\xi), \ \delta = \frac{4c}{\gamma h\left(1 + \frac{h}{R_e}\right)} \cdot \cos(2\xi), \ \alpha_1 = \delta - \frac{\beta^2}{8}, \ \alpha_2 = \delta$$

with: c = velocity of light, h = mean (raw) satellite altitude, $R_e =$ earth radius

 σ_p = PTR width (expressed in time), SWH = $2c\sigma_s$ (significant waveheight), $\sigma_c^2 = \sigma_p^2 + \sigma_s^2$

$$u_{1} = \frac{t - \tau - \alpha_{1}\sigma_{c}^{2}}{\sqrt{2}\sigma_{c}} \quad , \quad v_{1} = \alpha_{1} \left(t - \tau - \frac{\alpha_{1}\sigma_{c}^{2}}{2}\right) \quad , \quad w_{1} = 2u_{1}^{2} + 3\sqrt{2}\alpha_{1}\sigma_{c}u_{1} + 3\alpha_{1}^{2}\sigma_{c}^{2} - 1$$

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$$u_{2} = \frac{t - \tau - \alpha_{2}\sigma_{c}^{2}}{\sqrt{2}\sigma_{c}} , \ v_{2} = \alpha_{2} \left(t - \tau - \frac{\alpha_{2}\sigma_{c}^{2}}{2}\right) , \ w_{2} = 2u_{2}^{2} + 3\sqrt{2}\alpha_{2}\sigma_{c}u_{2} + 3\alpha_{2}^{2}\sigma_{c}^{2} - 1$$

and where the parameters to be estimated are:

- τ : the epoch
- σ_{c} % = : the composite Sigma
- P_u : the amplitude
- ξ : the mispointing angle (Ku-band only)
- P_n: the thermal noise level (estimated from an arithmetic average of samples of the first plateau)

Basic principle

The problem to solve is the estimation of a set of $N_{\theta}=4$ parameters $\theta=\{\theta_1=\tau, \theta_2=\sigma_c, \theta_3=P_u, \theta_4=\xi^2\}$ for Ku-band, and $N_{\theta}=3$ parameters $\theta=\{\theta_1=\tau, \theta_2=\sigma_c, \theta_3=P_u\}$ for C-band. The system to solve results from the maximization of the logarithm of the likelihood function $\Lambda(\theta)$, i.e. from the system:

$$C(\theta) = \nabla \left[-Ln(\Lambda) \right] = 0 \tag{2}$$

where C is the total cost function and ∇ is the gradient function.

This system is reduced to weighted Least Square Estimators, and is equivalent to set the Least Square function $\nabla \chi^2$ to 0, where the merit function χ^2 is defined by:

$$\chi^{2} = \sum_{i} \left(\frac{V_{i} V m_{i}}{\sigma_{i}} \right)^{2}$$
(3)

where V represents the measured waveform, and where the weighting function is $\{\sigma_i\} = \{Vm_i\}$.

This system may also be represented by the following set of N_{θ} equations:

$$\sum_{i} \left(\frac{Vm_{i} - V_{i}}{\sigma_{i}^{2}} \right) \frac{\partial Vm_{i}}{\partial \theta_{k}} = 0$$
(4)

An iterative solution is obtained by developing the total cost function in a Taylor series at the first order about an initial set $\theta_0 = \{\theta_{01} = \tau_0, \theta_{02} = \sigma_{c0}, \theta_{03} = P_{u0}, \theta_{40} = \xi^2_0\}$ of estimates (for C-band, θ_{40} is the Ku-band estimate of the square of the mispointing angle, and the square of the mispointing angle is not estimated) :

$$\theta_{n+1} = \theta_n - g \varepsilon_{\theta} \tag{5}$$

with: $\varepsilon_{\theta} = (BB^{T})^{-1}BD$ (valued to the current values θ_{n})

$$B_{ki} = \frac{1}{\sigma_i} \cdot \frac{\partial Vm_i}{\partial \theta_k}$$
, $D_{i1} = \frac{1}{\sigma_i} \cdot (Vm_i - V_i)$

and where g is a loop gain (positive value, unique to the parameter being estimated).

Using $\{\sigma_i\} = \{Vm_i\}$, the Least Square Estimators method described above would put the most weight on the regions with the least power, i.e. on the regions with the least information regarding the parameters to be estimated. For this reason, the weighting function is superseded by a factor constant over a waveform $(\{\sigma_i\} = \sigma)$. In order to normalize the residuals $(\{Vm_i-V_i\})$, this factor σ is set to the current estimate of the amplitude.

Main steps of the processing

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The main steps of the nominal processing are the following:

- Identification of the waveform validity:
 - The validity of the waveform is determined from the input waveform quality information. The retracking is then performed only if the input waveform is valid.
- Thermal noise estimation:
 - The thermal noise level (P_n) is computed from an arithmetic average of samples of the first plateau (in a predefined gate).
- Initialization:

A default value of the epoch (processing parameter) is used when the instrument is operating in closed loop, while this default value is superseeded by the estimate of the epoch output by "ALT_MAN_RET_04 - To initialise the LRM ocean retracking" for the processed band when the instrument is operating in closed loop.

- Estimation (weighted Least Square fit):
 - The fine estimates of the epoch (τ) , the composite Sigma (σ_c) , the amplitude (P_u) and for the Ku-band the square of the off-nadir angle (ξ^2) , are derived from the iterative process defined previously, which is initialized from default values τ_0 , σ_{c0} , P_{u0} and ξ^2_0 (input processing parameters, except ξ^2_0 for C-band, which is the Ku-band estimate of the square of the mispointing angle) for each waveform.
 - This estimation process is stopped when the value of the mean quadratic error between the normalized waveform (i.e. the waveform from which P_n is removed and weighted by 1/P_u) and the corresponding model built from the estimates is stable enough, with a minimum number of iterations performed, or when a maximum number of iterations is reached.

⁽¹⁾ Value to be selected according to the processed band

⁽⁵⁾ Square_Mis_IN is used only if the mispointing option (processing parameter) is set to "No Estimation"

⁽⁴⁾ Min_Iter is greater or equal to 2

⁽⁶⁾ 2 states: "Estimation" (the square of the mispointing angle is estimated) or "No Estimation" (the square of the mispointing angle is not estimated)

⁽⁷⁾ Relevant only if the mispointing option (processing parameter) is set to "Estimation", otherwise the output is set to the input value (Square_Mis_In) in the processing

⁽⁸⁾ M=4 if Mis_Option is set to "Estimation", M=3 if Mis_Option is set to "No Estimation"

⁽¹⁾ 3 states: "Model", "Derivatives" or "Model and Derivatives"

⁽²⁾ 2 states: "Estimation" or "No Estimation"

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2.33. ALT_RET_OCE_02 - To perform ocean/coastal zone retracking (SAR)

2.33.1. Heritage

None

2.33.2. Function

To fit the theoretical multi-looked waveform model to one 20-Hz Level 1B SAR waveform using the Levenberg-Marquardt method and to retrieve geophysical variables and fitting quality information.

2.33.3. Algorithm Definition

2.33.3.1. Input data

- L1b SAR mode waveforms
- Universal constants
- Instrumental characterization data
- Processing parameters

2.33.3.2. Output data

- Epoch relative to central gate position
- RMS height of specular points with reference to MSL

- Maximum Received Power
- Squared Mispointing Angle
- Inverse of the variance of ocean surface total slope (1/MSS)
- Abscissa of first WF sample for which to compute the theoretical DDM
- Abscissa of last WF sample for which to compute the theoretical DDM
- Thermal noise
- Least square fitting routine exit flag
- Number of iterations on exiting least square fitting loop
- Sum of squared residuals on exiting least square fitting loop

2.33.3.3. Mathematical statement

The algorithm consists of the following functional units:

- An initialisation unit, INIT, which checks various flags and prepares the waveform measurements according to the specification set by the user in the processing parameters related to INIT.
- A fitting unit, FIT, which performs the least-square fitting of the SAMOSA theoretical SAR waveform model to the measured waveforms, according to the specification set by the user in the FIT related processing parameters.

The fitting unit relies on two mechanisms (i.e., functional units) to perform the computation of, respectively, the single-look (SL) and multi-look (ML) theoretical waveforms. The SL unit depends

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solely on input data, while the ML unit is also controlled through the processing parameters of the ML mechanism.

The overall structure of the algorithm is illustrated in Figure 2.



Figure 2 - SAR ocean retracker global software structure

Mathematical assumptions for the derivation of the analytical expression of the Single-Look Model The analytical expression of the Single-Look Model is derived from convolving three terms:

$$W(\tau, f_a) = P_{FS}(\tau, f_a) * *S_R(\tau, f_a) * \left(\frac{c}{2}\right) P_z\left(\frac{c\tau}{2}\right)$$
(1)

The flat surface impulse response, $P_{FS}(\tau, f_a)$, the radar system point target response $S_R(\tau, f_a)$ and the

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surface probability density function, P_z . The system point target response is composed of two squared sinc functions, both approximated by Gaussian functions for simplification.

$$S_R(\tau, f_a) = \operatorname{sinc}^2(\mathrm{T} f_a) * \operatorname{sinc}^2(s \tau_u \tau)$$
⁽²⁾

$$S_{R}(\tau, f_{a}) = \exp\left(-\frac{f_{a}^{2}}{2\sigma_{v}^{2}}\right) * \exp\left(-\frac{\tau^{2}}{2\sigma_{p}^{2}}\right)$$
(3)

$$\sigma_p = \frac{\alpha_p}{B_r} = \alpha_p r_B \tag{4}$$

$$\sigma_v = \alpha_p \frac{1}{T} \tag{5}$$

We have used Least Squares (LS) to do such approximation, achieving a perfect fit in the main lobe of the sinc² by a Gaussian function when $\alpha_n = 0.366$.

 $\rm r_{\rm \scriptscriptstyle B}$ corresponds to the time resolution defined by the receiver bandwidth.

$$r_{B} = \frac{1}{BW}$$
(6)

and T corresponds to the along-track boxcar (Na/PRF, where Na is the number of echoes per burst).

Single-Look Model

The single-look model analytical expression for no across-track curvature effects and no across-track mispointing angle is given by:

$$W(\tau, f_{a}) = W_{0} \exp\left(-\frac{\left(f_{a} - \mu_{a}\right)^{2}}{2 \sigma_{a}^{2}}\right) \exp\left[-\frac{\left(\tau - m\sigma^{2}\right)^{2}}{4 \sigma^{2}} - m\left(\tau - m\sigma^{2}/2\right)\right]$$

$$\begin{cases} \frac{\sqrt{\tau - m\sigma^{2}}}{\sqrt{2}\sqrt{c/h}} K_{1/4} \left[\frac{1}{4\sigma^{2}}\left(\tau - m\sigma^{2}\right)^{2}\right] & \tau - m\sigma^{2} < 0 \\ \frac{\pi \sqrt{\tau - m\sigma^{2}}}{2\sqrt{c/h}} \left(I_{-1/4} \left[\frac{1}{4\sigma^{2}}\left(\tau - m\sigma^{2}\right)^{2}\right] + I_{1/4} \left[\frac{1}{4\sigma^{2}}\left(\tau - m\sigma^{2}\right)^{2}\right]\right) & \tau - m\sigma^{2} > 0 \end{cases}$$
(7)

where I and K are the modified Bessel functions of the first (I) and second (K) kind. The variables in the equation above are described in the table below.

The single-look model in Eq. 7 is a 2D matrix representing the distribution of power in Delay and Doppler space (hence, Delay-Doppler Maps; DDM).

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Symbol	Single-look Model Variables	Equation	Label	Units
2	Range gate or delay time with respect mean sea level (related to the epoch)	$\tau = t - t_0$	(8)	[s]
f_a	Doppler bin, or Doppler frequency (each scatterer is related to an along-	$f_a = \frac{2V_s}{\lambda_a h} (x_0 - x_a)$	(9)	[Hz]
	track position x_a ; x_0 corresponds to the altimeter along track position			
${W}_0$	Single-looked model amplitude factor	(see section 3.4.2.1)	(10)	[Watts/s]
μ_{a}	Along-track mean that results from applying FFT	$\mu_a = \frac{2\beta\alpha V_s}{\lambda_0 (\nu + 2\beta\cos 2\xi)} \sin 2\xi$	(11)	[Hz]
$\sigma_{ m v}$	Standard deviation derived from approximating the radar system point target response along-track sinc ² by	$\sigma_{v}^{2} = \left(\frac{\alpha_{p}}{T}\right)^{2}$	(12)	[Hz ²]
$\sigma_{\scriptscriptstyle m b}$	Standard deviation from the along- track flat surface impulse response	$\sigma_b^2 = \frac{2\alpha^2 V_s^2}{\lambda_0^2 (\nu + 2\beta \cos 2\xi)}$	(13)	[Hz ²]
$\sigma_{_a}$	Standard deviation that result from convolving the system flat surface impulse response and the radar point	$\sigma_a^2 = \sigma_v^2 + \sigma_b^2$	(14)	[Hz ²]
т	Variable related to mispointing angle and MSS	$m = \frac{c}{h} \left(\nu + 2\beta \cos^2 \xi \right)$	(15)	[Hz]
σ	Standard deviation derived from the convolution of the ocean surface p.d.f and the system point target response	$\sigma^2 = \left(\alpha_{\rm p} r_{\rm B}\right)^2 + \left(\frac{2\sigma_s}{c}\right)^2$	(16)	[s ²]

Single-Look model variables

Amplitude factor Wo

The amplitude factor multiplying is given by:

.

$$W_0 = P_u \exp\left(-2\beta \sin^2 \xi + \frac{\beta^2}{(\nu + 2\beta \cos 2\xi)} (\sin 2\xi)^2\right)$$
(17)

$$P_{u} = P_{t} G_{0}^{2} \sigma_{0}(0) \frac{\lambda_{0}^{3} c}{4(4\pi)^{2} L_{p} h^{3} \alpha V_{s}} \frac{1}{\sqrt{2\pi}} \frac{1}{\sigma} \alpha_{p} r_{B} \sigma_{v} \sigma_{b} \frac{1}{\sigma_{a}}$$
(18)

Multi-Look Model

For the generation of the multi-look waveforms we need to account for: Neff and Beam_Ang_Stack_TS; both are provided for each elementary record (approximately 20-Hz waveform) in the SAR L1b product.

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Neff corresponds to the number of effective looks for a given elementary record. This number represents the number of looks used for multi-looking at the present ground cell location. Neff can differ from the maximum number of looks available in principle, because some looks may not be suitable due to low Signal to Noise Ratio (SNR).

Beam_Ang_Stack_TS is the array of angles of the Doppler beams used for multi-looking for the given elementary record. It provides in radians the value of the angle of all beams staring at the ground resolution cell. This array can be easily related to the Doppler frequency of each effective burst bin used for multi-looking.

First, we will calculate for each angle in Beam_Ang_Stack_TS, the corresponding Doppler frequency:

Dopp_Freq_Stack_TS(n) =
$$\frac{2V_s}{\lambda_0} \cos(\text{Beam}_Ang_Stack_TS(n))$$
 $1 \le n \le N_{eff}$ (19)

This will define the Doppler bins of each burst that must be selected and added to the stack before incoherent integration.

The final expression for the multi-looked waveform is given by:

.

$$W_{ML}(\tau) = \sum_{n=1}^{N_{eff}} W(\tau, Dopp_Freq_Stack_TS(n))$$
(20)

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2.34. GEN_COR_ORB_01 - To derive the orbital altitude rate with respect to the reference MSS/geoid

2.34.1. Heritage

Jason-1, Jason-2

2.34.2. Function

To derive the orbital altitude rate with respect to the MSS/geoid from the orbital altitude rate with respect to the reference ellipsoid and from the map of slopes of the MSS/geoid with respect to the reference ellipsoid.

2.34.3. Algorithm Definition

2.34.3.1. Input data

- Pass:
 - Pass number of the measurement (indicating if the pass is ascending or descending)
- Location:
 - Latitude
 - Longitude
- Orbit:
 - Orbital altitude rate with respect to the reference ellipsoid
- Map of the slopes of the reference MSS/geoid with respect to the reference ellipsoid (SAD)

2.34.3.2. Output data

• Orbital altitude rate with respect to the reference MSS/geoid

2.34.3.3. Mathematical statement

The orbital altitude rate with respect to the reference MSS/geoid is the sum of the two following parameters:

- The input orbital altitude rate with respect to the reference ellipsoid
- The slope of the reference MSS/geoid with respect to the reference ellipsoid, which is derived by bilinear interpolation of the slopes of the input map to the measurement location, accounting for the pass direction (ascending or descending).

⁽¹⁾ Two values are provided for each point of the grid: one for the ascending passes, the other for the decending passes

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2.35. GEN_COR_RAN_01 - To compute the 10 meter wind vector, the surface pressure and the mean sea surface pressure from ECMWF model, the dry and wet tropospheric "operational" corrections (ocean surfaces) and the dry and wet tropospheric "pseudo-operationnal" corrections (continental surfaces)

2.35.1. Heritage

Jason-1

2.35.2. Function

To compute at the altimeter time tag and location the 10 meter wind vector components U (zonal component) and V (meridian component), the surface pressure and mean sea level pressure from the ECMWF meteorological model fields, the wet tropospheric corrections due to gases of the troposphere (ocean surfaces), to remove the climatological pressure from the surface pressure and to derive the dry tropospheric corrections due to gases of the troposphere from this surface pressure to which a model of S1 and S2 pressure variability is added (ocean surfaces), to compute the wet and dry tropospheric corrections using a vertical integration of the meteo 3D parameters (continental surfaces).

2.35.3. Algorithm definition

2.35.3.1. Input data

- Datation:
 - Altimeter time tag
- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Altitude
- Tracker range
- Geophysical corrections
- Meteorological data (DAD):
 - Meteorological data: U and V components of the 10 meter wind vector, surface pressure and mean sea level pressure. For each of these parameters, the data consist of two data files, 6 hours apart, bracketing the time of measurement (each file, excepted the mean sea surface pressure, contains the parameter given on the so-called Gaussian grid (quasi-regular in latitude, non-regular in longitude).
 - Humidity and temperature profiles from the vertical levels
 - Table providing the latitudes of the model grid points
 - Table providing the number of grid points in longitude for each model latitude
- Climatological pressure files (SAD)
 - The data consists of four data files, corresponding to 0h, 6h, 12h and 18h. Each file contains the climatological pressure referenced to the sea on a cartesian grid, for each of the twelve months of the year.
- S1 and S2 tide grids of monthly means of global amplitude and phase (SAD)

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• Processing parameters (SAD)

2.35.3.2. Output data

- U-component of the 10 meter model wind vector
- V-component of the 10 meter model wind vector
- Dry tropospheric "operational" and "pseudo-operational" corrections: δh_{dry} and δh_{dry-pseudo}
- Model wet tropospheric "operational" and "pseudo-operational" corrections: δh_{wet} and δh_{wet-pseudo}
- Surface pressure (climatological pressure removed)
- Mean sea level pressure

2.35.3.3. Mathematical statement

The wet tropospheric correction, the two components U and V of the 10 meter model wind vector, the surface pressure and the mean sea surface pressure at the altimeter measurement are obtained by linear interpolation in time between two consecutive (6 hours apart) ECMWF model data files, and by bilinear interpolation in space from the four nearby model grid values (excepted for the mean sea surface pressure). The ECMWF model grid is quasi-regular in latitude and non-regular in longitude (the number of grid points in longitude increases towards lower latitudes).

The climatological pressure (0h, 6h, 12h and 18h for each month) is then removed from the surface pressure.

Then, the dry/wet tropospheric corrections are computed as follows :

- "operational corrections" : both corrections described below are computed at the "sea level reference" so that coastal points do not suffer from interpolation between ocean and continental points corrections, the drawback being that the non ocean points will be affected with unrealistic values :
 - * The dry tropospheric correction is derived from the mean sea level pressure (climatological pressure removed) to which a model of S1 and S2 pressure variability (R D Ray and R M Ponte, 2003) is added.
 - * The wet troposhperic correction is computed from a "surface" reference that is the mean sea level pressure and the calculation is based on equation (21) described below.
- "pseudo-operational corrections" : for both corrections, the computation consists in a vertical integration of the 3D meteo parameters performed for each along-track altimeter measurement. The real altitude of the surface terrain along-track is deduced from the altimeter range. This surface altitude is then used inside the 3D meteo fields in order to determine the altitude of the real surface within the model:
 - * The dry tropospheric correction is computed from equation (15) described below, which requires a value of the surface pressure at the real surface altitude and a value of the gravity at the altitude/latitude of the measurement point for each model layer.
 - * The wet tropospheric correction is computed from equation (21) described below, whoch requires a value of the surface pressure at the real surface altitude, a value of the gravity at the altitude/latitude of the measurement point for each model layer and a value of specific humidity and temperature (given by the 3D ECMWF meteo fields) for each model layer.

Hereafter are detailed the mathematical statement to compute the surface pressure map and the wet tropospheric correction map. The input data for computing these maps are the model surface pressure, and the specific humidity and temperature profiles from the vertical levels of the ECMWF model.

Definitions of the refractive index and of the wet and dry tropospheric corrections

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The excess propagation path, also called path delay, induced by the neutral gases of the atmosphere between the backscattering surface and the satellite is given by:

$$\delta h = \int_{Hsurf}^{Hsat} (n(z)-1) dz$$
(1)

where n(z) is the index of refraction of air, H_{surf} and H_{sat} are respectively the altitudes of the surface and of the satellite above mean sea level.

The index of refraction is conveniently expressed in terms of the refractivity N(z), defined as:

$$10^{-6} N(z) = n(z) - 1$$
 (2)

N(z) is given by Bean and Dutton (1966):

N(z) = 77.6
$$\frac{P_d}{T}$$
 + 72 $\frac{e}{T}$ + 3.75 10⁵ $\frac{e}{T^2}$ (3)

where P_d is the partial pressure of dry air in hPa (1 hPa = 100 Pa), e is the partial pressure of water vapor in hPa, and T is temperature in K.

As the partial pressure of dry air is not easily measured, it is desirable to obtain an expression function of the total pressure of air. For deriving it, we have to consider that the dry air and the water vapor are ideal gases, i.e., they obey to the Mariotte-Gay Lussac law:

For dry air:
$$\frac{P_d}{\rho_d} = \frac{RT}{M_d}$$
 (4)

For water vapor:
$$\frac{e}{\rho_w} = \frac{RT}{M_w}$$
 (5)

where ρ_d and ρ_w are the volumic masses of dry air and water vapor respectively, M_d and M_w are the molar masses of dry air (28.9644 10⁻³ kg) and water vapor (18.0153 10⁻³ kg) respectively, R is the universal gas constant (8.31434 J.mole⁻¹.K⁻¹).

Combining (4), (5) and (3) leads to:

N(z) = 77.6 R
$$\frac{\rho_d}{M_d}$$
 + 72 R $\frac{\rho_w}{M_w}$ + 3.75 10⁵ $\frac{e}{T^2}$ (6)

The volumic mass of wet air is the sum of the volumic masses of dry air and water vapor:

$$\rho = \rho_{\rm d} + \rho_{\rm w} \tag{7}$$

Introducing the volumic mass of wet air given by (7) into (6) leads to:

N(z) = 77.6 R
$$\frac{\rho}{M_d}$$
 + (72 - 77.6 $\frac{M_w}{M_d}$) R $\frac{\rho_w}{M_w}$ + 3.75 10⁵ $\frac{e}{T^2}$ (8)

Reintroducing (5) into (8) leads to the final expression of refractivity N(z):

N(z) = 77.6 R
$$\frac{\rho}{M_d}$$
 + (72 - 77.6 $\frac{M_w}{M_d}$) $\frac{e}{T}$ + 3.75 10⁵ $\frac{e}{T^2}$ (9)

Combining this expression with (1) and (2) leads to the following equation for δh :

$$\delta h = 77.6 \ 10^{-6} \ \frac{R}{M_d} \ \int_{Hsurf}^{Hsat} \rho \, dz \ + (72 - 77.6 \ \frac{M_w}{M_d}) 10^{-6} \int_{Hsurf}^{Hsat} \frac{e}{T} \, dz \ + 3.75 \ 10^{-1} \ \int_{Hsurf}^{Hsat} \frac{e}{T^2} \, dz$$
(10)

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The first term is called the dry tropospheric correction δh_{dry} :

$$\delta h_{dry} = 77.6 \ 10^{-6} \ \frac{R}{M_d} \ \int_{Hsurf}^{Hsat} dz$$
(11)

The sum of the two remaining terms is called the wet tropospheric correction δh_{wet} :

$$\delta h_{wet} = (72 - 77.6 \ \frac{M_w}{M_d}) 10^{-6} \int_{Hsurf}^{Hsat} \frac{e}{T} dz + 3.75 \ 10^{-1} \ \int_{Hsurf}^{Hsat} \frac{e}{T^2} dz$$
 (12)

Introducing the numerical values for M_d and M_w into (12), and multiplying δh_{wet} by -1 to get a negative quantity to be added to the altimeter range, leads to the following equation for δh_{wet} in m:

$$\delta h_{wet} = -23.7 \ 10^{-6} \int_{Hsurf}^{Hsat} \frac{e}{T} dz - 3.75 \ 10^{-1} \int_{Hsurf}^{Hsat} \frac{e}{T^2} dz$$
 (13)

Calculation of the dry tropospheric correction as function of the surface pressure

It is commonly assumed that the atmosphere is in hydrostatic equilibrium, i.e. g being the acceleration due to gravity:

$$\frac{dP}{dz} = -\rho g \tag{14}$$

Combining (11) and (14) leads to the following equation for δh_{dry} , where P_{surf} is the atmospheric pressure at the ground surface:

$$\delta h_{dry} = 77.6 \ 10^{-6} \ \frac{R}{M_d} \ \int_0^{Psurf} \frac{1}{g} dP$$
 (15)

The acceleration of gravity is a function of latitude and altitude. This function can be modeled by:

$$g = g_0 \left[1 - 0.0026 \cos(2\phi) - 0.00031 z \right]$$
(16)

where ϕ is the latitude, z is altitude in km, and $g_0 = 9.80665 \text{ m/s}^2$

The variation of g with altitude is small and can be neglected by considering a mean value for g = 9.783 m/s² constant with altitude. This leads to the final expression for δh_{dry} :

$$\delta h_{drv} = -2.277 P_{suff} \left[1 + 0.0026 \cos(2\phi) \right]$$
(17)

(17) is the expression obtained by Saastamoinen (1972), where P_{surf} is in hPa, and δh_{dry} is in mm and is set here with a negative sign to be added to the altimeter range. Computing the dry tropospheric correction from (15) instead of from (17) (i.e., taking into account the variation of g with altitude, as given by (16)), leads to differences below the 1-mm level in dry tropospheric correction (below the 0.5-mm level for latitudes less than 50°).

<u>Note</u> In GEN_COR_RAN_01 algorithm, the dry tropospheric correction will be computed as described in (17) but using a surface pressure which is the interpolated surface pressure P_{surf} from which the climatological pressure is removed (over the ocean only) and to which a model of S1 and S2 waves pressure variability (R D Ray and R M Ponte, 2003) is added.

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Calculation of the surface pressure map

The main input for (17) is the atmospheric pressure at the ground surface, P_{surf} . As the ECMWF model surface is not the true Earth surface, it is necessary to correct the model surface pressure P_{sol} for the height difference between the ECMWF model surface height H_{sol} and the true surface height H. The true surface height H is given by the TerrainBase Digital Elevation Model, interpolated to the ECMWF model grid points. Then, P_{surf} is derived from P_{sol} using (18):

$$P_{surf} = P_{sol} \cdot \left(\frac{T_{sol} + \gamma(H - H_{sol})}{T_{sol}}\right)^{-\frac{M_a g}{R \gamma}}$$
(18)

Where γ is the mean vertical gradient of temperature (6.5°/km), and T_{sol} is the air temperature at the model surface, interpolated from the air temperature for the first model level:

$$T_{sol} = T_{lev} \cdot \left(1 + \frac{R\gamma}{M_a g} \left(\frac{P_{sol}}{P_{lev}} - 1 \right) \right)$$
(19)

<u>Note</u> In GEN_COR_RAN_01 algorithm, the climatological pressure is removed to the surface pressure to be output. This removal is performed for measurements over the ocean only because the climatological pressure is referenced to the sea (null altitude).

Calculation of the wet tropospheric correction map:

The humidity variable output by the model is the specific humidity q, given by :

$$q = \frac{\rho_w}{\rho_d + \rho_w}$$
(20)

Thus, (13) must be rewritten as function of q. After introducing (5), (7), (14) and (20) into (13), one gets:

$$\delta h_{wet} = -23.7 \ 10^{-6} \ \frac{R}{M_w} \ \int_{Psat}^{Psurf} \frac{1}{g} q \, dp \ - \ 3.75 \ 10^{-1} \ \frac{R}{M_w} \ \int_{Psat}^{Psurf} \frac{1}{g} \frac{q}{T} \, dp$$
(21)

As done for the dry tropospheric correction calculation, the expression for g given by (16) is then introduced in (21), and the variation of g with altitude is neglected by considering a mean value for g = 9.797 constant with altitude (which corresponds to a mean height of 3 km). This leads to the final expression for δh_{wet} :

$$\delta h_{wet} = - \{ 1.116454 \ 10^{-3} \int_{Psat}^{Psurf} q \ dp \ + \ 17.66543928 \ \int_{Psat}^{Psurf} \frac{q}{T} \ dp \} x \ [1 + 0.0026 \ \cos(2\phi)]$$
(22)

The wet tropospheric correction map is computed from (22), where the integrals are evaluated from the surface pressure P_{surf} defined above up to the model vertical level pressure P_{sat} above which humidity is negligible (typically 200 hPa). In (22), pressures are in hPa, temperature is in K, specific humidity q is in kg/kg and δh_{wet} is in m.

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⁽¹⁾ 2 states : "2 maps nominal" or "1 map"
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2.36. GEN_COR_RAN_02 - To compute the high frequency fluctuations of the sea surface topography from MOG2D model

2.36.1. Heritage

Jason-1, Jason-2, ENVISAT

2.36.2. Function

To compute the fluctuations of the sea surface topography at the altimeter time tag and location from MOG2D model.

2.36.3. Algorithm Definition

2.36.3.1. Input data

- Datation:
 - Altimeter time tag
- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- MOG2D data: sum of the high frequency variability of the sea surface height and of the low frequency part of the inverted barometer effect (DAD).
- The data consists of two data files, 6 hours apart, bracketing the time of measurement (each file containing the parameter given on regular grid).

2.36.3.2. Output data

• Fluctuations of the sea surface topography (sum of the high frequency variability of the sea surface height and of the low frequency part of the inverted barometer effect) at the altimeter measurement time tag and location

2.36.3.3. Mathematical statement

MOG2D parameter (sum of the high frequency variability of the sea surface height and of the low frequency part of the inverted barometer effect) at the altimeter measurement are obtained by linear interpolation in time between two consecutive (6 hours apart) MOG2D model data files, and by bilinear interpolation in space from the four nearby model grid values.

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2.37. GEN_ENV_BAT_01 - To compute the ocean depth / land elevation

2.37.1. Heritage

TOPEX-Poseidon, Jason-1, Jason-2, ENVISAT

2.37.2. Function

To compute the ocean depth or land elevation from a bathymetry / topography file.

2.37.3. Algorithm Definition

2.37.3.1. Input data

- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Surface type ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", or "land")
- Bathymetry / topography file (SAD)

2.37.3.2. Output data

• Ocean depth / land elevation

2.37.3.3. Mathematical statement

The ocean depth / land elevation is obtained by bilinear interpolation in space from the input bathymetry/topographygrid values. If the surface type of the altimeter measurement is set to "open ocean or semi-enclosed seas", only grid points having negative altitude are used in the interpolation. If no such grid points with negative altitude are found, then the four grid points having positive altitude are used. If the altimeter measurement is set to "enclosed seas or lakes", "continental ice", or "land", all grid points are used in the interpolation, regardless of their altitude.

⁽¹⁾ 4 states ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", "land").

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2.38. GEN_ENV_DIS_01 - To compute distance to shore

2.38.1. Heritage

None

2.38.2. Function

To compute the distance between the measurement location (over sea surface) and the closest point of the coastline.

2.38.3. Algorithm Definition

2.38.3.1. Input data

- Location, i.e. latitude and longitudes
- Distance to shore table (SAD)

2.38.3.2. Output data

• Distance to shore at altimeter location

2.38.3.3. Mathematical statement

The input SAD table provides the theoretical distance to shore on a lat/lon grid. This algorithms consists of getting the distance to shore of the grid point closest to the measurement location.

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2.39. GEN_ENV_ECH_01 - To determine the echo direction (SAR, Margin)

2.39.1. Heritage

Cryosat2.

2.39.2. Function

This function takes the standard method of slope correction that is used for LRM data and accounts for the effect of the footprint shape in SAR mode. The altitude and azimuth that is calculated by the standard method is projected into the across-track plane. This is used to determine the actual altitude and azimuth of the echoing point within the SAR footprint.

2.39.3. Algorithm Definition

2.39.3.1. Input data

- Uncorrected latitude: θ_0
- Uncorrected longitude: λ₀
- Satellite altitude: h_e
- Fitting retracker range estimate: R_{fit}
- Slope model(s) (SAD)
- Orbit (DAD)
 - Values extracted via the CFI [CFI-S-01]; see reference for methods.
 - Position of the satellite in the ITER frame: \vec{P}
 - Velocity of the satellite in the ITER frame: \vec{v}
 - Boresite vector of the satellite in the ITER frame: \vec{b}
- Geophysical constants
 - Semi-major axis of the reference ellipsoid: ae
 - Flattening coefficient of the ellipsoid: e

2.39.3.2. Output data

- Echo position altitude (η_{SAR}) and azimuth (ϕ_{SAR})
- Meridional radius of curvature of the ellipsoid ρ_{θ_n}
- Radius of parallel circle at geodetic latitude $\rho_{\lambda 0}$
- Flag application of correction

2.39.3.3. Mathematical statement

• Calculate the meridional radius of curvature of the ellipsoid for the nadir location $\rho_{\theta_0} = \frac{a_e \left(1 - e^2\right)}{\left(1 - e^2 \sin^2 \theta_0\right)^{3/2}}$

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• Slope model Cartesian frame coordinates are given by:

$$\begin{split} X &= 2\rho_{\theta_0} \cos\lambda_0 \sin\left[\frac{\left(\frac{\pi}{2} - |\theta_0|\right)}{2}\right] \\ Y &= 2\rho_{\theta_0} \sin\lambda_0 \sin\left[\frac{\left(\frac{\pi}{2} - |\theta_0|\right)}{2}\right] \end{split}$$

- Calculate the radius of parallel circle at geodetic latitude $\rho_{\lambda 0} = \frac{a_e \cos \theta_0}{\sqrt{1 e^2 \sin^2 \theta_0}}$
- Range derivatives in local co-ordinates can then be found by interpolating the appropriate slope model (for the current location) to get $s_x(X, Y)$ and $s_y(X, Y)$ and calculating:

$$\begin{split} \frac{\partial l}{\partial x}\Big|_{x=0} &\equiv s_{x} = \frac{1}{\rho_{\theta_{0}} + h_{e}} \left\{ s_{x}(X,Y) \frac{\partial X}{\partial \theta} + s_{y}(X,Y) \frac{\partial Y}{\partial \theta} \right\} \\ \frac{\partial l}{\partial y}\Big|_{y=0} &\equiv s_{y} = \frac{1}{\rho_{\lambda_{0}} + h_{e}\cos\theta_{0}} \left\{ s_{x}(X,Y) \frac{\partial X}{\partial \lambda} + s_{y}(X,Y) \frac{\partial Y}{\partial \lambda} \right\} \end{split}$$

• Echo direction angles uncorrected for SAR mode are given as Azimuth $\phi_{LRM} = atan(s_y/s_x)$

Altitude $\eta_{LRM} = a sin \sqrt{s_x^2 + s_y^2}$

• Calculate the geodetic coordinates of echo point:

$$\rho = \frac{\rho_{\theta_0} \rho_{\lambda_0}}{\rho_{\theta_0} \cos \theta_0 \sin^2 \phi_{LRM} + \rho_{\lambda_0} \cos^2 \phi_{LRM}}$$
$$\theta_{LRM} = \theta_0 + \frac{R_{fit} \sin \eta_{LRM} \cos \phi_{LRM}}{2}$$

$$\lambda_{LRM} = \lambda_0 + \frac{R_{fit} \sin \eta_{LRM} \sin \phi_{LRM}}{\rho_{\lambda_0}}$$

$$h_{LRM} = h_e - R_{fit} \cos \eta_{LRM} + \frac{\left(R_{fit} \sin \eta_{LRM}\right)^2}{2\rho}$$

- Form the uncorrected echo vector \vec{e} :
 - Convert echo position (λ, θ, h) to Cartesian \vec{E} using CFI [CFI-S-01]
 - $\vec{e} = \vec{E} \vec{P}$
- Calculate the across-track component of the uncorrected echo vector:
 - SAR corrected echo vector $\vec{d} = \frac{\vec{v} \times (\vec{e} \times \vec{v} / |\vec{v}|)}{|\vec{v}|}$ (will be in across-track plane)
 - Corrected azimuth φ_{SAR} is then calculated using the boresight vector:

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- * Get the component of the SAR corrected echo vector in the plane normal to the boresight $\vec{a} = \frac{\vec{b} \times \left(\vec{d} \times \vec{b} / \left| \vec{b} \right| \right)}{\left| \vec{b} \right|}$
- * Calculate the azimuth angle from the Z axis of the frame (North) $\varphi_{SAR} = acos\left(\frac{\vec{a}_z}{|\vec{a}|}\right)$

- Corrected altitude is
$$\eta_{SAR} = acos \left(\frac{\vec{d} \bullet \vec{b}}{\left| \vec{d} \right\| \vec{b} \right|} \right)$$

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2.40. GEN_ENV_ECH_02 - To determine the echo direction (LRM, Ice)

2.40.1. Heritage

Cryosat2, ENVISAT

2.40.2. Function

This function is the standard method of slope correction that is used for LRM data.

2.40.3. Algorithm Definition

2.40.3.1. Input data

- Uncorrected latitude: θ₀
- Uncorrected longitude: λ_0
- Satellite altitude: h_e
- Fitting retracker range estimate: R_{fit}
- Slope model(s) (SAD)
- Geophysical constants
 - Semi-major axis of the reference ellipsoid: a_e
 - Flattening coefficient of the ellipsoid: e

2.40.3.2. Output data

- Echo position altitude (η_{SAR}) and azimuth (ϕ_{SAR})
- Meridional radius of curvature of the ellipsoid ρ_{θ_0}
- Radius of parallel circle at geodetic latitude $\rho_{\lambda 0}$
- Flag application of correction

2.40.3.3. Mathematical statement

- Calculate the meridional radius of curvature of the ellipsoid for the nadir location $\rho_{\theta_0} = \frac{a_e \left(1 e^2\right)}{\left(1 e^2 \sin^2 \theta_0\right)^{3/2}}$
- Slope model Cartesian frame coordinates are given by:

$$\begin{split} X &= 2\rho_{\theta_0} \cos\lambda_0 \sin\left[\frac{\left(\frac{\pi}{2} - |\theta_0|\right)}{2}\right] \\ Y &= 2\rho_{\theta_0} \sin\lambda_0 \sin\left[\frac{\left(\frac{\pi}{2} - |\theta_0|\right)}{2}\right] \end{split}$$

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- Calculate the radius of parallel circle at geodetic latitude $\rho_{\lambda 0} = \frac{a_e \cos \theta_0}{\sqrt{1 e^2 \sin^2 \theta_0}}$
- Range derivatives in local co-ordinates can then be found by interpolating the approprate slope model (for the current location) to get $s_x(X, Y)$ and $s_y(X, Y)$ and calculating:

$$\frac{\partial l}{\partial x}\Big|_{x=0} \equiv s_{x} = \frac{1}{\rho_{\theta_{0}} + h_{e}} \left\{ s_{x}(X,Y) \frac{\partial X}{\partial \theta} + s_{y}(X,Y) \frac{\partial Y}{\partial \theta} \right\}$$
$$\frac{\partial l}{\partial y}\Big|_{y=0} \equiv s_{y} = \frac{1}{\rho_{\lambda_{0}} + h_{e} \cos\theta_{0}} \left\{ s_{x}(X,Y) \frac{\partial X}{\partial \lambda} + s_{y}(X,Y) \frac{\partial Y}{\partial \lambda} \right\}$$

• Echo direction angles are given as

Azimuth
$$\phi_{LRM} = atan(s_y/s_x)$$

Altitude η_{LRM} = asin $\sqrt{s_x^2 + s_y^2}$

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2.41. GEN_ENV_GEO_01 - To compute the geoid height

2.41.1. Heritage

TOPEX-Poseidon, ERS-1, ERS-2, Jason-1, Jason-2, ENVISAT

2.41.2. Function

To compute the height of the geoid above the reference ellipsoid at the location of the altimeter measurement, from the geoid input file.

2.41.3. Algorithm Definition

2.41.3.1. Input data

- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Geoid (geographical grid, SAD)
- Processing parameters (SAD):
 - Interpolation window size

2.41.3.2. Output data

• Height of the geoid.

2.41.3.3. Mathematical statement

The height of the geoid is computed at the altimeter measurement by spline or bilinear interpolation in latitude and longitude of the grid values at the altimeter measurement.

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2.42. GEN_ENV_MDT_01 - To compute the mean dynamic topography height

2.42.1. Heritage

Jason-2, Jason-1

2.42.2. Function

To compute the height of the mean dynamic topography (MDT) at the location of the altimeter measurement, from the MDT input file.

2.42.3. Algorithm Definition

2.42.3.1. Input data

- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- MDT value and accuracy (geographical grid, SAD)
- Processing parameters (SAD):
 - Interpolation window size
 - MDT offset

2.42.3.2. Output data

- Height of the mean dynamic topography
- MDT interpolation flag
- MDT accuracy

2.42.3.3. Mathematical statement

The height of the MDT is computed at the altimeter measurement using a squared window of NxN MDT grid points (typically N = 6) centered on the altimeter point. Spline functions are calculated within the window as function of grid point latitude for each MDT column. Each of these spline functions is evaluated at the altimeter latitude. The resulting values are then used for calculating a spline function of grid point longitude. The height of the MDT is derived by evaluating the spline at the altimeter longitude. When one MDT grid point has a default value (grid point over land), then a lower N value is tried. If spline interpolation fails (because N < 4), then bilinear interpolation is performed. An offset may be added to the computed height of the MDT.

A MDT flag is also derived. It addresses the quality of the interpolation by providing the number of grid cells used during the spline (or bilinear) interpolation process. The accuracy is also provided at the location of the measurement by the MSS accuracy map (calibrated formal errors) using a bi-linear interpolation.

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2.43. GEN_ENV_MET_01 - To compute the inverted barometer effect

2.43.1. Heritage

TOPEX/Poseidon, Jason-1, Jason-2, ENVISAT

2.43.2. Function

To compute the sea surface height correction due to atmospheric loading (the so-called inverted barometer effect), using a non constant mean reference pressure.

2.43.3. Algorithm Definition

2.43.3.1. Input data

- Surface atmospheric pressure:
 - Surface atmospheric pressure p
 - Mean sea surface atmospheric pressure over the global oceans P
 - Processing parameter (SAD)

2.43.3.2. Output data

• Inverted barometer height

2.43.3.3. Mathematical statement

The inverted barometer height correction (H_Baro) is computed (in mm) according to the following formula:

$$H_Baro = -b.(p - \overline{p})$$
(1)

where b = 9.948 mm/hPa, p is the surface atmospheric pressure at the location and time of the altimeter measurement, and \overline{p} is the global mean sea level atmospheric pressure, computed from the surface pressure field the closest in time from the altimeter measurement.

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2.44. GEN_ENV_MSS_01 - To compute the mean sea surface height

2.44.1. Heritage

TOPEX-Poseidon, ERS-1, ERS-2, Jason-1, Jason-2, ENVISAT

2.44.2. Function

To compute the height of the mean sea surface (MSS) at the location of the altimeter measurement, from the MSS input file.

2.44.3. Algorithm Definition

2.44.3.1. Input data

- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- MSS value and accuracy (geographical grid, SAD)
- Processing parameters (SAD):
 - Interpolation window size
 - MSS offset

2.44.3.2. Output data

- Height of the mean sea surface above the reference ellipsoid.
- MSS interpolation flag
- MSS accuracy

2.44.3.3. Mathematical statement

The height of the MSS is computed at the altimeter measurement using a squared window of NxN MSS grid points (typically N = 6) centered on the altimeter point. Spline functions are calculated within the window as function of grid point latitude for each MSS column. Each of these spline functions is evaluated at the altimeter latitude. The resulting values are then used for calculating a spline function of grid point longitude. The height of the MSS is derived by evaluating the spline at the altimeter longitude. When one MSS grid point has a default value (grid point over land), then a lower N value is tried. If spline interpolation fails (because N < 4), then bilinear interpolation is performed. An offset may be added to the computed height of the MSS.

A MSS flag is also derived. It addresses the quality of the interpolation by providing the number of grid cells used during the spline (or bilinear) interpolation process. The accuracy is also provided at the location of the measurement by the MSS accuracy map (calibrated formal errors) using a bi-linear interpolation.

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2.45. GEN_ENV_SUR_01 - To determine the radiometer surface type

2.45.1. Heritage

ERS-1/2 (MWR), ENVISAT (MWR), Jason-1 (JMR)

2.45.2. Function

To determine if the surface type corresponding to the radiometer measurement is over land or over ocean. Two surface types are derived: one for the brightness temperatures and the other one for the radiometer path delay.

2.45.3. Algorithm Definition

2.45.3.1. Input data

- Location:
 - Latitude of the radiometer measurement
 - Longitude of the radiometer measurement
- Land/sea mask file (SAD)
- Processing parameters (SAD) :
 - Characteristics of the reference ellipsoid (semi-major axis, flattening)
 - Radial ground distance data :
 - * The radial ground distance from the sub-satellite point along nadir at which land contamination would be sufficient to corrupt the subsequent path delay estimate by approximately 0.5 cm (used to flag the path delay)
 - * The radial ground distance from the sub-satellite point along nadir from which land contamination of path delay is lower with along-track averaging than without (used to flag the radiometer main beam brightness temperatures for their proper selection in the along-track averaging procedure).

2.45.3.2. Output data

- Land fraction of the radiometer measurement for path delay flag
- Land fraction of the radiometer measurement for main beam brightness temperatures flag

2.45.3.3. Mathematical statement

The mathematical statement is detailed in Ruf, 1999a. From the antenna pattern characteristics and an approximate path delay retrieval algorithm, a single radial ground distance from the sub-satellite point along nadir can be estimated at which land contamination would be sufficient to corrupt the subsequent path delay estimate by approximately 5 mm. This distance is 50 km. It is therefore recommended that path delay retrievals within 50 km of land be flagged as possibly contaminated. On the other hand, as path delay retrievals at distances from land greater than approximately 25 km have lower error with along track averaging than without, it is also recommended that brightness temperature samples be eliminated from the along track averaging algorithm when they are within 25 km from land. This 25-km distance is different from the 50-km distance at which the path delay algorithm begins to degrade. The difference is due to the fact that, even with degraded performance, it is still preferable to maintain along track averaging between 25 and 50 km from land in order to maximize the partial cancellation of brightness temperature errors in the path delay algorithm. The present algorithm thus outputs two radiometer

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surface type flags. The first one acts as a path delay quality flag : it corresponds to the 50-km⁻distance. The second one is only used for proper selection of main beam brightness temperatures in the along track averaging algorithm : it corresponds to the 25-km distance.

Each of these two distances is translated into the number of grid points of the land/sea mask file to include in a search for land presence around the location of the radiometer measurement (note that the same land/sea mask file is used in the altimeter processing to determine the surface type for the altimeter). The percentage of grid points within this search area that are set to "continental ice" or "land" is then determined. Subsequent computations will assume that if this percentage is > 0, then the measurement is contaminated by land.

⁽¹⁾ The surface type value is the percentage of grid points set to "continental ice" or "land" within the distance Dmin_PD

⁽²⁾ The surface type value is the percentage of grid points set to "continental ice" or "land" within the distance Dmin_TB

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2.46. GEN_ENV_SUR_02 - To compute the Ocean/Sea-Ice flag and Classes Memberships

2.46.1. Heritage

ENVISAT

2.46.2. Function

To compute a 6-states ocean/sea-ice flag indicating open water or sea-ice type (i.e. first-year ice, multiyear ice, wet ice, ambiguous / mixture of type) along with an additional "not evaluated" state in case of failure. This information is completed with the 4 memberships values (between 0 and 1) associated to the 4 classes (open water, first-year ice, multi-year ice, and wet ice) to allow user to set their own threshold on the membership value.

2.46.3. Algorithm definition

2.46.3.1. Input data

- Datation:
 - Altimeter time-tag (1 Hz)
- Location:
 - Latitude of the altimeter measurement (1 Hz)
 - Longitude of the altimeter measurement (1 Hz)
- Altimeter surface type
- Backscatter coefficient:
 - Backscatter coefficient corrected for atmospheric attenuation (main band)
 - Associated validity flag (main band)
- Brightness temperatures (interpolated at altimeter time tags):
 - 23.8 GHz brightness temperature (1 Hz)
 - 36.5 GHz brightness temperature (1 Hz)
- Radiometer interpolation quality flag
- Processing parameters (SAD)

2.46.3.2. Output data

- Ocean/Sea-ice flag
- Memberships value associated to the 4 classes (open water, first-year ice, multi-year ice, and wet ice)

2.46.3.3. Mathematical statement

The state of the flag (i.e. the open water/sea-ice type) is derived from a set of measurements that includes the Ku-band backscatter coefficient and the two brightness temperatures.

First, this set is used to compute the input parameters vector \vec{x} (x₁, x₂, x₃) of the clustering algorithm as:

• x_1 = average of TB,

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- $x_2 = Ku$ -band $\sigma 0$
- x₃ = TB difference defined as (TB_36.5 TB_23.8).

Then, the location and time of the measured data is used to identify the concerned polar region (i.e. Arctic or Antarctic) and the season (i.e. winter or summer) in order to determine the appropriate mask (seeFigure 3) that specifies where the algorithm has to be used.



Figure 3 - Geographical masks: in blue for winter and in red for summer.

The classes' memberships are computed from a matrix of tie-point M ($\vec{t}_{p1}, \vec{t}_{p2}, ...$) that was specified during the development phase (i.e. determination of the number of cluster and the coordinates of the tie-point associated to each cluster in the input space, see "References"). The tie-point matrix defines a partition of the input space into a given number of clusters.

Standard Euclidean distances are used to compute the different membership values between a given observation \vec{x} and each tie-point vector \vec{t}_{pi} of the clustering algorithm.

Then the observation \vec{x} is assigned to the cluster with the closest tie-point vector in term of distance which can also be said as: the observation \vec{x} is assigned to the cluster with the highest computed membership. The state of the flag can be set.

Finally, the validity mask and a post-classification correction are applied for specific known cases of bad classification.

⁽¹⁾ Set to "RA2" or "RA2+MWR"

⁽²⁾ Day of the year

⁽³⁾ 4 states ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", "land")

⁽⁴⁾ Two states : "valid", or "invalid"

⁽⁵⁾ 4 states: "good", "interpolation with gap", "extrapolation", or "fail"

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2.47. GEN_ENV_SUR_03 - To compute the Continental Ice flag

2.47.1. Heritage

None

2.47.2. Function

To compute a 14-state flag indicating the type of the ice-sheet snow facies ("0: not evaluated", "1: Greenland type 1", "2: Greenland type 2", "3: Greenland type 3", "4: Greenland type 4", "5: Greenland type 5", "6: Greenland type 6", "11: Antarctica type 1", "12: Antarctica type 2", "13: Antarctica type 3", "14: Antarctica type 4", "15: Antarctica type 5", "16: Antarctica type 6", "17: Antarctica type 7")

2.47.3. Algorithm definition

2.47.3.1. Input data

- Datation:
 - Altimeter time-tag (1 Hz)
- Location:
 - Latitude of the altimeter measurement (1 Hz)
 - Longitude of the altimeter measurement (1 Hz)
- Altimeter surface type
- Backscatter coefficient:
 - Backscatter coefficient corrected for atmospheric attenuation (main band)
 - Associated validity flag (main band)
 - Backscatter coefficient corrected for atmospheric attenuation (auxiliary band)
 - Associated validity flag (auxiliary band)
- Brightness temperatures (interpolated at altimeter time tags):
 - 23.8 GHz brightness temperature (1 Hz)
 - 36.5 GHz brightness temperature (1 Hz)
- Radiometer interpolation quality flag
- Processing parameters (SAD)

2.47.3.2. Output data

• Ice-sheet snow facies type flag

⁽⁶⁾ 6 states : "0: ocean", "1: first-year sea-ice", "2: wet ice", "3: multi-year sea-ice", "4: ambiguous / mixture of type" or "5: not evaluated"

⁽⁷⁾ Values between 0 and 1

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2.47.3.3. Mathematical statement

The state of the flag (i.e. the ice-sheet snow facies type) is derived from a set of measurements that includes the two backscatter coefficients and the two brightness temperatures.

First, this set is used to compute the input parameters vector \vec{x} (x₁, x₂, x₃, x₄) of the clustering algorithm as:

- $x_1 = Ku$ -band $\sigma 0$,
- x₂ = average of TB,
- x₃ = ratio of TB defined as (TB_23.8 TB_36.5) / (TB_23.8 + TB_36.5),
- $x_4 = \sigma 0$ difference defined as (Ku $\sigma 0 C \sigma 0$).

Then, the location of the measured data is used to identify the concerned ice-sheet (i.e. Greenland or Antarctica) in order to use the appropriate matrix of tie-point M (\vec{t}_{p1} , \vec{t}_{p2} , ...) among the two available ones that were specified during the development phase (i.e. determination of the number of cluster and the coordinates of the tie-point associated to each cluster in the input space, see "References"). Each tie-point matrix defines a partition of the input space into a given number of clusters.

Standard Euclidean distances are computed between a given observation \vec{x} and each tie-point vector \vec{t}_{ni} of the selected clustering algorithm.

Then the observation \vec{x} is assigned to the cluster with the closest tie-point vector in term of distance which can also be said as: the observation \vec{x} is assigned to the cluster with the highest computed membership. The state of the flag can be set.

⁽¹⁾ Set to "RA2" or "RA2+MWR"

⁽²⁾ 4 states ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", "land")

⁽³⁾ Two states : "valid", or "invalid"

⁽⁴⁾ Two states : "valid", or "invalid"

⁽⁵⁾ 4 states: "good", "interpolation with gap", "extrapolation", or "fail"

⁽⁶⁾ 14 states : "0: not evaluated", "1: Greenland type 1", "2: Greenland type 2", "3: Greenland type 3", "4: Greenland type 4", "5: Greenland type 5", "6: Greenland type 6", "11: Antarctica type 1", "12: Antarctica type 2", "13: Antarctica type 3", "14: Antarctica type 4", "15: Antarctica type 5", "16: Antarctica type 6", "17: Antarctica type 7"

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2.48. GEN_ENV_TID_01 - To compute the solid earth and the equilibrium long period ocean tide heights

2.48.1. Heritage

TOPEX/Poseidon-1, Jason-1, Jason-2, ENVISAT

2.48.2. Function

To compute the solid earth tide height and the height of the equilibrium long period ocean tide.

2.48.3. Algorithm Definition

2.48.3.1. Input data

- Datation:
 - Altimeter time tag
- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Cartwright and Edden tables of tide potential amplitudes of the 6 astronomical variables at the reference epoch (22 May 1960 at 12H).
- Frequencies ω_i and phases ϕ_i at 0h on 1/1/1900, of 5 astronomical variables, respectively the mean longitude of the moon, the mean longitude of the sun, the mean longitude of the lunar perigee, the negative of the mean longitude of the lunar ascending node and the mean longitude of the solar perigee
- Processing parameters:
 - Love numbers

2.48.3.2. Output data

- Height of the solid Earth tide
- Height of the equilibrium long period ocean tide

2.48.3.3. Mathematical statement

The gravitational potential V induced by an astronomical body can be decomposed into harmonic constituents s, each characterized by an amplitude, a phase and a frequency. Thus, the tide potential can be expressed as:

$$V = \sum_{n=2}^{\infty} \sum_{s} V_n(s)$$
 (1)

where the tide potential of constituents $V_n(s)$, is given by:

$$V_{n}(s) = g.c_{n}(s).\sum_{m=0}^{n} W_{n}^{m}.cos[\omega(s).t + \phi(s) + m.\lambda] \leftarrow for(m+n) = even$$

$$V_{n}(s) = g.c_{n}(s).\sum_{m=0}^{n} W_{n}^{m}.sin[\omega(s).t + \phi(s) + m.\lambda] \leftarrow for(m+n) = odd$$
(2)

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where the phase $\omega(s).t + \phi(s)$ of constituents at altimeter time tag t (relative to the reference epoch), is given by a linear combination of the corresponding phases of the 6 astronomical variables $\omega_i.t + \phi_i$:

$$\omega(\mathbf{s}).\mathbf{t} + \phi(\mathbf{s}) = \sum_{i=1}^{6} k_i(\mathbf{s}).[\boldsymbol{\varpi}_i.\mathbf{t} + \phi_i]$$
(3)

where λ is the altimeter longitude, where W_m^n is the associated Legendre polynomial (spherical harmonic) of degree n and order m ($W_m^n(\sin\theta)$, with θ altimeter latitude), and where g is gravity.

The Cartwright and Edden tables provide for degree n=2 and order m=0,1,2, and for degree n=3 and order m=0,1,2,3 the $k_i(s)$ coefficients and the amplitudes $c_n(s)$ for each constituent s (only amplitudes exceeding about 0.004 mm have been computed by Cartwright and Tayler (1971), and Cartwright and Edden (1973)). This allows for the potential to be computed.

The solid Earth tide height and the height of the equilibrium long period ocean tide are both proportional to the potential. The proportionality factors are the so-called Love number H_n and K_n .

The solid Earth tide height H_solid is thus:

H_Solid = H₂.
$$\frac{V_2}{g}$$
 + H₃. $\frac{V_3}{g}$ (4)

with: $H_2 = 0.609$ $H_3 = 0.291$ g = 9.80 $V_2 = V_{20} + V_{21} + V_{22}$ $V_3 = V_{30} + V_{31} + V_{32} + V_{33}$

The height of the static equilibrium long period ocean tide H_Equi is thus:

$$H_Equi = (1 - H_2 + K_2) \frac{V_{20}}{g} + (1 - H_3 + K_3) \frac{V_{30}}{g}$$
(5)

with: $K_2 = 0.302$ $K_3 = 0.093$

•

The above described tide contributions do not take into account the permanent tide.

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2.49. GEN_ENV_TID_02 - To compute the non equilibrium long period ocean tide height

2.49.1. Heritage

Jason-1, Jason-2

2.49.2. Function

In "GEN_ENV_TID_01 - To compute the solid earth and the equilibrium long period ocean tide heights", the long period waves of the tidal spectrum are computed using a specific algorithm derived from the works of Cartwright et al. This algorithm uses 15 equilibrium long period waves. Besides, FES2004 is distributed with 4 dynamical long period waves (Mf, Mm, Mtm, Msqm). The aim of this algorithm is to provide a correction to the long period ocean tide height (provided by GEN_ENV_TID_01), which will replace the 12 equilibrium waves Mm, Mf, Mtm, Msqm, Mm', Mf', Mf'', Mf''', Mtm', Mtm'', Msqm' and msqm' of the Cartwright algorithm by the 4 dynamical waves Mf, Mm, Mtm, Msqm of the FES2004 solution (Msqm is not included in the Cartwright algorithm).

This correction, called the "non equilibrium long period ocean tide height", is the difference between the sum of 4 dynamical long period tide from the harmonic components algorithm (using model FES) and the sum of the 12 equilibrium waves (using Cartwright algorithm).

2.49.3. Algorithm Definition

2.49.3.1. Input data

- Datation:
 - Altimeter time tag
- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Harmonic coefficients maps of 4 long period waves: Mf, Mm, Mtm, Msqm) (SAD)
- The frequencies and the phases at 0h on 1/1/1900 of five astronomical variables, respectively the mean longitude of the moon, the mean longitude of the sun, the mean longitude of the lunar perigee, the negative of the mean longitude of the lunar ascending node and the mean longitude of the solar perigee.
- The frequencies of the 12 tidal waves

2.49.3.2. Output data

• Non equilibrium long period ocean tide height (i.e. correction of the equilibrium long period tidal wave by the dynamical long period wave)

2.49.3.3. Mathematical statement

In the following we only take into account the long period components of the tidal spectrum. The semidiurnal and diurnal part of the tidal spectrum is computed by "GEN_ENV_TID_03 - To compute the diurnal and semidiurnal elastic ocean tide height and the load tide height (solution 2 - 11 waves)".

The height of the ocean tide (semi-diurnal, diurnal tidal waves) is the sum of N tidal constituents h_i:

$$\mathbf{h}_{i} = \mathbf{F}_{i} \left[\mathbf{A}_{i}(\phi, \mu) . \cos(\psi_{i}) + \mathbf{B}_{i}(\phi, \mu) . \sin(\psi_{i}) \right] \quad (i=1, N)$$
(1)

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with: $\psi_i = \sigma_i t + X_i + U_i$

F_i is the tidal coefficient of amplitude nodal correction (depends only on the altimeter time)

- U_i is the tidal phase nodal correction (depends only on the altimeter time)
- X_i is the tidal astronomical argument (depends only on the altimeter time)

 σ_i is the tidal frequency

t, ϕ and μ are respectively the altimeter time tag, latitude and longitude

 $A_i(\phi,\mu)$ and $B_i(\phi,\mu)$ are harmonic coefficients bilinearly interpolated at the altimeter location (ϕ,μ) from the input harmonic coefficients map given by the FES2004 model by Lyard & Lefèvre, et al. (2006). Harmonic coefficients A and B are tidal amplitude x cos(phase) and tidal amplitude x sin(phase) respectively.

N = 12 tidal constituents are used.

•

 $^{^{(1)}}$ The harmonic coefficients have to be converted from 10^{-4} m to m, excepted those which are set to a default value

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2.50. GEN_ENV_TID_03 - To compute the diurnal and semidiurnal elastic ocean tide height and the load tide height (solution 2 - 11 waves)

2.50.1. Heritage

TOPEX/Poseidon, ERS-1, ERS-2, Jason-1, Jason-2, ENVISAT

2.50.2. Function

- To compute the sum total of the diurnal and semidiurnal ocean tide from the harmonic components algorithm (using model FES) . The ocean tide height does not include the load tide height.
- To compute the height of the diurnal and semi-diurnal tidal loading induced by the ocean tide predicted by the model that was also used to compute the ocean tide height (solution 2).
- To add the ocean tide and the load tide to compute the elastic ocean tide.
- To add the height of the equilibrium long period ocean tide (issued from "GEN_ENV_TOD_01 To compute the solid earth and the equilibrium long period ocean tide heights") to the elastic ocean tide, to compute the geocentric ocean tide that is provided in output.

2.50.3. Algorithm Definition

2.50.3.1. Input data

- Datation:
 - Altimeter time tag
- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Height of the equilibrium long period ocean tide
- Harmonic coefficients maps of the principal tidal waves (SAD)
- Load tide harmonic coefficients maps of the principal tidal waves (SAD)
- Frequencies ω_i and phases ϕ_i at 0h on 1/1/1900, of 5 astronomical variables, respectively the mean longitude of the moon, the mean longitude of the sun, the mean longitude of the lunar perigee, the negative of the mean longitude of the lunar ascending node and the mean longitude of the solar perigee
- The frequencies of the 29 tidal waves
- The admittance parameters

2.50.3.2. Output data

- Geocentric ocean tide height (solution 2)
- Height of the tidal loading (solution 2)

2.50.3.3. Mathematical statement

- The height of the ocean tide (semi-diurnal and diurnal tidal waves) is the sum of N tidal constituents h_i :

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$$h_{i} = F_{i} [A_{i}(\phi, \mu) . \cos(\psi_{i}) + B_{i}(\phi, \mu) . \sin(\psi_{i})] \quad (i=1, N)$$
(1)

with: $\psi_i = \sigma_i t + X_i + U_i$

 F_i is the tidal coefficient of amplitude nodal correction (depends only on the altimeter time)

U_i is the tidal phase nodal correction (depends only on the altimeter time)

 X_i is the tidal astronomical argument (depends only on the altimeter time)

 σ_{i} is the tidal frequency

t, ϕ and μ are respectively the altimeter time tag, latitude and longitude

 $A_i(\phi,\mu)$ and $B_i(\phi,\mu)$ are harmonic coefficients bilinearly interpolated at the altimeter location (ϕ,μ) from the input harmonic coefficients map given by the FES2004 model by Lyard & Lefèvre, et al. (2006). Harmonic coefficients A and B are tidal amplitude x cos(phase) and tidal amplitude x sin(phase) respectively. N = 29 tidal constituents are used. Among these 29 tidal constituents, 11 principal ones are given in input amplitudes and phases maps, the 18 remaining ones are computed by admittance from the principal constituents 1 to 9, using processing parameters.

• The height of the tidal loading is the sum of N constituents h_i:

$$\mathbf{h}_{i} = \mathbf{F}_{i} \left[\mathbf{C}_{i}(\phi, \mu) \cdot \cos(\psi_{i}) + \mathbf{D}_{i}(\phi, \mu) \cdot \sin(\psi_{i}) \right] \quad (i=1, N)$$
(2)

 $C_i(\phi,\mu)$ and $D_i(\phi,\mu)$ are harmonic coefficients bilinearly interpolated at the altimeter location (ϕ,μ) from the input harmonic coefficients map. This map has been computed from Francis and Mazzega's method (1991): this method consists of evaluating a convolution integral over the loaded region (the oceans) with a kernel (so-called Green's function) which is the response of the media (the Earth) to a point mass load. The used ocean tide model is the FES2004 model (computations made by O. Francis).

• The height of the geocentric ocean tide height is the sum of the height of the ocean tide, the height of the tidal loading and the height of the equilibrium long period ocean tide (input of the algorithm)

•

 $^{^{(1)}}$ The harmonic coefficients have to be converted from 10^{-4} m to m, excepted those which are set to a default value

⁽¹⁾ Solution 2

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2.51. GEN_ENV_TID_04 - To compute the diurnal and semidiurnal elastic ocean tide height and the load tide height (solution 1 - 28 components)

2.51.1. Heritage

TOPEX/Poseidon, ERS-1, ERS-2, Jason-1, Jason-2, ENVISAT

2.51.2. Function

- To compute the sum total of the diurnal and semidiurnal ocean tide from the GOT00 (see "References") harmonic components algorithm (using GOT00 model). The ocean tide height does not include the load tide height.
- To compute the height of the diurnal and semi-diurnal tidal loading induced by the ocean tide predicted by the model that was also used to compute the ocean tide height (solution 1: GOT00 harmonic components).
- To add the ocean tide and the load tide to compute the elastic ocean tide.
- To add the height of the equilibrium long period ocean tide (issued from "GEN_ENV_TID_01 : To compute the solid earth and the equilibrium long period ocean tide heights") to the elastic ocean tide, to compute the geocentric ocean tide that is provided in output.

2.51.3. Algorithm Definition

2.51.3.1. Input data

- Datation:
 - Altimeter time tag
- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Height of the equilibrium long period ocean tide
- Harmonic coefficients maps of the principal tidal waves (SAD)
- Load tide harmonic coefficients maps of the principal tidal waves (SAD)
- The frequencies and the phases at 0h on 1/1/1900 of five astronomical variables, respectively the mean longitude of the moon, the mean longitude of the sun, the mean longitude of the lunar perigee, the negative of the mean longitude of the lunar ascending node and the mean longitude of the solar perigee
- The frequencies of the 28 tidal waves
- The admittance parameters

2.51.3.2. Output data

- Geocentric ocean tide height (solution 1 = GOT00 harmonic components)
- Height of the tidal loading (solution 1 = GOT00 harmonic components)

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2.51.3.3. Mathematical statement

• The height of the ocean tide (semi-diurnal and diurnal tidal waves) is the sum of N tidal constituents hi:

$$\mathbf{h}_{i} = \mathbf{F}_{i} \left[\mathbf{A}_{i}(\phi, \mu) . \cos(\psi_{i}) + \mathbf{B}_{i}(\phi, \mu) . \sin(\psi_{i}) \right] \quad (i=1, N)$$
(1)

with: $\psi_i = \sigma_i t + X_i + U_i$

 F_i is the tidal coefficient of amplitude nodal correction (depends only on the altimeter time)

- $U_{i}\xspace$ is the tidal phase nodal correction (depends only on the altimeter time)
- X_i is the tidal astronomical argument (depends only on the altimeter time)
- σ_i is the tidal frequency
- t, ϕ and μ are respectively the altimeter time tag, latitude and longitude

 $A_i(\phi,\mu)$ and $B_i(\phi,\mu)$ are harmonic coefficients bilinearly interpolated at the altimeter location (ϕ,μ) from the input harmonic coefficients map given by the GOT00 model (Ray, 1999). Harmonic coefficients A and B are tidal amplitude x cos(phase) and tidal amplitude x sin(phase) respectively.

• The height of the tidal loading is the sum of N constituents hi:

$$\mathbf{h}_{i} = \mathbf{F}_{i} \left[\mathbf{C}_{i}(\phi, \mu) \cdot \cos(\psi_{i}) + \mathbf{D}_{i}(\phi, \mu) \cdot \sin(\psi_{i}) \right] \quad (i=1, N)$$
(2)

 $C_i(\phi,\mu)$ and $D_i(\phi,\mu)$ are harmonic coefficients bilinearly interpolated at the altimeter location (ϕ,μ) from the input harmonic coefficients map. This map has been computed from Ray (1999). N = 26 tidal constituents were used. Among these 26 tidal constituents, 8 principal ones were given in input amplitudes and phases maps, the 18 remaining ones were computed by admittance from the principal constituents 1 to 8, using admittance coefficients.

Two additional principal waves (S1 and M4) are taken into account, leading thus to a total number of 28 components.

• The height of the geocentric ocean tide height is the sum of the height of the ocean tide, the height of the tidal loading and the height of the equilibrium long period ocean tide (input of the algorithm)

 $^{^{(1)}}$ The harmonic coefficients have to be converted from 10^{-4} m to m, excepted those which are set to a default value

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2.52. GEN_ENV_TID_05 - To compute the pole tide height

2.52.1. Heritage

TOPEX/Poseidon, Jason-1, Jason-2, ENVISAT

2.52.2. Function

To compute the geocentric tide height due to polar motion.

2.52.3. Algorithm Definition

2.52.3.1. Input data

- Datation:
 - Altimeter time tag
- Location:
 - Latitude of the measurement
 - Longitude of the measurement
- Surface type ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", or "land")
- Pole location data (DAD):
 - Date
 - x (along the 0° meridian arc second)
 - y (along the 90°W meridian arc second)
- Processing parameters (SAD):
 - Average pole position (arc second): x_avg, y_avg
 - Scaled amplitude factor: A

2.52.3.2. Output data

• Height of the pole tide: H_Pole

2.52.3.3. Mathematical statement

The Earth's rotational axis oscillates around its nominal direction with apparent periods of 12 and 14 months. This results in an additional centrifugal force which displaces the surface. The effect is called the pole tide. It is easily computed if the location of the pole is known (Wahr, 1985), by:

$$H_Pole = A.sin(2\phi) [(x - x_avg).cos(\lambda) - (y - y_avg).sin(\lambda)]$$
(1)

where H_Pole is expressed in m, and where λ and ϕ are respectively the longitude and latitude of the measurement. x and y are the nearest previous pole location data relative to the altimeter time.

A is the scaled amplitude factor in m:

$$A = -\frac{\Omega^2 R^2}{2 g} \cdot \frac{\pi}{180 \times 3600} \cdot (1 + K_2) \text{ open ocean or semi-enclosed seas}$$
(2)

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 $A = -\frac{\Omega^2 R^2}{2 g} \cdot \frac{\pi}{180 \times 3600} \cdot H_2 \text{ over other surfaces (enclosed seas or lakes, land, continental ice)(3)}$

where Ω is the nominal earth rotation angular velocity in radian/s, R is the earth radius in m, g is gravity in m/s², $\frac{\pi}{180 \times 3600}$ is a conversion factor from arc second to radian, H₂ and K₂ are Love numbers (H₂ = 0.609, K₂ = 0.302). Over ocean, A = -69.435 10⁻³.

•

⁽¹⁾ 4 states ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", "land").

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2.53. RAD_PHY_ATT_01 - To compute the SRAL sigma0 atmospheric attenuations

2.53.1. Heritage

ENVISAT

2.53.2. Function

To compute the altimeter backscatter coefficient (Sigma0) atmospheric attenuation in both bands.

2.53.3. Algorithm Definition

2.53.3.1. Input data

- Brightness temperatures:
 - Radiometer brightness temperatures
- Land flag:
 - Radiometer land flag
- Backscatter coefficient
 - Ku-band ocean backscatter coefficient
 - Ku-band ocean backscatter coefficient validity flag
- Processing parameters (SAD)

2.53.3.2. Output data

- Backscatter coefficient two-way atmospheric attenuation for Ku band
- Backscatter coefficient two-way atmospheric attenuation for C band

2.53.3.3. Mathematical statement

As for the ENVISAT mission, the Ku-band and C-band backscatter coefficient two-way atmospheric attenuations are computed from the MWR 23.8 GHz and 36.5 GHz brightness temperatures (interpolated at the SRAL time tag) and from the Ku-band sigma0, using a neural network function.

For non nominal cases (failure of the interpolation of radiometer data to altimeter time-tags, or MWR measurement over land, or brightness temperatures out-of-range, or invalid backscatter coefficient), the backscatter coefficient two-way atmospheric attenuations are computed (in dB) by:

$$Att_sigma0 = 2.\tau_c$$
 (1)

where τ_c is the opacity in dB, given by:

$$\tau_{c} = \gamma_{0} + \gamma_{P}.Vap_Clim + \gamma_{L}.Cloud_Liq_Clim$$
(2)

Vap_Clim and Cloud_Liq_Clim are climatological values for water vapor content in g.cm⁻² and for cloud liquid water content in kg.m⁻².. γ_0 , γ_p and γ_L are calculated - for Ku and C bands - by using the analytical expressions for the oxygen, water vapor and non-raining clouds absorption coefficients given in Ulaby et al. (1981). The US Standard atmosphere was used to compute the oxygen opacity γ_0 . The Arctic, US Standard and Tropical atmospheres were used to compute the water vapor opacity and finally γ_p was derived by regression against the columnar water content of the three atmospheres. γ_L was computed assuming a constant mean cloud temperature of 275 K.

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2.54. RAD_PHY_GEN_01 - To compute the MWR geophysical parameters at SRAL time tag

2.54.1. Heritage

ERS-1, ERS-2, ENVISAT

2.54.2. Function

To compute the MWR geophysical parameters (wet tropospheric correction, water vapor and cloud liquid water contents) at SRAL time tag.

2.54.3. Algorithm Definition

2.54.3.1. Input data

- Brightness temperatures:
 - Radiometer brightness temperatures
- Backscatter coefficient
 - Ku-band ocean backscatter coefficient
 - Ku-band ocean backscatter coefficient validity flag
- Processing parameters (SAD)

2.54.3.2. Output data

- Radiometer wet tropospheric correction
- Water vapor content
- Cloud liquid water content

2.54.3.3. Mathematical statement

As for the ENVISAT mission, the MWR geophysical parameters (wet tropospheric correction, water vapor and cloud liquid water contents) are computed from the MWR 23.8 GHz and 36.5 GHz brightness temperatures (interpolated at the SRAL time-tag) and from the Ku-band sigma0, using a neural network function.

⁽¹⁾ Set to "SRAL" or "SRAL+MWR"

⁽¹⁾ Two states : "valid", or "invalid"

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2.55. RAD_PHY_GEN_02 - To compute the wet troposphere correction at SRAL time tag (using SST and Gamma parameters)

2.55.1. Heritage

ENVISAT

2.55.2. Function

To compute the wet tropospheric correction from the radiometer brightness temperatures, from the Kuband backscattering coefficient, from the sea surface temperature and from the lapse rate (decreasing rate of the atmosphere temperature with altitude).

2.55.3. Algorithm Definition

2.55.3.1. Input data

- Time
- Location
- Radiometer measurements :
 - Brightness temperature at 23.8 GHz interpolated at the altimeter time tag
 - Brightness temperature at 36.5 GHz interpolated at the altimeter time tag
- Altimeter surface type
- Altimeter measurement :
 - Ku-band ocean backscattering coefficient not corrected for the atmospheric attenuation
 - Ku-band ocean backscattering coefficient validity flag
- Processing parameters
- Additional physical information
 - Sea surface temperature (4 seasonal tables, 2° resolution)
 - Lapse rate (climatological table, 1° resolution)

2.55.3.2. Output data

• Wet tropospheric correction

2.55.3.3. Mathematical statement

The wet tropospheric correction is computed from the 5 inputs using a neural network function.

⁽¹⁾ Two states : "valid", or "invalid"

⁽²⁾ 4 states ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", "land").

⁽³⁾ Set to "SRAL" or "SRAL+MWR"

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2.56. RAD_PHY_GEN_03 - To compute the wet tropospheric composite correction

2.56.1. Heritage

CNES/CLS PISTACH Jason-2 project.

2.56.2. Function

To compute a wet tropospheric correction based on both radiometer and model corrections over areas where the radiometer wet troposphere correction is missing or supposed as invalid due to the proximity of emerged lands: coastal areas and/or radiometer gaps in open oceans. The overall principle of this correction is to take advantage of the dynamics of the model correction where the radiometer correction cannot be used.

For example, in the basic ocean/land transition case, the composite wet tropospheric correction takes:

- the values of the radiometer correction when the satellite if far enough from the shoreline (50 km for Jason-2, adjustable for S3),
- the values of the model correction plus an offset that corresponds to the bias between the radiometer and the model correction at the place of the last valid radiometer correction.

2.56.3. Algorithm Definition

2.56.3.1. Input data

- Coastal configuration type (SAD)
- Model wet tropospheric correction
- Radiometer wet tropospheric correction
- Processing parameters (SAD)

2.56.3.2. Output data

• Composite wet tropospheric correction

2.56.3.3. Mathematical statement

The composite wet tropospheric correction is computed for an entire track segment.

The radiometer correction and the model correction must be computed over the entire track segment before starting the processing of the composite wet tropospheric correction. The coastal configuration type is also assumed to be defined for the considered track segment.

The methodology identifies several configuration types combining both the geographical position of the measurement relative to the coasts and/or the validity of the radiometer correction.

Description of the various configuration:

- OPEN_OCEAN:
 - \circ the nadir of the satellite is far enough (about ~50km) from the closest emerged land
 - the radiometer wet tropospheric correction is present and valid
 - then the composite correction is equal to the radiometer correction:

Composite_Correction(i) = Radiometer_Correction(i)

.....

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COASTAL PATH:

- the entire track segment is too close from any emerged land. Therefore, there is no valid 0 radiometer correction in the immediate vicinity of the measurement locations then the composite correction is equal to the model correction:
 - Composite_Correction(i) = Model_Correction(i)
- **TRANSITION:**
 - One end of the track segment holds a valid radiometer wet tropospheric correction (open 0 ocean end)
 - The other end of the track segment is located near the coasts, 0
 - Then, the composite correction is equal to the values of the model correction plus an 0 offset that corresponds to the bias between the radiometer and the model correction at open ocean end:

Composite Correction(i) = Model Correction(i) - DeltaModRad

where

DeltaModRad = Model_Correction - Radiometer_Correction at the open ocean end of the segment

SHORT_HOLE:

- Some radiometer wet tropospheric corrections are missing or are invalid along a short (< ~200km) track segment
- Then the composite correction is interpolated along the track segment based on the valid 0 radiometer wet corrections at each end of the segment:

Composite_Correction(i) = Radiometer_Correction(SegmentStartIndex)

+ (i - SegmentStartIndex) * Inc

where

Inc = (Radiometer_Correction(SegmentEndIndex) -

Radiometer_Correction(SegmentStartIndex))

/ (SegmentEndIndex - SegmentStartIndex)

LARGE HOLE:

- Some radiometer wet tropospheric corrections are missing or are invalid along a large (> 0 ~200km) track segment, too large so that the radiometer correction cannot be interpolated
- The model correction is used instead but is "detrented" so that each end of the segment fit the nearby valid radiometer wet tropospheric corrections:

Composite_Correction(i) = Model_Correction(i) + (i-SegmentStartIndex) * Slope

+ Radiometer_Correction(SegmentStartIndex)

Model_Correction(SegmentStartIndex)

where

Slope = ((Radiometer_Correction(SegmentEndIndex)

- Radiometer_Correction(SegmentStartIndex))

(Model_Correction(SegmentEndIndex))

- Model Correction(SegmentStartIndex)))

/ (SegmentEndIndex - SegmentStartIndex)

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2.57. RAD_PHY_TEM_01 - To co-localize the radiometer pixels

2.57.1. Heritage

Envisat

2.57.2. Function

To perform the co-location of radiometer measurements from the two channels

2.57.3. Algorithm Definition

2.57.3.1. Input data

- Radiometer time tags for the two channels
- Brightness temperatures for the two channels
- Latitude, Longitude of the channel 1 measurement
- Minimum number of measurement to be skipped (shift)
- Number of measurements to be checked to account satellite altitude and velocity variations (N_Dshift)

2.57.3.2. Output data

- Co-located Brightness temperature for the two channels
- Latitude, Longitude of the co-located measurements
- Time tag of the co-located measurements

2.57.3.3. Mathematical statement

Principle

Co-location involves pairing radiometer measurements from the two channels which coincide over the same point on the Earth's surface. This is done by matching forward and backward channels with the same or very similar latitude and longitude.

A first approximation of the number of measurements to skip for alignment of the two channels is evaluated using the satellite altitude and velocity and the viewing angles of the channels. Moreover, due to the satellite altitude and velocity variations, it is possible that a variation in localisation could occur. For this reason, a check in the "N_Dshift" measurements after the "expected" one shall be performed to find the best fit in terms of datation.

Main steps of the processing

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The 23.8 GHz channel is looking forward and therefore the location is first available for Channel 1 and then for channel 2. Hence, for every measurement of channel 1 - starting from the first valid data, the corresponding one of Channel 2 is searched in the record about "shift" samples far from the actual.

First the calculated shift is applied in order to account the mean value of skipped measurement due to the "hard" mispointing of the two feeds.

j = i + shift

where "i" is the actual index of the channel 1 measurement and "j" is the actual index of the channel 2 measurement about which the correct data will be found

Then, being the evaluation of the shift made, a certain variation of this value is expected inside a fixed range due to the satellite altitude and velocity variations. So all the time tags of the data inside this range are checked in order to find the closest to the 23.8 GHz one:

min($Time_Tag_ch1(i) - Time_Tag_ch2(j+k)$) with k=0,N_Dshift

where N_Dshift is the number of measurement to be checked to account the satellite altitude and velocity variations

Let $j+k_0$ be the index of the channel 2 measurement closest to the actual channel 1 measurement.

Finally, the co-located brightness temperatures, the time tag and the location are computed using the indexes i and $j+k_0$.

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Annexe A - List of acronyms

ACQ	Acquisition
AD	Applicable Document
CAL	Calibration
CLS	Collecte Localisation Satellites
COG	Centre Of Gravity
GNSS	Global Navigation Satellite System
GPRW	Gain Profile Range Window
GPS	Global Positioning System
НК	Housekeeping
ISP	Instrument Source Packets
LRM	Low Resolution Mode
MDS	Measurement Data Set
MWR	MicroWave Radiometer
NA	Not Applicable
NRT	Near Real Time
NTC	Non Time Critical
ОВ	On-Board
POD	Precise Orbit Determination
PTR	Point Target Response
RD	Reference Document
RTN	Real Time Navigation
SAR	Synthetic Aperture radar
SRAL	SAR Radar Altimeter
STC	Short Time Critical
STM	Surface Topography Mission
TAI	International Atomic Time
ТВС	To Be Confirmed
TBD	To be defined
USO	Ultra Stable Oscillator

For any acronym that does not appear in this list, please refer to AD 5.