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SSALTO

ALGORITHM DEFINITION, ACCURACY AND SPECIFICATION VOLUME 4: CMA ALTIMETER LEVEL 2 PROCESSING

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ABBREVIATIONS

Abbreviation	Definition
ADA	Algorithm Definition and Accuracy
ADx	Applicable Document x
CLS	Collecte Localisation Satellites
CMA	Centre Multi-missions Altimétrique
CNES	Centre National d'Etudes Spatiales
CSR	Center for Space Research
DAD	Dynamic Auxiliary Data
DFT	Discrete Fourier Transform
DIP	Magnetic Inclination
DS	Data Set
DSR	Data Set Record
EMB	ElectroMagnetic Bias
ESA	European Space Agency
ESRIN	European Space Research Institute
ESTEC	European Space Research and Technology Centre
FDGDR	Fast Delivery Geophysical Data Record
FES	Finite Element Solution (ocean tide solution)
FFT	Fast Fourier Transform
FOS	Flight Operation Segment
GDR	Geophysical Data Record
COG	Center of Gravity
CMA	Centre Multi-missions Altimètre
GPS	Global Positioning System
GRGS	Groupe de Recherche en Géodésie Spatiale
IERS	International Earth Rotation Service
ITRF	Inertial Terrestrial Reference Frame
IGDR	Interim Geophysical Data Record
JMR	JASON Microwave Radiometer
JPL	Jet Propulsion Laboratory
LS	Least Square
LSE	Least Square Estimators
MDS	Measurement Data Set
MJD	Modified Julian Date
MLE	Maximum Likelihood Estimators
MPH	Main Product Header
MQE	Mean Quadratic Error
MSS	Mean Sea Surface
MSSL	Mullard Space Science Laboratory
MWR	MicroWave Radiometer (ENVISAT)

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Abbreviation	Definition
NGDC/WDC-A	National Geophysical Data Center/World Data Center A
NRT	Near Real Time
OCOG	Offset Center Of Gravity
OFL	Off-Line
PF	Platform
PTR	Point Target Response
RA-2	Radar Altimeter (ENVISAT)
RMS	Root Mean Square
RDx	Reference Document x
SAD	Static Auxiliary Data
SGDR	Sensor Geophysical Data Record
SLR	Satellite Laser Ranging
SNR	Signal to Noise Ratio
SPH	Specific Product Header
SSALTO	Segment Sol Altimétrie et Orbitographie
SSB	Sea State Bias
SV	State Vector
SVD	Singular Value Decomposition
SWH	Significant Waveheight
SWT	Science Working Team
TB	Tracker Bias
TBC	To Be Confirmed
TBD	To Be Defined
TEC	Total Electron Content
UTC	Universal Time Coordinate

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APPLICABLE AND REFERENCE DOCUMENTS

Reference	Document title	
TP2-SB-J0-102-CNES	AD1	JASON-1 Science and Operational Requirements
SMM-ST-M2-EA-10658-CN	AD2	CMA Requirements Specification
SMM-ST-M-EA-10879-CN	AD3	SSALTO Products Specifications - Volume 1: JASON-1 User Products
PO-TN-ESA-GS-0178	AD4	ENVISAT-1 RA-2 and MWR Products Specification
TP2-SB-J0-459-CNES	AD5	JASON-1 Products Description
PO-RS-MDA-GS-2009	AD6	ENVISAT-1 Products Specification. Vol. 14: RA-2 Products Specifications
SMM-MIF-M-EA-20054-CN	AD7	Manuel des Interfaces
SMM-IF-M/MTO-EA-11560-CN	AD8	Spécifications d'interface externe entre SSALTO et Météo-France
SMM-IF-M/IERS-EA-11561-CN	AD9	Spécifications d'interface externe entre SSALTO et l'IERS
SMM-IF-M/MEUDON-EA-11562-CN	AD10	Spécifications d'interface externe entre SSALTO et le bureau des Ursigrammes de l'observatoire de Meudon
SMM-ST-M2-EA-11010-CN	AD11	Algorithm Definition, Accuracy and Specification Volume 9: CMA Mechanisms
SMM-ST-M1-EA-20078-CN	AD12	POSEIDON-2 Level 1.0 Altimeter data product
SMM-ST-M1-EA-31023-CLS	AD13	JMR Level 1.0 data product
SMM-IF-M/JALT-EA-11870-CN	AD14	Spécifications d'interface entre SSALTO et les experts altimètre
SMM-IF-M2-EA-20207-CN	AD15	SSALTO internal Interfaces specification : CMA (CAL & TEC products)
SMM-IF-M/JRAD-EA-11871-CN	AD16	Interface specifications between SSALTO and the radiometer experts
PO-NT-RAA-003-CLS	RD1	Definition of the RA-2 Level 2 Ocean and Ice Retracking Algorithms, Issue 1 Rev. 0
CLS.OC/NT/95.028	RD2	RA-2 Retracking Comparisons over Ocean Surfaces, Issue 3 Rev. 1
CT/ED/TU/UD/96.188	RD3	Etude du retracking des formes d'ondes altimètriques au dessus des calottes polaires (CNES contract 856/2/95/CNES/0060, B. Legresy, 1995)
Numerical Recipes, Ed. 2	RD4	The Art of Scientific Computing in C (Edition 2). William H. Press, Brian P. Flaneery, Saul A. Teukolsky, William T. Vetterling
PO-SP-RAA-0006-CLS	RD5	Algorithms Specifications (Ocean and Ice2 FDGDR Processing), Issue 3 Rev. 2 (1)
PO-NT-RAA-0004-CLS	RD6	Algorithms Definition and Accuracy, Issue 2 Rev. 1
12133/96/NL-GS-DPM	RD7	ENVISAT-Ice Detailed Processing Model Document, Issue 3 Rev. 4 (2)

(1) Together with the following evolutions applicable to the CMA processing : SPR-CLS-RA2-L2-xxx with xxx = 004, 005, 007b, 010, 012, 015, 016 and 018.

(2) Together with the following evolutions applicable to the CMA processing : SPR-MSSL-RA2-L2-xxx with xxx = 002 and 004, and SPR-LIP-xxx with xxx = 005, 006 and 007.

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Reference	Document title
SMM-ST-M2-EA-11003-CN	RD8 Algorithm Definition, Accuracy and Specification Volume 2: CMA Altimeter Level 1b Processing
SMM-ST-M2-EA-11004-CN	RD9 Algorithm Definition, Accuracy and Specification Volume 3: CMA Radiometer Level 1b Processing
TP2-JALT-NT-605-CNES	RD10 Etude sur l'algorithme d'estimation sol, Issue 1 Rev. 0
SMM-ST-M2-EA-11011-CN	RD11 Algorithm Definition, Accuracy and Specification Volume 10: CMA Expertise processing
SMM-SP-M2-EA-32012-CLS	RD12 CMA production: Specifications of the Data management Algorithms
	RD13 NAG Fortran Library Manual – Mark 18

TBC AND TBD LIST

TBC/TBD	Section	Brief description
TBC	3.1.4	Update of the Doppler correction and of the dual-frequency ionospheric correction in the JASON-1 GDR processing
TBC	ALT_RET_OCE_02 - To perform the ocean-2 retracking	Impact of the non accounting for the skewness effects on the trailing edge regarding the recovery of the slope of the logarithm of the trailing edge from waveforms samples
TBD	GEN_COR_RAN_02 - To compute the Bent model ionospheric corrections	Processing
TBC	GEN_ENV_TID_03 - To compute the solid earth and the equilibrium long period ocean tide heights	Propagation of Cartwright and Edden coefficient tides to the 2000's era
TBC	ALT_RET_OCE_02 - To perform the ocean-2 retracking	Accuracy of algorithms (not critical)
TBD	GEN_COR_ORB_01 - To derive the orbital altitude rate with respect to the reference MSS/geoid ALT_RET_ICE_01 - To perform the ice-1 retracking ALT_RET_OCE_02 - To perform the ocean-2 retracking ALT_RET_SEA_01 - To perform the sea-ice retracking ALT_PHY_RAN_05 - To compute the on-ground retracked altimeter ranges ALT_PHY_BAC_04 - To compute the on-ground retracked backscatter coefficients ALT_PHY_SWH_01 - To compute SWH from the on-ground retracked composite Sigma ALT_PHY_MIS_02 - To compute the square of the off-nadir angle from the on-ground waveform-derived estimates ALT_COR_RAN_06 - To correct the altimeter range for Doppler effects ALT_COM_GEN_01 - To identify the elementary measurements to be compressed ALT_COM_RAN_06 - To edit and compress the elevation of echoing points ALT_COM_RAN_05 - To edit and compress the on-ground retracked altimeter ranges ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients ALT_COM_SWH_01 - To edit and compress the on-ground retracked	Accuracy of algorithms (not critical)

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TBC/TBD	Section	Brief description
	significant waveheights ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH ALT_COM_SNR_01 - To edit and compress the on-ground retracked amplitude of waveforms ALT_COM_SNR_02 - To edit and compress the on-ground retracked thermal noise level ALT_COR_GEN_03 - To compute the modeled instrumental corrections on the on-ground retracked parameters ALT_COR_RAN_08 - To compute the corrected on-ground retracked altimeter ranges ALT_COR_RAN_05 - To compute the corrected tracker range rates ALT_COR_SWH_02 - To compute the corrected on-ground retracked significant waveheights ALT_COR_BAC_02 - To compute the corrected on-ground retracked backscatter coefficients ALT_COR_RAN_09 - To update the Doppler correction on the altimeter range RAD_PHY_GEN_01 - To compute the JMR geophysical parameters GEN_ENV_SUR_02 - To compute the ice flag	

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1. INTRODUCTION

This document is aimed at defining and specifying the main functions of the nominal off-line Level 2 processing of:

- The ENVISAT altimeter (RA-2) and radiometer (MWR) data
- The JASON-1 altimeter (POSEIDON-2) and radiometer (JMR) data

The nominal off-line Level 2 processing of the ENVISAT RA-2 and MWR data have been defined in the framework of a previous study carried out by CLS and MSSL for ESA and CNES. Regarding the processing of ENVISAT data, the current document will thus mainly merge the definitions provided by CLS for the ocean and ice-2 processing (RD6) and by MSSL for the sea-ice and ice-1 processing (RD7).

Regarding the JASON-1 mission, the highest level requirements placed by the JASON Science Working Team upon the JASON project to meet the scientific and operational objectives of the mission are listed in AD1, and the requirements aimed at defining the CMA facility inside the SSALTO system are established in AD2. The processing of JASON-1 data will be as much as possible consistent with the processing of ENVISAT data when requirements for both missions can be met simultaneously.

For both missions, the off-line Level 2 processing consist of an IGDR processing and of a GDR processing (see AD4 for ENVISAT and AD5 for JASON-1):

- For ENVISAT:
  - The IGDR processing is aimed at providing IGDR parameters, from RA-2/MWR level 1b unconsolidated parameters, using restituted auxiliary data (meteorological fields, solar activity indexes, pole location, platform data, DORIS ionospheric data) and a DORIS preliminary orbit. "Unconsolidated" means parameters which do not account for the final instrumental calibration data.
  - The GDR processing is aimed at providing GDR parameters, from RA-2/MWR level 1b consolidated parameters, using the best restituted auxiliary data (meteorological fields, solar activity indexes, pole location, platform data, DORIS ionospheric data) and a DORIS precise orbit. "Consolidated" means parameters which account for the updated instrumental calibration data.
- For JASON-1:
  - The IGDR processing is aimed at providing IGDR parameters, from POSEIDON-2/JMR level 1b parameters, using restituted auxiliary data (meteorological fields, pole location, DORIS ionospheric data) and a DORIS preliminary orbit.
  - The GDR processing is aimed at providing GDR parameters, from IGDR parameters using improved auxiliary data (pole location) and a precise orbit (accounting for DORIS and/or SLR and/or GPS data).

The delay for the production of these products is given in AD5.

As previously mentioned, this document deals with both the definition of the altimeter level 2 procedures and the specification of their main functions.

Definition of the altimeter level 2 procedures

The definition of the altimeter level 2 procedures 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.

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Specifications of the altimeter level 2 procedures

Regarding the specifications of the altimeter level 2 procedures, two kinds of algorithms are distinguished:

- The "scientific" algorithms, which represent the core of the processing
- The other algorithms, which will be called the "data management" algorithms, ensuring functions such as:
  - To get the input data
  - To prepare the data to be processed (for example to select the orbit data set requested to compute the location of each altimeter measurement)
  - To perform unit conversions or changes in reference systems
  - To perform general checks (relevant for example to the presence of input files, to the data conformity or to the compatibility of input data with the data set to be processed)
  - To build the output product(s)
  - To manage the processing
  - To control the argument of mathematical functions (for example, negative argument for logarithmic or square root functions…)

The scientific algorithms are specified in this document and in AD11 for the mechanisms, which represent the functions common to several algorithms or the functions frequently requested within an algorithm. The data management algorithms, which strongly depend on the format of the input and output data, are specified in RD12 (and AD11 for the corresponding mechanisms, if any). The complete set of specifications (to be associated with the corresponding interfaces documents) are intended for the team in charge of the software development.

Conventions

The IGDR and GDR procedures are represented in this document as linear sets of functions which are aimed at building a set of IGDR or GDR parameters from a set of level 1b or IGDR parameters. This representation has been chosen for historical reasons in order to ease the understanding of the overall procedures, but it does not anticipate the organization or the sequencing of the algorithms within the CMA processor.

The ENVISAT and JASON-1 SGDR procedures, aimed at providing SGDR products, i.e. GDR products including waveforms, are not defined in this document, because they do not involve any specific scientific processing. Indeed, they mainly consist of the acquisition of level 1b waveforms and of the level 2 GDR data, and of the merging of these data into a single product. Specific JMR parameters to be included in these products will be defined later. For the same reasons the subproducts are not defined in this document

Organization of the document

- The product tree pointing out the main features of the ENVISAT and JASON-1 IGDR and GDR procedures (grey cells) and of the corresponding output data levels is given in **Figure 1**.
- The interfaces of the IGDR and GDR procedures (input / output data) are defined in § 2.
- An overview of the overall IGDR and GDR procedures is then given in § 3. It consists of a brief description of the processing and a list of functions.
- The detailed description of each function is finally given in § 4, where each function is described using the following items:
  - Name and identifier of the algorithm
  - Heritage

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- Function
- Applicability to the various procedures, and to the surface types

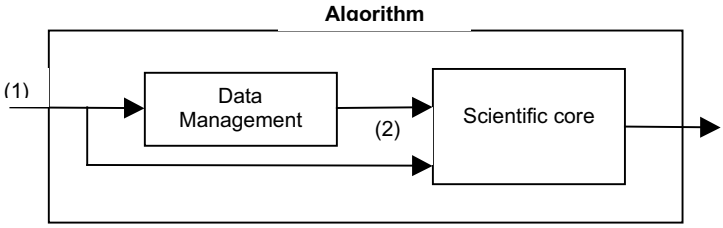
  The "applicability" item is aimed at pointing out the processing chain (JASON-1 IGDR, JASON-1 GDR, ENVISAT IGDR, ENVISAT GDR) in which the algorithm is carried out. It is not aimed at pointing out the product (JASON-1 IGDR, JASON-1 GDR, ENVISAT IGDR, ENVISAT GDR) in which the corresponding parameter(s) is(are) stored.

  For example, regarding algorithm "GEN_COR_RAN_03 – To compute the DORIS-derived ionospheric corrections":

  - **for the JASON-1 mission, this algorithm applies to IGDR and not to GDR. It means that the DORIS-derived ionospheric corrections are computed within the IGDR processing and not updated within the GDR processing. It does not mean of course that the DORIS-derived ionospheric corrections will be stored in the IGDR product only.**
  - **for the ENVISAT mission, this algorithm applies to both IGDR and GDR, because the ENVISAT GDR processing is a processing chain which operates from Level 1b parameters (as the IGDR processing), and not a processing chain which updates the IGDR parameters as for JASON-1 mission (see figure 1).**
- Algorithm definition:
  - Input data
  - Output data
  - Mathematical statement
- Algorithm specification:
  - Input data
  - Output data
  - Processing
- Accuracy (if any)
- Comments (if any)
- References (if any)

- For a better understanding of this document together with RD8, the management of instrumental corrections in the JASON-1 altimeter procedures in the particular case of a production scenario in three steps (Level 1b, IGDR and GDR) is clarified in Appendix 1.

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.



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

The detailed information required by the team in charge of the software development is provided in the “Algorithm specification” sections, which precisely define the scientific part (i.e. the core) of the algorithms.

Basic rules

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

- The specifications of an algorithm are always relevant to the processing of a single data point and not to a set of data points
- Elementary functions which are common to several algorithms (also called “mechanisms”) are specified in AD11.
- 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

Terminology

In this document, an altimeter "elementary measurement" refers to each individual measurement performed every 55.7 ms for the RA-2 and every 50 ms for POSEIDON-2 in nominal tracking operation. An "averaged measurement" refers to the compression of 20 elementary measurements (every 1.114 s for RA-2 and every 1 s for POSEIDON-2). The elementary measurements are sometimes also referred to as the 20 Hz measurements, and the averaged measurements are sometimes also referred to as the 1 Hz measurements. There is no ambiguity about radiometer measurements which are averaged measurements only (every 1.2 s for the MWR and every 1 s for the JMR).

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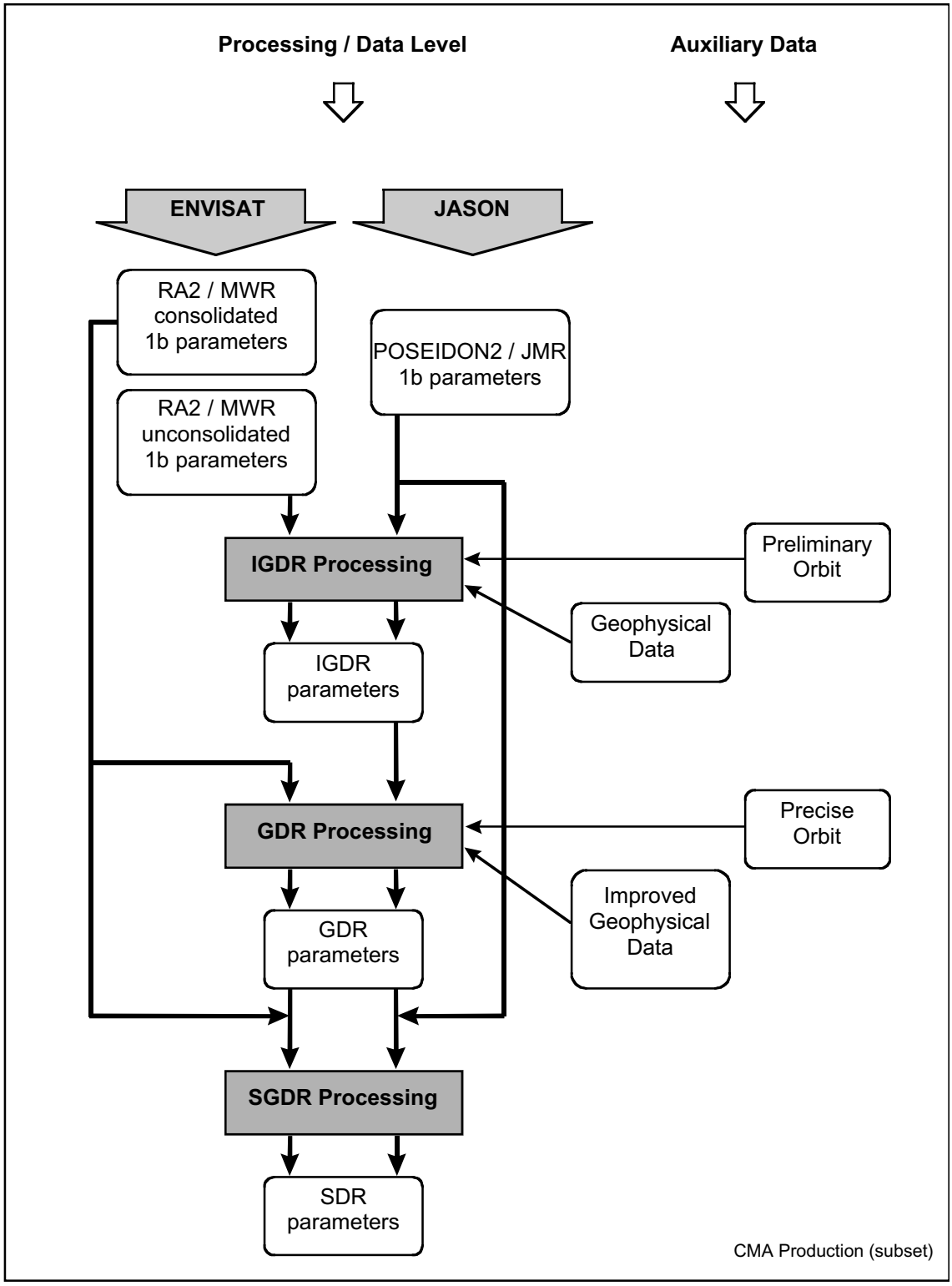

Figure 1: Product tree (ENVISAT and JASON-1 IGDR and GDR procedures)

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2. INPUT AND OUTPUT DATA

2.1. INPUT DATA

Two types of input data may be discriminated for the IGDR and GDR procedures (see AD2):

- "Product" data, which correspond to measurements performed by the altimeter or the radiometer instruments:
  - RA-2 / MWR level 1b parameters, for ENVISAT procedures
  - POSEIDON-2 / JMR level 1b parameters, for JASON-1 IGDR processing
  - POSEIDON-2 / JMR IGDR parameters, for JASON-1 GDR processing
- Auxiliary data, which may be dynamic or static:
  - Dynamic auxiliary data (DAD) are the time-varying data
  - Static auxiliary data (SAD) are constant data.

For the ENVISAT IGDR processing and for the JASON-1 IGDR and GDR procedures, the altimeter/radiometer dataset on input represents a sequential set of measurements. For the ENVISAT GDR processing, the altimeter/radiometer dataset on input (consolidated level 1b data) represents one pass (i.e. half an orbit from pole to pole).

2.1.1. PRODUCT DATA

- ENVISAT RA-2 / MWR Level 1b parameters:

  The ENVISAT altimeter/radiometer level 1b parameters are described in AD6.

- JASON-1 POSEIDON-2 and JMR Level 1b parameters:

  The JASON-1 POSEIDON-2 Level 1b parameters consist of the POSEIDON-2 level 1.0 parameters required on input of the IGDR processing and of the parameters computed by the POSEIDON-2 level 1b algorithms (see RD8).

  The JASON-1 JMR Level 1b parameters consist of the JMR level 1.0 parameters required on input of the IGDR processing and of the parameters computed by the JMR level 1b algorithms (see RD9).

  These parameters are considered as intermediate parameters within a global processing of the altimeter and radiometer measurements from level 1.0 (see AD12 for the altimeter and AD13 for the radiometer) to IGDR (see AD3).

- JASON-1 POSEIDON-2 / JMR IGDR parameters:

  The JASON-1 altimeter/radiometer IGDR parameters are described in AD3.

2.1.2. AUXILIARY DATA

- Dynamic auxiliary data:
  - Dynamic auxiliary data for ENVISAT IGDR and GDR procedures consist of:
    - ENVISAT DORIS orbit data (precise or preliminary orbit), described in AD7.
    - Meteorological restituted data, described in AD8

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- Solar activity data, described in AD10
- Pole location data, described in AD9
- DORIS-derived TEC maps, described in AD15
- Platform data (RA2 antenna off-nadir angle and COG motion), described in AD7.

– Dynamic auxiliary data for JASON-1 IGDR and GDR procedures consist of:

- JASON-1 orbit data (precise or DORIS preliminary orbit), described in AD7.
- Meteorological restituted data, described in AD8
- Pole location data, described in AD9
- DORIS-derived TEC maps, described in AD15

For ENVISAT and JASON-1 missions, the GDR procedures will be performed from the precise orbit data only. The IGDR procedures will be nominally performed from the standard DORIS preliminary orbit data, or from DORIS preliminary orbit data extrapolated from the previous day (backup solution).

The dynamic auxiliary data required on input of the level 2 procedures must be the data that at least cover the time span of the input dataset to be processed (with additional points before and after for the orbit data, due to the orbit interpolation method).

- Static auxiliary data:

– Static auxiliary data for ENVISAT IGDR and GDR procedures consist of:

- The RA-2 instrumental characterization data, described in AD6.
- The following data described in AD15:
  - Universal constant data
  - Land/sea mask file
  - Ku/S-band sea state bias table
  - Modified dip map
  - Coefficients for the model ionospheric correction
  - Cartwright and Edden tide potential amplitudes for the solid earth tide and the equilibrium long period ocean tide height calculation
  - Coefficient maps for the diurnal and semi-diurnal elastic ocean tide calculation (orthotide algorithm)
  - Coefficient maps for the tidal loading effect calculation (orthotide algorithm)
  - Coefficient maps for the diurnal and semidiurnal ocean tide calculation (solution 1)
  - Coefficients for the tidal loading effect calculation (solution 1)
  - Coefficient maps for the diurnal and semidiurnal ocean tide calculation (solution 2)
  - Coefficients for the tidal loading effect calculation (solution 2)
  - Geoid height
  - Mean sea surface height
  - Bathymetry / topography map (ocean depth, land elevation)

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- ◊ Surface slopes model(s)
- ◊ Wind table
- ◊ Processing parameters (all the constant parameters used in the processing)

– Static auxiliary data for JASON-1 IGDR and GDR procedures consist of:

- ∗ The following POSEIDON-2 features, described in AD14:
  - ◊ POSEIDON-2 instrumental characterization data
  - ◊ Instrumental corrections tables, built from a simulator of the altimeter and from the on-ground retracking algorithm, accounting in particular for the instrumental features provided by the POSEIDON-2 internal calibration, excluding the low-pass filter effects as the level 1b waveforms are already corrected for them.
- ∗ The JMR instrumental characterization data, described in AD16.
- ∗ The following data described in AD15:
  - ◊ Universal constant data
  - ◊ Land/sea mask file
  - ◊ Ku/C-band sea state bias table
  - ◊ Composite sea state bias table
  - ◊ Expected Ku-band sigma0 table (for the rain flag determination)
  - ◊ Ice latitude boundary table (for the ice flag determination)
  - ◊ Cartwright and Edden tide potential amplitudes for the solid earth tide and the equilibrium long period ocean tide height calculation
  - ◊ Coefficient maps for the diurnal and semi-diurnal elastic ocean tide calculation (orthotide algorithm)
  - ◊ Coefficient maps for the tidal loading effect calculation (orthotide algorithm)
  - ◊ Coefficient maps for the diurnal and semidiurnal ocean tide calculation (solution 1)
  - ◊ Coefficients for the tidal loading effect calculation (solution 1)
  - ◊ Coefficient maps for the diurnal and semidiurnal ocean tide calculation (solution 2)
  - ◊ Coefficients for the tidal loading effect calculation (solution 2)
  - ◊ Geoid height
  - ◊ Mean sea surface height
  - ◊ Bathymetry / topography map (ocean depth, land elevation)
  - ◊ Wind table
  - ◊ Processing parameters (all the constant parameters used in the processing)
  - ◊ Map of the slopes of the reference MSS/geoid with respect to the reference ellipsoid

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2.2. OUTPUT DATA

It is assumed that level 2 procedures do not modify the organization of the input data. Therefore, Level 2 procedures output one set of level 2 parameters (ENVISAT or JASON-1 IGDR or GDR product) that is structured identically to the set of input parameters.

- ENVISAT IGDR and GDR parameters are described in AD6.
- JASON-1 IGDR and GDR parameters are described in AD3.

2.3. SUMMARY OF THE INTERFACES

The interfaces of the ENVISAT and JASON-1 IGDR and GDR procedures are summed up in **Figure 2**.

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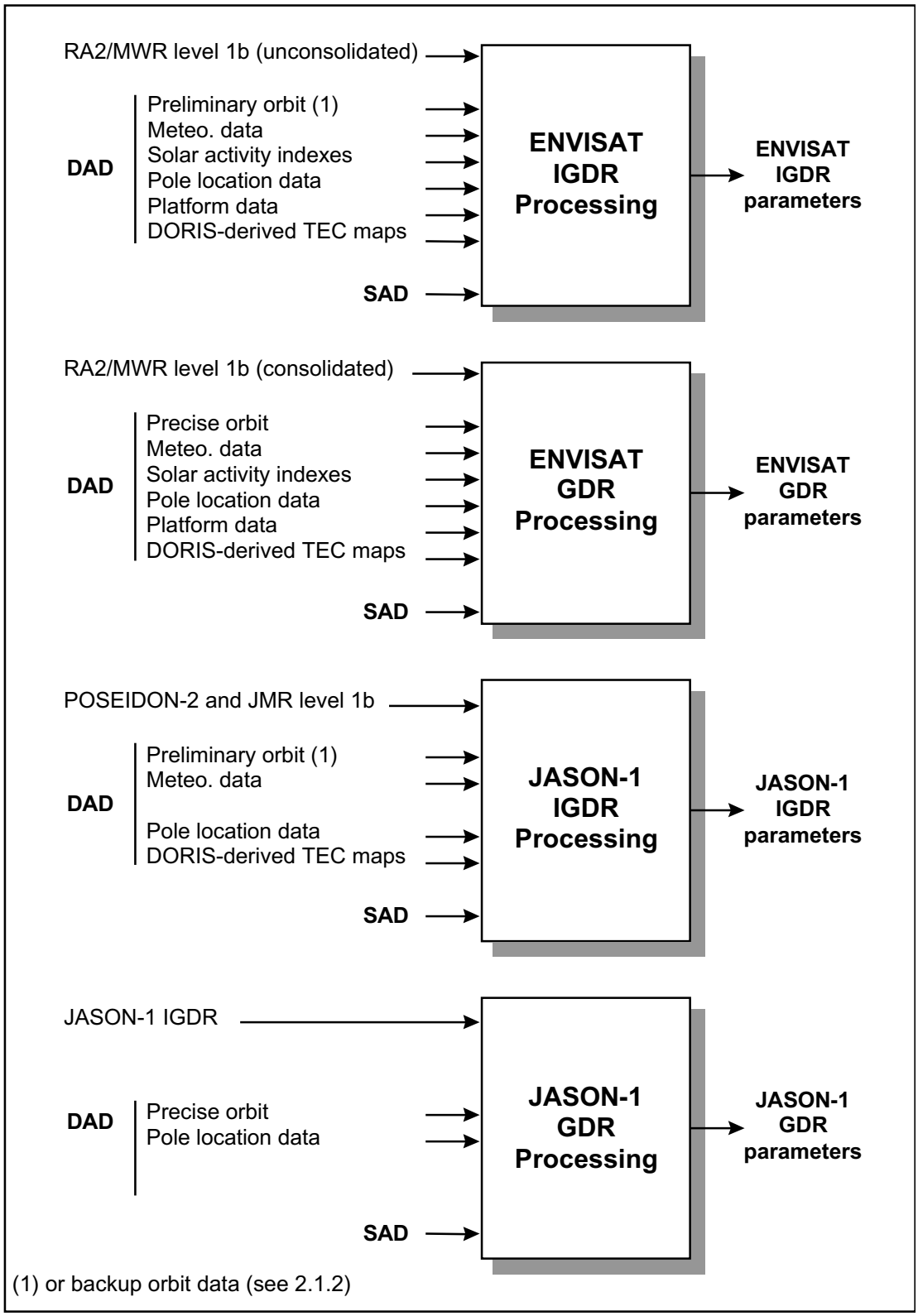

Figure 2: Interfaces of the ENVISAT and JASON-1 IGDR and GDR procedures

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3. PROCESSING OVERVIEW

3.1. BRIEF DESCRIPTION

A brief overview of the main functions of the nominal level 2 procedures is given in this section. A detailed description is provided in § 4.

3.1.1. ENVISAT IGDR PROCESSING

- The time-tag of the averaged measurements is derived from the time-tags of the elementary measurements.
- For each averaged measurement, the square of the platform-derived off-nadir angle is derived from the input platform data.
- The orbit altitudes corresponding to the elementary and averaged altimeter measurements, the orbital altitude rate with respect to the reference ellipsoid corresponding to the averaged altimeter measurements, and the location corresponding to the averaged altimeter measurements are recomputed from DORIS preliminary orbit data (see § 2.1.2 for backup solutions). In order to be able to compute the additional Doppler correction to the altimeter range over non ocean surfaces due to the effect of sloping surfaces, the interpolated satellite position and velocity vectors are also provided.
- The type of the overflown surface (4 states) is determined from a land/sea mask file.
- The Doppler corrections on the altimeter range that correspond to the elementary altimeter measurements are computed for Ku and S bands from the orbital altitude rates with respect to the reference ellipsoid derived from DORIS preliminary orbit data.
- The ice-1, ice-2, ocean-1 and sea-ice retrackings are performed for Ku and S bands (except for the sea-ice retracking which is performed from Ku band data only). The ocean retracking algorithm is nominally initialized by the outputs of the ice-2 retracking algorithm, and it accounts for the mispointing information derived from the platform data. In the ice-2 retracking algorithm, an estimate of the slope of the logarithm of the trailing edge is also derived from the Ku-band waveforms (which have been corrected for the effects of the low-pass filter in the level 1b processing).
- The input tracker ranges (for Ku and S bands) are normalized by accounting for the tracking point offset applied on-board, by adding the COG motion and by removing the level 1b Doppler correction.
- Physical parameters corresponding to the elementary altimeter measurements are derived from the ocean-1, ice-1, ice-2 and sea-ice retrackings outputs, combined with the normalized tracker range, and with the input scaling factors for Sigma0 evaluation (for Ku and S bands). These physical parameters refer to the following parameters:
  - Ocean-1, ice-1, ice-2 and sea-ice (Ku band only) altimeter ranges corrected for COG motion (on-ground retracked estimates)
  - Ocean-1, ice-1, ice-2 and sea-ice (Ku band only) backscatter coefficients (on-ground retracked estimates)
  - Significant waveheight (derived from the on-ground retracked estimates of the composite Sigma)
  - Square of the off-nadir angle (derived from the on-ground estimates of the slope of the trailing edge of the Ku-band waveforms)
- The elementary estimates of the ocean-1, ice-1, ice-2 and sea-ice (Ku band only) altimeter ranges are corrected for the Doppler effects previously computed from DORIS preliminary orbit data.
- The direction from which the power of the waveforms came (over non ocean surfaces) is determined by reference to a surface slopes model.

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- The ice-1 altimeter range and the echo direction are used to calculate the slope-corrected elevation of the surface and the slope-corrected location of the measurement.
- The additional Doppler correction to the altimeter range due to the effect of sloping surfaces is then determined.
- The elementary measurements to be compressed to provide 1-Hz measurements are identified. In particular, the possible change of emitted Ku bandwidth within a source packet is managed.
- The following ocean-1 physical parameters are then edited and compressed to provide 1-Hz estimates:
  - Slope-corrected elevation of the surface
  - Altimeter range
  - Backscatter coefficient
  - Significant waveheight
  - Square of the off-nadir angle

  Moreover, an altimeter echo type (“ocean-like” or “non ocean-like”) is derived from the number of valid estimates of the altimeter range and from the corresponding standard deviation.
- The radiometer brightness temperatures (2 channels) and the radiometer land flag are interpolated to the 1-Hz altimeter time tags.
- The backscatter coefficient atmospheric attenuations are computed for the Ku and S bands, using brightness temperatures.
- The Ku and S band ocean backscatter coefficients are corrected for atmospheric attenuation and the 10 meter altimeter wind speed is derived (from the Ku-band estimate).
- Then, the radiometer level 2 parameters (wet tropospheric correction, water vapor and cloud liquid water contents) are computed from the brightness temperatures, using in particular the altimeter wind speed as a correction term.
- The two components (U and V) of the 10 meter wind vector, the surface pressure, the mean sea surface pressure over the ocean (averaged value over the ocean), and the wet and dry tropospheric corrections are computed using ECMWF meteorological fields.
- The sea surface height correction due to atmospheric loading, i.e. the so-called inverted barometer correction, is computed at the 1-Hz altimeter time tags using the ECMWF fields. The magnitude of the correction is computed with respect to the mean sea surface pressure over the oceans determined in the previous step.
- The sea state bias is computed for the 1-Hz ranges from the Ku and S bands.
- Three types of ionospheric corrections are computed for the 1-Hz ranges from the Ku and S bands:
  - Dual-frequency correction
  - DORIS-derived ionospheric correction (computed from DORIS-derived TEC maps)
  - Correction derived from Bent model using sunspot numbers
- The diurnal and semidiurnal elastic ocean tide height is computed from two algorithms:
  - The solution 1 algorithm
  - The solution 2 algorithm

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- The following tide heights are also computed:
  - The height of the tidal loading induced by the solution 2 ocean tide model.
  - The solid earth tide height using the Cartwright and Edden tide potential, and the height of the equilibrium long period ocean tide using the Cartwright and Edden long-period tide potential
- The pole tide height (geocentric tide height due to polar motion) is computed using pole locations
- The height of the mean sea surface above the reference ellipsoid is computed
- The height of the geoid is computed.
- The ocean depth or land elevation is computed using a bathymetry / topography file.
- Finally, the parameters of the radiometer data set records of the output product are computed:
  - The altimeter wind speed is interpolated to radiometer time tags
  - The radiometer level 2 parameters (i.e. the wet tropospheric correction due to water vapor in the troposphere, and the water vapor and cloud liquid water contents) are computed at MWR time tag, from the MWR brightness temperatures and using the altimeter wind speed interpolated at MWR time tag as a correction term.

3.1.2. ENVISAT GDR PROCESSING

The ENVISAT GDR processing is the same as the ENVISAT IGDR processing except for the following points:

- Orbit data consist of DORIS precise orbit data, instead of preliminary data.
- The pole tide height is computed from improved pole location data (with respect to the pole location data used in the IGDR processing).

Be aware that for validation purposes, CMA will be able to add in the IGDR or GDR procedures, the following computations which correspond to standard functions in the JASON-1 IGDR or GDR procedures:

- Ocean-2 retracking (Ku and S bands)
- Computation of the ice flag
- Computation of the composite sea state bias
- Computation of the height of the tidal loading induced by the ocean tide corresponding to the solution 1 ocean tide model

The corresponding estimates will be reserved for internal use within CMA, and will not be provided in the ENVISAT IGDR product.

3.1.3. JASON-1 IGDR PROCESSING

- The orbit altitudes corresponding to the elementary and averaged altimeter measurements, the orbital altitude rate with respect to the reference MSS/geoid corresponding to the averaged altimeter measurements and the location corresponding to the averaged altimeter measurements are recomputed from preliminary orbit data (see § 2.1.2 for backup solutions).

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- The Doppler corrections on the altimeter range that correspond to the averaged altimeter measurements are computed for Ku and C bands from the orbital altitude rates with respect to the reference MSS/geoid derived from preliminary orbit data.
- The on-ground retracking is performed for Ku and C bands, accounting for the mispointing information (interpolated platform data or possibly waveforms-derived data, computed in the level 1b processing, see RD8). An estimate of the slope of the logarithm of the trailing edge is also derived from the Ku-band waveforms (which have been corrected for the effects of the low-pass filter in the level 1b processing, see RD8).
- Physical parameters corresponding to the elementary altimeter estimates are derived from the on-ground retracking outputs combined with the input tracker ranges and scaling factors for Sigma0 evaluation (for Ku and C bands). These physical parameters refer to the following three parameters:
  - Altimeter range (on-ground retracked estimates)
  - Backscatter coefficient (on-ground retracked estimates)
  - Square of the off-nadir angle (derived from the on-ground estimates of the slope of the trailing edge of the Ku-band waveforms)
- The following parameters are then edited and compressed to provide 1-Hz estimates:
  - Altimeter range
  - Backscatter coefficient
  - Composite Sigma (σ_c), from which the averaged estimate of the significant waveheight is derived
  - Amplitude output by the on-ground retracking algorithm
  - Thermal noise level output by the on-ground retracking algorithm
  - Square of the off-nadir angle

  Moreover, an altimeter echo type (“ocean-like” or “non ocean-like”) is derived from the number of valid estimates of the altimeter range and from the corresponding standard deviation.
- The signal to noise ratio (Ku and C bands) is computed from the averaged on-ground estimates of the amplitude and of the thermal noise level of the waveforms.
- The 1-Hz modeled corrections of the instrumental errors on the altimetric estimates (altimeter range, altimeter range rate, significant waveheight and backscatter coefficient) are computed for Ku and C bands, using correction tables built from a simulator of the altimeter and from the on-ground retracking algorithm (see § 2.1.2). The entries in the table are the significant waveheight and the signal to noise ratio (see Appendix A1).
- The corrections for instrument errors and system biases (see appendix A1) are applied to the on-ground retracked altimeter ranges, significant waveheights and backscatter coefficients. The Doppler correction is also applied to the altimeter range. Moreover, the corrected altimeter range rate is computed.
- The radiometer brightness temperatures (3 channels) and associated flags are interpolated to the 1-Hz altimeter time tags.
- Then, the JMR geophysical parameters (wet tropospheric correction, water vapor and cloud liquid water contents, wind speed, Ku-band and C-band backscatter coefficients atmospheric attenuations) are computed from the brightness temperatures.
- The Ku and C bands ocean backscatter coefficients are corrected for atmospheric attenuation and the 10-meter altimeter wind speed is derived (from the Ku-band estimate).
- The rain flag is determined from Ku and C band ocean backscatter coefficients comparison.

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- The ice flag is computed from climatologic estimates of the latitudinal boundary of the ice shelf, and from altimeter windspeed.
- The two components (U and V) of the 10 meter wind vector, the surface pressure, the mean sea surface pressure over the ocean (averaged value over the ocean) and the wet and dry tropospheric corrections are computed using ECMWF meteorological fields.
- The sea surface height correction due to atmospheric loading, i.e. the so-called inverted barometer correction, is computed at the 1-Hz altimeter time tags using the ECMWF fields. The magnitude of the correction is computed with respect to the mean sea surface pressure over the oceans determined in the previous step.
- The sea state bias is computed for the 1-Hz ranges from the Ku and C bands.
- The composite sea state bias is computed.
- Two types of ionospheric corrections are computed for the 1-Hz ranges from the Ku and C bands:
  - Dual-frequency correction
  - DORIS-derived ionospheric correction (computed from DORIS-derived TEC maps)
- The diurnal and semidiurnal elastic ocean tide height is computed from two algorithms:
  - The solution 1 algorithm
  - The solution 2 algorithm
- The following tide heights are also computed:
  - The heights of the tidal loading induced by the ocean tide corresponding respectively to both elastic ocean tide models
  - The solid earth tide height using the Cartwright and Edden tide potential, and the height of the equilibrium long period ocean tide using the Cartwright and Edden long-period tide potential
- The pole tide height (geocentric tide height due to polar motion) is computed using pole locations
- The height of the mean sea surface above the reference ellipsoid is computed
- The height of the geoid is computed.
- Finally, the ocean depth or land elevation is computed using a bathymetry / topography file.

[Be aware that for internal validation purposes, CMA will be able to add in the IGDR or GDR procedures the computation of a tracker bias and an electromagnetic bias, as well as the following computations which correspond to standard functions of the ENVISAT IGDR and GDR procedures:

- Ice-1 retracking (Ku and C bands)
- Ice-2 retracking (Ku and C bands)
- Ocean-1 retracking (Ku and C bands)
- Sea-ice retracking (Ku band)

All these estimates will be reserved for internal use within CMA, and will not be provided in the JASON-1 IGDR product.]

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3.1.4. JASON-1 GDR PROCESSING

- The orbit altitudes corresponding to the elementary and averaged altimeter measurements, the orbital altitude rate with respect to the reference MSS/geoid corresponding to the averaged altimeter measurements and the location corresponding to the averaged altimeter measurements are recomputed from precise orbit data.
- The Doppler corrections on the altimeter range corresponding to the averaged altimeter measurements are computed for Ku and C bands from the orbital altitude rates with respect to the MSS/geoid derived from precise orbit data [(1)].
- The Doppler correction on the altimeter range is updated (i.e. the correction computed in the IGDR processing is superseded by the updated one) [(1)]
- The dual-frequency ionospheric corrections are recomputed for Ku and C bands (accounting for the updated Doppler correction on the altimeter ranges) [(1)]
- The pole tide height is recomputed from improved pole location data with respect to those used in the IGDR processing.

The sign of the the various instrumental and geophysical corrections computed in the ENVISAT and JASON-1 IGDR and GDR processing is such as the corrected value of a physical parameter (altimeter range, altimeter range rate, significant waveheight, backscatter coefficient, etc.) is the sum of its raw value and of the corresponding corrections.

3.2. LIST OF FUNCTIONS

A list of the functions of the nominal ENVISAT and JASON-1 IGDR and GDR procedures is given in **Figure 3**.

Regarding the altimeter measurements, the functions defined hereafter only concern measurements in tracking mode for POSEIDON-2 and in tracking, preset tracking and preset loop output modes (see AD6) for the RA-2 (assuming that the specificities of these three tracking modes, if any, are accounted for and managed in the level 1b processing, and thus that the level 2 processing for these three modes is exactly the same).

[(1)] The need to update the Doppler correction and the dual-frequency correction in the GDR processing will be analysed during the JASON-1 commissioning phase, depending on the impact of the orbit improvement on the altimeter range estimate.

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FUNCTION	APPLICABILITY			
	ENVISAT		JASON-1	
	IGDR	GDR	IGDR	GDR
ALT_COM_TIM_01 - To compute the averaged time tags (1)				
PLA_PHY_MIS_01 - To compute the platform-derived off-nadir angle (2)				
LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location				
GEN_COR_ORB_01 - To derive the orbital altitude rate with respect to the reference MSS/geoid				
GEN_ENV_SUR_01 - To determine the surface type (6)				
ALT_COR_RAN_02 - To compute the Doppler correction				(7)
ALT_RET_ICE_01 - To perform the ice-1 retracking				
ALT_RET_ICE_02 - To perform the ice-2 retracking				
ALT_RET_OCE_01 - To perform the ocean-1 retracking				
ALT_RET_OCE_02 - To perform the ocean-2 retracking				
ALT_RET_SEA_01 - To perform the sea-ice retracking				
ALT_PHY_RAN_04 - To normalize the tracker ranges				
ALT_PHY_RAN_05 - To compute the on-ground retracked altimeter ranges				
ALT_PHY_BAC_04 - To compute the on-ground retracked backscatter coefficients				
ALT_PHY_SWH_01 - To compute SWH from the on-ground retracked composite Sigma				
ALT_PHY_MIS_02 - To compute the square of the off-nadir angle from the on-ground waveform-derived estimates				
ALT_COR_RAN_06 - To correct the altimeter range for Doppler effects (3)				
GEN_ENV_ECH_01 - To determine the echo direction				
ALT_PHY_GEN_01 - To compute the elevation and location of echoing points				
ALT_COR_RAN_07 - To compute the Doppler slope correction				
ALT_COM_GEN_01 - To identify the elementary measurements to be compressed				
ALT_COM_RAN_06 - To edit and compress the elevation of echoing points				
ALT_COM_RAN_05 - To edit and compress the on-ground retracked altimeter ranges				
ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients				
ALT_COM_SWH_01 - To edit and compress the on-ground retracked significant waveheights				
ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH				
ALT_COM_SNR_01 - To edit and compress the on-ground retracked amplitude of waveforms				
ALT_COM_SNR_02 - To edit and compress the on-ground retracked thermal noise level				
ALT_COM_MIS_02 - To edit and compress the square of the off-nadir angle (on-ground waveform-derived)				
ALT_PHY_SNR_02 - To compute the SNR from the on-ground estimates (4)				
ALT_COR_GEN_03 - To compute the modeled instrumental corrections on the on-ground retracked parameters (4)				
ALT_COR_RAN_08 - To compute the corrected on-ground retracked altimeter ranges (3) (5)				
ALT_COR_RAN_05 - To compute the corrected tracker range rates				
ALT_COR_SWH_02 - To compute the corrected on-ground retracked significant waveheights				
ALT_COR_BAC_02 - To compute the corrected on-ground retracked backscatter coefficients				
ALT_COR_RAN_09 - To update the Doppler correction on the altimeter range (3)				(7)
RAD_MAN_INT_01 - To interpolate radiometer data to altimeter time tags				
RAD_PHY_GEN_01 - To compute the JMR geophysical parameters				
RAD_PHY_ATT_01 - To compute the RA-2 sigma0 atmospheric attenuations				
ALT_PHY_WIN_01 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Witter and Chelton, 1991)				
ALT_PHY_WIN_02 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Gourrion et al., 2000)				
ALT_PHY_GEN_02 - To compute the rain flag				
GEN_ENV_SUR_02 - To compute the ice flag				
RAD_PHY_GEN_02 - To compute the MWR geophysical parameters at RA-2 time tag				
GEN_COR_RAN_01 - To compute the 10 meter wind vector, and the wet and dry tropospheric corrections from ECMWF model				
GEN_ENV_MET_02 - To compute the inverted barometer effect				
ALT_COR_RAN_10 - To compute the sea state biases				
ALT_COR_RAN_11 - To compute the composite sea state bias				

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FUNCTION	APPLICABILITY			
	ENVISAT		JASON-1	
	IGDR	GDR	IGDR	GDR
ALT_COR_RAN_12 - To compute the dual-frequency ionospheric corrections				(7)
GEN_COR_RAN_03 - To compute the DORIS-derived ionospheric corrections				
GEN_COR_RAN_02 - To compute the Bent model ionospheric corrections				
GEN_ENV_TID_05 - To compute the diurnal and semidiurnal elastic ocean tide height and the loading tide height (orthotide algorithm)				
GEN_ENV_TID_02 - To compute the diurnal and semidiurnal elastic ocean tide height and the load tide height (solution 2)				
GEN_ENV_TID_01 - To compute the diurnal and semidiurnal elastic ocean tide height and the load tide height (solution 1)				
GEN_ENV_TID_03 - To compute the solid earth and the equilibrium long period ocean tide heights				
GEN_ENV_TID_04 - To compute the pole tide height				
GEN_ENV_MSS_01 - To compute the mean sea surface height				
GEN_ENV_GEO_01 - To compute the geoid height				
GEN_ENV_BAT_01 - To compute the ocean depth / land elevation				
ALT_MAN_INT_01 - To interpolate RA-2 data to MWR time tag				
RAD_PHY_GEN_03 - To compute the MWR geophysical parameters at MWR time tag				

Figure 3: Functions of the nominal ENVISAT and JASON-1 IGDR and GDR procedures

Comments

1. ENVISAT level 1b products contain a set of 20-Hz altimeter measurements. The time-tag of the 1-Hz altimeter measurements are built in the level 2 procedures. This function does not apply to JASON-1 because 1-Hz measurements are built in the level 1.0 processing.

2. For JASON-1, the platform-derived off-nadir angle is computed in the level 1b processing (see RD8).

3. The Doppler correction on the altimeter range is applied to 20-Hz measurements in the ENVISAT IGDR and GDR procedures, while it is applied to 1-Hz measurements in the JASON-1 IGDR processing, with a possible update in the GDR processing (see Appendix 1).

4. The modeled instrumental corrections computed in the JASON-1 level 1b processing are recomputed in the JASON-1 IGDR processing using specific tables (see Appendix 1). The inputs of these tables are the most accurate estimates of the significant waveheight and of the signal to noise ratio (outputs from the on-ground retracking). Regarding ENVISAT, this type of corrections is performed in the level 1b processing only.

5. The only correction to be applied to the ENVISAT measurements is the Doppler correction on the altimeter range, which has been already applied to the 20-Hz estimates.

6. For JASON-1, the determination of the surface type from a land/sea mask file map is performed in the level 1b processing (see RD8).

7. See note (1) in section 3.1.4.

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4. FUNCTIONS

A detailed description of the functions of the nominal ENVISAT and JASON-1 IGDR and GDR procedures is given in this section.

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ALT_COM_TIM_01 - To compute the averaged time tags

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
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Approved by:	P. VINCENT CNES	

Document ref:	SMM-ST-M2-EA-11005-CN	18th October, 2001	Issue: 3	Update: 3

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HERITAGE

None

FUNCTION

To compute the time tag of the averaged altimeter measurements.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the averaged time tags is relevant to all surface types.

ALGORITHM DEFINITION

Input data

- Product data:
  - 20-Hz altimeter time tags
  - Data block numbers
- Computed data: None
- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data
    - Number of elementary measurements per averaged measurement
  - Processing parameters
    - Center of the averaged measurement

Output data

- 1-Hz altimeter time tags

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Mathematical statement

The elementary time-tag associated with a data block represents the time when the middle of the 100 averaged corresponding Ku-band waveforms is on the ground. The averaged measurements provided in the level 2 output product correspond to the source packets of the telemetry. The time-tag of the averaged measurements are computed by linear regression of the corresponding elementary RA-2 time tags, at the middle of the source packet.

ALGORITHM SPECIFICATION

For each averaged measurement, the computation of the 1-Hz altimeter time tag from the 20-Hz altimeter time tags is specified hereafter.

Input data

- Elementary altimeter time tags : RA2_Time_Tag [0:Ne-1] (seconds elapsed since 01/01/1950 0 h.)
- Data block numbers : Rec_Count [0:Ne-1] (/)
- RA-2 instrumental characterization data:
  - Number of elementary measurements per averaged measurement : Ne (/)
- Processing parameters:
  - Center of the averaged measurement : Wf_Center (/)

Output data

- Averaged altimeter time tag : RA2_Time_Tag_Mean (seconds elapsed since 01/01/1950 0 h.)
- Execution status

Processing

The mechanism "GEN_MEC_COM_02 - Linear regression / Least square method" (AD11) is run with the following inputs:

- Number of points of the regression : Ne
- Set of ordinates : RA2_Time_Tag [0:Ne-1]
- Set of corresponding abscissa : Rec_Count [0:Ne-1]

The averaged time tag (RA2_Time_Tag_Mean) is then derived from the order 1 and the order 0 coefficients of the linear model (C1 and C0) and from the center of the averaged measurement (Wf_Center), by:

$$RA2_Time_Tag_Mean = C1 * Wf_Center + C0 \quad (1)$$

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ACCURACY

The elementary time-tags within a source packet are derived from the on-board datation of the source packet. As the level 1b algorithm is such as these time-tags are equidistant, there will be no error due to the interpolation method (linear regression).

COMMENTS

None

REFERENCES

None

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PLA_PHY_MIS_01 - To compute the platform-derived off-nadir angle

DEFINITION, ACCURACY AND SPECIFICATION

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Checked by:	For the JASON-1 SWT M. SROKOSZ For the JASON-1 Project P. VINCENT CNES S. DESAI JPL For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To compute the square of the off-nadir angle from the platform data.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the platform-derived off-nadir angle is relevant to all surface types.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "ALT_COM_TIM_01 - To compute the averaged time tags":
    - 1-Hz altimeter time tag
- Dynamic auxiliary data:
  - Platform data and associated time-tags:
    - Altimeter antenna off-nadir angle
- Static auxiliary data:
  - Processing parameter for the computation of the square of the platform-derived off-nadir angle:
    - Threshold on the square of the off-nadir angle

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Output data

- Square of the off-nadir angle: ξ^2
- Validity flag for the square of the off-nadir angle

Mathematical statement

The altimeter antenna off-nadir angle corresponding to each 1-Hz input altimeter measurement is the closest value which preceeds the altimeter time-tag. The square of this value is derived and a validity flag is determined using a threshold.

ALGORITHM SPECIFICATION

Warning: The selection of the antenna off-nadir angle for each altimeter time-tag is considered as a "data management" algorithm (see section 1). It is specified in RD12.

For each averaged measurement, the computation of the square of the off-nadir angle from the platform data is performed using algorithm "PLA_PHY_MIS_01 - To compute the platform-derived off-nadir angle" (RD8), with the following inputs:

- Platform data (selected):
  - Altimeter antenna off-nadir angle : Alt_Off_Nad (degree)
- Processing parameter:
  - Threshold on the square of the off-nadir angle : Thresh_Off_Nad_Pf2 (degree^2)

The outputs are:

- Square of the off-nadir angle : Off_Nad_Pf2_Mean (degree^2)
- Validity flag for the square of the off-nadir angle : Off_Nad_Pf2_Mean_Val_Flag (/)
- Execution status

ACCURACY

See "PLA_PHY_MIS_01 - To compute the platform-derived off-nadir angle" (RD8).

COMMENTS

This function also applies to the JASON-1 level 1b processing (RD8).

REFERENCES

None

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LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

POSEIDON-1

FUNCTION

To compute the orbit altitude (i.e. the altitude of the platform center of gravity above the reference ellipsoid), the orbital altitude rate with respect to the reference ellipsoid and the location of the measurements from orbit files.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	Yes

  The IGDR procedures are performed from a (DORIS) preliminary orbit (see § 2.1.2 for backup solutions), while the GDR procedures are performed from a precise orbit (without backup solution).

- Surface type:

  The computation of the orbit altitude, the orbital altitude rate and the location from orbit files is relevant to all surface types.

ALGORITHM DEFINITION

Input data

- Product data:
  - For ENVISAT:
    - 20-Hz altimeter time tags
  - For JASON-1:
    - 1-Hz altimeter time tags
    - Information to derive the elementary time tags (offset to derive the time-tag of the first elementary measurement, and time interval between two elementary measurements)
- Computed data:
  - From "ALT_COM_TIM_01 - To compute the averaged time tags" for ENVISAT:
    - 1-Hz altimeter time tag

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- Dynamic auxiliary data:
  - Orbit data covering the time span of the input product, i.e. at regular time steps:
    - Position of the satellite in a terrestrial reference frame: $\vec{P} = (P_X, P_Y, P_Z)$
    - Velocity of the satellite in a terrestrial reference frame: $\vec{V} = (V_X, V_Y, V_Z)$
- Static auxiliary data:
  - Processing parameters for the orbit interpolation (see RD12)
  - Processing parameters for the determination of the orbit altitude and of the latitude:
    - Desired accuracy for the orbit altitude
    - Desired accuracy for the latitude
  - Universal constants:
    - Flattening coefficient of the reference ellipsoid
    - Semi major axis of the reference ellipsoid

Output data

- For ENVISAT:
  - Orbit altitudes (1 Hz and 20 Hz)
  - Orbital altitude rates (1 Hz and 20 Hz)
  - Location, i.e. latitude and longitude (1 Hz and 20 Hz)
  - Interpolated satellite position vectors (20 Hz)
  - Interpolated satellite velocity vectors (20 Hz)
- For JASON-1:
  - Orbit altitudes (1 Hz and 20 Hz)
  - Orbital altitude rates (1 Hz)
  - Location, i.e. latitude and longitude (1 Hz)

Mathematical statement

- The orbit altitude h, the latitude φ and the longitude λ corresponding to an input 20-Hz or 1-Hz altimeter time-tag t, are computed as follows:
  - N (typically N=8) position vectors are selected from the input orbit file (N/2 before and N/2 after the altimeter time tag), and are interpolated at the altimeter time tag using Everett's formula (Abramowitz, 1965).
  - The interpolated position $\overrightarrow{P_S} = (P_{SX}, P_{SY}, P_{SZ})$ of the satellite is then projected onto the reference ellipsoid to provide h, φ and λ (see Nouel, 1980 or Klinkrad, 1985 or Guinn, 1990).
- The orbital altitude rate with respect to the reference ellipsoid (h') corresponding to an input 20-Hz or 1-Hz altimeter time-tag t is computed as follows, using the corresponding latitude φ and longitude λ (computed as defined above):

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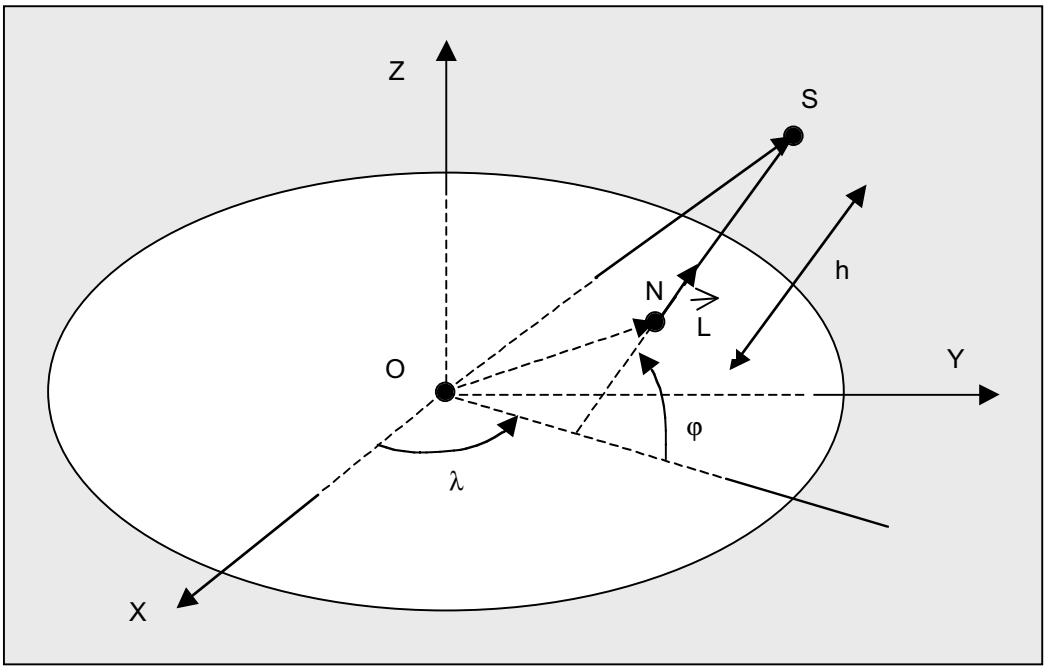
- The position $\overrightarrow{P_N} = (P_{NX}, P_{NY}, P_{NZ})$ of the geodetic subsatellite point (denoted as the nadir point) is derived from φ and λ, using a simple change of co-ordinate system (see Nouel, 1980).
- The normalized line of sight vector, in the direction NS defined by the satellite (S) and the corresponding nadir point (N)) is then computed by:

$$\vec{L} = \frac{\overrightarrow{P_S} - \overrightarrow{P_N}}{\left\| \overrightarrow{P_S} - \overrightarrow{P_N} \right\|} \tag{1}$$

- M (typically M=8) velocity vectors are selected from the input orbit file (M/2 before and M/2 after the altimeter time tag), and are interpolated at the altimeter time tag using Everett's formula (Abramowitz, 1965).
- The orbital altitude rate h' is finally obtained by forming a scalar product of the interpolated satellite velocity vector $\overrightarrow{V_S} = (V_{SX}, V_{SY}, V_{SZ})$ with the normalized line of sight vector $\vec{L}$, i.e. by:

$$h' = \frac{V_{SX}.(P_{SX} - P_{NX}) + V_{SY}.(P_{SY} - P_{NY}) + V_{SZ}.(P_{SZ} - P_{NZ})}{\sqrt{(P_{SX} - P_{NX})^2 + (P_{SY} - P_{NY})^2 + (P_{SZ} - P_{NZ})^2}} \tag{2}$$



ALGORITHM SPECIFICATION

Warning: The following computations:

- Derivation of the 20-Hz time-tags from the 1-Hz time-tags (for JASON-1)
- Selection, possible change of frame and interpolation of the orbit position and velocity vectors to the altimeter time-tags (for ENVISAT and for JASON-1)

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are considered as "data management" algorithms (see section 1). They are specified in RD12. Be aware that the processing will be stopped if the interpolated orbit position and velocity vectors cannot be computed.

For each measurement to be processed, the computation of the latitude, longitude, orbit altitude and orbital altitude rate (above a reference ellipsoid), are specified hereafter from the corresponding interpolated position and velocity vectors.

Input data

- Position of the satellite (interpolated):
  - X co-ordinate : PSx (m)
  - Y co-ordinate : PSy (m)
  - Z co-ordinate : PSz (m)
- Velocity of the satellite (interpolated):
  - X co-ordinate : VSx (m/s)
  - Y co-ordinate : VSy (m/s)
  - Z co-ordinate : VSz (m/s)
- Characteristics of the reference ellipsoid:
  - Semi major axis : SM_Axis (m)
  - Flattening : Flattening (/)
- Thresholds for the iterative process:
  - Desired accuracy for the orbit altitude : Acc_Orb_Alt (m)
  - Desired accuracy for the latitude : Acc_Lat (degree)

Output data

- Orbit altitude : Orb_Alt (m)
- Orbital altitude rate (w.r.t. the reference ellipsoid) : Orb_Alt_Rate (m/s)
- Latitude : Lat (degree)
- Longitude : Lon (degree [0, 360[)
- Execution status

Processing

- The Orbit altitude (Orb_Alt), the latitude (Lat) and the longitude (Lon) are computed using mechanism "GEN_MEC_CON_06 – Conversion of a position vector from Cartesian to geodetic co-ordinates" (AD11), with the following inputs:
  - Position of the satellite:
    - X co-ordinate : PSx
    - Y co-ordinate : PSy

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  - Z co-ordinate : PSz
- Characteristics of the reference ellipsoid:
  - Semi major axis : SM_Axis
  - Flattening : Flattening
- Thresholds for the iterative process:
  - Desired accuracy for the orbit altitude : Acc_Orb_Alt
  - Desired accuracy for the latitude : Acc_Lat

- If the three components (VSx, VSy, VSz) of the input satellite velocity vector are set to their default value, then the orbital altitude rate (Orb_Alt_Rate) is set to its default value. Else:
  - The three components (X-component PNx, Y-component PNy, and Z-component PNz, expressed in meters) of the position of the nadir point are computed using mechanism "GEN_MEC_CON_03 - Conversion of a position vector from geodetic to Cartesian co-ordinates" (AD11), with the following inputs:
    - Geodetic components of the position vector:
      - Elevation above the reference ellipsoid : set to "0"
      - Geodetic latitude : Lat
      - Longitude : Lon
    - Characteristics of the reference ellipsoid:
      - Semi major axis : SM_Axis
      - Square of the eccentricity : Ecc2

      Where the square of the eccentricity (Ecc2) is determined by:

$$\text{Ecc2} = \text{Flattening} * (2 - \text{Flattening}) \tag{1}$$

  - The orbit altitude rate is then derived by:

$$\text{Orb_Alt_Rate} = \frac{\text{VSx} * (\text{PSx} - \text{PNx}) + \text{VSy} * (\text{PSy} - \text{PNy}) + \text{VSz} * (\text{PSz} - \text{PNz})}{\sqrt{(\text{PSx} - \text{PNx})^2 + (\text{PSy} - \text{PNy})^2 + (\text{PSz} - \text{PNz})^2}} \tag{2}$$

ACCURACY

- The error due to Everett interpolation method is smaller than 1 mm if the number N of orbit points taken into account is large enough (typically N=8, i.e. 4 points before and 4 points after the altimeter time).

COMMENTS

"tg" represents the tangent function, while "Arctg" represents the inverse tangent function.

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

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

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.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	Yes

- Surface type:

  The computation of the orbital altitude rate with respect to the MSS/geoid is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Pass number of the measurement (indicating if the pass is ascending or descending)
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Orbital altitude rates with respect to the reference ellipsoid (1 Hz)
    - Location, i.e. latitude and longitude (1 Hz)
- Static auxiliary data:
  - Map of the slopes of the reference MSS/geoid with respect to the reference ellipsoid

Output data

- Orbital altitude rates with respect to the reference MSS/geoid (1 Hz)

Mathematical statement

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

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- 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).

ALGORITHM SPECIFICATION

For each averaged measurement, the computation of the orbital altitude rate with respect to the reference MSS/geoid is specified hereafter.

Input data

- Pass number : Pass_Num (/)
- Orbital altitude rate w.r.t. the reference ellipsoid : Orb_Alt_Rate_Ellipsoid (m/s)
- Latitude : Lat (degree)
- Longitude : Lon (degree [0, 360[)
- Map of the slopes of the reference MSS/geoid with respect to the reference ellipsoid:
  - Longitude of first grid point : Lon_First (minute $\in$ [0,21600[)
  - Grid step in longitude : Step_Lon (minute)
  - Number of points in longitude : Nb_Pts_Lon (/)
  - Latitude of first grid point : Lat_First (minute)
  - Grid step in latitude : Step_Lat (minute)
  - Number of points in latitude : Nb_Pts_Lat (/)
  - Doppler/MSS values [1] : Dop_MSS [0:Nb_Pts_Lon-1][0:Nb_Pts_Lat-1] (m/s)
  - Default value in MSS/geoid map : Def_Value (/)

Output data

- Orbital altitude rate w.r.t. the reference MSS/geoid : Orb_Alt_Rate_MSSGeoid (m/s)
- Execution status

Processing

- The input latitude (Lat) and longitude (Lon) are multiplied by 60 to be expressed in minutes.
- The indexes of the four surrounding grid points in the map are computed from Lat and Lon, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

---

[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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- The input parameters being:
  - X = Lon
  - Y = Lat
  - DX = Step_Lon
  - DY = Step_Lat
  - XFIR = Lon_First
  - YFIR = Lat_First
  - Nb_Ptx = Nb_Pts_Lon
  - Nb_Pty = Nb_Pts_Lat
  - Xcyc = 21600
  - Ycyc = 0
  - Xcut = 0
  - Ycut = 0
- And the output parameters of which being:
  - The indexes of the four grid corners surrounding the (Lon,Lat) point: Ileft, Iright, Jlow, Jup
  - The weights of these corners: W_LL, W_LR, W_UL, W_UR
  - The execution status

- The slope of the reference MSS/geoid with respect to the reference ellipsoid (Slope_MSSGeoid) is computed at (Lon,Lat) by bilinear interpolation of the Doppler/MSS values at the grid corners corresponding to the pass direction (values for ascending tracks if the pass number of the altimeter measurement is odd, and values for descending tracks if the pass number of the altimeter measurement is even), using mechanism “GEN_MEC_INT_03 - Bilinear interpolation”,
  - The input parameters of which being:
    - VAL_LL = Dop_MSS (Ileft, Jlow)
    - VAL_LR = Dop_MSS (Iright, Jlow)
    - VAL_UL = Dop_MSS (Ileft, Jup)
    - VAL_UR = Dop_MSS (Iright, Jup)
    - W_LL
    - W_LR
    - W_UL
    - W_UR
    - NIL = Def_Value
  - And the output parameters of which being:
    - Slope_MSSGeoid
    - Nb_Pts_Valid (unused)
    - The execution status

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- The orbital altitude rate w.r.t. the reference MSS/geoid (Orb_Alt_Rate_MSSGeoid) is finally derived by:

$$Orb_Alt_Rate_MSSGeoid = Orb_Alt_Rate_Ellipsoid + Slope_MSSGeoid \quad (1)$$

ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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GEN_ENV_SUR_01 - To determine the surface type

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To determine the type of the overflown surface ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice" or "land") from a dedicated land/sea mask file.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

This function also applies to the JASON-1 level 1b processing (see RD8).

- Surface type: /

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Latitude of the measurement (1 Hz)
    - Longitude of the measurement (1 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Land/sea mask file

Output data

- Surface type, set to "open ocean or semi-enclosed seas", or "enclosed seas or lakes", or "continental ice" or "land".

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Mathematical statement

See RD8 "GEN_ENV_SUR_01 - To determine the surface type".

ALGORITHM SPECIFICATION

See RD8 "GEN_ENV_SUR_01 - To determine the surface type".

ACCURACY

See RD8 "GEN_ENV_SUR_01 - To determine the surface type".

COMMENTS

None

REFERENCES

None

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ALT_COR_RAN_02 - To compute the Doppler correction

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To compute the Doppler corrections on the altimeter range.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	See 3.1.4

- Surface type:

  The computation of the Doppler corrections is performed whatever the surface type is. It is nevertheless relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - For ENVISAT:
    - Elementary Ku bandwidth identifier
    - RF subsystem identifier
  - For JASON:
    - Altimeter configuration data
- Computed data:
  - For ENVISAT:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Orbital altitude rate with respect to the reference ellipsoid (20 Hz)
  - For JASON-1:
    - From "GEN_COR_ORB_01 - To derive the orbital altitude rate with respect to the reference MSS/geoid":
      - Orbital altitude rate with respect to the reference MSS/geoid (1 Hz)
- Dynamic auxiliary data: None

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- Static auxiliary data:
  - RA-2 / POSEIDON-2 instrumental characterization data:
    - Emitted frequency
    - Pulse duration
    - Emitted bandwidth
    - Sign of the slope of the transmitted chirp

Output data

- For ENVISAT:
  - Ku and S bands Doppler correction (20 Hz)
- For JASON-1:
  - Ku and C bands Doppler correction (1 Hz)

Mathematical statement

For each band, the Doppler correction to be added to the altimeter range is computed as defined in RD8 "ALT_COR_RAN_02 - To compute the Doppler correction".

ALGORITHM SPECIFICATION

The computation of the Doppler correction on the altimeter range estimate (20-Hz estimate for ENVISAT, 1-Hz estimate for JASON-1) for Ku band or for the auxiliary band (S for ENVISAT, C for JASON-1) is specified hereafter.

Symbol [Ku/C/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C/S-band value(s)).

Input data

- Orbital altitude rate : Orb_Alt_Rate (m/s)
- Instrumental characterization data:
  - Emitted frequency [1] : Frequency (Hz)
  - Pulse duration : Pulse_Duration (s)
  - Emitted bandwidth [2] : Bandwidth (Hz)
  - Sign of the slope of the transmitted chirp : Sign_Slope (-1 or +1)

---

[1] Value to be selected according to the processed band and to the operating RF subsystem (for ENVISAT)

[2] Value to be selected according to the processed band and the emitted bandwidth (altimeter configuration data for JASON-1, Ku bandwidth identifier for ENVISAT) and to the operating RF subsystem (for ENVISAT)

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Output data

- Doppler correction [Ku/C/S] : Cor_Dop_Range (m)
- Execution status

Processing

The Doppler correction is computed using mechanism "GEN_MEC_COR_03 - Computation of the Doppler correction on the altimeter range" (AD11), with the inputs mentioned above.

ACCURACY

Assuming an orbital altitude rate of ± 25 m/s, the order of magnitude of the Doppler correction variation will be about:

- For ENVISAT:
  - ± 2.1 cm for Ku band 320 MHz
  - ± 8.5 cm for Ku band 80 MHz
  - ± 34.0 cm for Ku band 20 MHz
  - ± 1.0 cm for S band 160 MHz
- For JASON-1:
  - ± 10.7 cm for Ku band 320 MHz
  - ± 4.1 cm for C band 320 MHz
  - ± 13.3 cm for C band 100 MHz

COMMENTS

This function also applies to JASON-1 level 1b processing (see RD8).

- In order to ensure the continuity of the Doppler correction whatever the surface type is, the altitude rate involved in its expression originates from the orbit, and is not the tracker estimate or an estimate derived from the altimeter range retracked estimates (e.g. slope of these estimates over 1 second, as it was done for POSEIDON-1).
- For ENVISAT, although the Doppler corrections are computed whatever the surface type is, they are fully consistent with ocean measurements only, and not with measurements relative to other surfaces. Indeed, these corrections are computed from the orbital altitude rate with respect to a reference ellipsoid. For JASON-1, the orbital altitude rate is referenced to a reference MSS/geoid. It is nevertheless consistent with ocean measurements only, because the point of measurement is assumed to be the subsatellite point on the reference ellipsoid.
- The Doppler correction is computed for each elementary measurement in the ENVISAT IGDR and GDR procedures in order to account for possible Ku bandwidth changes within a source packet.
- Regarding the JASON-1 GDR processing, the recomputation of the Doppler correction will be performed only if the improvement on the correction is significant.

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ALT_RET_ICE_01 - To perform the ice-1 retracking

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To perform the ice-1 retracking (the so-called OCOG algorithm from MSSL, see RD7) on the waveforms.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The ice-1 retracking is performed whatever the surface type is. Nevertheless, it is optimized for continental ice sheet surfaces.

ALGORITHM DEFINITION

Input data

- Product data:
  - Waveform (128 FFT samples for Ku band, 64 FFT samples for S band)
  - Ku bandwidth identifier for Ku band
  - Instrument mode identifier at datablock level
  - RF subsystem identifier
- Computed data: None
- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data for the preparation of data for the ice-1 retracking (see RD12)
  - RA-2 instrumental characterization data for the ice-1 retracking:
    - Sampling interval of the analysis window
  - Processing parameters (the exhaustive list is given in section "Algorithm specification / Input data")

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Output data

For each band, the following 20-Hz parameters:

- Epoch (or "range offset"): τ
- Amplitude: P_u
- Quality information, such as an execution flag (valid / invalid)

Mathematical statement

The ice-1 retracking algorithm is performed on the Ku and on the S band waveforms. The only difference in the retracking of Ku and S waveforms is the processed data (waveform, processing and instrumental parameters). A single description is thus given below.

Background

The ice-1 retracking algorithm is defined in RD7. The aim of the ice-1 retracking algorithm is to determine the tracking offset (or epoch) and the amplitude of the waveform, from an Offset Center Of Gravity parameterization.

Basic principle and main steps of the processing (see RD7)

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

- Estimation of the amplitude (P_u):

  In a predefined part of the analysis window (representing almost the whole window), the waveform, expressed in power, is replaced by a box which have the same center of area as the waveform. The amplitude (more exactly the power) P_u^2 of this box is derived from this condition by:

$$P_u^2 = \frac{\sum_i V_i^4}{\sum_i V_i^2} \qquad (1)$$

  where $\{V_i\}$ represent the waveform samples, and where the summations turn on the above-mentioned predefined interval. The amplitude P_u of the waveform is then derived by square root extraction.

- Estimation of the epoch:

  The epoch (τ) of the waveform in the estimation window is then determined by finding the point on the waveform (by interpolation) where the waveform amplitude exceeds a threshold determined from the estimated amplitude P_u.

ALGORITHM SPECIFICATION

Warning: The following computations:

- Building of the processing flag for the ice-1 retracking from the instrument mode identifier at datablock level (corresponding to the elementary measurements in "Tracking" or "Preset tracking" mode, see "Lost track" flag in RD7)

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- Building of the table of abscissa of the waveform samples (starting from 0 and increased by a factor of 1 for each sample, ignoring the 2 additional DFT samples for Ku band)
- Determination of the abscissa of the reference sample for tracking for Ku and S bands (i.e. the reference abscissa in the analysis window for the tracker range estimates), depending on the processed band

are considered as part of "data management" algorithms (see section 1). They are specified in RD12.

For each waveform, the ice-1 retracking is specified hereafter.

Input data

- Processing flag for the ice-1 retracking : Ice1_Proc_Flag ("valid" or "invalid")
- Waveform:
  - Number of samples : Nb_Sample (/)
  - Abscissa of samples in the analysis window : Wf_Abs [0:Nb_Sample-1] (/)
  - Samples amplitude : Wf_Ampl [0:Nb_Sample-1] (FFT power unit)
- Waveform features:
  - Sampling interval of the analysis window [(1)] : FFT_Step (s)
  - Abscissa of the reference sample for tracking : Abs_Ref_Track (/)
- Processing parameters for the ice-1 retracking [(2)]:
  - First bin used in the retracking calculation : First_Bin (/)
  - Last bin used in the retracking calculation : Last_Bin (/)
  - Threshold for determination of the leading edge position : Tresh_Pos_LE (/)
  - Lower bound for the retracking point : Low_Bound (/)
  - Upper bound for the retracking point : Upp_Bound (/)

Output data

- Retracking estimates:
  - Epoch : Epoch_Ice1 (s)
  - Amplitude : Ampl_Ice1 (FFT power unit)
- Quality information:
  - Execution of the retracking algorithm : Flag_Retrack_Ice1 ("valid" or "invalid")
- Execution status

---

(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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Processing

If Ice1_Proc_Flag is set to "invalid", then:

- Flag_Retrack_Ice1 is set to "invalid"
- Epoch_Ice1 and Ampl_Ice1 are set to default values

Else (Ice1_Proc_Flag set to "valid"):

- The flag relative to the execution of the retracking algorithm (Flag_Retrack_Ice1) is initialized to "valid".
- The sum of the squares of the sample amplitudes (Sum_Sqr) is computed as follows, where the summation turns on indexes i such that $First_Bin \le Wf_Abs(i) \le Last_Bin$:

$$Sum_Sqr = \sum_i Wf_Ampl(i)^2 \tag{1}$$

- If $Sum_Sqr = 0$, then:
  - Flag_Retrack_Ice1 is set to "invalid"
  - Epoch_Ice1 = 0
  - Ampl_Ice1 is set to default value
- Else:
  - The amplitude Ampl_Ice1 of the waveform is computed according to (2) where the summation turns on indexes i such that $First_Bin \le Wf_Abs(i) \le Last_Bin$:

$$Ampl_Ice1 = \sqrt{\sum_i \left(\frac{Wf_Ampl(i)^4}{Sum_Sqr} \right)} \tag{2}$$

  - The threshold amplitude Thresh is then computed by:

$$Thresh = Tresh_Pos_LE * Ampl_Ice1 \tag{3}$$

  - Let j be the index such that Wf_Abs(j) be the smallest abscissa satisfying the following condition:

$$First_Bin \le Wf_Abs(j) \le Last_Bin \quad \text{and} \quad Wf_Ampl(j) > Thresh \tag{4}$$

    - If such an index does not exist or if EMBED $j-1 < First_Bin$, then:
      - Flag_Retrack_Ice1 is set to "invalid"
      - Epoch_Ice1 = 0
    - Else:
      - The abscissa corresponding to the threshold amplitude is computed by:

$$Abs_Thresh = Wf_Abs(j) - 1 + \frac{Thresh - Wf_Ampl(j-1)}{Wf_Ampl(j) - Wf_Ampl(j-1)} \tag{5}$$

      - The epoch of the waveform is derived by:

$$Epoch_Ice1 = (Abs_Tresh - Abs_Ref_Track) * FFT_Step \tag{6}$$

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◊ Finally, if the following condition is satisfied:

$$Abs_Thresh < Low_Bound \text{ or } Abs_Thresh > Upp_Bound \quad (7)$$

then:

Flag_Retrack_Ice1 is set to "invalid"

ACCURACY

TBD

COMMENTS

- The two additional DFT samples for Ku band are not accounted for in the processing.
- In RD7, the ice-1 and the sea-ice retracking algorithms are performed after a pre-processing step aimed at identifying the waveforms validity and at computing the peakiness of waveforms (for Ku and S bands).
  - The validity of waveforms is determined from the following criteria:
    - Computation of the thermal noise level by averaging of samples in the early part the waveform. With echo waveforms from non-ocean surfaces, this value may be contaminated by the surface return, and so thresholding is used in the next step to identify waveforms so contaminated, and for other reasons.
    - Computation of the total averaged amplitude of the waveform. If this value is smaller than a multiple of the thermal noise level, the waveform is regarded as not valid.
    - Computation of the averaged amplitude of the waveform in two contiguous windows which span the entire range window. The purpose of this test is to check that the leading edge of the waveform lies within the range window. The waveform is regarded as not valid if the first amplitude exceeds a multiple of the second one.
  - Regarding the "peakiness" of waveforms, it is essentially the ratio of the maximum amplitude to the mean amplitude of samples to the right of the tracking point, and it represents an independent waveform quality information.

  This pre-processing is considered as a "data management" algorithm (see section 1), especially because its outputs consists only of quality information to be used to build the output product, but which are not requested on input of the algorithms defined and specified in this document. This pre-processing algorithm is specified in RD12.

REFERENCES

None

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ALT_RET_ICE_02 - To perform the ice-2 retracking

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

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

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The ice-2 retracking is performed whatever the surface type is. Nevertheless, it is optimized for continental ice sheets surfaces, except the computation of the slope of the logarithm of the trailing edge for the mispointing estimation which is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Waveform (128 FFT samples + 2 DFT samples for Ku band, 64 FFT samples for S band)
  - Ku bandwidth identifier for Ku band
  - Instrument mode identifier at source packet level
  - Instrument mode identifier at datablock level
  - Quality information:
    - AGC fault identifier
    - RX delay fault identifier
    - Waveform samples fault identifier
    - RF subsystem identifier
  - Noise power measurement
- Computed data: None
- Dynamic auxiliary data: None

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- Static auxiliary data:
  - RA-2 instrumental characterization data for the preparation of data for the ice-2 retracking (see RD12)
  - RA-2 instrumental characterization data for the ice-2 retracking:
    - Sampling interval of the analysis window
  - Processing parameters (the exhaustive list is given in section "Algorithm specification / Input data")
  - Universal constants:
    - Light velocity

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: s_{T2}
- Slope of the first part of the logarithm of the trailing edge for mispointing estimation: s_{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)

Mathematical statement

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

Background

The ice-2 retracking algorithm is an adaptation to the ENVISAT RA-2 background, of the algorithm designed by GRGS to process ERS data over continental ice sheets (Legresy, 1995).

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.

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

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

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 RD1)

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

  – 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

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- 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, in press), 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.)

ALGORITHM SPECIFICATION

Warning: The following computations:

- Building of the processing flag for the ice-2 retracking from the instrument mode identifiers at source packet and at datablock level, and from the input quality information (corresponding to the "RA-2 nominal tracking data", subset of the elementary measurements which are in "Tracking", "Preset tracking" or "Preset loop output" mode, see RD5)
- Building of the table of abscissa of the waveform samples (starting from 0 and increased by a factor of 1 for each sample, except for the 2 additional DFT samples for Ku band which must be accounted for)
- Building of the Ku-band and S-band waveforms quality flags (from the input waveform samples fault identifiers)
- Determination of the abscissa of the reference sample for tracking for Ku and S bands (i.e. the reference abscissa in the analysis window for the tracker range estimates), depending on the processed band and on the emitted bandwidths
- Conversion of the input thermal noise level, accounting for the AGC values used in tracking and NPM modes

are considered as part of "data management" algorithms (see section 1). They are specified in RD12.

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For each waveform, the ice-2 retracking is specified hereafter.

Input data

- Processing flag for the ice-2 retracking : Ice2_Proc_Flag ("valid" or "invalid")
- Waveform:
  - Number of samples : Nb_Sample (/)
  - Abscissa of samples in the analysis window : Wf_Abs [0:Nb_Sample-1] (/)
  - Samples amplitude : Wf_Ampl [0:Nb_Sample-1] (FFT power unit)
- Waveform features:
  - Sampling interval of the analysis window [(1)] : FFT_Step (s)
  - Abscissa of the reference sample for tracking : Abs_Ref_Track (/)
  - Waveform quality flag : Flag_Wf ("valid" or "invalid")
  - Thermal noise level : NPM (FFT power unit)
- Processing parameters for the ice-2 retracking [(2)]:
  - Minimum expected abscissa of the central sample : Cs_Min (/)
  - Maximum expected abscissa of the central sample : Cs_Max (/)
  - Option for thermal noise computation : Tn_Opt (/)
  - Abscissa of the first sample for noise estimation : Tn_First (/)
  - Abscissa of the last sample for noise estimation : Tn_Last (/)
  - Minimum abscissa of the leading edge : Le_Min (/)
  - Thermal noise weighting factor for leading edge id. : Tn_Id (/)
  - Maximum abscissa for leading edge evaluation : Le_Max (/)
  - Leading edge width threshold : Le_Width (s)
  - Maximum left gap of the leading edge : Le_Gap (/)
  - Thermal noise weighting factor for estimation conditions : Tn_Estim (/)
  - Left shift of the beginning of the leading edge : Le_Left (/)
  - Right shift of the end of the leading edge : Le_Right (/)
  - Minimum abscissa of the estimation window : Ew_Min (/)
  - Maximum abscissa of the estimation window : Ew_Max (/)
  - Right offset of the estimation window : Ew_Right (/)

---

(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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- Maximum abscissa of the slope window : Sw_Max (/)
- Maximum abscissa of the slope window for mispointing : Swm_Max (/)
- Width of the first slope window : Sw1_Width (s)
- Width of the second slope window : Sw2_Width (s)
- Width of the slope window for mispointing : Swm_Width (s)
- Initial value of the residual : Res_Init (/)
- Minimum expected width of the leading edge : Lew_Min (/)
- Maximum expected width of the leading edge : Lew_Max (/)
- Step for the fine estimation of Epoch : Epoch_Step2 (/)
- Step for the fine estimation of SigmaL : SigL_Step2 (/)
- Default thermal noise level : Default_Noise (FFT power unit)
- Limit argument for the erf function (absolute value) : Arg_Limit (/)

- Light velocity : Light_Vel (m/s)

Output data

- Retracking estimates:
  - Epoch : Epoch_Ice2 (s)
  - Width of the leading edge (m) : SigmaL_Ice2 (m)
  - Amplitude : Ampl_Ice2 (FFT power unit)
  - Mean amplitude : Ampl_Mean_Ice2 (FFT power unit)
  - Thermal noise level : Therm_Noise_Ice2 (FFT power unit)
  - Slope of the first part of the log. of the trailing edge : Slope1_Ice2 (s^{-1})
  - Slope of the second part of the log. of the trailing edge : Slope2_Ice2 (s^{-1})
  - Slope of the log. of the trailing edge for mispointing : SlopeM_Ice2 (s^{-1})
- Quality information:
  - Execution of the retracking algorithm : Flag_Retrack_Ice2 ("valid" or "invalid")
  - Computation of the first slope : Flag_Slope1_Ice2 ("valid" or "invalid ")
  - Computation of the second slope : Flag_Slope2_Ice2 ("valid" or "invalid ")
  - Computation of the slope for mispointing : Flag_SlopeM_Ice2 ("valid" or "invalid ")
  - Detection of the beginning of the leading edge : Flag_Le_Detect_Ice2 ("valid" or "invalid")
  - Detection of the end of the leading edge : Flag_Le_Limit_Ice2 ("valid" or "invalid")
  - End of the leading edge : Flag_Le_End_Ice2 ("valid" or "invalid")
  - Amplitude of the waveform : Flag_Ampl_Ice2 ("valid" or "invalid")
  - Position of the reference sample for tracking : Flag_Central_Ice2 ("valid" or "invalid")
  - Mean quadratic error in the estimation window : MQE_Ice2 (/)

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- Execution status

Processing

If {Ice2_Proc_Flag is set to "invalid"} or if {Ice2_Proc_Flag is set to "valid" and Flag_Wf is set to "invalid"}, then:

- Flag_Retrack_Ice2, Flag_Slope1_Ice2, Flag_Slope2_Ice2, Flag_SlopeM_Ice2, Flag_Le_Detect_Ice2, Flag_Le_Limit_Ice2, Flag_Le_End_Ice2, Flag_Ampl_Ice2 and Flag_Central_Ice2 are set to "invalid"
- Epoch_Ice2, SigmaL_Ice2, Ampl_Ice2, Ampl_Mean_Ice2, Therm_Noise_Ice2, Slope1_Ice2, Slope2_Ice2, SlopeM_Ice2 and MQE_Ice2 are set to default values

Else (Ice2_Proc_Flag and Flag_Wf set to "valid"), the retracking is performed according the following flowchart:

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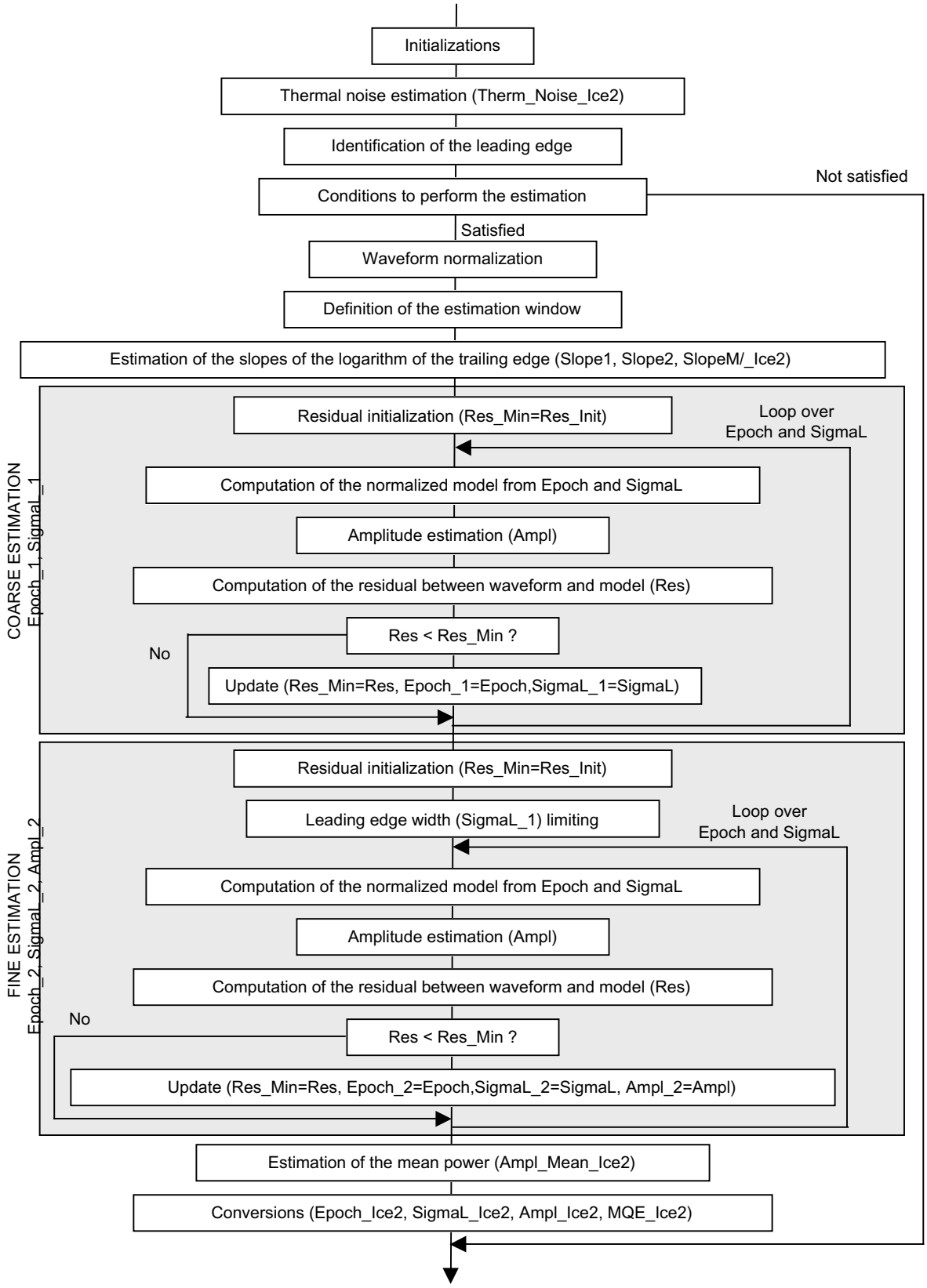

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- Initializations:

  All the flags (i.e. Flag_Retrack_Ice2, Flag_Slope1_Ice2, Flag_Slope2_Ice2, Flag_SlopeM_Ice2, Flag_Le_Detect_Ice2, Flag_Le_Limit_Ice2, Flag_Le_End_Ice2, Flag_Ampl_Ice2 and Flag_Central_Ice2) are initialized to "valid".

- Thermal noise estimation:

  The thermal noise level Therm_Noise_Ice2 is determined as follows:

  – If TN_Opt = 0, then:

  $$\text{Therm_Noise_Ice2} = \text{NPM} \tag{1}$$

  – Else if TN_Opt = 1, then:

  $$\text{Thermal_Noise_Ice2} = \frac{\sum_i \text{Wf_Ampl(i)}}{\sum_i 1} \tag{2}$$

  where the summations turn on indexes i such that $\text{Tn_First} \le \text{Wf_Abs(i)} \le \text{Tn_Last}$, and where $\sum_i 1$ represents the number of points taken into account in the averaging process.

  – Else:

  $$\text{Therm_Noise_Ice2} = \text{Default_Noise} \tag{3}$$

- Identification of the leading edge:

  This stage of the process is aimed at identifying the beginning (abscissa Abs_Min) and the end (abscissa Abs_Max) of the leading edge, and the maximum amplitude V_Max of the waveform.

  – Indexes i of the waveform samples are processed in the ascending order. If the three following conditions are satisfied:

  * Abs_Min still not detected (4)
  * $\text{Wf_Abs(i)} \ge \text{Le_Min}$ (5)
  * $\text{Tn_Id} * \text{Therm_Noise_Ice2} < \text{Wf_Ampl(i)} < \text{Wf_Ampl(i+1)}$ (6)

  then Abs_Min is detected and:

  $$\text{Abs_Min} = \text{Int}[\text{Wf_Abs}(i-1)]\text{, where Int represents the integer truncation} \tag{7}$$

  – V_Max is the maximum amplitude of the waveform limited to the abscissa interval [Le_Min, Le_Max], and Abs_Max is the corresponding abscissa.

  – If the two following conditions are satisfied:

  * Abs_Min is detected (8)
  * $\text{Abs_Max} > \text{Abs_Min} + \frac{\text{Le_Width}}{\text{FFT_Step}}$ (9)

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then:

$$* \quad Abs_Max = Int\left[Abs_Min + \frac{Le_Width}{FFT_Step}\right] \tag{10}$$

$$* \quad V_Max = Wf_Ampl(j) \text{ where } j \text{ is such as } Wf_Abs(j) = Abs_Max \tag{11}$$

$$* \quad \text{Flag_Le_Limit_Ice2 is set to "invalid"} \tag{12}$$

- Conditions to perform the estimation:

  If at least one of the following conditions is satisfied:

  – Condition 1 : $Abs_Ref_Track < Cs_Min$ or $Abs_Ref_Track > Cs_Max$ (13)

  – Condition 2 : Abs_Min not detected (14)

  – Condition 3 : $(Abs_Ref_Track - Abs_Max) > Le_Gap$ or $Abs_Max \leq Abs_Min$ (15)

  – Condition 4 : $V_Max \leq Tn_Estim * Therm_Noise_Ice2$ (16)

  then:

  – the corresponding flag(s), among:

    * Flag_Central_Ice2 (condition 1)
    * Flag_Le_Detect_Ice2 (condition 2)
    * Flag_Le_End_Ice2 (condition 3)
    * Flag_Ampl_Ice2 (condition 4)

    is(are) set to "invalid"

  – Flag_Retrack_Ice2 is set to "invalid"

  – The processing of the waveform is stopped.

- Waveform normalization:

  The normalized waveform Wf_Norm is defined by:

$$Wf_Norm(i) = \frac{Wf_Ampl(i) - Therm_Noise_Ice2}{V_Max - Therm_Noise_Ice2} \quad (i = 0, Nb_Sample-1) \tag{17}$$

- Definition of the estimation window:

  – The first and last abscissa of the estimation window (Abs_Est_First and Abs_Est_Last) are computed by:

$$Abs_Est_First = Abs_Min - Le_Left \tag{18}$$

$$Abs_Est_Last = Abs_Max + Le_Right \tag{19}$$

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They are limited as follows:

$$Abs_Est_First < Ew_Min \Rightarrow Abs_Est_First = Ew_Min \quad (20)$$

$$Abs_Est_Last > Ew_Max \Rightarrow Abs_Est_Last = Ew_Max \quad (21)$$

– The width Width_Est of the estimation window is computed by:

$$Width_Est = Abs_Est_Last - Abs_Est_First \quad (22)$$

– The abscissa Abs_Est_Center of the center of the estimation window is computed by:

$$Abs_Est_Center = Abs_Est_Last - \frac{Width_Est}{2} \quad (23)$$

- Estimation of the slope of the logarithm of the trailing edge:
  – The abscissa Abs_S1_First and Abs_S1_Last delimiting the first window for the slope computation are defined by:

$$Abs_S1_First = Min(Abs_Est_Last + Ew_Right, Sw_Max - 2) \quad (24)$$

$$Abs_S1_Last = Min\left(Abs_S1_First + \frac{Sw1_Width}{FFT_Step}, Sw_Max - 1\right) \quad (25)$$

  – Slope1_Ice2 and Flag_Slope1_Ice2 are computed using mechanism "GEN_MEC_COM_05 - Estimation of the slope of the logarithm of the trailing edge of a waveform (linear regression)", with the following inputs:
    * Window for the estimation:
      ◊ Abscissa of the beginning : Abs_S1_First
      ◊ Abscissa of the end : Abs_S1_Last
    * Waveform:
      ◊ Number of samples : Nb_Sample
      ◊ Abscissa of samples : Wf_Abs [0:Nb_Sample-1]
      ◊ Samples amplitude : Wf_Norm [0:Nb_Sample-1]
      ◊ Offset for normalization : 0
      ◊ Sampling interval of the analysis window : FFT_Step
  – The abscissa Abs_S2_First and Abs_S2_Last delimiting the second window for the slope computation are defined by:

$$Abs_S2_First = Abs_S1_Last \quad (26)$$

$$Abs_S2_Last = Min\left(Abs_S2_First + \frac{Sw2_Width}{FFT_Step}, Sw_Max\right) \quad (27)$$

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- Slope2_Ice2 and Flag_Slope2_Ice2 are computed using mechanism "GEN_MEC_COM_05 - Estimation of the slope of the logarithm of the trailing edge of a waveform (linear regression)", with the following inputs:
  - Window for the estimation:
    - Abscissa of the beginning : Abs_S2_First
    - Abscissa of the end : Abs_S2_Last
  - Waveform:
    - Number of samples : Nb_Sample
    - Abscissa of samples : Wf_Abs [0:Nb_Sample-1]
    - Samples amplitude : Wf_Norm [0:Nb_Sample-1]
    - Offset for normalization : 0
    - Sampling interval of the analysis window : FFT_Step
- The abscissa Abs_Sm_First and Abs_Sm_Last delimiting the window for the slope computation for mispointing are defined by:

$$Abs_Sm_First = Abs_S1_First \tag{28}$$

$$Abs_Sm_Last = Min\left(Abs_Sm_First + \frac{Swm_Width}{FFT_Step}, Swm_Max\right) \tag{29}$$

- SlopeM_Ice2 and Flag_SlopeM_Ice2 are computed using mechanism "GEN_MEC_COM_05 - Estimation of the slope of the logarithm of the trailing edge of a waveform (linear regression)", with the following inputs:
  - Window for the estimation:
    - Abscissa of the beginning : Abs_Sm_First
    - Abscissa of the end : Abs_Sm_Last
  - Waveform:
    - Number of samples : Nb_Sample
    - Abscissa of samples : Wf_Abs [0:Nb_Sample-1]
    - Samples amplitude : Wf_Norm [0:Nb_Sample-1]
    - Offset for normalization : 0
    - Sampling interval of the analysis window : FFT_Step

- Coarse estimation:

  The Least Square fit is performed in two stages (coarse and fine estimations), from the normalized waveform samples in the estimation window.

  This first stage of the Least Square process is aimed at providing a coarse estimate of the epoch in the estimation window (Epoch_1 with a resolution Epoch_Step: computed), and of the width of the leading edge (SigmaL_1 with a resolution SigL_Step: computed).

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– The following parameters, where the summations turn on indexes i such that $Abs_Est_First \le Wf_Abs(i) \le Abs_Est_Last$, are computed:

$$Sum0 = \sum_i 1 \tag{30}$$

$$Sum1 = \sum_i Wf_Norm^2(i) \tag{31}$$

– The minimum value of the residual is initialized:

$$Res_Min = Res_Init \tag{32}$$

– For each possible value of the epoch:

$$Epoch \in \left[-\frac{Width_Est}{2}, \frac{Width_Est}{2} \right] \tag{33}$$

by step of: $Epoch_Step1 = \sqrt{Width_Est * Epoch_Step2}$ (34)

and for each possible value of the width of the leading edge:

$$SigmaL \in [Lew_Min, Lew_Max] \tag{35}$$

by step of: $SigL_Step1 = \sqrt{(Lew_Max - Lew_Min) * SigL_Step2}$ (36)

the following operations are performed:

1) The normalized model Mod_Norm is computed in the estimation window, i.e. for indexes i is such that $Abs_Est_First \le Wf_Abs(i) \le Abs_Est_Last$:

$$x = \frac{[Wf_Abs(i) - Abs_Est_Center] - Epoch}{SigmaL} \tag{37}$$

– If $x < -Arg_Limit$, then: $Mod_Norm(i) = 0$ (38)

– Else if $x > Arg_Limit$, then: $Mod_Norm(i) = 1$ (39)

– Else: $Mod_Norm(i) = \frac{1}{2} * [1 + erf(x)]$ (40)

where the "erf" function is defined by: $erf(x) = \frac{2}{\sqrt{\pi}} * \int_0^x e^{-t^2} dt$ (41)

2) The following parameters are then computed in the estimation window:

$$Sum2 = \sum_i Mod_Norm^2(i) \tag{42}$$

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$$Sum12 = \sum_i Wf_Norm(i) * Mod_Norm(i) \tag{43}$$

3) The amplitude Ampl of the normalized waveform is computed by:

$$Ampl = \frac{Sum12}{Sum2} \tag{44}$$

4) The residual Res between the normalized waveform and the weighted normalized model in the estimation window, is computed by:

$$Res = \frac{Sum1 + Ampl^2 * Sum2 - 2 * Ampl * Sum12}{Sum0} \tag{45}$$

(Ampl is not computed and Res is set Res = Res_Init if $\sum_i Mod_Norm^2(i) = 0$)

5) If Res < Res_Min, then the estimates are updated, by

$$Res_Min = Res\ ,\ Epoch_1 = Epoch\ ,\ SigmaL_1 = SigmaL \tag{46}$$

- Fine estimation:

This second stage of the Least Square process is aimed at providing a fine estimate of the epoch in the estimation window (Epoch_2 with a resolution Epoch_Step2), of the width of the leading edge (SigmaL_2 with a resolution SigL_Step2), and of the amplitude of the normalized waveform (Ampl_2).

– As in the coarse stage, the minimum value of the residual is initialized:

$$Res_Min = Res_Init \tag{47}$$

– Then, for each possible value of the epoch:

$$Epoch \in \left[Epoch_1 - \frac{Epoch_Step1}{2}, Epoch_1 + \frac{Epoch_Step1}{2} \right] \tag{48}$$

by step of: Epoch_Step2 (Epoch_Step 1 is computed in (34))

and for each possible value of the width of the leading edge:

$$SigmaL \in \left[SigmaL_1 - \frac{SigL_Step1}{2}, SigmaL_1 + \frac{SigL_Step1}{2} \right] \tag{49}$$

by step of: SigL_Step2 (SigL_Step1 is computed in (36))

the following operations are performed:

1) The normalized model Mod_Norm is computed in the estimation window as in (38) to (40)
2) Parameters Sum2 and Sum12 are computed as in (42) and (43)
3) The amplitude Ampl of the normalized waveform is computed as in (44)

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4) The residual Res between the normalized waveform and the weighted normalized model in the estimation window, is computed as in (45)

5) If $Res < Res_Min$, then the estimates are updated, by:

$$Res_Min = Res\ ,\ Epoch_2 = Epoch\ ,\ SigmaL_2 = SigmaL\ ,\ Ampl_2 = Ampl \tag{50}$$

- Estimation of the mean amplitude:

  The abscissa of the first and last samples (Abs_Ma_First and Abs_Ma_Last) of the window used to compute the mean amplitude are defined by:

$$Abs_Ma_First = Min(Abs_Min, Sw_Max - 1) \tag{51}$$

$$Abs_Ma_Last = Abs_S1_Last \quad \text{(computed in (25))} \tag{52}$$

  The mean amplitude Ampl_Mean_Ice2 of the waveform around the leading edge is then computed as follows from the waveforms samples, where the summation turns on indexes i such that $Abs_Ma_First \le Wf_Abs(i) \le Abs_Ma_Last$:

$$Ampl_Mean_Ice2 = \frac{\sum_i \left[Wf_Ampl(i) - Therm_Noise_Ice2\right]}{\sum_i 1} \tag{53}$$

- Conversions:

  – The epoch Epoch_Ice2 (s) is derived from Epoch_2 by:

$$Epoch_Ice2 = (Abs_Est_Center + Epoch_2 - Abs_Ref_Track) * FFT_Step \tag{54}$$

  – The width of the leading edge SigmaL_Ice2 (m) is derived from SigmaL_2 by:

$$SigmaL_Ice2 = SigmaL_2 * \frac{Light_Vel * FFT_Step}{2} \tag{55}$$

  – The denormalized amplitude Ampl_Ice2 is derived from Ampl_2 by:

$$Ampl_Ice2 = Ampl_2 * (V_Max - Therm_Noise_Ice2) \tag{56}$$

  – The mean quadratic error MQE_Ice2 is defined by:

$$MQE_Ice2 = Res_Min \tag{57}$$

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ACCURACY

The performances of the ice2 retracking algorithm have been valued in RD1, from ice waveforms built from the model given in formula (1), including speckle, and using nominal values of the RA-2 instrumental parameters. The on-board tracker operation and thus the jitter on the position of the waveform in distance and amplitude has not been simulated.

The main results obtained in standard conditions, i.e. with:

- σ_L = .761 m (equivalent to an ocean waveheight of 2 m)
- SNR = 15 dB
- s_T = -13.34 km^{-1} (ocean-like slope of the logarithm of the trailing edge),

are summarized below. The dependency of these results with the various parameters (i.e. width of the leading edge, slope of the logarithm of the trailing edge and signal to noise ratio) are described in RD1.

- Epoch (τ):

  The mean error is about 2 cm for Ku band 320 MHz, 3 cm for Ku band 80 MHz, 30 cm for Ku band 20 MHz and -4 cm for S band 160 MHz. It becomes more important when the slope of the trailing edge is positive (e.g. for Ku band 320 MHz, it is about -1 cm for s_T = 0 and -11 cm for s_T = 13.34 km^{-1}).
  The standard deviation is about 6 cm for Ku band 320 MHz, 8 cm for Ku band 80 MHz, 23 cm for Ku band 20 MHz and 22 cm for S band 160 MHz. It increases with the width of the leading edge (σ_L) and decreases with SNR. The high values observed for S band proceed from an increase of the speckle on the waveforms samples by a factor of 2 for S band, due to the number of averaged individual echoes.

- Width of the leading edge (σ_L):

  For low values of σ_L, the mean error logically increases with the sampling interval for Ku band. For σ_L = 0, it is about -2 cm at 320 MHz, -28 cm at 80 MHz and -177 cm at 20 MHz. It should consequently be between -2 cm and -28 cm at 160 MHz. Actually, it is more important (about -38 cm) because of the absence of the two additional DFT samples for S band, which improve the resolution for Ku band. For these reasons, the estimate of σ_L can not be accurate for Ku band 20 MHz, whatever the conditions are. In standard conditions, the error is small for the other bandwidths. It is about 0.5 cm for Ku band 320 MHz, 7 cm for Ku band 80 MHz and 3 cm for S band 160 MHz. It does not depend on SNR, and its dependency with the slope of the trailing edge is small.

  The standard deviation is about 12.5 cm for Ku band 320 MHz, 17 cm for Ku band 80 MHz, 38 cm for Ku band 20 MHz and 44 cm for S band (high value due to the speckle features for S band). It increases with σ_L, except for Ku band 20 MHz where it is constant because the whole leading edge is always included in one FFT filter. It also increases with the slope of the trailing edge, but does not depend on the signal to noise ratio.

- Amplitude (Pu):

  In standard conditions but with a flat trailing edge (s_T=0), the mean error is small (i.e. between -0.01 and -0.1 dB) whatever the bandwidth is. It becomes important in case of a negative and overall a positive slope (e.g. for s_T = 13.34 km^{-1}, the error is about -0.5 to -0.6 dB for Ku bands 320 and 80 MHz and for S band, and about -0.9, dB for Ku band 20 MHz).This error should be smaller for real waveforms, due to the existence of a volume signal at the end of the leading edge over continental ice sheets (not accounted for in the simulation). For Ku bands, the standard deviation is about 5 to 7% of the amplitude for a flat trailing edge, and it does not depend on σ_L or SNR. For S band, it is higher in standard conditions (about 11% of the amplitude) and its dependency with σ_L is important, due to the speckle features (the standard deviation is about 25% of the amplitude for an equivalent significant waveheight of 8 m).

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- Mean amplitude (P_t):

  The accuracy of the estimate of the mean amplitude of the waveform has not be assessed because the reference value is unknown (it is not an input parameter of the simulation). Nevertheless, the order of magnitude of the mean amplitude is satisfactory in regard with the simulated amplitude P_u, and with the tests conditions.

- Slope of the logarithm of the trailing edge (s_{T1}, s_{T2}):

  The standard deviation on the slope estimates is important due to the speckle affecting the waveforms and to the limited number of samples which can be accounted for. The interpretation of the mean errors is thus not obvious from a limited amount of simulated measurements. In standard conditions and for a 320-MHz bandwidth, the standard deviation on s_{T1} is about 2 km^{-1}.

COMMENTS

- For Ku band, all the processing systematically accounts for the two additional DFT samples.

REFERENCES

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ALT_RET_OCE_01 - To perform the ocean-1 retracking

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To perform the ocean-1 retracking (the so-called ESA/CNES/CLS algorithm) on the waveforms.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The ocean-1 retracking algorithm is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- Product data:
  - Waveform (128 FFT samples + 2 DFT samples for Ku band, 64 FFT samples for S band)
  - Ku bandwidth identifier for Ku band
  - Instrument mode identifier at source packet level
  - Instrument mode identifier at datablock level
  - Quality information:
    - AGC fault identifier
    - RX delay fault identifier
    - Waveform samples fault identifier
    - RF subsystem identifier
  - Noise power measurement
- Computed data:
  - From "ALT_RET_ICE_02 - To perform the ice-2 retracking", outputs corresponding to the processed waveform:

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    - Epoch
    - Width of the leading edge
    - Amplitude
    - Mean quadratic error
    - Execution flag
  - From "PLA_PHY_MIS_01 - To compute the platform-derived off-nadir angle":
    - Square of the off-nadir angle: ξ^2
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Orbit altitudes (20-Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data for the preparation of data for the ocean-1 retracking (see RD12)
  - RA-2 instrumental characterization data for the ocean-1 retracking:
    - Sampling interval of the analysis window
    - Antenna beamwidth
    - Ratio between the PTR width and the sampling interval of the analysis window
  - Processing parameters (the exhaustive list is given in section "Algorithm specification / Input data")
  - Universal constants:
    - Light velocity
    - Earth radius

Output data

For each band, the following 20-Hz parameters:

- Epoch: τ
- Composite Sigma: σ_c
- Amplitude: P_u
- Thermal noise level: P_n
- Mean quadratic error between the normalized waveform and its model
- Number of iterations
- Quality information, such as an execution flag (valid / invalid)

Mathematical statement

The ocean-1 retracking algorithm is performed on the Ku and on the S band waveforms. The only difference in the retracking of Ku and S waveforms is the processed data (waveform, processing and instrumental parameters). A single description is thus given below.

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Background

The ocean-1 retracking algorithm has been defined by CLS, from a comparative study of the various standard ocean retracking algorithms (see RD2), i.e. of:

- CNES/CLS algorithm designed to process POSEIDON altimeter data
- JPL algorithm designed to process TOPEX altimeter data
- ESTEC algorithm designed to process ERS altimeter data
- ALENIA algorithm designed to process ENVISAT altimeter data

The aim of the ocean-1 retracking algorithm is to make the measured waveform coincide with a return power model, according to weighted Least Square estimators.

The expression of the return power as a function of time is given by Hayne (Hayne, 1980). Accounting for a skewness coefficient (λ_s = processing parameter), and assuming a gaussian point target response (Hamming weighting performed on-board the RA-2 altimeter), it is given by:

$$\boxed{Vm(t) = a_\xi \frac{P_u}{2} \exp(-v)\left\{[1+\mathrm{erf}(u)] + \frac{\lambda_s}{6}\left(\frac{\sigma_s}{\sigma_c}\right)^3 \left\{[1+\mathrm{erf}(u)]c_\xi^3\sigma_c^3 - \frac{\sqrt{2}}{\sqrt{\pi}}\left[2u^2 + 3\sqrt{2}c_\xi\sigma_c u + 3c_\xi^2\sigma_c^2 - 1\right]\exp(-u^2)\right\}\right\} + P_n} \quad (1)$$

with: $\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}.\int_0^x e^{-t^2}dt$

$a_\xi = \exp\left(\frac{-4\sin^2\xi}{\gamma}\right)$, ξ = mispointing (off-nadir angle), $\gamma = \frac{2}{\mathrm{Log}_e(2)}.\sin^2(\frac{\theta_0}{2})$, θ_O = antenna beamwidth

$b_\xi = \cos(2\xi) - \frac{\sin^2(2\xi)}{\gamma}$, $c_\xi = b_\xi\alpha$

$\alpha = \frac{4c}{\gamma h\left(1+\frac{h}{R_e}\right)}$, 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), $\sigma_c^2 = \sigma_p^2 + \sigma_s^2$

$u = \frac{t-\tau-c_\xi\sigma_c^2}{\sqrt{2}\sigma_c}$, $v = c_\xi\left(t-\tau-\frac{c_\xi\sigma_c^2}{2}\right)$

and where the parameters to be estimated are:

τ : the epoch

σ_c : the composite Sigma

P_u : the amplitude

P_n : the thermal noise level (estimated from an arithmetic average of samples of the first plateau)

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Basic principle (see RD2)

The problem to solve is the estimation of a set of N_θ=3 parameters $\theta=\{\theta_1=\tau,\theta_2=\sigma_c,\theta_3=P_u\}$. The system to solve results from the minimization of the following χ^2 merit function:

$$\chi^2 = \sum_i \left(\frac{V_i - Vm_i}{\sigma_i} \right)^2 \tag{3}$$

i.e. from the system $\nabla\chi^2 = 0$, where ∇ is the gradient function, $\sigma=\{\sigma_i\}$ is a weighting function and where V represents the measured waveform.

This system may also be represented by the following set of N_θ equations:

$$\sum_i \left(\frac{Vm_i - V_i}{\sigma_i^2} \right) \frac{\partial Vm_i}{\partial \theta_k} = 0 \tag{4}$$

The least square function is developed in a Taylor series about an initial set $\theta_0=\{\theta_{01}=\tau_0,\theta_{02}=\sigma_{c0},\theta_{03}=P_{u0}\}$ of estimates. The following iterative solution is given by the Levenberg-Marquardt's method:

$$\alpha.(\theta_{n+1} - \theta_n) = \beta \tag{5}$$

with: $\alpha_{ij(i\neq j)} = \sum_k \frac{1}{\sigma_k^2} . \left[\frac{\partial Vm_k}{\partial \theta_i} . \frac{\partial Vm_k}{\partial \theta_j} \right]$, $\alpha_{ii} = (1+\lambda).\sum_k \frac{1}{\sigma_k^2} . \left[\frac{\partial Vm_k}{\partial \theta_i} . \frac{\partial Vm_k}{\partial \theta_i} \right]$

$$\beta_i = \sum_k \left(\frac{V_k - Vm_k}{\sigma_k^2} \right) . \frac{\partial Vm_k}{\partial \theta_i}$$

and where λ is an internal gain initially set to a modest value, and then decreased or increased by a factor of 10 after each iteration, depending on the value of the difference $\chi^2(\theta+\delta\theta)$- $\chi^2(\theta)$.

Main steps of the processing (see RD1)

The main steps of the processing are described 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:

  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).

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- Initialization of the weighted Least Square fit:

  Initial values (τ_0, σ_{c0}, P_{u0}) of the parameters to be estimated are then computed. Depending on the features of the ice-2 retracking for the processed waveform (i.e. algorithm performed or not, value of the mean quadratic error OK or not), these initial values will be:

  – either derived from the ice-2 retracking estimates (nominal solution)

  – or from an estimation process (backup solution).

  In the backup solution, σ_{c0} is set to a default value, while τ_0 and P_{u0} are derived from an iterative uniform Least Square fit of the normalized waveform with the mean return power model, using Levenberg-Marquardt's method which allows a smooth variation between the extremes of the inverse-Hessian method and the steepest descent method (see RD4). The iterative estimation process is initialized from initial coarse guesses of the epoch and amplitude (derived from an analysis of the shape of the waveform). It is stopped when the convergence is assumed, or when a maximum number of iterations is reached.

- Estimation (weighted Least Square fit):

  The fine estimates of the epoch (τ), the composite Sigma (σ_c) and the amplitude (P_u) are derived from the iterative process defined previously, which is initialized from the results of the previous step of the processing (i.e. by τ_0, σ_{c0}, P_{u0}).

  This estimation process is stopped when the convergence is assumed or when the value of the mean quadratic error between the normalized waveform and the corresponding model is stable enough (with a minimum number of iterations performed), or finally when a maximum number of iterations is reached.

  To account for the distribution of the useful information in the waveform, the weighting function should be such that little weight is given to the first plateau, maximum weighting is applied to the leading edge itself, and an intermediate weighting is given to the trailing edge.

Finally, outputs are converted (the amplitude P_u is denormalized, etc.)

Be aware that the platform-derived off-nadir angle is taken into account in the processing using the mean return power model used in the Least Square fits.

Note also that parameters a_ξ and b_ξ required within the estimation process are computed assuming small off-nadir angles (i.e. assuming sinx=x and cosx=1-x^2/2 for small angles x).

ALGORITHM SPECIFICATION

Warning: The following computations:

- Building of the processing flag for the ocean-1 retracking from the instrument mode identifiers at source packet and at datablock level, and from the input quality information (corresponding to the "RA-2 nominal tracking data", subset of the elementary measurements which are in "Tracking", "Preset tracking" or "Preset loop output" mode, see RD5)
- Building of the table of abscissa of the waveform samples (starting from 0 and increased by a factor of 1 for each sample, except for the 2 additional DFT samples for Ku band which must be accounted for)
- Building of the Ku-band and S-band waveforms quality flags (from the input waveform samples fault identifiers)
- Determination of the abscissa of the reference sample for tracking for Ku and S bands (i.e. the reference abscissa in the analysis window for the tracker range estimates), depending on the processed band and on the emitted bandwidths

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- Conversion of the input thermal noise level, accounting for the AGC values used in tracking and NPM modes are considered as part of "data management" algorithms (see section 1). They are specified in RD12.

For each waveform, the ocean-1 retracking is specified hereafter.

Input data

- Processing flag for the ocean-1 retracking : Ocean1_Proc_Flag ("valid" or "invalid")
- Waveform:
  - Number of samples : Nb_Sample (/)
  - Abscissa of samples in the analysis window : Wf_Abs [0:Nb_Sample-1] (/)
  - Samples amplitude : Wf_Ampl [0:Nb_Sample-1] (FFT power unit)
- Waveform features:
  - Sampling interval of the analysis window [(1)] : FFT_Step (s)
  - Abscissa of the reference sample for tracking : Abs_Ref_Track (/)
  - Waveform quality flag : Flag_Wf ("valid" or "invalid")
  - Thermal noise level : NPM (FFT power unit)
  - Antenna beamwidth [(2)] : Ant_Beam (degree)
  - Ratio PTR width / FFT step : Ratio_PTR_FFT (/)
- Initialization parameters (outputs of ice-2 retracking):
  - Execution of the retracking algorithm : Flag_Retrack_Init ("valid" or "invalid")
  - Epoch : Epoch_Init (s)
  - Width of the leading edge : SigmaL_Init (m)
  - Amplitude : Ampl_Init (FFT power unit))
  - Mean quadratic error in the estimation window : MQE_Init (/)
- Square of the off-nadir angle : Sq_Off_Nad (degree^2)
- Orbit altitude : Sat_Alt (m)
- Processing parameters for the ocean-1 retracking [(3)]:
  - Skewness coefficient : Skew_Coef (/)
  - Minimum expected abscissa of the central sample : Cs_Min (/)
  - Maximum expected abscissa of the central sample : Cs_Max (/)

---

(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) Value to be selected according to the processed band

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

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- Option for thermal noise computation : Tn_Opt (/)
- Abscissa of the first sample for noise estimation : Tn_First (/)
- Abscissa of the last sample for noise estimation : Tn_Last (/)
- Width of the amplitude window : Aw_Width (/)
- Abscissa of the first sample for estimation : Ew_First (/)
- Abscissa of the last sample for estimation : Ew_Last (/)
- Thermal noise weighting factor for estimation conditions : Tn_Estim (/)
- Initialization MQE threshold : Th_MQE_Init (/)
- Weighting factor for amplitude estimation : Weight_Ampl (/)
- Normalized amplitude threshold for epoch initialization : Th_Ampl (/)
- Default value of SigmaC : SigC_Def (s)
- Maximum number of iterations for the uniform LSE : It_Max_Uni (/)
- Uniform weighting constant : Weight_Uni (/)
- Minimum value of the adaptative gain Lambda : Lam_Min (/)
- Maximum value of the adaptative gain Lambda : Lam_Max (/)
- Width of the fine estimation window : Few_Width (s)
- Half width of the leading edge weighting zone : Lez_Width (/)
- Order 0 to 5 weighting coefficients for the first plateau : Weight_1i (i = 0, 5) (/)
- Order 0 to 5 weighting coefficients for the leading edge : Weight_2i (i = 0, 5) (/)
- Order 0 to 5 weighting coefficients for the trailing edge : Weight_3i (i = 0, 5) (/)
- First initial value of the MQE : MQE_Ini_1 (/)
- Second initial value of the MQE : MQE_Ini_2 (/)
- Maximum number of iterations of the weighted LSE : It_Max_Wei (/)
- Minimum SWH value in the estimation process : SWH_Min (m)
- Maximum SWH value in the estimation process : SWH_Max (m)
- Minimum number of iterations in the estimation process : It_Min_Est (/)
- Threshold for the MQE ratio testing : Th_Ratio (/)
- Default thermal noise level : Default_Noise (FFT power unit)
- Limit argument for the erf function (absolute value) : Arg_Limit (/)

- Earth radius : Earth_Rad (m)
- Light velocity : Light_Vel (m/s)

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Output data

- Retracking estimates:
  - Epoch : Epoch_Ocean1 (s)
  - Width of the leading edge (composite Sigma) : SigmaC_Ocean1 (s)
  - Amplitude : Ampl_Ocean1 (FFT power unit)
  - Thermal noise level : Therm_Noise_Ocean1 (FFT power unit)
- Quality information:
  - Execution of the retracking algorithm : Flag_Retrack_Ocean1 ("valid" or "invalid")
  - Position of the reference sample for tracking : Flag_Central_Ocean1 ("valid" or "invalid")
  - Amplitude of the waveform : Flag_Ampl_Ocean1 ("valid" or "invalid")
  - Initialization by the "initialization parameters" : Flag_Init_Ocean1 ("valid" or "invalid ")
  - Convergence due to Lambda value : Flag_Conv_Ocean1 ("valid" or "invalid")
  - Mean quadratic error in the estimation window : MQE_Ocean1 (/)
  - Number of iterations : Iter_Ocean1 (/)
- Execution status

Processing

If {Ocean1_Proc_Flag is set to "invalid"} or if {Ocean1_Proc_Flag is set to "valid" and Flag_Wf is set to "invalid"}, then:

- Flag_Retrack_Ocean1, Flag_Central_Ocean1, Flag_Ampl_Ocean1, Flag_Init_Ocean1 and Flag_Conv_Ocean1 are set to "invalid"
- Epoch_Ocean1, SigmaC_Ocean1, Ampl_Ocean1, Therm_Noise_Ocean1, MQE_Ocean1 and Iter_Ocean1 are set to default values

Else (Ocean1_Proc_Flag and Flag_Wf set to "valid"), the retracking is performed according the following flowchart:

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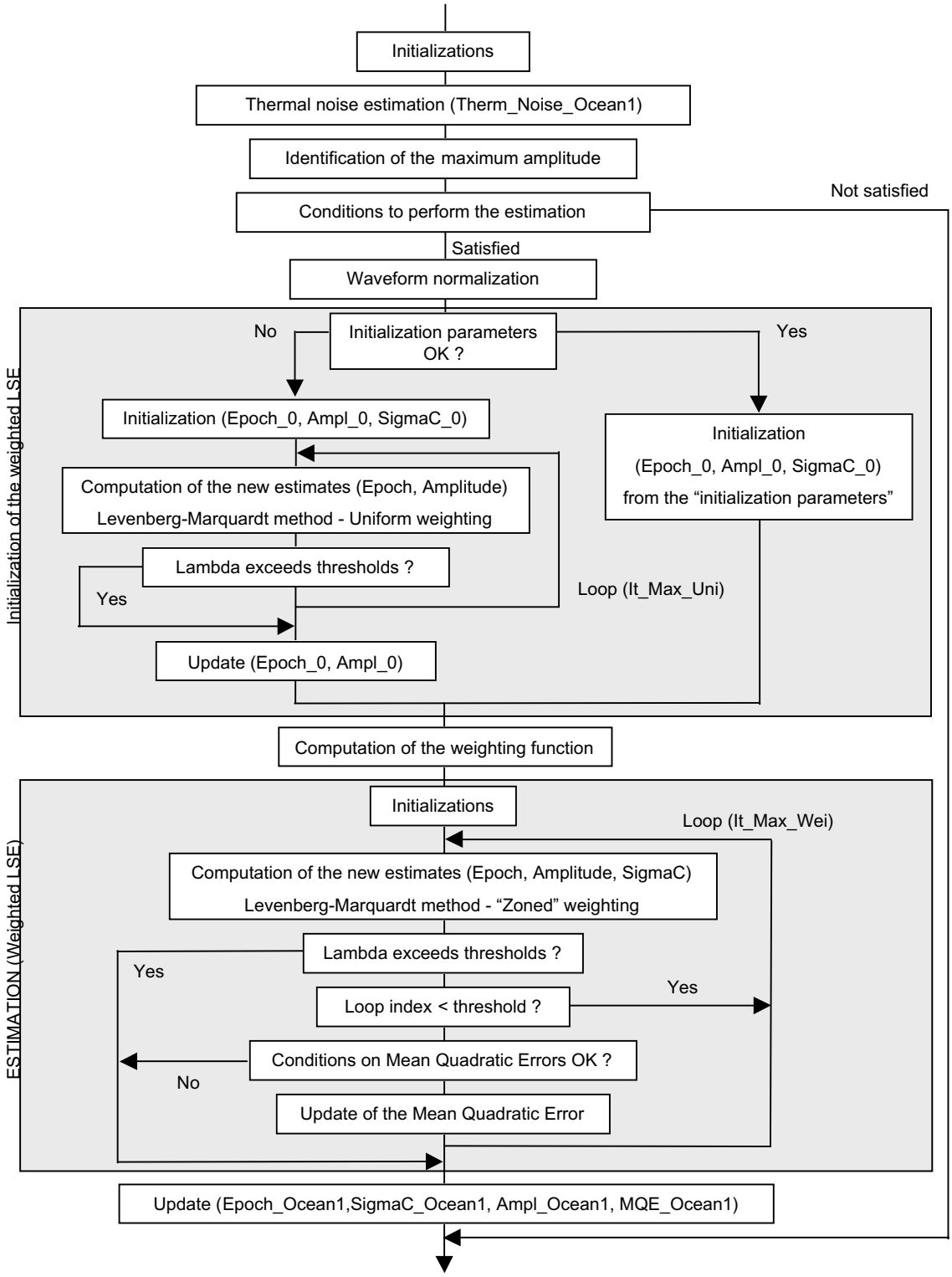

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- Initializations:
  - All the flags (i.e. Flag_Retrack_Ocean1, Flag_Central_Ocean1, Flag_Ampl_Ocean1, Flag_Init_Ocean1 and Flag_Conv_Ocean1) are initialized to "valid".
  - The square of the off-nadir angle is converted from degree^2 to radian^2, by:

$$Sq_Off_Nad_Conv = \left(\frac{\pi}{180}\right)^2 * Sq_Off_Nad \tag{1}$$

  - The following parameters are computed:

    Gamma and Alpha are computed using mechanism "GEN_MEC_MOD_04 - Computation of "Gamma" and "Alpha" altimeter parameters" (AD11), from Ant_Beam, Sat_Alt, Earth_Rad and Light_Vel.

$$PTR_Width = Ratio_PTR_FFT * FFT_Step \tag{58}$$

$$A = \exp\left(\frac{-4 * Sq_Off_Nad_Conv}{Gamma}\right) \tag{2}$$

$$B = 1 - 2 * Sq_Off_Nad_Conv * \left(1 + \frac{2}{Gamma}\right) \tag{3}$$

$$SigC_Inf = 10^9 * \sqrt{PTR_Width^2 + \left(\frac{SWH_Min}{2 * Light_Vel}\right)^2} \tag{4}$$

$$SigC_Sup = 10^9 * \sqrt{PTR_Width^2 + \left(\frac{SWH_Max}{2 * Light_Vel}\right)^2} \tag{5}$$

(SigC_Inf and SigC_Sup are expressed in nanoseconds)

- Thermal noise estimation:

  The thermal noise level Therm_Noise_Ocean1 is determined as follows:
  - If TN_Opt = 0, then:

$$Therm_Noise_Ocean1 = NPM \tag{6}$$

  - Else if TN_Opt = 1, then:

$$Thermal_Noise_Ocean1 = \frac{\sum_i Wf_Ampl(i)}{\sum_i 1} \tag{7}$$

  where the summations turn on indexes i such that $Tn_First \le Wf_Abs(i) \le Tn_Last$, and where $\sum_i 1$ represents the number of points taken into account in the averaging process.

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– Else:

$$Therm_Noise_Ocean1 = Default_Noise \tag{8}$$

- Identification of the maximum amplitude:

  The maximum amplitude V_Max of the waveform is computed as follows, where the summations turn on i such that $Wf_Abs(j) \le Wf_Abs(i) \le Wf_Abs(j) + Aw_Width$, and where the Max function turns on j such that $Ew_First \le Wf_Abs(j) \le Ew_Last - Aw_Width$:

$$V_Max = Max_j \left[\frac{\sum_i Wf_Ampl(i)}{\sum_i 1} \right] \tag{9}$$

- Conditions to perform the estimation:

  If at least one of the following conditions is satisfied:

  – Condition 1 : $Abs_Ref_Track < Cs_Min$ or $Abs_Ref_Track > Cs_Max$ (10)

  – Condition 2 : $V_Max \le Tn_Estim * Therm_Noise_Ocean1$ (11)

  then:

  – the corresponding flag(s), among:

    * Flag_Central_Ocean1 (condition 1)
    * Flag_Ampl_Ocean1 (condition 2)

  is(are) set to "invalid"

  – Flag_Retrack_Ocean1 is set to "invalid"

  – The processing of the waveform is stopped.

- Waveform normalization:

  The normalized waveform Wf_Norm is computed as follows where i is such that $Ew_First \le Wf_Abs(i) \le Ew_Last$:

$$Wf_Norm(i) = \frac{Wf_Ampl(i) - Therm_Noise_Ocean1}{V_Max - Therm_Noise_Ocean1} \tag{12}$$

- Initialization of the weighted LSE:

  This step of the process is aimed at computing the initial values (Epoch_0, SigmaC_0, Ampl_0) to be used on input of the weighted Least Square estimation process. Depending on the features of the input initialization parameters, these initial values will be either derived from the initialization parameters (case 1), or from the outputs of a uniform Least Square fit (case 2).

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Case 1: the "initialization parameters" are OK

If the "initialization parameters" are OK, i.e. if the two following conditions are satisfied:

– Flag_Retrack_Init set to "valid" (13)

– $MQE_Init \leq Th_MQE_Init$ (14)

then:

– $Epoch_0 = Epoch_Init$ (15)

– $SigmaC_0 = \dfrac{\sqrt{2} * SigmaL_Init}{Light_Vel}$ (16)

– $Ampl_0 = \dfrac{Weight_Ampl * Ampl_Init}{V_Max - Therm_Noise_Ocean1}$ (17)

Case 2: the "initialization parameters" are not OK

If the "initialization parameters" are not OK (negation of the conditions (13) and (14) mentioned above), then the flag Flag_Init_Ocean1 is set to "invalid", and the initial values (Epoch_0, SigmaC_0, Ampl_0) are computed as follows:

– Initializations:

∗ Initial estimates are defined as follows, where the index k is such that Wf_Abs(k) is the greatest abscissa verifying $Wf_Norm(k) < Th_Ampl$ and $Wf_Abs(k) < Ew_Last$ (Epoch_0 = 0 if k is not found):

$$Epoch_0 = [Wf_Abs(k) - Abs_Ref_Track] * FFT_Step \quad (18)$$

$$SigmaC_0 = SigC_Def \quad (19)$$

$$Ampl_0 = Weight_Ampl \quad (20)$$

∗ The Levenberg-Marquardt's method is initialized as follows:

◊ The weighting function {sig(i)} for i such that $Ew_First \leq Wf_Abs(i) \leq Ew_Last$, is set to:

$$sig(i) = Weight_Uni \quad (21)$$

◊ The array "a" of estimates (epoch in ns, sigmac in ns, amplitude in FFT power unit) is initialized:

$$a1 = Epoch_0 * 10^9 \quad (22)$$

$$a2 = SigmaC_0 * 10^9 \quad (23)$$

$$a3 = Ampl_0 \quad (24)$$

◊ The adaptative gain of Levenberg-Marquardt's method is set to:

$$Lambda = -1 \quad (25)$$

◊ The mean quadratic error is set to:

$$Chisq = 0 \quad (26)$$

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– Computation of the new estimates (epoch, amplitude):

The epoch and the amplitude are estimated from an iterative Least Square fit, using the implementation of Levenberg-Marquardt's method described in RD4 (the following notations are consistent with those used in RD4), while parameter sigmac is held fixed to its initial value.

For j = 0 to It_Max_Uni - 1:

∗ The "mrqmin" function (see RD4 and section "Comments / Numerical Recipes") is called with the following arguments:

x	= array of the ndata abscissa Wf_Abs(i) from Ew_First to Ew_Last	[input]
y	= array of waveform samples Wf_Norm(i) corresponding to x	[input]
sig	= array of individual standard deviations corresponding to x	[input]
ndata	= number of samples to be processed	[input]
a	= array of the current values of epoch, sigmac, amplitude	[input/output]
ia	= array of selected parameters (such as sigmac is not estimated)	[input]
ma	= number of parameters (ma = 3)	[input]
covar	= covariance matrix	[output]
alpha	= curvature matrix	[output]
chisq	= mean quadratic error (merit function)	[input/output]
funcs	= model and partial derivatives function [1]	[input]
Lambda	= adaptative gain	[input/output]
Additional arguments	= parameters requested by "funcs" [1]	[input]

∗ The iterative process is stopped if:

$$\text{Lambda} < \text{Lam_Min} \ \text{ or } \ \text{Lambda} > \text{Lam_Max} \tag{27}$$

– Update of the estimates:

The estimations of epoch and amplitude are updated at the end of the loop, while the estimation of sigmac is unchanged (SigmaC_0: see (19)):

$$\text{Epoch_0} = \text{a1} * 10^{-9} \quad \text{(s)} \tag{28}$$

$$\text{Ampl_0} = \text{a3} \tag{29}$$

- Computation of the weighting function:

This step of the processing is aimed at determining the abscissa Few_End of the end of the fine estimation window, and three weighting zones from the initial estimation of the epoch (Epoch_0), and at defining the weighting function Weight(i), for indexes i such that $\text{Ew_First} \le \text{Wf_Abs(i)} \le \text{Few_End}$.

[1] See section "Echo Model and Partial Derivatives ("funcs")" at the end of the specifications

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$$\text{Few_End} = \text{Min}\left(\text{Abs_Ref_Track} + \frac{\text{Epoch_0} + \text{Few_Width}}{\text{FFT_Step}}, \text{Ew_Last}\right) \tag{30}$$

$$\text{End_Zone_1} = \text{Abs_Ref_Track} + \frac{\text{Epoch_0}}{\text{FFT_Step}} - \text{Lez_Width} \tag{31}$$

$$\text{End_Zone_2} = \text{Abs_Ref_Track} + \frac{\text{Epoch_0}}{\text{FFT_Step}} + \text{Lez_Width} \tag{32}$$

- For indexes i such that $\text{Ew_First} \le \text{Wf_Abs(i)} < \text{End_Zone_1}$:

$$\text{Weight(i)} = \sum_{j=0}^{5} \text{Weight_1j} * \left[\text{Wf_Abs(i)} - \left(\text{Abs_Ref_Track} + \frac{\text{Epoch_0}}{\text{FFT_Step}}\right)\right]^j \tag{33}$$

- For indexes i such that $\text{End_Zone_1} \le \text{Wf_Abs(i)} \le \text{End_Zone_2}$:

$$\text{Weight(i)} = \sum_{j=0}^{5} \text{Weight_2j} * \left[\text{Wf_Abs(i)} - \left(\text{Abs_Ref_Track} + \frac{\text{Epoch_0}}{\text{FFT_Step}}\right)\right]^j \tag{34}$$

- For indexes i such that $\text{End_Zone_2} < \text{Wf_Abs(i)} \le \text{Few_End}$:

$$\text{Weight(i)} = \sum_{j=0}^{5} \text{Weight_3j} * \left[\text{Wf_Abs(i)} - \left(\text{Abs_Ref_Track} + \frac{\text{Epoch_0}}{\text{FFT_Step}}\right)\right]^j \tag{35}$$

- Estimation (weighted LSE):
  - The Levenberg-Marquardt's method is initialized as follows:
    - The weighting function {sig(i)} for i such that $\text{Ew_First} \le \text{Wf_Abs(i)} \le \text{Few_End}$, is set to:

$$\text{sig(i)} = \text{Weight(i)} \tag{36}$$

    - The array "a" of estimates (epoch in ns, sigmac in ns, amplitude in FFT power unit) is initialized:

$$a1 = \text{Epoch_0} * 10^9 \tag{37}$$

$$a2 = \text{SigmaC_0} * 10^9 \tag{38}$$

$$a3 = \text{Ampl_0} \tag{39}$$

    - The adaptative gain of Levenberg-Marquardt's method is set to:

$$\text{Lambda} = -1 \tag{40}$$

    - The mean quadratic error is set to:

$$\text{chisq} = 0 \tag{41}$$

$$\text{chisq1} = \text{MQE_Ini_1} \tag{42}$$

$$\text{chisq2} = \text{MQE_Ini_2} \tag{43}$$

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– Computation of the new estimates (epoch, "waveheight", amplitude):

The epoch, the parameter sigmac and the amplitude are estimated from an iterative Least Square fit, using the implementation of Levenberg-Marquardt's method described in RD4 (the following notations are consistent with those used in RD4).

For j = 0 to It_Max_Wei - 1:

* The "mrqmin" function (see RD4 and section "Comments / Numerical Recipes") is called with the following arguments:

x	= array of the ndata abscissa Wf_Abs(i) from Ew_First to Few_End	[input]
y	= array of waveform samples Wf_Norm(i) corresponding to x	[input]
sig	= array of individual standard deviations corresponding to x	[input]
ndata	= number of samples to be processed	[input]
a	= array of the current values of epoch, sigmac, amplitude	[input/output]
ia	= array of selected parameters (the three parameters are estimated)	[input]
ma	= number of parameters (ma = 3)	[input]
covar	= covariance matrix	[output]
alpha	= curvature matrix	[output]
chisq	= mean quadratic error (merit function)	[input/output]
funcs	= model and partial derivatives function (1)	[input]
Lambda	= adaptative gain	[input/output]
Additional arguments	= parameters requested by "funcs" (1)	[input]

* The iterative process is stopped if:

$$\text{Lambda} < \text{Lam_Min} \quad \text{or} \quad \text{Lambda} > \text{Lam_Max} \tag{44}$$

* A new iteration of the process must be performed if:

$$j + 1 < \text{It_Min_Est} \tag{45}$$

* The flag Flag_Conv_Ocean1 is set to "invalid", and the iterative process is stopped if:

$$1 \le \frac{\text{chisq1}}{\text{chisq}} \le 1 + \text{Th_Ratio} \quad \text{and} \quad 1 \le \frac{\text{chisq2}}{\text{chisq}} \le 1 + \text{Th_Ratio} \tag{46}$$

* The previous values of the mean quadratic error are updated by:

$$\text{chisq2} = \text{chisq1} \quad \text{and} \quad \text{chisq1} = \text{chisq} \tag{47}$$

The number Iter_Ocean1 of iterations performed in the loop, which is the last value of the index j augmented by 1, will be provided on output.

(1) See section "Echo Model and Partial Derivatives ("funcs")" at the end of the specifications

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- Update of the estimates:
  - The estimations are updated as follows at the end of the loop:
    - Epoch_Ocean1 (s) is derived from a1 by:

$$\text{Epoch_Ocean1} = a1 * 10^{-9} \tag{48}$$

    - SigmaC_Ocean1 (s) is derived from a2 by:

$$\text{SigmaC_Ocean1} = a2 * 10^{-9} \tag{49}$$

    - The normalized amplitude is:

$$\text{Ampl_Norm} = a3 \tag{50}$$

  - Each element yfit(i) of the echo model corresponding to the abscissa Wf_Abs(i) such that $\text{Ew_First} \le \text{Wf_Abs(i)} \le \text{Few_End}$, is computed from the updated estimates of the epoch (Epoch_Ocean1), of the composite sigma (SigmaC_Ocean1) and of the amplitude (Ampl_Norm) by running the 3 following mechanisms:
    - "GEN_MEC_MOD_01 - Ocean echo model and partial derivatives : Initialization (1)"
    - "GEN_MEC_MOD_02 - Ocean echo model and partial derivatives : Initialization (2)"
    - "GEN_MEC_MOD_03 - Ocean echo model and partial derivatives: Computation", with option set to "Model"

    as defined in section "Echo Model and Partial Derivatives ("funcs")".
  - Then, the mean quadratic error MQE_Ocean1 between the input waveform and the updated echo model is derived for indexes i such that $\text{Ew_First} \le \text{Wf_Abs(i)} \le \text{Few_End}$, by:

$$\text{MQE_Ocean1} = \frac{1}{N}.\sum_i \left[\text{Wf_Norm(i)} - \text{yfit(i)}\right]^2 \tag{51}$$

    where N is the number of samples accounted for.
  - The amplitude Ampl_Ocean1 is derived from Ampl_Norm, by:

$$\text{Ampl_Ocean1} = \text{Ampl_Norm} * (\text{V_Max} - \text{Therm_Noise_Ocean1}) \tag{52}$$

<u>Echo Model and Partial Derivatives ("funcs")</u>

This section describes the so-called "funcs" function, which is called by the "mrqcof" function.

- **Input and output data:**

  The "funcs" function is called by the "mrqcof" function with the following arguments:

– x(i)	= abscissa (ndata possible values from Ew_First to Ew_Last)	[input]
– a	= array of the current values of epoch, sigmac and amplitude	[input/output]
– yfit	= echo model sample corresponding to the input abscissa	[output]
– dyda	= partial derivatives samples corresponding to the input abscissa	[output]

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- ma = number of parameters (ma =3) [input]
- Additional arguments = parameters requested by "funcs": [input]
  - Alpha
  - A
  - B
  - SigC_Inf
  - SigC_Sup
  - Abs_Ref_Track
  - FFT_Step
  - Skew_Coef
  - PTR_Width
  - Arg_Limit

- **Processing:**
  - For the first call of the "funcs" function among the ndata calls performed within the "mrqcof" function, the following computations are performed, and the corresponding results (Epoch, SigmaC, Ampl, M, L, C, D, C12 and K1) are memorized to be used in the ndata-1 next calls:
    - Limitation of a2:

$$a2 \leq SigC_Inf \Rightarrow a2 = SigC_Inf \quad (53)$$

$$a2 \geq SigC_Sup \Rightarrow a2 = SigC_Sup \quad (54)$$

    - Conversions:

$$Epoch = a1 * 10^{-9} \quad (55)$$

$$SigmaC = a2 * 10^{-9} \quad (56)$$

$$Ampl = a3 \quad (57)$$

    - Parameters constant over one iteration of the estimation process (M, L, C, D, C12 and K1) are computed using mechanism "GEN_MEC_MOD_01 - Ocean echo model and partial derivatives : Initialization (1)", with the following inputs:
      - Altimetric estimates:
        - Composite sigma : SigmaC
        - Amplitude : Ampl
      - A and B parameters:
        - A parameter : A
        - B parameter : B
      - Instrumental parameters:
        - Alpha parameter : Alpha
        - PTR width : PTR_Width

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◊ Skewness coefficient : Skew_Coef

– Then, for each sample to be processed (i.e. for each call of the "funcs" function), the following computations are performed:

∗ Parameters U, Y and V are computed using mechanism "GEN_MEC_MOD_02 - Ocean echo model and partial derivatives: Initialization (2)", with the following inputs:

◊ Abscissa of the sample to be processed : x(i)

◊ Abscissa of the reference sample for tracking : Abs_Ref_Track

◊ Sampling interval of the analysis window : FFT_Step

◊ Altimetric estimates:

Epoch : Epoch

Composite sigma : SigmaC

◊ C and D parameters:

C parameter : C

D parameter : D

∗ The echo model yfit and the partial derivative of the echo model with respect to the epoch (dyda1), the composite sigma (dyda2) and the amplitude (dyda3), corresponding to the input abscissa x(i) and to parameters Epoch, SigmaC and Ampl, are computed using mechanism "GEN_MEC_MOD_03 – Ocean echo model and partial derivatives: Computation", with the following inputs:

◊ Altimetric estimates:

Composite sigma : SigmaC

Thermal noise level : set to "0"

◊ A parameter : A

◊ M, L, C, D, C12 and K1 parameters:

M parameter : M

L parameter : L

C parameter : C

D parameter : D

C12 parameter : C12

K1 parameter : K1

◊ U, Y and V parameters:

U parameter : U

Y parameter : Y

V parameter : V

◊ Limit argument for the erf function (absolute value) : Arg_Limit

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◊ Processing option [1] : set to "Model and Derivatives"

∗ dyda1 and dyda2 must then be converted in power unit / nanosecond (division by 10^9).

ACCURACY

The performances of the ocean-1 retracking algorithm have been valued in RD1, from ocean waveforms built from the model given in formula (1), including speckle, and using nominal values of the RA-2 instrumental parameters. The on-board tracker operation and thus the jitter on the position of the waveform in distance and amplitude has not been simulated.

The main results obtained in standard conditions, i.e. with:

- SWH = 2 m
- SNR = 15 dB
- ξ = 0 (no mispointing),

are summarized below. The dependency of these results with the various parameters (i.e. significant waveheight, signal to noise ratio and mispointing) are described in RD1.

- Epoch (τ):

  For Ku bands 320 and 80 MHz and for S band, the mean error is nearly independent of the significant waveheight (SWH) and of the signal to noise ratio (SNR). It is always smaller than 1 cm for Ku band 320 MHz, 4 cm for Ku band 80 MHz and 8 cm for S band (160 MHz).

  The standard deviation increases with SWH and decreases with SNR. In standard conditions, it is about 4 cm for Ku band 320 MHz, 8 cm for Ku band 80 MHz and 18 cm for S band . The high values for S band proceed from an increase of the speckle due to the number of averaged individual echoes.

  For Ku band 20 MHz, the behavior of the estimator is different. First, the mean error and the standard deviation decrease when SWH becomes important, due to the correlation of the estimates, and to the sampling interval of the waveforms which prevents an accurate estimation of SWH for low waveheights. Then, the mean error and the standard deviation increase when SNR grows. These features are linked to the error on the estimate of the significant waveheight. They become better when the error on SWH is smaller.

  Finally, as expected the mean error and the standard deviation do not depend on the mispointing, which is taken into account in the mean return power model used in the Least Square fit.

- "Waveheight" (σ_c):

  For Ku band 320 and 80 MHz and for S band, the error is nearly independent of SWH and of SNR. Moreover, it is always very small. In standard conditions, the mean estimate is about 2.00 m for Ku band 320 MHz, 1.92 m for Ku band 80 MHz and 1.99 m for S band. For null waveheights, the mean estimate is about 0.30 m for Ku band 320 MHz, 1.20 m for Ku band 80 MHz and 1.50 m for S band. The important error for S band with regard to the error for Ku band 80 MHz is probably due to the absence of the two additional DFT samples for S band.

  The error is important for Ku band 20 MHz at low waveheights, due to the sampling interval of the analysis window for this bandwidth. In standard conditions, the mean estimate is about 4.8 m for SWH = 0 m, 5.1 m for SWH = 2 m, 4.8 m for SWH = 4 m and 7.0 for SWH = 8 m.

---

[1] 3 states: "Model", "Derivatives" or "Model and Derivatives"

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The standard deviation on SWH lightly increases with SWH and decreases with SNR. Here again, the high noise level observed for S band is due to the speckle features. In standard conditions, the standard deviation on σ_c is about 8 cm for Ku band 320 MHz, 18 cm for Ku band 80 MHz and 33 cm for S band . The high values for S band proceed from an increase of the speckle due to the number of averaged individual echoes.

Finally, as expected the mean error and the standard deviation on SWH do not significantly depend on the mispointing, which is taken into account in the mean return power model used in the Least Square fit.

- Amplitude (P_u):

  For Ku bands 320 and 80 MHz and for S band, the mean error on the amplitude is always very small (less than 0.03 dB whatever the conditions may be). The standard deviation is nearly independent of SWH and SNR. In standard conditions, the standard deviation on P_u is about 0.2 for Ku band 320 and 80 MHz, and 0.4 for S band, assuming a total amplitude equal to 10 FFT units. The high noise level observed for S band is due to the speckle features, and as expected results do not depend on the mispointing.

  For Ku band 20 MHz, the error is more important as for the other estimates (about 0.05 dB in standard conditions).

COMMENTS

- For Ku band, all the processing systematically accounts for the two additional DFT samples.
- **Numerical Recipes:** Some precision about the various functions requested to implement the Levenberg-Marquardt's method as proposed in RD4, are given below:
  - The "mrqmin" function calls the "mrqcof" function, which in turn calls a user-supplied "funcs" function, aimed at computing the echo model and its partial derivatives with respect to the epoch, the parameter sigmac and the amplitude. Additional arguments, i.e. all the additional parameters requested by the "funcs" function, must be added to the "mrqmin" and "mrqcof" functions, to be transferred to the "funcs" function.
  - The "mrqmin" function also calls the "gaussj" and "covsrt" functions.
  - The following updates of the functions described in RD4 are requested:
    - Types must be modified to conform with those used in the current application.
    - Printed messages must be transferred in a macro in order to set an error and return to the calling program. This one will then test and manage the error.
- With respect to the real-time processing, formula (45) has been modified (≤ superseded by <) so as the minimum and the maximum number of iterations be consistent.

REFERENCES

- Hayne G.S. 1980: "Radar Altimeter Mean Return Waveforms from Near-Normal-Incidence Ocean Surface Scattering". IEEE Trans. on antennas and propagation, Vol. AP-28, n°5, pp. 687-692

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ALT_RET_OCE_02 - To perform the ocean-2 retracking

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

POSEIDON-1

FUNCTION

To perform the ocean-2 retracking (the so-called CNES/CLS algorithm) on the waveforms, and to estimate the slope of the logarithm of the trailing edge of these waveforms.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

The ocean-2 retracking algorithm is also used in the processing of JASON-1 calibration data (see RD8).

- Surface type:

The ocean-2 retracking algorithm is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- Product data:
  - Ku and C bands waveforms (128 FFT samples, or 40 FFT samples for C-band 100 MHz)
  - Waveforms validity flags
  - Altimeter configuration data
  - Platform-derived and waveform-derived off-nadir angle (square value) together with the associated validity flags
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Orbit altitudes (20-Hz)
- Dynamic auxiliary data: None

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- Static auxiliary data:
  - POSEIDON-2 instrumental characterization data for the preparation of data for the ocean-2 retracking (see RD12)
  - POSEIDON-2 instrumental characterization for the ocean-2 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 for the activation of the ocean-2 retracking algorithm:
    - Option for the type of off-nadir angle to be accounted for (platform-derived or waveform-derived)
  - Processing parameters for the ocean-2 retracking (the exhaustive list is given in section "Algorithm specification / Input data")
  - Universal constants:
    - Light velocity
    - Earth radius

Output data

For each band, the following 20-Hz parameters:

- Epoch: τ
- Composite Sigma: σ_c
- Amplitude: P_u
- Thermal noise level: P_n
- Slope of the logarithm of the trailing edge [(1)]: s_T
- Mean quadratic error between the normalized waveform and its model
- Number of iterations
- Quality information, such as an execution flag (valid / invalid)

Mathematical statement

The ocean-2 retracking algorithm is performed on the Ku-band and on the C-band waveforms. Nominally, the only difference in the retracking of Ku and C band waveforms is the processed data (waveform, processing and instrumental parameters). Nevertheless in the case of a 100-MHz bandwidth for C-band, it will be possible to run a specific scenario (depending on the input processing option) designed to account for the Ku-band estimate of the composite sigma. In this case, the retracking of the Ku-band waveforms must be performed prior to the retracking on the C-band waveforms. A single description is given below.

---

(1) Ku-band only

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Background

The ocean-2 retracking algorithm is an improved version of the POSEIDON-2 on-board retracking algorithm (e.g. partial derivatives of the ocean echo model are not superseded by square gates), accounting for some changes with respect to the algorithm used in the on-ground processing of POSEIDON-1 waveforms (e.g. estimation of the composite Sigma instead of the significant waveheight, see RD11). Moreover, some refinements are introduced (e.g. accounting for mispointing, improvement of the convergence criteria, etc.).

The aim of the ocean-2 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.

The expression of the return power as a function of time is given by Hayne (Hayne, 1980). Accounting for a skewness coefficient (λ_s: processing parameter), and assuming a gaussian Point Target Response, it is given by:

$$\boxed{Vm(t) = a_\xi \frac{P_u}{2} \exp(-v)\left\{[1+\mathrm{erf}(u)] + \frac{\lambda_s}{6}\left(\frac{\sigma_s}{\sigma_c}\right)^3 \left\{[1+\mathrm{erf}(u)]c_\xi^3\sigma_c^3 - \frac{\sqrt{2}}{\sqrt{\pi}}\left[2u^2 + 3\sqrt{2}c_\xi\sigma_c u + 3c_\xi^2\sigma_c^2 - 1\right]\exp\left(-u^2\right)\right\}\right\} + P_r} \quad (1)$$

with: $\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}.\int_0^x e^{-t^2}dt$

$a_\xi = \exp\left(\frac{-4\sin^2\xi}{\gamma}\right)$, ξ = mispointing (off-nadir angle), $\gamma = \frac{2}{\mathrm{Log}_e(2)}.\sin^2(\frac{\theta_0}{2})$, θ_O = antenna beamwidth

$b_\xi = \cos(2\xi) - \frac{\sin^2(2\xi)}{\gamma}$, $c_\xi = b_\xi\alpha$

$\alpha = \frac{4c}{\gamma h\left(1+\frac{h}{R_e}\right)}$, 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), $\sigma_c^2 = \sigma_p^2 + \sigma_s^2$

$u = \frac{t-\tau-c_\xi\sigma_c^2}{\sqrt{2}\sigma_c}$, $v = c_\xi\left(t-\tau-\frac{c_\xi\sigma_c^2}{2}\right)$

and where the parameters to be estimated are:

τ : the epoch

σ_c : the composite Sigma

P_u : the amplitude

P_n : the thermal noise level (estimated from an arithmetic average of samples of the first plateau)

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Basic principle (see RD2 and RD11)

The problem to solve is the estimation of a set of N_θ=3 parameters $\theta=\{\theta_1=\tau,\theta_2=\sigma_c,\theta_3=P_u\}$. 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:

$$\chi^2 = \sum_i \left(\frac{V_i - Vm_i}{\sigma_i}\right)^2 \tag{3}$$

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:

$$\sum_i \left(\frac{Vm_i - V_i}{\sigma_i^2}\right)\frac{\partial Vm_i}{\partial \theta_k} = 0 \tag{4}$$

An iterative solution is obtained by developing the total cost function in a Taylor series at the first order about an initial set $\theta_0=\{\theta_{01}=\tau_0,\theta_{02}=\sigma_{c0},\theta_{03}=P_{u0}\}$ of estimates:

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

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

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

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 (see RD11)

- Nominal processing of Ku-band and C-band waveforms

  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.

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- 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).

- Estimation (weighted Least Square fit):

  The fine estimates of the epoch (τ), the composite Sigma (σ_c) and the amplitude (P_u) are derived from the iterative process defined previously, which is initialized from default values τ_0, σ_{c0} and P_{u0} (input processing parameters) 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.

- Be aware that the off-nadir angle is accounted for in the processing using the mean return power model used in the Least Square fits. The off-nadir angle estimate used in the algorithm will be either the platform-derived estimate or the waveforms-derived estimate. Indeed, both options are foreseen. The option for the type of off-nadir angle to be accounted for (platform-derived or waveform-derived) is an input processing parameter.
- Note also that parameters a_ξ and b_ξ required within the estimation process are computed assuming small off-nadir angles (i.e. assuming sinx=x and cosx=1-x^2/2 for small angles x).
- Specific processing of C band waveforms with a 100-MHz bandwidth:

  As mentioned previously, it will be possible to run a specific scenario to process C-band waveforms with a 100-MHz bandwidth (processing option). This scenario is designed to account for the Ku-band estimate of the composite sigma. The different steps of this scenario are the following:

  - To perform the ocean-2 retracking on the Ku band waveform
  - To convert the estimated composite Sigma, accounting for the dependency of the PTR width on the bandwidth (100 MHz instead of 320 MHz)
  - To estimate the epoch and the amplitude of the C-band waveform (as described in the nominal processing), using the converted composite Sigma on input of each iteration. The composite sigma provided on ouput will be the converted Ku-band estimate.

Estimation of the slope of the logarithm of the trailing edge

The estimation of the slope of the logarithm of the trailing edge is decorrelated from the estimation of the other parameters (τ, σ_c, P_u).

Ignoring the skewness effects, the trailing edge of the mean return power model may be represented by:

$$Vm(t) = a_\xi P_u \exp(-v) + P_n \tag{6}$$

which may be expressed as follows, using the definition of v given in (1):

$$\mathrm{Log}_e\left[Vm(t) - P_n\right] = -c_\xi t + \left(c_\xi \tau + \frac{c_\xi^2 \sigma_c^2}{2} + \log_e\left(a_\xi P_u\right)\right) \tag{7}$$

The estimation of the slope s_T of the logarithm of the trailing edge (s_T = -c_ξ) will be performed for Ku-band (processing option) by linear regression of the logarithm of the waveform samples (from which the thermal noise

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level estimate is removed), in a predefined gate set on the trailing edge. Quality information such as validity flags will be built for each estimate.

ALGORITHM SPECIFICATION

Warning: The following computations:

- Building of the processing flag for the ocean-2 retracking (accounting in particular for the validity flag of the square of the off-nadir angle, and depending also on the position in the analysis window of the reference sample for tracking)
- Building of the table of abscissa of the waveform samples (starting from 0 and increased by a factor of 1 for each sample)
- Building of the Ku-band and C-band waveforms quality flag (from the input waveform validity flags)

are considered as part of "data management" algorithms (see section 1). They are specified in RD12.

Be aware that due to the possible accounting for the Ku-band estimate of the composite Sigma in the retracking of C-band waveforms, the retracking of the Ku-band waveforms should always be performed prior to the retracking of the C-band waveforms.

For each waveform, the ocean-2 retracking is specified hereafter.

Input data

- Processing flag for the ocean-2 retracking : Ocean2_Proc_Flag ("valid" or "invalid")
- Waveform:
  - Number of samples : Nb_Sample (/)
  - Abscissa of samples in the analysis window : Wf_Abs [0:Nb_Sample-1] (/)
  - Samples amplitude : Wf_Ampl [0:Nb_Sample-1] (FFT power unit)
- Waveform features:
  - Sampling interval of the analysis window (1) : FFT_Step (s)
  - Abscissa of the reference sample for tracking (1) : Abs_Ref_Track (/)
  - Waveform quality flag : Flag_Wf ("valid" or "invalid")
  - Antenna beamwidth (2) : Ant_Beam (degree)
  - Ratio PTR width / FFT step : Ratio_PTR_FFT (/)
- Initialization parameters:
  - Execution of the retracking algorithm (3) : Flag_Retrack_Init ("valid" or "invalid")

---

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

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

(3) Outputs of the ocean-2 retracking for the Ku-band waveform of the processed measurement: requested only if the retracking option (Retrack_Option) is set to "Reduced"

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- Width of the leading edge [3] : SigmaC_Init (s)
- Sampling interval of the analysis window [4] : FFT_Step_Init (s)

- Square of the off-nadir angle [5] : Sq_Off_Nad (degree^2)
- Orbit altitude : Sat_Alt (m)
- Processing parameters for the ocean-2 retracking [6]:
  - Retracking option [7] : Retrack_Option (/)
  - Slope option [8] : Slope_Option (/)
  - Skewness coefficient : Skew_Coef (/)
  - Default value of the epoch : Epoch_Def (s)
  - Default value of the significant waveheight [9] : SWH_Def (m)
  - Default value of the amplitude : Ampl_Def (FFT power unit)
  - Abscissa of the first sample for noise estimation : Tn_First (/)
  - Abscissa of the last sample for noise estimation : Tn_Last (/)
  - Maximum number of iterations in the estimation process : Max_Iter (/)
  - Minimum SWH value in the estimation process : SWH_Min (m)
  - Maximum SWH value in the estimation process : SWH_Max (m)
  - Abscissa of the first sample for estimation : Ew_First (/)
  - Abscissa of the last sample for estimation : Ew_Last (/)
  - Threshold for the F04AMF NAG routine : Thresh_F04AMF (/)
  - Estimation loop gain for the epoch : Loop_Gain_Epoch (/)
  - Estimation loop gain for the composite sigma : Loop_Gain_SigmaC (/)
  - Estimation loop gain for the amplitude : Loop_Gain_Ampl (/)
  - Maximum value of the epoch increments : Max_Inc_Epoch (s)

---

(4) Value used to perform the ocean-2 retracking on the Ku-band waveform of the processed measurement: requested only if the retracking option (Retrack_Option) is set to "Reduced"

(5) Value to be selected according to the corresponding processing option

(6) Values to be selected according to the processed band and the emitted bandwidth (altimeter configuration data)

(7) 2 states: "Nominal" (nominal processing) or "Reduced" (accounting for the Ku-band estimate of the composite sigma). "Reduced" option is allowed for C-band processing only.

(8) 2 states: "Yes" (estimation of the slope of the trailing edge) or "No"

(9) Requested only if the retracking option (Retrack_Option) is set to "Nominal"

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- Maximum value of the composite sigma increments : Max_Inc_SigmaC (s)
- Maximum value of the amplitude increments : Max_Inc_Ampl (FFT power unit)
- Minimum value of the amplitude : Min_Ampl (FFT power unit)
- Minimum number of iterations in the estimation process [10] : Min_Iter (/)
- Threshold for the MQE ratio testing : Th_Ratio (/)
- Limit argument for the erf function (absolute value) : Arg_Limit (/)
- Beginning of the window for the slope of the trailing edge : Abs_S_First (/)
- End of the window for the slope of the trailing edge : Abs_S_Last (/)

- Earth radius : Earth_Rad (m)
- Light velocity : Light_Vel (m/s)

Output data

- Retracking estimates:
  - Epoch : Epoch_Ocean2 (s)
  - Width of the leading edge (composite Sigma) [11] : SigmaC_Ocean2 (s)
  - Amplitude : Ampl_Ocean2 (FFT power unit)
  - Thermal noise level : Therm_Noise_Ocean2 (FFT power unit)
  - Slope of the log. of the trailing edge for mispointing : Slope_Ocean2 (s^{-1})
- Quality information:
  - Execution of the retracking algorithm : Flag_Retrack_Ocean2 ("valid" or "invalid")
  - Slope of the trailing edge : Flag_Slope_Ocean2 ("valid" or "invalid")
  - Inversion of BB^T matrix : Flag_Inversion_Ocean2 ("valid" or "invalid ")
  - Epoch, composite sigma and amplitude increments : Flag_Increment_Ocean2 ("valid" or "invalid")
  - Mean quadratic error in the estimation window : MQE_Ocean2 (/)
  - Number of iterations : Iter_Ocean2 (/)
- Execution status

Processing

If {Ocean2_Proc_Flag is set to "invalid"} or {if Ocean2_Proc_Flag is set to "valid" and Flag_Wf is set to "invalid"} or {if Ocean2_Proc_Flag is set to "valid", Retrack_Option is set to "Reduced" and Flag_Retrack_Init is set to "invalid"}, then:

---

[10] Min_Iter is greater or equal to 2

[11] Converted Ku-band estimate if Retrack_Option is set to "Reduced"

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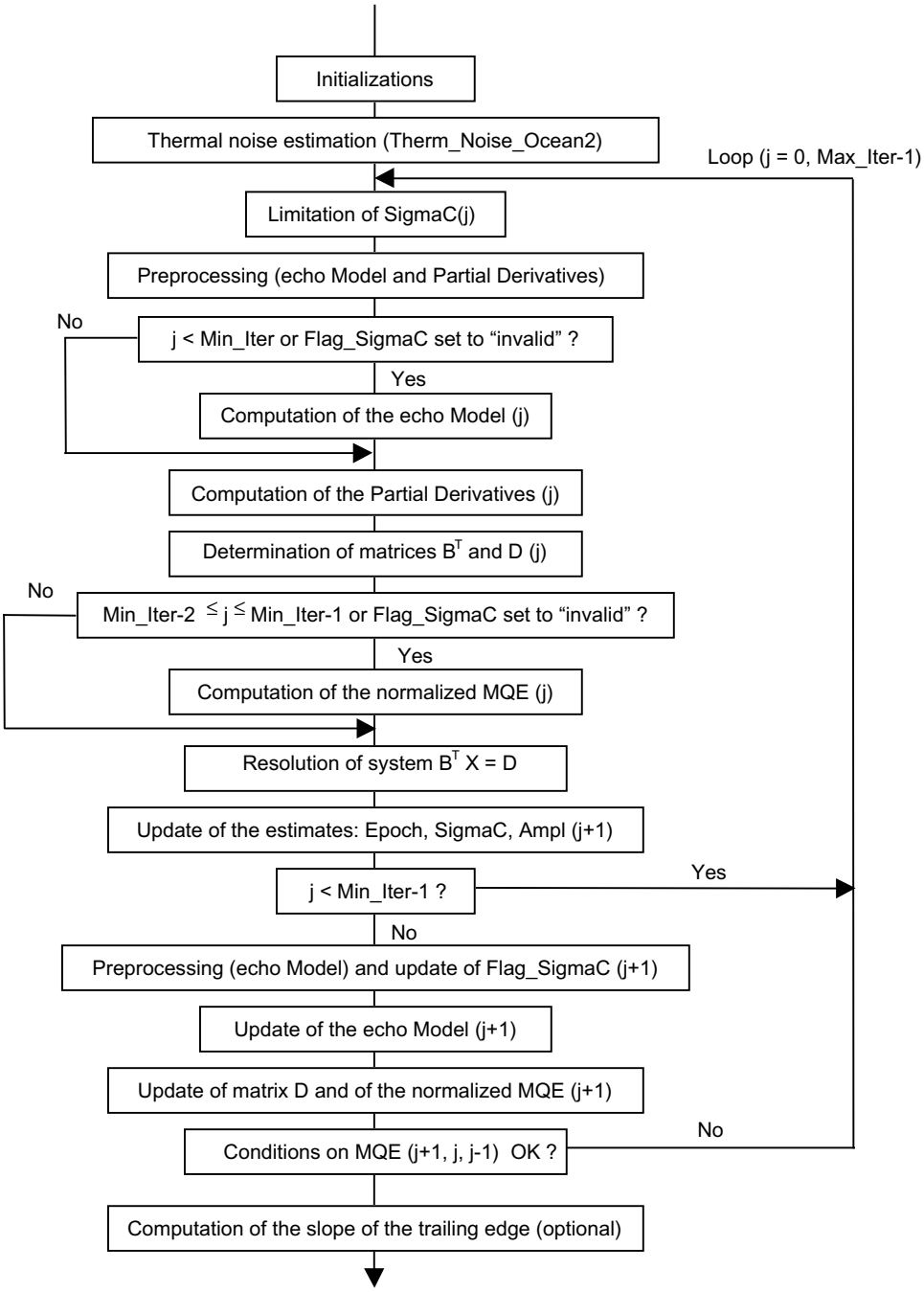
- Flag_Retrack_Ocean2, Flag_Inversion_Ocean2, Flag_Increment_Ocean2 and Flag_Slope_Ocean2 are set to "invalid"
- Epoch_Ocean2, SigmaC_Ocean2, Ampl_Ocean2, Therm_Noise_Ocean2, Slope_Ocean2, MQE_Ocean2 and Iter_Ocean2 are set to default values

Else, the retracking is performed according the following flowchart:



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- Initializations:
  - The following flags (Flag_Retrack_Ocean2, Flag_Inversion_Ocean2, Flag_Increment_Ocean2, and Flag_SigmaC) are initialized to "valid".
  - The square of the off-nadir angle is converted from degree^2 to radian^2, by:

$$Sq_Off_Nad_Conv = \left(\frac{\pi}{180}\right)^2 * Sq_Off_Nad \tag{1}$$

  - The following parameters are computed:

    Gamma and Alpha are computed using mechanism "GEN_MEC_MOD_04 - Computation of "Gamma" and "Alpha" altimeter parameters" (AD11), from Ant_Beam, Sat_Alt, Earth_Rad and Light_Vel.

$$PTR_Width = Ratio_PTR_FFT * FFT_Step \tag{45}$$

$$A = \exp\left(\frac{-4 * Sq_Off_Nad_Conv}{Gamma}\right) \tag{2}$$

$$B = 1 - 2 * Sq_Off_Nad_Conv * \left(1 + \frac{2}{Gamma}\right) \tag{3}$$

$$SigC_Inf = \sqrt{PTR_Width^2 + \left(\frac{SWH_Min}{2 * Light_Vel}\right)^2} \tag{4}$$

$$SigC_Sup = \sqrt{PTR_Width^2 + \left(\frac{SWH_Max}{2 * Light_Vel}\right)^2} \tag{5}$$

  - The estimates of the epoch, the composite Sigma and the amplitude are initialized by:
    - $Epoch(0) = Epoch_Def$ (6)
    - $Ampl(0) = Ampl_Def$ (7)
    - If Retrack_Option is set to "Nominal", then:

$$SigmaC(0) = \sqrt{PTR_Width^2 + \left(\frac{SWH_Def}{2 * Light_Vel}\right)^2} \tag{8}$$

    Else (Retrack_Option set to "Reduced"):

$$PTR_Width_Init = Ratio_PTR_FFT * FFT_Step_Init \tag{48}$$

    If $SigmaC_Init^2 + PTR_Width^2 - PTR_Width_Init^2 \geq 0$, then:

$$SigmaC(0) = \sqrt{SigmaC_Init^2 + PTR_Width^2 - PTR_Width_Init^2} \tag{9}$$

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Else:

$$SigmaC(0) = 0 \tag{10}$$

– The following parameters relative to the part of the waveform to be accounted for in the estimation process, are determined:

∗ Index_First is the smallest index i such that $Ew_First \le Wf_Abs(i)$ (11)

∗ Index_Last is the greatest index such that $Wf_Abs(i) \le Ew_Last$ (12)

∗ $N_Sample = Index_Last - Index_First + 1$ (13)

- Thermal noise estimation:

  The thermal noise level Therm_Noise_Ocean2 is computed by:

$$Therm_Noise_Ocean2 = \frac{\sum_i Wf_Ampl(i)}{\sum_i 1} \tag{14}$$

where the summations turn on indexes i such that $Tn_First \le Wf_Abs(i) \le Tn_Last$, and where $\sum_i 1$ represents the number of points taken into account in the averaging process.

For j = 0 to Max_Iter-1:

- Limitation of SigmaC:

  If $SigmaC(j) < SigC_Inf$, then $SigmaC(j) = SigC_Inf$ (15)

  If $SigmaC(j) > SigC_Sup$, then $SigmaC(j) = SigC_Sup$ (16)

- Preprocessing (echo model and partial derivatives):

  A set of parameters (M, L, C, D, C12 and K1) and tables (U, Y, V defined for $i \in$ [Index_First,Index_Last]), are computed from the current estimates Epoch(j), SigmaC(j) and Ampl(j), using procedure 1 (with n = j) defined at the end of this section.

- Computation of the echo model:

  If the following condition is satisfied:

  $j < Min_Iter$ or Flag_SigmaC set to "invalid" (17)

  then the echo model $\{yfit_j(i)\}_{i \in [Index_First, Index_Last]}$ corresponding to the current estimates Epoch(j), SigmaC(j) and Ampl(j), is computed according to procedure 2 (with n = j) defined at the end of this section.

  (For $j \ge Min_Iter$ and for Flag_SigmaC set to "valid", the echo model $yfit_j$ has been already computed at the end of the previous iteration).

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- Computation of the partial derivatives:

  The partial derivatives of the echo model with respect to the epoch ($\{dyda1(i)\}_{i\in[Index_First,Index_Last]}$), the composite sigma ($\{dyda2(i)\}_{i\in[Index_First,Index_Last]}$), and the amplitude ($\{dyda3(i)\}_{i\in[Index_First,Index_Last]}$), are computed according to procedure 3 (with n = j) defined at the end of this section.

- Determination of matrices B^T and D (see "Comments"):

  For i = Index_First to Index_Last:

  – Let k be the index defined by: $k = i - Index_First$ (18)

  – Matrix BT_Mat (N_Sample rows, 3 columns) is build according to:

$$BT_Mat(k,0) = \frac{dyda1(i)}{Ampl(j)} * 10^{-9} \qquad (ns^{-1}) \tag{19}$$

$$BT_Mat(k,1) = \frac{dyda2(i)}{Ampl(j)} * 10^{-9} \qquad (ns^{-1}) \tag{20}$$

$$BT_Mat(k,2) = \frac{dyda3(i)}{Ampl(j)} \qquad (/) \tag{21}$$

  – Matrix D_Mat (N_Sample rows, 1 column) is computed from the echo model $yfit_j$ according to:

$$D_Mat_j(k) = \frac{yfit_j(i) - Wf_Ampl(i)}{Ampl(j)} \qquad (/) \tag{22}$$

- Computation of the normalized mean quadratic error:

  If $Min_Iter - 2 \le j \le Min_Iter - 1$, then the normalized mean quadratic error MQE(j) between the input waveform and the model built from the current estimates Epoch(j), SigmaC(j) and Ampl(j), is computed by:

$$MQE(j) = \frac{1}{N_Sample} * \sum_{k=0}^{N_Sample-1} D_Mat_j(k)^2 \tag{23}$$

- Resolution of system $B^T X = D$ (see "Comments"):

  Vector $\{Res_Mat(i)\}_{(i=0,2)}$, solution of system $B^T X = D$ is computed using routine F04AMF of the NAG Fortran library (RD13).

  This function is called with the following arguments:

A	= BT_Mat (N_Sample rows, 3 columns matrix)	[input]
IA	= N-Sample	[input]
X	= Res_Mat (3 components solution vector)	[output]
IX	= 3	[input]
B	= D_Mat (N_Sample rows, 1 column matrix)	[input]
IB	= N-Sample	[input]
M	= N-Sample	[input]
N	= 3	[input]
IR	= 1	[input]

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EPS	= Thresh_F04AMF (processing parameter)	[input]
QR	= IQR rows, N column matrix	[output]
IQR	= N_Sample	[input]
ALPHA	= 3 components vector	[output]
E	= 3 components vector	[workspace]
Y	= 3 components vector	[workspace]
Z	= 3 components vector	[workspace]
R	= N_Sample components vector	[workspace]
IPIV	= 3 components vector	[output]
IFAIL	= See RD13	[input/output]

If IFAIL = 1 or 2, then:

- Flag_Inversion_Ocean2 is set to "invalid"
- Flag_Retrack_Ocean2 is set to "invalid"
- The processing of the waveform is stopped.

- Update of the estimates:
  - The epoch, composite sigma and amplitude increments are obtained by:
    - Epoch_Inc = Res_Mat(0) $*$ 10^{-9} (27)
    - Ampl_Inc = Res_Mat(2) (28)
    - If Retrack_Option is set to "Nominal", then:

      SigmaC_Inc = Res_Mat(1) $*$ 10^{-9} (29)

      Else (Retrack_Option set to "Reduced"), then:

      SigmaC_Inc = 0 (30)
  - If at least one of the three following conditions is satisfied:
    - $|\text{Epoch_Inc}| \geq \text{Max_Inc_Epoch}$ (31)
    - $|\text{SigmaC_Inc}| \geq \text{Max_Inc_SigmaC}$ (32)
    - $|\text{Ampl_Inc}| \geq \text{Max_Inc_Ampl}$ (33)

    Then:
    - Flag_Increment_Ocean2 is set to "invalid"
    - Flag_Retrack_Ocean2 is set to "invalid"
    - The processing of the waveform is stopped.

    Else:
    - The updated estimates are computed by:

      $$\text{Epoch}(j+1) = \text{Epoch}(j) - \text{Loop_Gain_Epoch} * \text{Epoch_Inc} \quad (34)$$

      $$\text{SigmaC}(j+1) = \text{SigmaC}(j) - \text{Loop_Gain_SigmaC} * \text{SigmaC_Inc} \quad (35)$$

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$$Ampl(j+1) = Ampl(j) - Loop_Gain_Ampl * Ampl_Inc \quad (36)$$

* If $Ampl(j+1) \leq 0$ then $Ampl(j+1) = Min_Ampl$ (37)

- A new iteration of the process must be performed if:

$$j < Min_Iter - 1 \quad (38)$$

- Preprocessing (echo model) and update of the "limitation flag for SigmaC":
  - If $SigC_Inf \leq SigmaC(j+1) \leq SigC_Sup$, then Flag_SigmaC is set to "valid"

    Else, Flag_SigmaC is set to "invalid"
  - A set of parameters (M, L, C, D, C12 and K1) and tables (U, Y, V defined for $i \in$ [Index_First,Index_Last]), are computed from the updated estimates Epoch(j+1), SigmaC(j+1) and Ampl(j+1), using procedure 1 (with n = j+1) defined at the end of this section.
- Update of the echo model:

  The echo model $\{yfit_{j+1}(i)\}_{i \in [Index_First,Index_Last]}$ corresponding to the updated estimates Epoch(j+1), SigmaC(j+1) and Ampl(j+1), is computed according to procedure 2 (with n = j+1) defined at the end of this section
- Update of matrix D and of the normalized mean quadratic error:
  - The updated matrix D_Mat_{j+1} is computed from the echo model $yfit_{j+1}$ and the updated amplitude Ampl(j+1) according to (22).
  - The normalized mean quadratic error MQE(j+1) between the input waveform and the model built from the updated estimates Epoch(j+1), SigmaC(j+1) and Ampl(j+1), is computed from D_Mat_{j+1}, according to (23).
- The iterative process is stopped if:

$$1 \leq \frac{MQE(j)}{MQE(j+1)} \leq 1 + Th_Ratio \quad \text{and} \quad 1 \leq \frac{MQE(j-1)}{MQE(j+1)} \leq 1 + Th_Ratio \quad (39)$$

Let Index be the greatest value reached by index j in the estimation loop, the estimates to be provided on output are:

$$Iter_Ocean2 = Index + 1 \quad (40)$$

$$Epoch_Ocean2 = Epoch(Index + 1) \quad (41)$$

$$SigmaC_Ocean2 = SigmaC(Index + 1) \quad (42)$$

$$Ampl_Ocean2 = Ampl(Index + 1) \quad (43)$$

$$MQE_Ocean2 = MQE(Index + 1) \quad (44)$$

- Computation of the slope of the trailing edge:
  - If Slope_Option is set to "Yes", then Slope_Ocean2 and Flag_Slope_Ocean2 are computed using mechanism "GEN_MEC_COM_05 - Estimation of the slope of the logarithm of the trailing edge of a waveform (linear regression)", with the following inputs:
    * Window for the estimation:
      ◊ Abscissa of the beginning : Abs_S_First

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- ◊ Abscissa of the end : Abs_S_Last
- ∗ Waveform:
  - ◊ Number of samples : Nb_Sample
  - ◊ Abscissa of samples : Wf_Abs [0:Nb_Sample-1]
  - ◊ Samples amplitude : Wf_Ampl [0:Nb_Sample-1]
  - ◊ Offset for normalization : Thermal_Noise_Ocean2
  - ◊ Sampling interval of the analysis window : FFT_Step
- Else, Slope_Ocean2 is set to default value and Flag_Slope_Ocean2 is set to "invalid".

Procedure 1

- Parameters constant over one iteration of the estimation process (M, L, C, D, C12 and K1) are computed using mechanism "GEN_MEC_MOD_01 - Ocean echo model and partial derivatives : Initialization (1)", with the following inputs:
  - Altimetric estimates:
    - ∗ Composite sigma : SigmaC(n) (s)
    - ∗ Amplitude : Ampl(n) (FFT power unit)
  - A and B parameters:
    - ∗ A parameter : A (/)
    - ∗ B parameter : B (/)
  - Instrumental parameters:
    - ∗ Alpha parameter : Alpha (s-1)
    - ∗ PTR width : PTR_Width (s)
  - Skewness coefficient : Skew_Coef (/)

  The corresponding outputs are:
  - M parameter : M (s^{-1})
  - L parameter : L (/)
  - C parameter : C (s^{-1})
  - D parameter : D (/)
  - C12 parameter : C12 (/)
  - K1 parameter : K1 (FFT power unit)
- Then, for each sample to be processed, i.e. for i = Index_First to Index_Last, parameters U(i), Y(i), and V(i) are computed using mechanism "GEN_MEC_MOD_02 - Ocean echo model and partial derivatives: Initialization (2)", with the following inputs:
  - Abscissa of the sample to be processed : Wf_Abs(i) (/)
  - Abscissa of the reference sample for tracking : Abs_Ref_Track (/)

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- Sampling interval of the analysis window : FFT_Step (s)
- Altimetric estimates:
  - Epoch : Epoch(n) (s)
  - Composite sigma : SigmaC(n) (s)
- C and D parameters:
  - C parameter : C (s^{-1})
  - D parameter : D (/)

The corresponding outputs are:

- U parameter : U(i) (/)
- Y parameter : Y(i) (/)
- V parameter : V(i) (s^{-1})

Procedure 2

For i = Index_First to Index_Last, the echo model $yfit_n(i)$ corresponding to the input abscissa Wf_Abs(i) and to parameters Epoch(n), SigmaC(n) and Ampl(n), is computed using mechanism "GEN_MEC_MOD_03 - Ocean echo model and partial derivatives: Computation", with the following inputs:

- Altimetric estimates:
  - Composite sigma : SigmaC(n) (s)
  - Thermal noise level : Therm_Noise_Ocean2 (FFT power unit)
- A parameter : A (/)
- M, L, C, D, C12 and K1 parameters:
  - M parameter : M (s-1)
  - L parameter : L (/)
  - C parameter : C (s-1)
  - D parameter : D (/)
  - C12 parameter : C12 (/)
  - K1 parameter : K1 (FFT power unit)
- U, Y and V parameters:
  - U parameter : U(i) (/)
  - Y parameter : Y(i) (/)
  - V parameter : V(i) (s-1)
- Limit argument for the erf function (absolute value) : Arg_Limit (/)

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- Processing option [1] : set to "Model"

The corresponding output is:

- Sample of the echo model : $yfit_n(i)$ (FFT power unit)

Procedure 3

For i = Index_First to Index_Last, the partial derivatives of the echo model with respect to the epoch (dyda1(i)), the composite sigma (dyda2(i)), and the amplitude (dyda3(i)), corresponding to the input abscissa Wf_Abs(i) and to parameters Epoch(n), SigmaC(n) and Ampl(n), are computed using mechanism "GEN_MEC_MOD_03 - Ocean echo model and partial derivatives: Computation", with the following inputs:

- Altimetric estimates:
  - Composite sigma : SigmaC(n) (s)
  - Thermal noise level : Therm_Noise_Ocean2 (FFT power unit)
- A parameter : A (/)
- M, L, C, D, C12 and K1 parameters:
  - M parameter : M (s-1)
  - L parameter : L (/)
  - C parameter : C (s-1)
  - D parameter : D (/)
  - C12 parameter : C12 (/)
  - K1 parameter : K1 (FFT power unit)
- U, Y and V parameters:
  - U parameter : U(i) (/)
  - Y parameter : Y(i) (/)
  - V parameter : V(i) (s-1)
- Limit argument for the erf function (absolute value) : Arg_Limit (/)
- Processing option [1] : set to "Derivatives"

The corresponding outputs are:

- Sample of the partial derivative of the echo model w.r.t. epoch : dyda1(i) (FFT power unit/s)
- Sample of the partial derivative of the echo model w.r.t. composite sigma : dyda2(i) (FFT power unit/s)
- Sample of the partial derivative of the echo model w.r.t. amplitude : dyda3(i) (/)

[1] 3 states: "Model", "Derivatives" or "Model and Derivatives"

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ACCURACY

TBD

Regarding the recovery of the slope of the logarithm of the trailing edge from waveforms samples, the limitation due to mean return power model and in particular to the non accounting for the skewness effects on the trailing edge, may be considered as negligible (TBC, to be estimated).

COMMENTS

- As mentioned in section "Mathematical statement", an iterative solution of the system to be solved is given by:

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

with: $\varepsilon_\theta = (BB^T)^{-1}BD$ (valued to the current values θ_n), $B_{ki} = \frac{1}{\sigma_i}.\frac{\partial Vm_i}{\partial \theta_k}$, $D_{i1} = \frac{1}{\sigma_i}.(Vm_i - V_i)$, g = loop gain

It is known (RD13) that solving this system by calculation of ε_θ, including the inversion of matrix BB^T, is definitely not recommended. It is the reason why the resolution of the following equivalent system has been preferred:

$$B^T X = D, \text{ with } X = \frac{\theta_{n+1} - \theta_n}{-g}$$

This system is solved (i.e. vector X = ε_θ is estimated) using the F04AMF NAG Fortran routine (RD13), which calculates the accurate least-squares solution of a set of m linear equations in n unknowns, m ≥ n and rank = n, with multiple right-hand sides, AX = B, using a QR factorization and iterative refinement.

- An additional weighting of matrices B_Mat and D_Mat is under investigation.
- The first two columns of matrix BT_Mat are scaled by 10^{-9} to prevent numerical instabilities within the matrix inversion process
- The algorithm is designed to process non-equidistant waveform samples (the input waveform is characterized by a table of abscissa and a table of amplitudes). It will be thus possible to process ENVISAT waveforms for example (128 FFT samples and of 2 additional DFT samples), without any modification of the algorithm.
- The ocean-2 retracking algorithm is also used in the Level 1b CAL processing, to evaluate the influence of the PTR and LPF parameters on the altimetric parameters.

REFERENCES

- Hayne G.S. 1980: "Radar Altimeter Mean Return Waveforms from Near-Normal-Incidence Ocean Surface Scattering". IEEE Trans. on antennas and propagation, Vol. AP-28, n°5, pp. 687-692

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ALT_RET_SEA_01 - To perform the sea-ice retracking

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To perform the sea-ice retracking (the so-called MSSL algorithm) on the waveforms.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The sea-ice retracking is performed whatever the surface type is. Nevertheless, it is optimized for sea-ice surfaces.

ALGORITHM DEFINITION

Input data

- Product data:
  - Waveform (128 FFT samples for Ku band)
  - Ku bandwidth identifier for Ku band
  - Instrument mode identifier at datablock level
  - RF subsystem identifier
- Computed data: None
- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data for the preparation of data for the sea-ice retracking (see RD12)
  - RA-2 instrumental characterization data for the sea-ice retracking:
    - Sampling interval of the analysis window
  - Processing parameters (the exhaustive list is given in section "Algorithm specification / Input data")

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Output data

For Ku-band only, the following 20-Hz parameters:

- Epoch or "range offset": τ
- Amplitude: P_u
- Quality information, such as an execution flag (valid / invalid)

Mathematical statement

The sea-ice retracking algorithm is performed on the Ku band waveforms only.

Background

The sea-ice retracking algorithm is defined in RD7. The aim of the sea-ice retracking algorithm is to determine the tracking offset (or epoch) and the amplitude of the waveform, from a parameterization based on peak threshold retracking.

Basic principle and main steps of the processing (see RD7)

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

- Estimation of the amplitude:
  The waveform amplitude (P_u) is determined by finding the maximum value of the waveform samples.
- Estimation of the epoch:
  The epoch (τ) of the waveform in the estimation window is then determined by finding the point on the waveform (by interpolation) where the waveform amplitude exceeds a threshold determined from the estimated amplitude P_u.

ALGORITHM SPECIFICATION

Warning: The following computations:

- Building of the processing flag for the sea-ice retracking from the instrument mode identifier at datablock level (corresponding to the elementary measurements in "Tracking" or "Preset tracking" mode, see "Lost track" flag in RD7)
- Building of the table of abscissa of the waveform samples (starting from 0 and increased by a factor of 1 for each sample, ignoring the 2 additional DFT samples for Ku band)
- Determination of the abscissa of the reference sample for tracking for Ku and S bands (i.e. the reference abscissa in the analysis window for the tracker range estimates), depending on the processed band

are considered as part of "data management" algorithms (see section 1). They are specified in RD12.

For each waveform, the sea-ice retracking is specified hereafter.

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Input data

- Processing flag for the sea-ice retracking : SeaIce_Proc_Flag ("valid" or "invalid")
- Waveform:
  - Number of samples : Nb_Sample (/)
  - Abscissa of samples in the analysis window : Wf_Abs [0:Nb_Sample-1] (/)
  - Samples amplitude : Wf_Ampl [0:Nb_Sample-1] (FFT power unit)
- Waveform features:
  - Sampling interval of the analysis window [(1)] : FFT_Step (s)
  - Abscissa of the reference sample for tracking : Abs_Ref_Track (/)
- Processing parameters for the sea-ice retracking [(2)]:
  - First bin used in the retracking calculation : First_Bin (/)
  - Last bin used in the retracking calculation : Last_Bin (/)
  - Threshold for determination of the leading edge position : Tresh_Pos_LE (/)
  - Lower bound for the retracking point : Low_Bound (/)
  - Upper bound for the retracking point : Upp_Bound (/)

Output data

- Retracking estimates:
  - Epoch : Epoch_SeaIce (s)
  - Amplitude : Ampl_SeaIce (FFT power unit)
- Quality information:
  - Execution of the retracking algorithm : Flag_Retrack_SeaIce ("valid" or "invalid")
- Execution status

Processing

If SeaIce_Proc_Flag is set to "invalid", then:

- Flag_Retrack_SeaIce is set to "invalid"
- Epoch_SeaIce and Ampl_SeaIce are set to default values

---

(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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Else (SeaIce_Proc_Flag set to "valid"):

- The flag relative to the execution of the retracking algorithm (Flag_Retrack_SeaIce) is initialized to "valid".
- Let k be the index such that Wf_Abs(k) be the greatest abscissa satisfying the following condition:

$$\text{First_Bin} \leq \text{Wf_Abs(k)} \leq \text{Last_Bin} \quad \text{and} \quad \text{Wf_Ampl(k) is maximum} \tag{1}$$

  and let Ampl_SeaIce be the corresponding amplitude:

$$\text{Ampl_SeaIce} = \text{Wf_Ampl(k)} \tag{2}$$

- The threshold amplitude Thresh is computed by:

$$\text{Thresh} = \text{Tresh_Pos_LE} * \text{Ampl_SeaIce} \tag{3}$$

- Let j be the index such that Wf_Abs(j) be the smallest abscissa satisfying the following condition:

$$\text{First_Bin} \leq \text{Wf_Abs(j)} \leq \text{Last_Bin} \quad \text{and} \quad \text{Wf_Ampl(j)} > \text{Thresh} \tag{4}$$

  - If such an index does not exist or if EMBED $j-1 < \text{First_Bin}$, then:
    - Flag_Retrack_SeaIce is set to "invalid"
    - Epoch_SeaIce = 0
  - Else:
    - The abscissa corresponding to the threshold amplitude is computed by:

$$\text{Abs_Thresh} = \text{Wf_Abs(j)} - 1 + \frac{\text{Thresh} - \text{Wf_Ampl(j-1)}}{\text{Wf_Ampl(j)} - \text{Wf_Ampl(j-1)}} \tag{5}$$

    - The epoch of the waveform is derived by:

$$\text{Epoch_SeaIce} = (\text{Abs_Tresh} - \text{Abs_Ref_Track}) * \text{FFT_Step} \quad 6)$$

    - Finally, if the following condition is satisfied:

$$\text{Abs_Thresh} < \text{Low_Bound} \quad \text{or} \quad \text{Abs_Thresh} > \text{Upp_Bound} \tag{7}$$

      then:

      Flag_Retrack_SeaIce is set to "invalid"

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ACCURACY

TBD

COMMENTS

- The two additional DFT samples for Ku band are not accounted for in the processing.
- In RD7, the ice-1 and the sea-ice retracking algorithms are performed after a pre-processing step aimed at identifying the waveforms validity and at computing the peakiness of waveforms (for Ku band and for S bands).

  – The validity of waveforms is determined from the following criteria:

    * Computation of the thermal noise level by averaging of samples in the early part the waveform. With echo waveforms from non-ocean surfaces, this value may be contaminated by the surface return, and so thresholding is used in the next step to identify waveforms so contaminated, and for other reasons.
    * Computation of the total averaged amplitude of the waveform. If this value is smaller than a multiple of the thermal noise level, the waveform is regarded as not valid.
    * Computation of the averaged amplitude of the waveform in two contiguous windows which span the entire range window. The purpose of this test is to check that the leading edge of the waveform lies within the range window. The waveform is regarded as not valid if the first amplitude exceeds a multiple of the second one.

  – Regarding the "peakiness" of waveforms, it is essentially the ratio of the maximum amplitude to the mean amplitude of samples to the right of the tracking point, and it represents an independent waveform quality information.

  This pre-processing is considered as a "data management" algorithm (see section 1), especially because its outputs consists only of quality information to be used to build the output product, but which are not requested on input of the algorithms defined and specified in this document. This pre-processing algorithm is specified in RD12.

REFERENCES

None

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ALT_PHY_RAN_04 - To normalize the tracker ranges

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To account in the tracker range estimates (Ku and S bands), for the tracking point offset applied on-board, to remove the Doppler correction and to add the distance antenna - COG.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The normalization of the tracker ranges is performed whatever the surface type is.

ALGORITHM DEFINITION

Input data

- Product data:
  - Instrument mode identifier at source packet level
  - Instrument mode identifier at datablock level
  - Altimeter time-tag (1 Hz)
  - Tracker ranges (20 Hz, Ku and S bands)
  - Offset for reference tracking point (20 Hz)
  - Doppler corrections on the altimeter range (20 Hz, Ku and S bands)
- Computed data: None
- Dynamic auxiliary data:
  - Platform data and associated time-tags:
    - Distance antenna-COG
- Static auxiliary data:
  - Instrumental characterization data:
    - Emitted bandwidth

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  - Sampling interval of the analysis window
- Universal constants:
  - Light velocity

Output data

- Normalized tracker ranges and associated validity flag (20 Hz, Ku and S bands)
- Distance antenna – COG (1 Hz)

Mathematical statement

For each elementary measurement in Ku and S bands:

- For each measurement to be processed, the distance antenna - COG to be used is the one which just precedes the averaged measurement. Let d be the selected distance.
- The normalized tracker range (tracker range relative to the effective tracking point, corrected for COG motion and from which the level 1b Doppler correction is removed) is computed by:

$$h_t^{'} = h_t + \text{offset} + d - \delta h_{1b} \qquad (1)$$

where: offset is the distance corresponding to the tracking point offset applied-on-board
h_t is the tracker range
d is the selected distance antenna - COG
δh_{1b} is the Doppler correction on the altimeter range

ALGORITHM SPECIFICATION

Warning: The following computations:

- Building of the processing flag for the normalization of the tracker ranges, from the instrument mode identifiers at source packet and datablock levels (corresponding to the elementary measurements in "Tracking", "Preset tracking" or "Preset loop output" mode).
- Conversion of the offset in meters
- Selection of the distance antenna - COG for each averaged measurement
- Possible conversions of the input parameters in meters

are considered as "data management" algorithms (see section 1). They are specified in RD12.

For each elementary measurement, the normalization of the tracker range (for Ku band or for S band) is specified hereafter.

Symbol [Ku/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and S-band value(s)).

Input data

- Processing flag for the tracker range normalization : Trk_Range_Norm_Flag ("valid" or "invalid")

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- Tracker range [Ku/S] : Trk_Range (m)
- Tracking point offset [Ku/S] : Offset (m)
- Doppler correction on the altimeter range [Ku/S] : Cor_Dop_Range (m)
- Distance antenna – COG (selected) : Dist_Ant_COG (m)

Output data

- Normalized tracker range [Ku/S] : Trk_Range_Norm (m)
- Validity flag for the normalized tracker range [Ku/S] : Trk_Range_Norm_Val_Flag (/)
- Execution status

Processing

- If the processing flag for the tracker range normalization (Trk_Range_Norm_Flag) is set to "valid", then:
  - The normalized tracker range is computed by:

$$Trk_Range_Norm = Trk_Range + Offset - Cor_Dop_Range + Dist_Ant_COG \quad (1)$$

  - The corresponding validity flag (Trk_Range_Norm_Val_Flag) is set to "valid"
- Else:
  - The normalized tracker range (Trk_Range_Norm) is set to a default value
  - The corresponding validity flag (Trk_Range_Norm_Val_Flag) is set to "invalid"

ACCURACY

None

COMMENTS

None

REFERENCES

None

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ALT_PHY_RAN_05 - To compute the on-ground retracked altimeter ranges

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

For each elementary measurement, to compute the Ku-band and C/S-band on-ground retracked estimates of the altimeter range.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:
  - For ENVISAT, the computation of the retracked altimeter ranges is performed whatever the surface type is. Nevertheless, ocean-1 parameters are relevant to ocean surfaces only, ice-1 and ice-2 parameters are relevant to ice surfaces only, while sea-ice parameters are relevant to sea-ice surfaces only.
  - For JASON-1, the computation of the retracked altimeter ranges is performed whatever the surface type is. Nevertheless, these parameters are relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- For ENVISAT:
  - Computed data:
    - From "ALT_RET_ICE_01 - To perform the ice-1 retracking" (Ku and S bands):
      - Epoch
      -
    - From "ALT_RET_ICE_02 - To perform the ice-2 retracking" (Ku and S bands):
      - Epoch
      - Execution flag (valid / invalid)
    - From "ALT_RET_OCE_01 - To perform the ocean-1 retracking" (Ku and S bands):
      - Epoch
      - Execution flag (valid / invalid)

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    - From "ALT_RET_SEA_01 - To perform the sea-ice retracking" (Ku band only):
        - Epoch
        -
    - From "ALT_PHY_RAN_04 - To normalize the tracker ranges" (Ku and S bands):
        - Tracker range (normalized)
        - Validity flag for the tracker range (normalized)
  - Dynamic auxiliary data: None
  - Static auxiliary data: None
- For JASON-1:
  - Product data:

    The following 20-Hz parameters for Ku and C bands:
    - Tracker range (corrected in the level 1b processing)
    - Validity flag for the tracker range
  - Computed data:
    - From "ALT_RET_OCE_02 - To perform the ocean-2 retracking" (Ku and C bands):
        - Epoch
        - Execution flag (valid / invalid)
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - Universal constants:
        - Light velocity

Output data

- For ENVISAT (Ku and S bands), the following 20-Hz parameters:
  - Ice-1 altimeter ranges and associated validity flags
  - Ice-2 altimeter ranges and associated validity flags
  - Ocean-1 altimeter ranges and associated validity flags
  - Sea-ice altimeter range (for Ku band only) and associated validity flag
- For JASON-1 (Ku and C bands), the following 20-Hz parameters:
  - Altimeter ranges and associated validity flags

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Mathematical statement

- For ENVISAT:

  For each elementary measurement in Ku and S bands, the ice-1, ice-2, ocean-1 and sea-ice (Ku-band only) altimeter ranges are computed as follows, where h_t represents the normalized tracker range and τ represents the epoch estimate output by the corresponding retracking algorithm:

$$h = h_t + \tau \tag{1}$$

- For JASON-1:

  For each elementary measurement in Ku and C 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 on-ground retracking algorithm.

For both cases, as in the JASON-1 Level 1b processing (see RD8 "ALT_PHY_RAN_03 - To compute the on-board retracked altimeter ranges"), the validity of the on-ground retracked altimeter ranges is determined from the validity of the tracker ranges and from the retracking execution flags, excepted for the ice-1 and sea-ice estimates where the retracking execution flag is always considered as valid to be consistent with RD7. Default values are provided in case of invalidity of the on-ground retracked altimeter range estimates.

ALGORITHM SPECIFICATION

For each elementary measurement, the computation of the on-ground retracked altimeter ranges (ice-1 Ku/S bands, ice-2 Ku/S bands, ocean-1 Ku/S bands, sea-ice Ku band, ocean-2 Ku/C bands) and of the corresponding validity flag is specified hereafter.

Symbol [Ku/C/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C/S-band value(s)).

Input data

- Tracker range and validity flag [Ku/C/S]:
  - Tracker range : Trk_Range (m)
  - Tracker range validity flag [1] : Trk_Range_Val_Flag (/)
- On-ground retracked epoch and execution flag [Ku/C/S]:
  - On-ground retracked epoch : Epoch (s)
  - Execution flag [1] [2] : Flag_Retrack (/)
- Light velocity : Light_Vel (m/s)

---

[1] 2 states: "valid" and "invalid"

[2] Must be set to "valid" for the ice-1 and sea-ice parameters

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Output data

- On-ground retracked altimeter range [Ku/C/S] : Retrk_Range (m)
- On-ground retracked altimeter range validity flag [Ku/C/S] (1) : Retrk_Range_Val_Flag (/)
- Execution status

Processing

The on-ground retracked altimeter range and the associated validity flag are computed using mechanism "GEN_MEC_COR_01 - Computation of a tracking/retracking combined parameter" (AD11), with the following inputs:

- Tracking-derived parameter : Trk_Range
- Tracking-derived parameter validity flag : Trk_Range_Val_Flag
- Retracking-derived parameter : Epoch
- Retracking-derived parameter validity flag : Flag_Retrack
- Type of conversion for the retracking-derived parameter : set to "Second to meter"
- Light velocity : Light_Vel

ACCURACY

TBD

COMMENTS

- In both ENVISAT and JASON-1 level 1b input products, the tracker or tracker-derived estimates associated with a 20-Hz measurement correspond to the settings applied on-board to the waveform associated with this measurement. Indeed, the management of these information is accounted for in the level 1b processing for ENVISAT and on-board for JASON-1.

REFERENCES

None

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ALT_PHY_BAC_04 - To compute the on-ground retracked backscatter coefficients

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

For each elementary measurement, to compute the Ku-band and C/S-band on-ground retracked estimates of the backscatter coefficient.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:
  - For ENVISAT, the computation of the backscatter coefficients is performed whatever the surface type is. Nevertheless, ocean-1 parameters are relevant to ocean surfaces only, ice-1 and ice-2 parameters are relevant to ice surfaces only, while sea-ice parameters are relevant to sea-ice surfaces only.
  - For JASON-1, the computation of the backscatter coefficients is performed whatever the surface type is. Nevertheless, these parameters are relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- For ENVISAT:
  - Product data:
    - Scaling factor for sigma0 evaluation (20 Hz, Ku and S bands)
  - Computed data:
    - From "ALT_RET_ICE_01 - To perform the ice-1 retracking" (Ku and S bands):
      - Amplitude
      -
    - From "ALT_RET_ICE_02 - To perform the ice-2 retracking" (Ku and S bands):
      - Amplitude
      - Mean amplitude
      - Execution flag (valid / invalid)

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    - From "ALT_RET_OCE_01 - To perform the ocean-1 retracking" (Ku and S bands):
        - Amplitude
        - Execution flag (valid / invalid)
    - From "ALT_RET_SEA_01 - To perform the sea-ice retracking" (Ku band only):
        - Amplitude
        -
  - Dynamic auxiliary data: None
  - Static auxiliary data: None
- For JASON-1:
  - Product data:

    The following 20-Hz parameters for Ku and C bands:
    - Scaling factors for sigma0 evaluation (corrected in level 1b processing)
    - Tracker AGC validity flags
  - Computed data:
    - From "ALT_RET_OCE_02 - To perform the ocean-2 retracking" (Ku and C bands):
        - Amplitude
        - Execution flag (valid / invalid)
  - Dynamic auxiliary data: None
  - Static auxiliary data: None

Output data

- For ENVISAT (Ku and S bands), the following 20-Hz parameters:
  - Ice-1 backscatter coefficients and associated validity flags
  - Ice-2 backscatter coefficients, leading edge backscatter coefficients and associated validity flags
  - Ocean-1 backscatter coefficients and associated validity flags
  - Sea-ice backscatter coefficient (for Ku band only) and associated validity flag
- For JASON-1 (Ku and C bands), the following 20-Hz parameters:
  - Backscatter coefficients and associated validity flags

Mathematical statement

- For ENVISAT:

  For each elementary measurement in Ku and S bands, the ice-1, ice-2, ocean-1 and sea-ice (Ku-band only) backscatter coefficients are computed as follows, where P_u represents the amplitude estimate output by the corresponding retracking algorithm and where K_{cal} is the scaling factor for Sigma0 evaluation:

$$\sigma_0 = K_{cal} + 10.\log_{10}(P_u) \quad (1)$$

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For the ice-2 retracking, the backscatter coefficient is derived from the mean amplitude, while the leading edge backscatter coefficient is derived from the amplitude.

The validity of the on-ground retracked backscatter coefficients is determined from the retracking execution flags only (the input scaling factors for Sigma0 evaluation are considered always valid). Default values are provided in case of invalidity of the on-ground retracked backscatter coefficient estimates.

- For JASON-1:

  For each elementary measurement in Ku and C bands, the backscatter coefficient is computed using (1), where P_u represents the amplitude estimate output by the on-ground retracking algorithm.

  As in the level 1b processing (see RD8 "ALT_PHY_BAC_03 - To compute the on-board retracked backscatter coefficients"), the validity of the on-ground retracked backscatter coefficients is determined from the validity of the tracker AGC and from the retracking execution flags, excepted for the ice-1 and sea-ice estimates where the retracking execution flag is always considered as valid to be consistent with RD7. Default values are provided in case of invalidity of the on-ground retracked backscatter coefficient estimates.

ALGORITHM SPECIFICATION

For each elementary measurement, the computation of the on-ground retracked backscatter coefficients (ice-1 Ku/S bands, ice-2 Ku/S bands, ocean-1 Ku/S bands, sea-ice Ku band, ocean-2 Ku/C bands) and of the corresponding validity flag is specified hereafter.

Symbol [Ku/C/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C/S-band value(s)).

Input data

- Scaling factor for Sigma0 evaluation [Ku/C/S] : Scale_Sigma0 (dB)
- Tracker AGC validity flag [Ku/C] (1) (2) : Trk_AGC_Val_Flag (/)
- On-ground retracked amplitude and execution flag [Ku/C/S]:
  - On-ground retracked amplitude : Ampl (FFT power unit)
  - Execution flag (1) (3) : Flag_Retrack (/)

Output data

- On-ground retracked backscatter coefficient [Ku/C/S] : Retrk_Sigma0 (dB)
- On-ground retracked backscatter coefficient validity flag [Ku/C/S] (1) : Retrk_Sigma0_Val_Flag (/)
- Execution status

(1) 2 states: "valid" and "invalid"

(2) Not used for ENVISAT

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

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Processing

The on-ground retracked backscatter coefficient and the associated validity flag are computed using mechanism "GEN_MEC_COR_01 - Computation of a tracking/retracking combined parameter" (AD11), with the following inputs:

- Tracking-derived parameter : Scale_Sigma0
- Tracking-derived parameter validity flag : Trk_AGC_Val_Flag (set to "valid" for ENVISAT)
- Retracking-derived parameter : Ampl
- Retracking-derived parameter validity flag : Flag_Retrack
- Type of conversion for the retracking-derived parameter : set to "Power to dB"
- Light velocity : not requested

ACCURACY

TBD

COMMENTS

- In both ENVISAT and JASON-1 level 1b input products, the tracker or tracker-derived estimates associated with a 20-Hz measurement correspond to the settings applied on-board to the waveform associated with this measurement. Indeed, the management of these information is accounted for in the level 1b processing for ENVISAT and on-board for JASON-1.

REFERENCES

None

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ALT_PHY_SWH_01 - To compute SWH from the on-ground retracked composite Sigma

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

For each elementary measurement, to derive the Ku-band and S-band estimates of the significant waveheight from the on-ground retracked estimates of the composite Sigma.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the significant waveheight is performed whatever the surface type is. Nevertheless, it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Ku bandwidth identifier
  - RF subsystem identifier
- Computed data:
  - From "ALT_RET_OCE_01 - To perform the ocean-1 retracking" (Ku and S bands):
    - Composite Sigma
    - Execution flag (valid / invalid)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Instrumental characterization data:
    - Sampling interval of the analysis window
    - Ratio between the PTR width and the sampling interval of the analysis window

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- Universal constants:
  - Light velocity

Output data

- Significant waveheight (20 Hz, Ku and S bands) and associated validity flags

Mathematical statement

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

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

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.

ALGORITHM SPECIFICATION

For each elementary measurement, the computation of the significant waveheight (for Ku or for S band) and of the corresponding validity flag is specified hereafter.

Symbol [Ku/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and S-band value(s)).

Input data

- Composite Sigma and execution flag [Ku/S]:
  - Composite Sigma : SigmaC (s)
  - Execution flag [1] : Flag_Retrack (/)
- Sampling interval of the analysis window [2] : FFT_Step (s)
- Ratio PTR width / FFT step : Ratio_PTR_FFT (/)
- Light velocity : Light_Vel (m/s)

Output data

- Significant waveheight [Ku/S] : SWH (m)
- Significant waveheight validity flag [Ku/S] [1] : SWH_Val_Flag (/)

---

[1] 2 states: "valid" or "invalid"

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

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Processing

The significant waveheight and the associated validity flag are computed using mechanism "GEN_MEC_CON_01 - Derivation of the significant waveheight from the composite Sigma" (AD11), with the following inputs:

- Composite Sigma : SigmaC
- Composite Sigma validity flag : Flag_Retrack
- PTR width:
  - Sampling interval of the analysis window : FFT_Step
  - Ratio PTR width / FFT step : Ratio_PTR_FFT
- Light velocity : Light_Vel

ACCURACY

TBD

COMMENTS

- For ENVISAT, SWH will be set to 0 when the argument of the square root is negative. It means that at low waveheights, estimates of σ_c such as $\sigma_c < \sigma_p$ (which may be statistically correct) will be forced to $\sigma_c = \sigma_p$. Nevertheless, this operation should not lead to a significative error on the significant waveheight for Ku band, due to the existence of the two additional DFT samples on the leading edge.
- For JASON-1, the significant waveheight will be derived from the averaged value of σ_c (see "ALT_COM_SWH_01 - To edit and compress the on-ground retracked significant waveheights").
- In both ENVISAT and JASON-1 level 1b input products, the tracker or tracker-derived estimates associated with a 20-Hz measurement correspond to the settings applied on-board to the waveform associated with this measurement. Indeed, the management of these information is accounted for in the level 1b processing for ENVISAT and on-board for JASON-1.

REFERENCES

None

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ALT_PHY_MIS_02 - To compute the square of the off-nadir angle from the on-ground waveform-derived estimates

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

For each elementary measurement, to derive the square of the off-nadir angle from the on-ground estimate of the slope of the logarithm of the trailing edge of the Ku-band waveform.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  For ENVISAT and JASON-1, the computation of the square of the off-nadir angle is performed whatever the surface type is. Nevertheless, this parameter is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- For ENVISAT:
  - Product data: None
  - Computed data:
    - From "ALT_RET_ICE_02 - To perform the ice-2 retracking":
      - Slope s_{T1m} of the first part of the logarithm of the trailing edge (Ku band)
      - Quality information (execution flag and slope computation flag)
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Orbit altitudes (20-Hz)
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - Instrumental characterization data:
      - Antenna beamwidth

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    - Universal constants:
        - Light velocity
        - Earth radius
- For JASON-1:
  - Product data: None
  - Computed data:
    - From "ALT_RET_OCE_02 - To perform the ocean-2 retracking":
        - Slope of the logarithm of the trailing edge (Ku band)
        - Quality information (execution flag and slope computation flag)
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Orbit altitudes (20-Hz)
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - Instrumental characterization data:
        - Antenna beamwidth
    - Universal constants:
        - Light velocity
        - Earth radius

Output data

For ENVISAT and JASON-1, the following 20-Hz parameters:

- Square of the off-nadir angle and associated validity flag

Mathematical statement

- For ENVISAT:

  For each elementary measurement, the square of the off-nadir angle (ξ^2) is computed from the slope of the logarithm of the trailing edge s_{T1m} (Ku band), by:

$$\xi^2 = \frac{1}{2} \cdot \frac{1 + \frac{s_{T1m}}{\alpha}}{1 + \frac{2}{\gamma}} \qquad (1)$$

  This expression is derived from Hayne's model (see (1) in "ALT_RET_ICE_01 - To perform the ice-1 retracking"), assuming that the impact of the part of the model which depends on the skewness coefficient is negligible on the trailing edge (γ and α parameters are derived from the antenna beamwidth and the orbit altitude).

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- For JASON-1:

  For each elementary measurement, the square of the off-nadir angle is computed using (1) from the slope of the logarithm of the trailing edge s_T (derived from Ku-band data). This expression is derived from Hayne's model (see (1) and (7) in "ALT_RET_OCE_02 - To perform the ocean-2 retracking"), assuming that the impact of the part of the model which depends on the skewness coefficient is negligible on the trailing edge.

For both cases, the validity of the square of the off-nadir angles is determined from the retracking execution flags and from the slope computation flags. Default values are provided in case of invalidity of square of the off-nadir angles.

ALGORITHM SPECIFICATION

For each elementary measurement, the computation of the square of the off-nadir angle and of the associated validity flag is specified hereafter.

Input

- Slope of the logarithm of the trailing edge (Ku band) and associated validity flag:
  - Slope : Slope (s^{-1})
  - Execution flag [1] : Flag_Retrack (/)
  - Slope computation flag [1] : Flag_Slope (/)
- Satellite altitude : Sat_Alt (m)
- Antenna beamwidth [2] : Ant_Beam (degree)
- Earth radius : Earth_Rad (m)
- Light velocity : Light_Vel (m/s)

Output

- Square of the off-nadir angle : Sq_Off_Nad ($degree^2$)
- Validity flag for the square of the off-nadir angle [1] : Sq_Off_Nad_Val_Flag (/)
- Execution status

Processing

- Gamma and Alpha parameters are computed using mechanism "GEN_MEC_MOD_04 - Computation of "Gamma" and "Alpha" altimeter parameters" (AD11), with the following inputs:
  - Antenna beamwidth : Ant_Beam
  - Satellite altitude : Sat_Alt

---

[1] 2 states: "valid" or "invalid"

[2] Value to be selected according to the processed band

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- Earth radius : Earth_Rad
- Light velocity : Light_Vel

The corresponding outputs are:

- "Gamma" parameter : Gamma
- "Alpha" parameter : Alpha

- The square of the off-nadir angle (Sq_Off_Nad) and the corresponding validity flag (Sq_Off_Nad_Val_Flag) are computed using mechanism "GEN_MEC_CON_02 - Derivation of the square of the off-nadir angle from the slope of the trailing edge" (AD11), with the following inputs:
  - Gamma instrumental parameter : Gamma
  - Alpha instrumental parameter : Alpha
  - Slope of the logarithm of the trailing edge : Slope
  - Flags: (1)
    - Retracking execution flag : Flag_Retrack
    - Slope computation flag : Flag_Slope

ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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ALT_COR_RAN_06 - To correct the altimeter range for Doppler effects

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

TOPEX

FUNCTION

To correct the 20-Hz altimeter ranges for the Doppler effects.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The Doppler correction is applied whatever the surface type is.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "ALT_PHY_RAN_05 - To compute the on-ground retracked altimeter ranges", for Ku and S bands:
    - Ice-1 altimeter range and associated validity flag
    - Ice-2 altimeter range and associated validity flag
    - Ocean-1 altimeter range and associated validity flag
    - Sea-ice altimeter range (Ku band only) and associated validity flag
  - From "ALT_COR_RAN_02 - To compute the Doppler correction", for Ku and S bands:
    - Doppler correction
- Dynamic auxiliary data: None
- Static auxiliary data: None

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Output data

For each band, the following 20-Hz parameters:

- Ice-1 altimeter range corrected for Doppler effects
- Ice-2 altimeter range corrected for Doppler effects
- Ocean-1 altimeter range corrected for Doppler effects
- Sea-ice altimeter range corrected for Doppler effects (Ku band only)

Mathematical statement

For each elementary measurement, the corrected altimeter ranges (h_c) are computed as follows for Ku and S bands, where h represent the input altimeter ranges and where δh represent the Doppler correction:

$$h_c = h + \delta h \tag{1}$$

The corrected altimeter ranges are set to a default value if the corresponding input parameter is not valid.

ALGORITHM SPECIFICATION

For each elementary measurement, the computation of the altimeter ranges (ice-1 Ku/S bands, ice-2 Ku/S bands, ocean-1 Ku/S bands, or sea-ice Ku band) corrected for the Doppler effects is specified hereafter.

Symbol [Ku/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and S-band value(s)).

Input data

- Altimeter range and associated validity flag [Ku/S]:
  - Altimeter range : Range (m)
  - Altimeter range validity flag [1] : Range_Val_Flag (/)
- Doppler correction [Ku/S] : Cor_Dop_Range (m)

Output data

- Altimeter range corrected for Doppler effects [Ku/S] : Range_Cor (m)

Processing

The altimeter range corrected for Doppler effects is computed using mechanism "GEN_MEC_COR_02 - Computation of a corrected parameter from its raw value and its corrections" (AD11), with the following inputs:

---

[1] 2 states: "valid" or "invalid"

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- Raw value : Range
- Validity flag of the raw value (1) : Range_Val_Flag
- Number of corrections : 1
- Corrections : Cor_Dop_Range

ACCURACY

TBD

COMMENTS

This function applied to 20-Hz measurements because of the possible change of emitted bandwidth in Ku band (320, 80 or 20 MHz) within a source packet (1-Hz measurement). For JASON-1, this function applies to 1-Hz measurement in "ALT_COR_RAN_08 - To compute the corrected on-ground retracked altimeter ranges", after the averaging of 20-Hz estimates (see Appendix 1).

REFERENCES

None

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GEN_ENV_ECH_01 - To determine the echo direction

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To determine the direction (in a local Cartesian co-ordinate frame) from which the power of the waveforms came.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The determination of the echo direction is relevant to surfaces where a slope model exists on input of the processing. Otherwise, the nadir direction is used.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Location (latitude θ, longitude λ) of the measurements (20 Hz)
    - Orbit altitudes (20 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Processing parameters
    - Default value of the slope components in the surface slope models
  - Surface slopes model(s)
  - Universal constants:
    - Flattening coefficient of the reference ellipsoid
    - Semi major axis of the reference ellipsoid

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Output data

- Satellite attitude angle in the local Cartesian co-ordinate frame: η (20 Hz)
- Satellite azimuth angle in the local Cartesian co-ordinate frame: φ (20 Hz)
- Meridional radius of curvature of the ellipsoid: ρ_θ (20 Hz)
- Radius of the parallel circle of the ellipsoid: ρ_λ (20 Hz)
- Slope model flag (20 Hz)

Mathematical statement (see RD7)

The direction from which the power of the leading edge of the waveforms came (satellite attitude and azimuth angles: φ and η) is determined in a local Cartesian co-ordinate frame (x,y) with its origin at the sub-satellite point on the ellipsoid, by reference to a surface slopes model. This frame is the tangent plane to the ellipsoid, and provides a local approximation to the ellipsoid at the point in question. The meridional radius of curvature of the ellipsoid (ρ_θ) and the radius of the parallel circle of the ellipsoid (ρ_λ) are also provided on output.

- First, the meridional radius of curvature of the ellipsoid (ρ_θ), and the radius of the corresponding parallel circle at the geodetic latitude (ρ_λ) are computed:

$$\rho_\theta = \frac{a_e\left(1-e^2\right)}{\left[1-e^2\sin^2\theta\right]^{\frac{3}{2}}} \quad \text{and} \quad \rho_\lambda = \frac{a_e\cos\theta}{\left[1-e^2\sin^2\theta\right]^{\frac{1}{2}}} \tag{1}$$

  (where a_e is the semi-major axis and e is the eccentricity of the reference ellipsoid)

- The input measurements location (geodetic latitude θ and longitude λ) is then converted in a hemispherical Cartesian co-ordinate frame (positions X and Y). This conversion is performed by using the meridional radius of curvature of the ellipsoid (ρ_θ), and by deriving the corresponding positions (X and Y) from the Lambert equal-area projection:

$$X = 2\rho_\theta\cos(\lambda)\sin\left(\frac{\frac{\pi}{2}-|\theta|}{2}\right) \quad \text{and} \quad Y = 2\rho_\theta\sin(\lambda)\sin\left(\frac{\frac{\pi}{2}-|\theta|}{2}\right) \tag{2}$$

  This co-ordinate transformation is performed to facilitate correct interpolation of the range for the echo direction determination. The situation arises because one must work with partial derivatives of the range, and the range must be interpolated in a Cartesian frame in order to compute these derivatives. It also provides a convenient co-ordinate system for the slope models. Note that the reasonable assumption is made that the ice sheets are close to the North / South poles.

  Note also that the co-ordinate transformation cannot distinguish the hemisphere of the earth under consideration. Therefore, a "hemisphere flag" has been introduced into the slope model files, so that files from the wrong hemisphere cannot be accessed.

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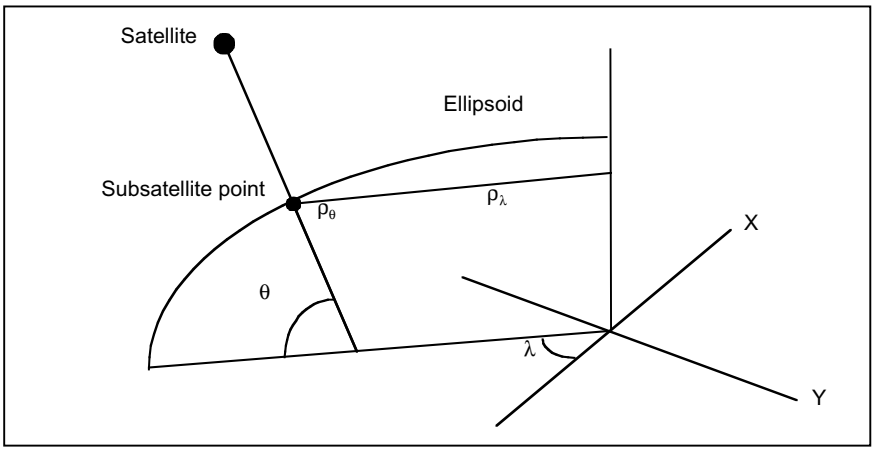

Figure 4: The global geodetic ellipsoidal and the global hemispherical Cartesian co-ordinate frames

- The satellite position in the global hemispherical Cartesian co-ordinate frame is then used to determine whether the overflown surface has an associated slope model or not. If not, the nadir direction is assumed (the output angles are set to zero). Else, the processing proceeds as follows.
- The slope model is interpolated to get the X and Y components of the slope ($s_X(X,Y)$ and $s_Y(X,Y)$), using a six-point bivariate interpolator (which is exact if second order derivatives are zero or negligible).
- Then, a set of partial derivatives of X and Y with respect to latitude and longitude:

  $$\frac{\partial X}{\partial \theta}, \frac{\partial Y}{\partial \theta}, \frac{\partial X}{\partial \lambda}, \frac{\partial Y}{\partial \lambda}$$

  are computed, so that the quantities calculated in the global hemispherical Cartesian frame (X,Y,Z) may be related to the local Cartesian frame (x,y,z).

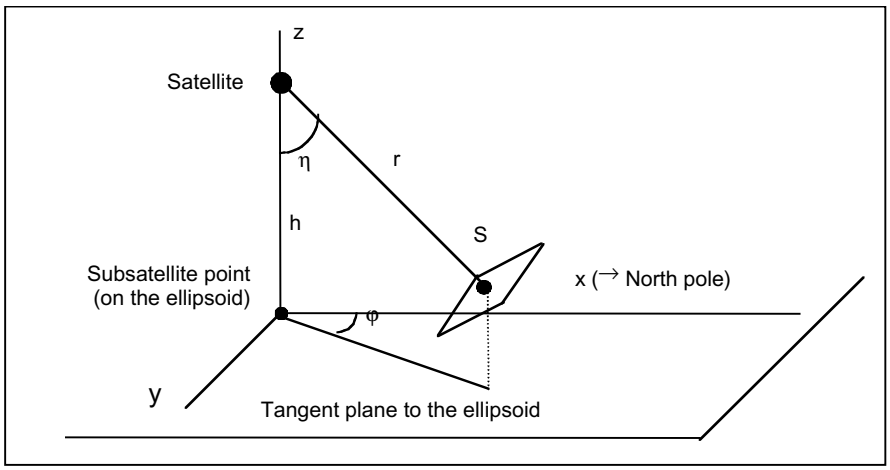

Figure 5: The local Cartesian co-ordinate frame

- The interpolated slope values (in X,Y), the set of partial derivatives and also the orbit altitude h, the latitude θ and radiuses ρ_θ and ρ_λ are then used to compute the range derivatives $(\partial r / \partial x)_{x=0} \equiv s_x$ and $(\partial r / \partial y)_{y=0} \equiv s_y$ in local co-ordinates.

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$$s_x = \frac{1}{\rho_\theta + h}\left[s_X(X,Y)\frac{\partial X}{\partial \theta} + s_Y(X,Y)\frac{\partial Y}{\partial \theta}\right] \quad \text{and} \quad s_y = \frac{1}{\rho_\lambda + h\cos\theta}\left[s_X(X,Y)\frac{\partial X}{\partial \lambda} + s_Y(X,Y)\frac{\partial Y}{\partial \lambda}\right] \qquad (3)$$

- The echo direction angles (attitude η and azimuth φ) in local co-ordinates are finally derived from the range derivatives.

$$\varphi = \tan^{-1}\left(\frac{s_y}{s_x}\right) \quad \text{and} \quad \eta = \sin^{-1}\left(\sqrt{s_x^2 + s_y^2}\right) \qquad \text{(expressed in radian)} \qquad (4)$$

ALGORITHM SPECIFICATION

For each elementary measurement, the computation of the satellite attitude and azimuth angles in the local Cartesian co-ordinate frame, of the meridional radius of curvature of the ellipsoid and of the radius of the parallel circle of the ellipsoid, is specified hereafter.

Input data

- Location of the measurement:
  - Latitude : Lat (degree)
  - Longitude : Lon (degree [0, 360[)
- Orbit altitude : Orb_Alt (m)
- Characteristics of the reference ellipsoid:
  - Semi major axis : SM_Axis (m)
  - Flattening : Flattening (/)
- Default value of the slope components in the surface slope models : Default_Slope (/)
- Surface slopes models:

  Each surface slope model consists of the following parameters (AD6 and RD7):
  - Model number : SM_Index (/)
  - Hemisphere flag [(1)] : SM_Hem_Flag (/)
  - X co-ordinate of point of the corner of the slope model : SM_X_Corner (m)
  - Y co-ordinate of point of the corner of the slope model : SM_Y_Corner (m)
  - Number of X-samples in the model : SM_X_Nb (/)
  - Number of Y-samples in the model : SM_Y_Nb (/)
  - Resolution of the slope model : SM_Res (m)
  - X-components of the slope : SM_X_Slope [0:SM_X_Nb-1][0:SM_Y_Nb-1] (/)
  - Y-components of the slope : SM_Y_Slope [0:SM_X_Nb-1][0:SM_Y_Nb-1] (/)

---

(1) 2 states: "North" or "South"

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Output data

- Satellite attitude angle in the local Cartesian co-ordinate frame : Sat_Att (degree [0, 90])
- Satellite azimuth angle in the local Cartesian co-ordinate frame : Sat_Azim (degree [0, 360[)
- Meridional radius of curvature of the ellipsoid : Merid_Rad (m)
- Radius of the parallel circle of the ellipsoid : Rad_Par (m)
- Slope model flag [(2)] : Slope_Mod_Flag (/)
- Execution status

Processing

Initializations

- The square of the eccentricity (Ecc2) is computed:

$$\text{Ecc2} = \text{Flattening} * (2 - \text{Flattening}) \tag{1}$$

- The meridional radius of curvature of the ellipsoid (Merid_Rad in meters) and the radius of the parallel circle of the ellipsoid (Rad_Par in meters) are computed by:

$$\text{Merid_Rad} = \frac{\text{SM_Axis} * (1 - \text{Ecc2})}{\left[1 - \text{Ecc2} * \sin^2\left(\frac{\pi}{180} * \text{Lat}\right)\right]^{\frac{3}{2}}} \tag{2}$$

$$\text{Rad_Par} = \frac{\text{SM_Axis} * \cos(\frac{\pi}{180} * \text{Lat})}{\left[1 - \text{Ecc2} * \sin^2\left(\frac{\pi}{180} * \text{Lat}\right)\right]^{\frac{1}{2}}} \tag{3}$$

- The position (X_Sat and Y_Sat in meters) of the satellite in a hemispherical Cartesian co-ordinate frame is then derived from Lat, Lon and Merit_Rad, by:

$$\text{X_Sat} = 2 * \text{Merid_Rad} * \cos(\frac{\pi}{180} * \text{Lon}) * \sin\left(\frac{\pi}{180} * \frac{90 - |\text{Lat}|}{2}\right) \tag{4}$$

$$\text{Y_Sat} = 2 * \text{Merid_Rad} * \sin(\frac{\pi}{180} * \text{Lon}) * \sin\left(\frac{\pi}{180} * \frac{90 - |\text{Lat}|}{2}\right) \tag{5}$$

- The slope model flag (Slope_Mod_Flag) is initialized to "unavailable"

---

(2) 2 states: "available" or "unavailable"

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Research of the slope model available for the processed measurement

The aim of this step of the processing research is to determine whether a slope model is available for the present echo location.

For each slope model on input:

- The X and Y indexes corresponding in the model to the position of the satellite, are computed as follows, where Int represents the integer truncation:
  - $$\text{Index_X} = \text{Int}\left[\frac{\text{X_Sat} - \text{SM_X_Corner}}{\text{SM_Res}}\right] \quad (6)$$
  - $$\text{Index_Y} = \text{Int}\left[\frac{\text{Y_Sat} - \text{SM_Y_Corner}}{\text{SM_Res}}\right] \quad (7)$$
- If the three following conditions are satisfied:
  - $0 < \text{Index_X} < \text{SM_X_Nb} - 1$ and (8)
  - $0 < \text{Index_Y} < \text{SM_Y_Nb} - 1$ and (9)
  - $[\text{SM_Hem_Flag set to "North" and Lat} \geq 0]$ or $[\text{SM_Hem_Flag set to "South" and Lat} < 0]$ (10)

  then:
  - The slope model flag (Slope_Mod_Flag) is set to "available"
  - This step of the processing is finished

Computation of the satellite attitude and azimuth angles (in the local Cartesian co-ordinate frame)

- If Slope_Mod_Flag is set to "unavailable" at the end of the previous research step

  Or

  If Slope_Mod_Flag is set to "available" but:

```
        SM_X_Slope  (Index_X-1, Index_Y)     = Default_Slope
or      SM_X_Slope  (Index_X,   Index_Y-1)   = Default_Slope
or      SM_X_Slope  (Index_X,   Index_Y)     = Default_Slope
or      SM_X_Slope  (Index_X,   Index_Y+1)   = Default_Slope
or      SM_X_Slope  (Index_X+1, Index_Y)     = Default_Slope
or      SM_X_Slope  (Index_X+1, Index_Y+1)   = Default_Slope
or      SM_Y_Slope  (Index_X-1, Index_Y)     = Default_Slope
or      SM_Y_Slope  (Index_X,   Index_Y-1)   = Default_Slope
or      SM_Y_Slope  (Index_X,   Index_Y)     = Default_Slope
or      SM_Y_Slope  (Index_X,   Index_Y+1)   = Default_Slope
or      SM_Y_Slope  (Index_X+1, Index_Y)     = Default_Slope
or      SM_Y_Slope  (Index_X+1, Index_Y+1)   = Default_Slope
```

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  - Then:
- $Sat_Att = 0$ (11)
- $Sat_Azim = 0$ (12)
- The processing is finished
- Slope_Mod_Flag is set to "unavailable" (if not)

- Else, the following computations are performed, <u>from the slope model selected in the previous research step</u>:
  - The relative position (X_Sat_Cell and Y_Sat_Cell, $\in$ [0,1[) of the satellite within the model cell is computed by:
    - $$X_Sat_cell = \frac{X_Sat - SM_X_Corner}{SM_Res} - Index_X \quad (13)$$
    - $$Y_Sat_cell = \frac{Y_Sat - SM_Y_Corner}{SM_Res} - Index_Y \quad (14)$$
  - The X-component model slope interpolated to the satellite position (X_Slope_Int: no unit) and the Y-component model slope interpolated to the satellite position (Y_Slope_Int: no unit) are computed using mechanism "GEN_MEC_INT_04 - Bivariate interpolation from six points" (AD11), with the following inputs:
    - X parameters:
      - Relative position in the cell : X_Sat_Cell
    - Y parameters:
      - Relative position in the cell : Y_Sat_Cell
    - Values of the table for the six points:
      - For the interpolation of the X-component model slope:

        Point (x-,y) : SM_X_Slope (Index_X-1, Index_Y)
        Point (x,y-) : SM_X_Slope (Index_X, Index_Y-1)
        Point (x,y) : SM_X_Slope (Index_X, Index_Y)
        Point (x,y+) : SM_X_Slope (Index_X, Index_Y+1)
        Point (x+,y) : SM_X_Slope (Index_X+1, Index_Y)
        Point (x+,y+) : SM_X_Slope (Index_X+1, Index_Y+1)
      - For the interpolation of the Y-component model slope:

        Point (x-,y) : SM_Y_Slope (Index_X-1, Index_Y)
        Point (x,y-) : SM_Y_Slope (Index_X, Index_Y-1)
        Point (x,y) : SM_Y_Slope (Index_X, Index_Y)
        Point (x,y+) : SM_Y_Slope (Index_X, Index_Y+1)
        Point (x+,y) : SM_Y_Slope (Index_X+1, Index_Y)
        Point (x+,y+) : SM_Y_Slope (Index_X+1, Index_Y+1)

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– The partial derivatives of the satellite position with respect to latitude and longitude (Deriv_X_Lat, Deriv_Y_Lat, Deriv_X_Lon and Deriv_Y_Lon, in meters) are computed by:

$$* \quad Temp_Lat = Merid_Rad * \left[\frac{3 * Ecc2 * \sin(\frac{\pi}{90} * Lat) * \sin\left(\frac{\pi}{180} * \frac{90 - |Lat|}{2}\right)}{1 - Ecc2 * \sin^2(\frac{\pi}{180} * Lat)} - sgn(Lat) * \cos\left(\frac{\pi}{180} * \frac{90 - |Lat|}{2}\right) \right] \quad (15)$$

$$Deriv_X_Lat = Temp_Lat * \cos(\frac{\pi}{180} * Lon) \quad (16)$$

$$Deriv_Y_Lat = Temp_Lat * \sin(\frac{\pi}{180} * Lon) \quad (17)$$

$$* \quad Temp_Lon = 2 * Merid_Rad * \sin\left(\frac{\pi}{180} * \frac{90 - |Lat|}{2}\right) \quad (18)$$

$$Deriv_X_Lon = -Temp_Lon * \sin(\frac{\pi}{180} * Lon) \quad (19)$$

$$Deriv_Y_Lon = Temp_Lon * \cos(\frac{\pi}{180} * Lon) \quad (20)$$

where "sgn" is the sign function, accounting for the convention that sgn(0) = +1

– The slopes in correct co-ordinates (X_Slope and Y_Slope: no unit) are derived by:

$$X_Slope = \frac{X_Slope_Int * Deriv_X_Lat + Y_Slope_Int * Deriv_Y_Lat}{Merid_Rad + Orb_Alt} \quad (21)$$

$$Y_Slope = \frac{X_Slope_Int * Deriv_X_Lon + Y_Slope_Int * Deriv_Y_Lon}{Rad_Par + Orb_Alt * \cos(\frac{\pi}{180} * Lat)} \quad (22)$$

– Finally, the satellite attitude and azimuth angles (Sat_Att and Sat_Azim in degree) are derived by:

$$Sat_Att = \frac{180}{\pi} * \sin^{-1}\left(\sqrt{X_Slope^2 + Y_Slope^2}\right) \quad (23)$$

$$Sat_Azim = \frac{180}{\pi} * \tan^{-1}\left(\frac{Y_Slope}{X_Slope}\right) \quad (24)$$

Note that Sat_Azim is defined between 0 and 360 degrees. The Arctg function must place it in the correct quadrant of the x-y plane, and zero divides in the argument must be trapped, and the result set to ±nπ/2 as appropriate.

ACCURACY

See RD7.

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COMMENTS

- The number of models initially required by MSSL was two, one for Greenland and one for Antarctica. However the system should be able to take additional slope models as more and better models become available.

REFERENCES

None

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ALT_PHY_GEN_01 - To compute the elevation and location of echoing points

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

Document ref:	SMM-ST-M2-EA-11005-CN	18th October, 2001	Issue: 3	Update: 3

Algorithm change record	creation	date	Issue:	Update:
	CCM			

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HERITAGE

None

FUNCTION

To determine the slope-corrected elevation and location of the echoing point of the surface in the global geodetic co-ordinate frame.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The slope-corrected parameters are significant over surfaces where a slope model exists.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Latitude of the measurements: θ (20 Hz)
    - Longitude of the measurements: λ (20 Hz)
    - Orbit altitudes: h (20 Hz)
  - From "ALT_COR_RAN_06 - To correct the altimeter range for Doppler effects":
    - Ku-band ice-1 altimeter range corrected for Doppler effects: h_{ice-1}(20 Hz)
    - Associated validity flag
  - From "GEN_ENV_ECH_01 - To determine the echo direction":
    - Satellite attitude angle in the local Cartesian co-ordinate frame: η (20 Hz)
    - Satellite azimuth angle in the local Cartesian co-ordinate frame: φ (20 Hz)
    - Meridional radius of curvature of the ellipsoid: ρ_θ (20 Hz)
    - Radius of the parallel circle of the ellipsoid: ρ_λ (20 Hz)

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- Dynamic auxiliary data: None
- Static auxiliary data: None

Output data

- Slope-corrected elevation of echoing point: z_e (20 Hz)
- Slope-corrected latitude of echoing point: θ_c (20 Hz)
- Slope-corrected longitude of echoing point: λ_c (20 Hz)
- Validity flag for the elevation and location of echoing points (20 Hz)

Mathematical statement (see RD7)

The Ku-band ice-1 altimeter range (corrected for the Doppler effects) and the echo direction (satellite attitude and azimuth angles in the local Cartesian co-ordinate frame) are used to calculate the slope-corrected elevation in the geodetic (i.e. altimetric) ellipsoidal reference frame. Ant the local co-ordinates of the echo direction are transformed using the geometry of the ellipsoid.

- The radius of curvature ρ of the local ellipse in the direction of the echo azimuth (φ) is first computed by:

$$\rho = \frac{\rho_\theta . \rho_\lambda}{\rho_\theta . \cos\theta . \sin^2\varphi + \rho_\lambda . \cos^2\varphi} \qquad (1)$$

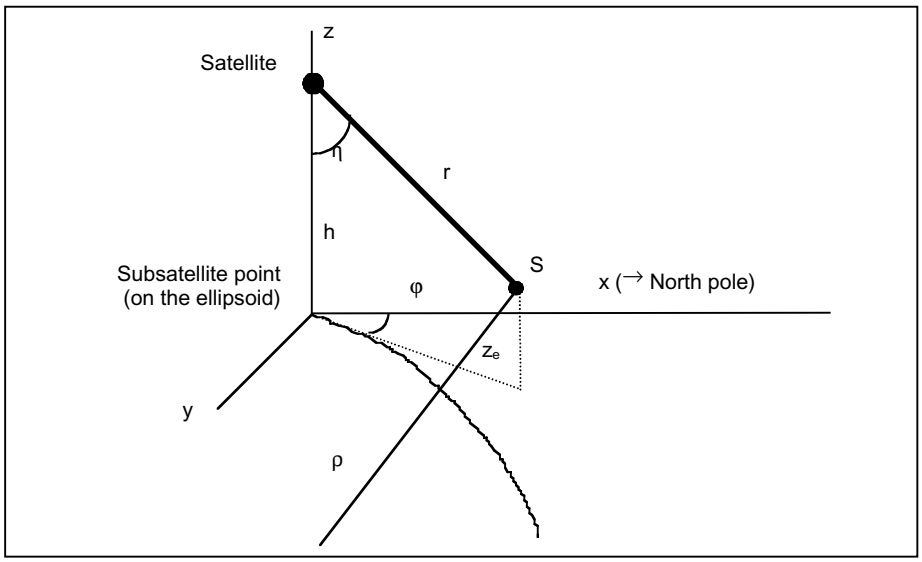

Figure 6: The local Cartesian co-ordinate frame

- Then, the three following expressions are evaluated to determine the slope-corrected latitude (θ_c), longitude (λ_c) and elevation (z_e) of the echoing point, in global geodetic ellipsoidal co-ordinates, i.e. the altimeter reference frame:

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$$z_e = h - h_{ice-1}.\cos\eta + \frac{(h_{ice-1}.\sin\eta)^2}{2\rho} \quad (2)$$

$$\theta_c = \theta + \frac{h_{ice-1}.\sin\eta.\cos\varphi}{\rho_\theta} \quad \text{(expressed in radian)} \quad (3)$$

$$\lambda_c = \lambda + \frac{h_{ice-1}.\sin\eta.\sin\varphi}{\rho_\lambda} \quad \text{(expressed in radian)} \quad (4)$$

In case of invalidity of the input Ku-band ice-1 altimeter range, the slope-corrected parameters are set to default values, and the validity flag for the elevation and location of echoing points is set.

ALGORITHM SPECIFICATION

For each elementary measurement, the computation of the slope-corrected elevation and location of the echoing point in the global geodetic co-ordinate frame, is specified hereafter.

Input data

- Location of the measurement:
  - Latitude : Lat (degree)
  - Longitude : Lon (degree [0, 360[)
- Orbit altitude : Orb_Alt (m)
- Ice-1 parameters:
  - Ku-band ice-1 altimeter range (corrected for Doppler effects) : Ice1_Range (m)
  - Ku-band ice-1 altimeter range validity flag [(1)] : Ice1_Range_Val_Flag (/)
- Satellite attitude angle (local Cartesian co-ordinate frame) : Sat_Att (degree [0, 90])
- Satellite azimuth angle (local Cartesian co-ordinate frame) : Sat_Azim (degree [0, 360[)
- Meridional radius of curvature of the ellipsoid : Merid_Rad (m)
- Radius of the parallel circle of the ellipsoid : Rad_Par (m)

Output data

- Slope-corrected latitude of echoing point : Slope_Cor_Lat (degree)
- Slope-corrected longitude of echoing point : Slope_Cor_Lon (degree [0, 360[)
- Slope-corrected elevation of echoing point : Slope_Cor_Elev (m)
- Validity flag for the elevation and location of echoing points : Elev_Loc_Val_Flag (/)
- Execution status

---

(1) 2 states: "valid" or "invalid"

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Processing

- If the Ku-band ice-1 altimeter range validity flag (Ice1_Range_Val_Flag) is set to "valid", then:
  - The slope-corrected latitude of the echoing point (Slope_Cor_Lat in degree) is computed by:

$$Slope_Cor_Lat = Lat + \frac{180}{\pi} * \frac{Ice1_Range * \sin(\frac{\pi}{180} * Sat_Att) * \cos(\frac{\pi}{180} * Sat_Azim)}{Merid_Rad} \quad (1)$$

  - The slope-corrected longitude of the echoing point (Slope_Cor_Lon in degree, which must belong to [0, 360[) is computed by:

$$Slope_Cor_Lon = Lon + \frac{180}{\pi} * \frac{Ice1_Range * \sin(\frac{\pi}{180} * Sat_Att) * \sin(\frac{\pi}{180} * Sat_Azim)}{Rad_Par} \quad (2)$$

  - The slope-corrected elevation of the echoing point (Slope_Cor_Elev in meter) is computed by:

$$Slope_Cor_Elev = Orb_Alt - Ice1_Range * \cos(\frac{\pi}{180} * Sat_Att) + \frac{\left[Ice1_Range * \sin(\frac{\pi}{180} * Sat_Att)\right]^2}{2 * Rad_Curv} \quad (3)$$

    where the radius of curvature of the local ellipse in the direction of the echo azimuth (Rad_Curv in meter) is given by:

$$Rad_Curv = \frac{Merid_Rad * Rad_Par}{Merid_Rad * \cos(\frac{\pi}{180} * Lat) * \sin^2(\frac{\pi}{180} * Sat_Azim) + Rad_Par * \cos^2(\frac{\pi}{180} * Sat_Azim)} \quad (4)$$

  - The validity flag for the elevation and location of echoing points (Elev_Loc_Val_Flag) is set to "valid"
- Else (Ice1_Range_Val_Flag set to "invalid"), then:
  - Slope_Cor_Lat, Slope_Cor_Lon and Slope_Cor_Elev are set to default values
  - The validity flag for the elevation and location of echoing points (Elev_Loc_Val_Flag) is set to "invalid"

ACCURACY

See RD7.

COMMENTS

None

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REFERENCES

None

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ALT_COR_RAN_07 - To compute the Doppler slope correction

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To determine the additional Doppler correction to the altimeter range due to the effect of sloping surfaces (with respect to the Doppler effect due to the satellite orbital altitude rate).

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The additional Doppler correction due to the effect of sloping surfaces is significant over surfaces where a slope model exists.

ALGORITHM DEFINITION

Input data

- Product data:
  - Elementary Ku bandwidth identifier
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Interpolated satellite position vectors: $\vec{P} = (P_X, P_Y, P_Z)$ (20 Hz)
    - Interpolated satellite velocity vectors: $\vec{V} = (V_X, V_Y, V_Z)$ (20 Hz)
  - From "ALT_COR_RAN_02 - To compute the Doppler correction":
    - Ku and S bands Doppler correction: $\Delta h_{Doppler}$ (20 Hz)
  - From "ALT_PHY_GEN_01 - To compute the elevation and location of echoing points":
    - Slope-corrected latitude of echoing point: θ_c (20 Hz)
    - Slope-corrected longitude of echoing point: λ_c (20 Hz)
    - Slope-corrected elevation of echoing point: z_e (20 Hz)
    - Validity flag for the elevation and location of echoing point (20 Hz)

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- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data:
    - Emitted frequency
    - Pulse duration
    - Emitted bandwidth
    - Sign of the slope of the transmitted chirp
  - Universal constants:
    - Flattening coefficient of the reference ellipsoid
    - Semi major axis of the reference ellipsoid

Output data

- Ku-band Doppler slope correction (20 Hz)
- S-band Doppler slope correction (20 Hz)

Mathematical statement (see RD7)

Over sloping surfaces, with respect to the classical Doppler correction due to the satellite orbital altitude rate, there is an additional contribution to range due to the Doppler effect that arises because of the echo direction is no longer to the nadir of the satellite (in general). This algorithm determines this additional Doppler correction to the altimeter range (which is known as the Doppler slope correction or delta-Doppler correction).

- The Cartesian components (P_{eX},P_{eY},P_{eZ}) of the position $\dot{P}_e$ of the echoing points are derived from the input slope-corrected geodetic co-ordinates (elevation z_e, latitude θ_c, longitude λ_c).
- The line of sight vector $\vec{L} = (L_X, L_Y, L_Z)$ is then determined from the position of the satellite and of the echoing point, by:

$$\vec{L} = \vec{P} - \vec{P}_e \tag{1}$$

- The driving parameter for the Doppler range effect is the velocity component of the satellite in the line of sight of the observer. This parameter (r') is obtained by forming a scalar product of the satellite velocity vector ($\vec{V}$) with the unit line of sight vector, i.e. by:

$$r' = \frac{V_X.(P_X - P_{eX}) + V_Y.(P_Y - P_{eY}) + V_Z.(P_Z - P_{eZ})}{\sqrt{(P_X - P_{eX})^2 + (P_Y - P_{eY})^2 + (P_Z - P_{eZ})^2}} \tag{2}$$

- The total Doppler correction $\Delta h_{Doppler}^{Total}$ is then computed (for Ku and S bands), using the standard formulation given by (1) in "To compute the Doppler correction" (RD8), where the orbital altitude rate h' is superseded by the velocity component r' of the satellite in the line of sight of the observer.
- Finally, the Doppler slope correction $\Delta h_{Doppler}^{Slope}$, i.e. the part of the Doppler correction due to the effects of sloping surface only, is derived from the total Doppler correction and from the input Doppler correction, by:

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$$\Delta h_{Doppler}^{Slope} = \Delta h_{Doppler}^{Total} - \Delta h_{Doppler} \quad (3)$$

In case of invalidity of the elevation and location of echoing points, the Ku-band and S-band Doppler slope corrections are set to default values.

ALGORITHM SPECIFICATION

Warning: The selection, possible change of frame and interpolation of the orbit position and velocity vectors to the altimeter time-tags (see "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location") are considered as "data management" algorithms (see section 1). They are specified in RD12.

For each elementary measurement, the computation of the Doppler slope correction on the altimeter range (Ku or S band) is specified hereafter.

Symbol [Ku/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and S-band value(s)).

Input data

- Position of the satellite (interpolated):
  - X co-ordinate : PSx (m)
  - Y co-ordinate : PSy (m)
  - Z co-ordinate : PSz (m)
- Velocity of the satellite (interpolated):
  - X co-ordinate : VSx (m/s)
  - Y co-ordinate : VSy (m/s)
  - Z co-ordinate : VSz (m/s)
- Doppler correction [Ku/S] : Cor_Dop_Range (m)
- Slope-corrected parameters of echoing point:
  - Latitude : Slope_Cor_Lat (degree)
  - Longitude : Slope_Cor_Lon (degree [0, 360[)
  - Elevation : Slope_Cor_Elev (m)
  - Validity flag : Elev_Loc_Val_Flag (/)
- Instrumental characterization data:
  - Emitted frequency [(1)] : Frequency (Hz)
  - Pulse duration : Pulse_Duration (s)
  - Emitted bandwidth [(2)] : Bandwidth (Hz)

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

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- Sign of the slope of the transmitted chirp : Sign_Slope (-1 or +1)

- Characteristics of the reference ellipsoid:
  - Semi major axis : SM_Axis (m)
  - Flattening : Flattening (/)

Output data

- Doppler slope correction [Ku/S] : Cor_Dop_Slope_Range (m)
- Execution status

Processing

- If the validity flag for the elevation and location of echoing points (Elev_Loc_Val_Flag) is set to "valid", then:
  - The square of the eccentricity (Ecc2) is computed:

$$\text{Ecc2} = \text{Flattening} * (2 - \text{Flattening}) \tag{1}$$

  - The three Cartesian components (X-component PEx, Y-component PEy, and Z-component PEz, in meters) of the position of the echoing point are computed using mechanism "GEN_MEC_CON_03 - Conversion of a position vector from geodetic to Cartesian co-ordinates" (AD11), with the following inputs:
    - Geodetic components of the position vector:
      - Elevation above the reference ellipsoid : Slope_Cor_Elev
      - Geodetic latitude : Slope_Cor_Lat
      - Longitude : Slope_Cor_Lon
    - Characteristics of the reference ellipsoid:
      - Semi major axis : SM_Axis
      - Square of the eccentricity : Ecc2
  - The velocity component of the satellite in the line of sight of the observer (Vel_Line_Sight in m/s) is then derived by:

$$\text{Vel_Line_Sight} = \frac{\text{VSx} * (\text{PSx} - \text{PEx}) + \text{VSy} * (\text{PSy} - \text{PEy}) + \text{VSz} * (\text{PSz} - \text{PEz})}{\sqrt{(\text{PSx} - \text{PEx})^2 + (\text{PSy} - \text{PEy})^2 + (\text{PSz} - \text{PEz})^2}} \tag{2}$$

  - The total Doppler correction on the altimeter range (Total_Cor_Dop_Range in meter) is then computed using mechanism "GEN_MEC_COR_03 - Computation of the Doppler correction on the altimeter range" (AD11), with the following inputs:
    - Altitude rate : Vel_Line_Sight

---

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

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- Instrumental characterization data:
  - Emitted frequency : Frequency
  - Pulse duration : Pulse_Duration
  - Emitted bandwidth : Bandwidth
  - Sign of the slope of the transmitted chirp : Sign_Slope
- The Doppler slope correction (Cor_Dop_Slope_Range in meters) is finally derived by:

$$Cor_Dop_Slope_Range = Total_Cor_Dop_Range - Cor_Dop_Range \quad (3)$$

- Else (Elev_Loc_Val_Flag set to "invalid"), then:
  - The Doppler slope correction (Cor_Dop_Slope_Range) is set to a default value

ACCURACY

See RD7.

COMMENTS

- Be aware of the following difference with respect to the "real time" processing (FDGDR) processing:
  - In the off-line processing, the satellite position and velocity vectors interpolated to each elementary measurement, and expressed in the global hemispherical Cartesian co-ordinate frame (see **Figure 4**), are available from the orbit files on input.
  - In the real time processing (see RD7), as no orbit data is available on input:
    - the satellite position vectors are computed from the orbit altitude and from the geodetic latitude and longitude, by conversion of geodetic co-ordinates in geocentric co-ordinates and then computation of the Cartesian components
    - the satellite velocity vectors are derived from the computed position vectors, using a differentiation process (which must manage data gaps).

REFERENCES

None

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ALT_COM_GEN_01 - To identify the elementary measurements to be compressed

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To identify the elementary measurements to be compressed, accounting for the emitted bandwidth (for Ku band) and for the mean quadratic error issued from the ocean-1 retracking.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type: /

ALGORITHM DEFINITION

Input data

- Product data:
  - Ku bandwidth identifier for Ku band
- Computed data:
  - From "ALT_RET_OCE_01 - To perform the ocean-1 retracking", for Ku and S bands:
    - Mean quadratic error
    - Execution flag (valid / invalid)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data:
    - Number of elementary measurements per averaged measurement
  - Processing parameters:
    - Threshold on the mean quadratic error for compression

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Output data

- Ku bandwidth identifier for the averaged measurement (1 Hz)
- Map of elementary estimates to be compressed for Ku band (1 Hz)
- Map of elementary estimates to be compressed for S band (1 Hz)

MATHEMATICAL STATEMENT

- For Ku band:
  - The possible change of the emitted bandwidth within a source packet is accounted for. The Ku bandwidth identifier for the averaged measurement is defined as the higher bandwidth (among 320, 80 and 20 MHz) within the 20 elementary measurements of the averaged measurement
  - The elementary measurements selected for the compression process are measurements performed with the same bandwidth as the one determined for the averaged measurement, and such as the mean quadratic error issued from the ocean-1 retracking is smaller than a threshold (processing parameter)
- For S band, the elementary measurements selected for the compression process are measurements such as the mean quadratic error issued from the ocean-1 retracking is smaller than a threshold (processing parameter)

ALGORITHM SPECIFICATION

For each averaged measurement, the identification of the elementary estimates to be compressed for Ku and S bands, is specified hereafter.

Input data

- Ku bandwidth identifiers for Ku band [1] : Chirp_Id [0:Ne-1] (/)
- Ku-band ocean-1 parameters:
  - Mean quadratic errors : MQE_Ocean1_Ku [0:Ne-1] (/)
  - Execution flags : Flag_Retrack_Ocean1_Ku [0:Ne-1] (/)
- S-band ocean-1 parameters:
  - Mean quadratic errors : MQE_Ocean1_S [0:Ne-1] (/)
  - Execution flags : Flag_Retrack_Ocean1_S [0:Ne-1] (/)
- Number of elementary measurements per averaged measurement : Ne (/)
- Processing parameter:
  - Threshold on the mean quadratic error for compression [2] : MQE_Ocean1_Thresh (/)

---

[1] 3 states: "320 MHz", "80 MHz" or "20 MHz"

[2] Table with 4 significative values, corresponding to Ku-band 320 MHz, Ku-band 80 MHz, Ku band 20 MHz and S band

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Output data

- Ku bandwidth identifier for the averaged measurement : Mean_Chirp_Id (/) [1]
- Map of elementary estimates to be compressed for Ku band [3] : Map_Comp_Ku [0:Ne-1] (/)
- Map of elementary estimates to be compressed for S band [3] : Map_Comp_S [0:Ne-1] (/)
- Execution status

Processing

- The Ku bandwidth identifier for the averaged measurement is determined by:
  - If at least one of the input Ku bandwidth identifiers {Chirp_Id(j)} is set to "320 MHz", then Mean_Chirp_Id is set to "320 MHz"
  - Else, If at least one of the input Ku bandwidth identifiers {Chirp_Id(j)} is set to "80 MHz", then Mean_Chirp_Id is set to "80 MHz"
  - Else, Mean_Chirp_Id is set to "20 MHz"
- The map of elementary estimates to be compressed for Ku band is determined as follows for $j \in [0,Ne-1]$:
  - Let MQE_Ocean1_Thresh_Ku be the value of MQE_Ocean1_Thresh corresponding to the Ku bandwidth of the averaged measurement (320, 80 or 20 MHz, pointed out by Mean_Chirp_Id)
  - If the two following conditions are satisfied:
    - Flag_Retrack_Ocean1_Ku set to "valid"
    - $\text{Chirp_Id}(j) = \text{Mean_Chirp_Id}$ (1)
    - $\text{MQE_Ocean1_Ku}(j) \leq \text{MQE_Ocean1_Thresh_Ku}$ (2)

    then Map_Comp_Ku(j) is set to "valid"
  - Else Map_Comp_Ku(j) is set to "invalid"
- The map of elementary estimates to be compressed for S band is determined as follows for $j \in [0,Ne-1]$:
  - Let MQE_Ocean1_Thresh_S be the value of MQE_Ocean1_Thresh corresponding to the S band:
  - If the following conditions are satisfied:
    - Flag_Retrack_Ocean1_S set to "valid"
    - $\text{MQE_Ocean1_S}(j) \leq \text{MQE_Ocean1_Thresh_S}$ (3)

    then Map_Comp_S(j) is set to "valid"
  - Else Map_Comp_S(j) is set to "invalid"

---

[3] 2 states for each point of the map: "valid" or "invalid"

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ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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ALT_COM_RAN_06 - To edit and compress the elevation of echoing points

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To compute the 1-Hz averaged estimate of the slope-corrected elevation of echoing points.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "ALT_PHY_GEN_01 - To compute the elevation and location of echoing points":
    - Slope-corrected elevation of echoing point (20 Hz)
    - Validity flag for the elevation and location of echoing points (20 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data:
    - Number of elementary measurements per averaged measurement

Output data

- Averaged value of the slope-corrected elevation of echoing point (1-Hz)

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Mathematical statement (see RD7)

The compression process only consists of an arithmetic averaging of the valid elementary estimates. No specific editing is performed.

ALGORITHM SPECIFICATION

For each averaged measurement, the averaging of the elementary estimates of the slope-corrected elevation of echoing point is specified hereafter.

Input data

- Slope-corrected elevation of echoing point : Slope_Cor_Elev (m)
- Validity flag for the elevation and location of echoing points : Elev_Loc_Val_Flag (/)
- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)

Output data

- Averaged value of the slope-corrected elevation of echoing point : Slope_Cor_Elev_Mean (m)
- Execution status

Processing

The averaging of the elementary estimates of the slope-corrected elevation of echoing point is performed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:

- Number of estimates to be compressed : Ne
- Estimates : Slope_Cor_Elev [0:Ne -1]
- Map of estimates to be compressed : set to "valid" for each of the Ne measurements
- Validity flags for the estimates : Elev_Loc_Val_Flag [0:Ne -1]
- Processing parameters:
  - Type of compression : set to "Arithmetic Averaging"
  - Minimum number of estimates requested for the compression : set to "0"
  - Minimum value of the standard deviation for outliers identification : set to "+ ∞"
  - Standard deviation scale factor for outliers identification : set to "0"
  - Center of the averaged measurement : not requested

The corresponding outputs are the compressed estimate (Slope_Cor_Elev_Mean) and the associated quality information (standard deviation, map of valid estimates, number of valid estimates, validity of the compressed estimate) not used in the following.

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ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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ALT_COM_RAN_05 - To edit and compress the on-ground retracked altimeter ranges

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

POSEIDON-1

FUNCTION

To compute a 1-Hz compressed estimate of the on-ground retracked altimeter ranges (Ku and C/S bands) from elementary estimates, and to derive a 1-Hz altimeter echo type (“ocean-like” or “non ocean-like”).

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- For ENVISAT:
  - Product data: None
  - Computed data:
    - From "ALT_PHY_RAN_05 - To compute the on-ground retracked altimeter ranges", for Ku and S bands:
      - Validity flag for the on-ground retracked altimeter range
    - From "ALT_COR_RAN_06 - To correct the altimeter range for Doppler effects", for Ku and S bands:
      - Ocean-1 altimeter range
    - From "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed", for Ku and S bands:
      - Map of elementary estimates to be compressed (1 Hz)
      - Ku bandwidth identifier for the averaged measurement
  - Dynamic auxiliary data: None

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  - Static auxiliary data:
    - RA-2 instrumental characterization data:
      - Number of elementary measurements per averaged measurement
    - Processing parameters:
      - Type of compression
      - Minimum number of estimates requested for the compression
      - Minimum value of the standard deviation for outliers identification
      - Standard deviation scale factor for outliers identification
      - Center of the averaged measurement
      - Threshold on the standard deviation for the echo type determination
      - Threshold on the number of valid estimates for the echo type determination
- For JASON-1:
  - Product data:
    - Altimeter configuration data
  - Computed data:
    - From "ALT_PHY_RAN_05 - To compute the on-ground retracked altimeter ranges", for Ku and C bands:
      - On-ground retracked altimeter range and associated validity flag
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - POSEIDON-2 instrumental characterization data:
      - Number of elementary measurements per averaged measurement
    - Processing parameters:
      - Type of compression
      - Minimum number of estimates requested for the compression
      - Minimum value of the standard deviation for outliers identification
      - Standard deviation scale factor for outliers identification
      - Center of the averaged measurement
      - Threshold on the standard deviation for the echo type determination
      - Threshold on the number of valid estimates for the echo type determination

Output data

- For ENVISAT, for each parameter (Ku and S bands on-ground ocean-1 retracked altimeter ranges):
  - Compressed value (1 Hz)
  - Standard deviation

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  - Updated quality information
- For JASON-1, for each parameter (Ku and C bands on-ground retracked altimeter ranges):
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information
- For ENVISAT and JASON-1:
  - Altimeter echo type: “ocean-like” or “non ocean-like” (1 Hz)

Mathematical statement

- Compression:
  - For ENVISAT, the set of elementary measurements to be compressed is restricted to the measurements identified in "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed". The compression process is performed from the valid elementary estimates. It consists of a linear regression, based on the Least Square method.
  - For JASON-1, the compression principle is the same as the one defined in the level 1b processing (see RD8 "ALT_COM_RAN_04 - To edit and compress the on-board retracked altimeter ranges"). The compression process is performed from the valid elementary estimates. It consists of a linear regression, based either on the absolute deviation method (nominal solution) or on the Least Square method.
  - In both cases, outliers are detected and rejected within the compression process. The outliers detection is based on the comparison of residuals (estimate - model) to a threshold (scaled standard deviation). To account for some special cases (low noise level), this detection is performed only if the standard deviation exceeds a threshold (heritage from POSEIDON-1). The compressed estimate will be valid only if the final number of selected elementary estimates exceeds the minimum requested value. The updated corresponding quality information (validity flags, number of valid estimates, map of valid points) are provided on output.
- Determination of the echo type:

  For ENVISAT and JASON-1, the values of the number of valid points for Ku-band range and of the corresponding standard deviation are checked against some given thresholds:
  - If the number of valid points is greater than a threshold (e.g. 10) and if the range standard deviation is smaller than a threshold, then the surface type is set to "ocean-like"
  - Else it is set to "non ocean-like".

ALGORITHM SPECIFICATION

For each averaged measurement, the editing and compression of the elementary estimates of the on-ground retracked altimeter ranges (Ku-band or C/S-band) is specified hereafter.

Symbol [Ku/C/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C/S-band value(s)).

Input data

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- On-ground retracked altimeter range parameters [Ku/C/S]:
  - Elementary estimates : Retrk_Range [0:Ne -1] (m)
  - Map of elementary estimates to be compressed (1) : Map_Comp [0:Ne-1] (/)
  - Validity flags (2) : Retrk_Range_Val_Flag [0:Ne -1] (/)
- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)
- Editing and compression parameters [Ku/C/S] (3):
  - Type of compression (4) : Type_Comp_Retrk_Range (/)
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Range (/)
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Range (m)
  - Standard deviation scale factor for outliers identification : Scale_Retrk_Range (/)
  - Center of the averaged measurement : Center_Av_Meas (/)
- Parameters for the echo type determination (5):
  - Threshold on the standard deviation : Thresh_Alt_Range_Std (m)
  - Threshold on the number of valid estimates : Thresh_Alt_Range_Nval (/)

Output data

- The following parameters for the on-ground retracked range [Ku/C/S]:
  - Compressed estimate : Retrk_Range_Mean (m)
  - Standard deviation : Retrk_Range_Std (m)
  - Map of valid estimates (6) : Retrk_Range_Map [0:Ne-1] (/)
  - Number of valid estimates : Retrk_Range_Nval (/)
  - Validity of the compressed estimate (2) : Retrk_Range_Mean_Val_Flag (/)
- Altimeter echo type (7) : Alt_Echo_Type (/)

---

(1) Not requested for JASON-1

(2) 2 states: "valid" or "invalid"

(3) Values to be selected according to the processed band and the emitted bandwidth (altimeter configuration data for JASON-1, Ku bandwidth identifier for ENVISAT)

(4) For JASON-1: one state among the 2 followings: "linear regression / absolute deviation method" or "linear regression / least square method". "Linear regression / least square method" for ENVISAT

(5) Requested for Ku-band data processing only

(6) 2 states for each point of the map: "valid" or "invalid"

(7) Meaningful for Ku-band data processing only

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- Execution status

Processing

- The above-mentioned "parameters for the on-ground retracked range" are computed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:
  - Number of estimates to be compressed : Ne
  - Estimates : Retrk_Range [0:Ne -1]
  - Map of estimates to be compressed : Map_Comp [0:Ne-1] [8]
  - Validity flags for the estimates : Retrk_Range_Val_Flag [0:Ne -1]
  - Processing parameters:
    - Type of compression : Type_Comp_Retrk_Range
    - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Range
    - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Range
    - Standard deviation scale factor for outliers identification : Scale_Retrk_Range
    - Center of the averaged measurement : Center_Av_Meas
- Using the following outputs of the mechanism when processing Ku-band data:
  - Alt_Range_Nval_Ku: number of valid Ku-band altimeter range estimates
  - Alt_Range_Std_Ku: standard deviation of the valid Ku-band altimeter range estimates,

  the altimeter echo type is determined as follows:
  - If Alt_Range_Std_Ku > Thresh_Alt_Range_Std or if Alt_Range_Nval_Ku < Thresh_Alt_Range_Nval, then Alt_Echo_Type is set to “non ocean-like”
  - Else: Alt_Echo_Type is set to “ocean-like”

ACCURACY

TBD

COMMENTS

None

[8] For JASON-1: set to "valid" for each of the Ne measurements

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REFERENCES

None

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ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
Checked by:	For the JASON-1 SWT D. HANCOCK E. RODRIGUEZ M. SROKOSZ For the JASON-1 Project P. VINCENT CNES S. DESAI JPL For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
Approved by:	P. VINCENT CNES	

Document ref:	SMM-ST-M2-EA-11005-CN	18th October, 2001	Issue: 3	Update: 3

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	CCM			

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HERITAGE

POSEIDON-1

FUNCTION

To compute a 1-Hz compressed estimate of the on-ground retracked backscatter coefficients (Ku and C/S bands) from elementary estimates.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- For ENVISAT:
  - Product data: None
  - Computed data:
    - From "ALT_PHY_BAC_04 - To compute the on-ground retracked backscatter coefficients", for Ku and S bands:
      - Ocean-1 backscatter coefficient and associated validity flag
    - From "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed", for Ku and S bands:
      - Map of elementary estimates to be compressed (1 Hz)
      - Ku bandwidth identifier for the averaged measurement
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - RA-2 instrumental characterization data:
      - Number of elementary measurements per averaged measurement

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    - Processing parameters:
        - Minimum number of estimates requested for the compression
        - Minimum value of the standard deviation for outliers identification
        - Standard deviation scale factor for outliers identification
- For JASON-1:
  - Product data:
    - Altimeter configuration data
  - Computed data:
    - From "ALT_PHY_BAC_04 - To compute the on-ground retracked backscatter coefficients", for Ku and C bands:
        - On-ground retracked backscatter coefficient and associated validity flag
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - POSEIDON-2 instrumental characterization data:
        - Number of elementary measurements per averaged measurement
    - Processing parameters:
        - Minimum number of estimates requested for the compression
        - Minimum value of the standard deviation for outliers identification
        - Standard deviation scale factor for outliers identification

Output data

- For ENVISAT, for each parameter (Ku and S bands on-ground ocean-1 retracked backscatter coefficients):
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information
- For JASON-1, for each parameter (Ku and C bands on-ground retracked backscatter coefficients):
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information

Mathematical statement

- For ENVISAT, the set of elementary measurements to be compressed is restricted to the measurements identified in "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed". The compression process is performed from the valid elementary estimates. It consists of an arithmetic averaging.
- For JASON-1, the compression process is performed from the valid elementary estimates. It consists of an arithmetic averaging.

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- In both cases, outliers are detected and rejected within the compression process. The outliers detection is based on the comparison of residuals (estimate - model) to a threshold (scaled standard deviation). To account for some special cases (low noise level), this detection is performed only if the standard deviation exceeds a threshold (heritage from POSEIDON-1). The compressed estimate will be valid only if the final number of selected elementary estimates exceeds the minimum requested value. The updated corresponding quality information (validity flags, number of valid estimates, map of valid points) are provided on output.

ALGORITHM SPECIFICATION

For each averaged measurement, the editing and compression of the elementary estimates of the on-ground retracked backscatter coefficients (Ku-band or C/S-band) is specified hereafter.

Symbol [Ku/C/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C/S-band value(s)).

Input data

- On-ground retracked backscatter coefficient parameters [Ku/C/S]:
  - Elementary estimates : Retrk_Sigma0 [0:Ne -1] (dB)
  - Map of elementary estimates to be compressed [1] : Map_Comp [0:Ne-1] (/)
  - Validity flags [2] : Retrk_Sigma0_Val_Flag [0:Ne -1] (/)
- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)
- Editing and compression parameters [Ku/C/S] [3]:
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Sigma0 (/)
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Sigma0 (dB)
  - Standard deviation scale factor for outliers identification : Scale_Retrk_Sigma0 (/)

Output data

- The following parameters for the on-ground retracked backscatter coefficient [Ku/C/S]:
  - Compressed estimate : Retrk_Sigma0_Mean (dB)
  - Standard deviation : Retrk_Sigma0_Std (dB)
  - Map of valid estimates [4] : Retrk_Sigma0_Map [0:Ne-1] (/)

---

[1] Not requested for JASON-1

[2] 2 states: "valid" or "invalid"

[3] Values to be selected according to the processed band and the emitted bandwidth (altimeter configuration data for JASON-1, Ku bandwidth identifier for ENVISAT)

[4] 2 states for each point of the map: "valid" or "invalid"

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- Number of valid estimates : Retrk_Sigma0_Nval (/)
- Validity of the compressed estimate [2] : Retrk_Sigma0_Mean_Val_Flag(/)

- Execution status

Processing

The above-mentioned parameters are computed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:

- Number of estimates to be compressed : Ne
- Estimates : Retrk_Sigma0 [0:Ne -1]
- Map of estimates to be compressed : Map_Comp [0:Ne-1] [5]
- Validity flags for the estimates : Retrk_Sigma0_Val_Flag [0:Ne -1]
- Processing parameters:
  - Type of compression : set to "arithmetic averaging"
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Sigma0
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Sigma0
  - Standard deviation scale factor for outliers identification : Scale_Retrk_Sigma0
  - Center of the averaged measurement : not requested

ACCURACY

TBD

COMMENTS

- Statistics relative to the backscatter coefficient are performed from elementary estimates expressed in dB. This operation is correct over ocean surfaces where the variation of the backscatter coefficient is small enough within one source packet so the logarithmic transfer function may be considered linear.

REFERENCES

None

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[5] For JASON-1: set to "valid" for each of the Ne measurements

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ALT_COM_SWH_01 - To edit and compress the on-ground retracked significant waveheights

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
Checked by:	For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
Approved by:	P. VINCENT CNES	

Document ref:	SMM-ST-M2-EA-11005-CN	18th October, 2001	Issue: 3	Update: 3

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HERITAGE

None

FUNCTION

To compute a 1-Hz compressed estimate of the on-ground retracked significant waveheights (Ku and S bands) from elementary estimates.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "ALT_PHY_SWH_01 - To compute SWH from the on-ground retracked composite Sigma", for Ku and S bands:
    - Significant waveheight and associated validity flag
  - From "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed", for Ku and S bands:
    - Map of elementary estimates to be compressed (1 Hz)
    - Ku bandwidth identifier for the averaged measurement
- Dynamic auxiliary data: None
- Static auxiliary data:
  - RA-2 instrumental characterization data:
    - Number of elementary measurements per averaged measurement

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- Processing parameters:
  - Minimum number of estimates requested for the compression
  - Minimum value of the standard deviation for outliers identification
  - Standard deviation scale factor for outliers identification

Output data

- For each parameter (Ku and S bands on-ground retracked significant waveheights):
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information

Mathematical statement

The set of elementary measurements to be compressed is restricted to the measurements identified in "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed". The compression process is performed from the valid elementary estimates. It consists of an arithmetic averaging.

Outliers are detected and rejected within this process. The outliers detection is based on the comparison of residuals (estimate - model) to a threshold (scaled standard deviation). The compressed estimate will be valid only if the final number of selected elementary estimates exceeds the minimum requested value. The updated corresponding quality information (validity flags, number of valid estimates, map of valid points) are provided on output.

ALGORITHM SPECIFICATION

For each averaged measurement, the editing and compression of the elementary estimates of the on-ground retracked significant waveheights (Ku-band or S-band) is specified hereafter.

Symbol [Ku/S] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and S-band value(s)).

Input data

- On-ground retracked significant waveheight parameters [Ku/S]:
  - Elementary estimates : Retrk_SWH [0:Ne -1] (m)
  - Map of elementary estimates to be compressed [1] : Map_Comp [0:Ne-1] (/)
  - Validity flags [2] : Retrk_SWH_Val_Flag [0:Ne -1] (/)

---

[1] 2 states for each point of the map: "valid" or "invalid"

[2] 2 states: "valid" or "invalid"

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- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)
- Editing and compression parameters [Ku/S] (3):
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_SWH (/)
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_SWH (m)
  - Standard deviation scale factor for outliers identification : Scale_Retrk_SWH (/)

Output data

- The following parameters for the on-ground retracked significant waveheight [Ku/S]:
  - Compressed estimate : Retrk_SWH_Mean (m)
  - Standard deviation : Retrk_SWH_Std (m)
  - Map of valid estimates (1) : Retrk_SWH_Map [0:Ne-1] (/)
  - Number of valid estimates : Retrk_SWH_Nval (/)
  - Validity of the compressed estimate (2) : Retrk_SWH_Mean_Val_Flag(/)
- Execution status

Processing

The above-mentioned parameters are computed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:

- Number of estimates to be compressed : Ne
- Estimates : Retrk_SWH [0:Ne -1]
- Map of estimates to be compressed : Map_Comp [0:Ne-1]
- Validity flags for the estimates : Retrk_SWH_Val_Flag [0:Ne -1]
- Processing parameters:
  - Type of compression : set to "arithmetic averaging"
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_SWH
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_SWH
  - Standard deviation scale factor for outliers identification : Scale_Retrk_SWH
  - Center of the averaged measurement : not requested

ACCURACY

TBD

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

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COMMENTS

For ENVISAT, the 1-Hz significant waveheight is computed as follows:

- Estimation of the 20-Hz composite Sigma (ALT_RET_OCE_01 - To perform the ocean-1 retracking)
- Derivation of the 20-Hz significant waveheights (ALT_PHY_SWH_01 - To compute SWH from the on-ground retracked composite Sigma)
- Compression of the 20-Hz significant waveheights (ALT_COM_SWH_01 - To edit and compress the on-ground retracked significant waveheights)

For JASON-1, the 1-Hz significant waveheight is computed as follows:

- Estimation of the 20-Hz composite Sigma (ALT_RET_OCE_02 - To perform the ocean-2 retracking)
- Compression of the 20-Hz composite Sigma and derivation of the 1-Hz significant waveheight (ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH)

REFERENCES

None

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ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
Checked by:	For the JASON-1 SWT D. HANCOCK E. RODRIGUEZ M. SROKOSZ For the JASON-1 Project P. VINCENT CNES S. DESAI JPL	
Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To compute a 1-Hz compressed estimate of the on-ground retracked composite Sigma (Ku and C bands) from elementary estimates, and to derive the significant waveheight estimate.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- Product data:
  - Altimeter configuration data
- Computed data:
  - From "ALT_RET_OCE_02 - To perform the ocean-2 retracking", for Ku and C bands:
    - Composite Sigma (σ_c) and retracking execution flag (valid/invalid)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - POSEIDON-2 instrumental characterization data:
    - Number of elementary measurements per averaged measurement
    - Sampling interval of the analysis window
    - Ratio between the PTR width and the sampling interval of the analysis window

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- Processing parameters:
  - Minimum number of estimates requested for the compression
  - Minimum value of the standard deviation for outliers identification
  - Standard deviation scale factor for outliers identification
- Universal constants:
  - Velocity of light

Output data

- For each parameter (Ku and C bands on-ground retracked composite Sigma):
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information
- Compressed estimate (1 Hz) of the significant waveheight (Ku and C bands) and associated validity flag

Mathematical statement

The compression process is performed from the valid elementary estimates. It consists of an arithmetic averaging

Outliers are detected and rejected within this process. The outliers detection is based on the comparison of residuals (estimate - model) to a threshold (scaled standard deviation). To account for some special cases (low noise level), this detection is performed only if the standard deviation exceeds a threshold (heritage from POSEIDON-1). The compressed estimate will be valid only if the final number of selected elementary estimates exceeds the minimum requested value. The updated corresponding quality information (validity flags, number of valid estimates, map of valid points) are provided on output.

The significant waveheight is then derived from the compressed value of the composite Sigma (σ_c), according to (see "ALT_PHY_SWH_01 - To compute SWH from the on-ground retracked composite Sigma"):

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

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

ALGORITHM SPECIFICATION

For each averaged measurement, the editing and compression of the elementary estimates of the on-ground retracked composite Sigma (Ku-band or C-band) and the derivation of the significant waveheight is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

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Input data

- On-ground retracked composite Sigma parameters [Ku/C]:
  - Elementary estimates : Retrk_SigmaC [0:Ne -1] (s)
  - Retracking execution flags [1] : Flag_Retrk [0:Ne -1] (/)
- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)
  - PTR width:
    - Sampling interval of the analysis window [2] : FFT_Step (s)
    - Ratio PTR width / FFT step : Ratio_PTR_FFT (/)
- Editing and compression parameters [Ku/C] [2]:
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_SigmaC (/)
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_SigmaC (s)
  - Standard deviation scale factor for outliers identification : Scale_Retrk_SigmaC (/)
- Light velocity : Light_Vel (m/s)

Output data

- The following parameters for the on-ground retracked SigmaC [Ku/C]:
  - Compressed estimate : Retrk_SigmaC_Mean (s)
  - Standard deviation : Retrk_SigmaC_Std (s)
  - Map of valid estimates [3] : Retrk_SigmaC_Map [0:Ne-1] (/)
  - Number of valid estimates : Retrk_SigmaC_Nval (/)
  - Validity of the compressed estimate [1] : Retrk_SigmaC_Mean_Val_Flag (/)
- Significant waveheight parameters [Ku,C]:
  - Compressed estimate of the significant waveheight : Retrk_SWH_Mean (m)
  - Significant waveheight validity flag [1] : Retrk_SWH_Mean_Val_Flag (/)
- Execution status

---

[1] 2 states: "valid" or "invalid"

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

[3] 2 states for each point of the map: "valid" or "invalid"

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Processing

- The above-mentioned "parameters for the on-ground retracked SigmaC" are computed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:
  - Number of estimates to be compressed : Ne
  - Estimates : Retrk_SigmaC [0:Ne -1]
  - Map of estimates to be compressed : set to "valid" for each of the Ne measurements
  - Validity flags for the estimates : Flag_Retrk [0:Ne -1]
  - Processing parameters:
    - Type of compression : set to "arithmetic averaging"
    - Minimum number of estimates requested for the compression : Min_Pts_Retrk_SigmaC
    - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_SigmaC
    - Standard deviation scale factor for outliers identification : Scale_Retrk_SigmaC
    - Center of the averaged measurement : not requested
- The significant waveheight (Retrk_SWH_Mean, expressed in meters) and the corresponding validity flag (Retrk_SWH_Mean_Val_Flag) are then derived from the compressed estimate of the composite Sigma (Retrk_SigmaC_Mean, expressed in seconds), using mechanism "GEN_MEC_CON_01 - Derivation of the significant waveheight from the composite Sigma" (AD11) with the following inputs:
  - Composite Sigma : Retrk_SigmaC_Mean
  - Composite Sigma validity flag : Retrk_SigmaC_Mean_Val_Flag
  - PTR width
    - Sampling interval of the analysis window : FFT_Step
    - Ratio PTR width / FFT step : Ratio_PTR_FFT
  - Light velocity : Light_Vel

ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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ALT_COM_SNR_01 - To edit and compress the on-ground retracked amplitude of waveforms

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
Checked by:	For the JASON-1 SWT D. HANCOCK E. RODRIGUEZ M. SROKOSZ For the JASON-1 Project P. VINCENT CNES S. DESAI JPL	
Approved by:	P. VINCENT CNES	

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HERITAGE

POSEIDON-1

FUNCTION

To compute a 1-Hz compressed estimate of the on-ground retracked amplitude of waveforms (Ku and C bands) from elementary estimates.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- Product data:
  - Altimeter configuration data
- Computed data:
  - From "ALT_RET_OCE_02 - To perform the ocean-2 retracking", for Ku and C bands:
    - Amplitude and retracking execution flag (valid / invalid)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - POSEIDON-2 instrumental characterization data:
    - Number of elementary measurements per averaged measurement
  - Processing parameters:
    - Minimum number of estimates requested for the compression
    - Minimum value of the standard deviation for outliers identification
    - Standard deviation scale factor for outliers identification

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Output data

- For each parameter (Ku and C bands on-ground retracked amplitudes):
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information

Mathematical statement

The compression process is performed from the valid elementary estimates. It consists of an arithmetic averaging.

Outliers are detected and rejected within this process. The outliers detection is based on the comparison of residuals (estimate - model) to a threshold (scaled standard deviation). To account for some special cases (low noise level), this detection is performed only if the standard deviation exceeds a threshold (heritage from POSEIDON-1). The compressed estimate will be valid only if the final number of selected elementary estimates exceeds the minimum requested value. The updated corresponding quality information (validity flags, number of valid estimates, map of valid points) are provided on output.

ALGORITHM SPECIFICATION

For each averaged measurement, the editing and compression of the elementary estimates of the on-ground retracked amplitudes (Ku-band or C-band) is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

Input data

- On-ground retracked amplitude parameters [Ku/C]:
  - Elementary estimates : Retrk_Amp [0:Ne -1] (FFT power unit)
  - Retracking execution flags [(1)] : Flag_Retrk [0:Ne -1] (/)
- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)
- Editing and compression parameters [Ku/C] [(2)]:
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Amp (/)
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Amp (FFT p.u.)
  - Standard deviation scale factor for outliers identification : Scale_Retrk_Amp (/)

---

(1) 2 states: "valid" or "invalid"

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

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Output data

- The following parameters for the on-ground retracked amplitude [Ku/C]:
  - Compressed estimate : Retrk_Amp_Mean (FFT power unit)
  - Standard deviation : Retrk_Amp_Std (FFT power unit)
  - Map of valid estimates [3] : Retrk_Amp_Map [0:Ne-1] (/)
  - Number of valid estimates : Retrk_Amp_Nval (/)
  - Validity of the compressed estimate [1] : Retrk_Amp_Mean_Val_Flag (/)
- Execution status

Processing

The above-mentioned parameters are computed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:

- Number of estimates to be compressed : Ne
- Estimates : Retrk_Amp [0:Ne -1]
- Map of estimates to be compressed : set to "valid" for each of the Ne measurements
- Validity flags for the estimates : Flag_Retrk [0:Ne -1]
- Processing parameters:
  - Type of compression : set to "arithmetic averaging"
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Amp
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Amp
  - Standard deviation scale factor for outliers identification : Scale_Retrk_Amp
  - Center of the averaged measurement : not requested

ACCURACY

TBD

COMMENTS

None

[3] 2 states for each point of the map: "valid" or "invalid"

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REFERENCES

None

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31401 TOULOUSE CEDEX 4

ALT_COM_SNR_02 - To edit and compress the on-ground retracked thermal noise level

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
Checked by:	For the JASON-1 SWT D. HANCOCK E. RODRIGUEZ M. SROKOSZ For the JASON-1 Project P. VINCENT CNES S. DESAI JPL	
Approved by:	P. VINCENT CNES	

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HERITAGE

POSEIDON-1

FUNCTION

To compute a 1-Hz compressed estimate of the on-ground retracked thermal noise of waveforms (Ku and C bands) from elementary estimates.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

- Product data:
  - Altimeter configuration data
- Computed data:
  - From "ALT_RET_OCE_02 - To perform the ocean-2 retracking", for Ku and C bands:
    - Thermal noise level and retracking execution flag (valid/invalid)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - POSEIDON-2 instrumental characterization data:
    - Number of elementary measurements per averaged measurement
  - Processing parameters:
    - Minimum number of estimates requested for the compression
    - Minimum value of the standard deviation for outliers identification
    - Standard deviation scale factor for outliers identification

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Output data

- For each parameter (Ku and C bands on-ground retracked thermal noise):
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information

Mathematical statement

The compression process is performed from the valid elementary estimates. It consists of an arithmetic averaging.

Outliers are detected and rejected within this process. The outliers detection is based on the comparison of residuals (estimate - model) to a threshold (scaled standard deviation). To account for some special cases (low noise level), this detection is performed only if the standard deviation exceeds a threshold (heritage from POSEIDON-1). The compressed estimate will be valid only if the final number of selected elementary estimates exceeds the minimum requested value. The updated corresponding quality information (validity flags, number of valid estimates, map of valid points) are provided on output.

ALGORITHM SPECIFICATION

For each averaged measurement, the editing and compression of the elementary estimates of the on-ground retracked thermal noise levels (Ku-band or C-band) is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

Input data

- On-ground retracked thermal noise parameters [Ku/C]:
  - Elementary estimates : Retrk_Noise [0:Ne -1] (FFT power unit)
  - Retracking execution flags (1) : Flag_Retrk [0:Ne -1] (/)
- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)
- Editing and compression parameters [Ku/C] (2):
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Noise (/)
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Noise (FFT p.u.)
  - Standard deviation scale factor for outliers identification : Scale_Retrk_Noise (/)

---

(1) 2 states: "valid" or "invalid"

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

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Output data

- The following parameters for the on-ground retracked thermal noise level [Ku/C]:
  - Compressed estimate : Retrk_Noise_Mean (FFT power unit)
  - Standard deviation : Retrk_Noise_Std (FFT power unit)
  - Map of valid estimates [3] : Retrk_Noise_Map [0:Ne-1] (/)
  - Number of valid estimates : Retrk_Noise_Nval (/)
  - Validity of the compressed estimate [1] : Retrk_Noise_Mean_Val_Flag (/)
- Execution status

Processing

The above-mentioned parameters are computed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:

- Number of estimates to be compressed : Ne
- Estimates : Retrk_Noise [0:Ne -1]
- Map of estimates to be compressed : set to "valid" for each of the Ne measurements
- Validity flags for the estimates : Flag_Retrk [0:Ne -1]
- Processing parameters:
  - Type of compression : set to "arithmetic averaging"
  - Minimum number of estimates requested for the compression : Min_Pts_Retrk_Noise
  - Minimum value of the standard deviation for outliers identification : Min_Std_Retrk_Noise
  - Standard deviation scale factor for outliers identification : Scale_Retrk_Noise
  - Center of the averaged measurement : not requested

ACCURACY

TBD

COMMENTS

None

[3] 2 states for each point of the map: "valid" or "invalid"

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REFERENCES

None

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ALT_COM_MIS_02 - To edit and compress the square of the off-nadir angle (on-ground waveform-derived)

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
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HERITAGE

POSEIDON-1

FUNCTION

To compute a 1-Hz compressed estimate of the square of the off-nadir angle.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The compression of the elementary estimates is performed whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

ALGORITHM DEFINITION

Input data

- For ENVISAT:
  - Product data: None
  - Computed data:
    - From "ALT_PHY_MIS_02 - To compute the square of the off-nadir angle from the on-ground waveform-derived estimates":
      - Square of the off-nadir angle (derived from Ku-band data) and associated validity flag
    - From "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed", for Ku band:
      - Map of elementary estimates to be compressed (1 Hz)
      - Ku bandwidth identifier for the averaged measurement
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - RA-2 instrumental characterization data:
      - Number of elementary measurements per averaged measurement

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    - Processing parameters:
        - Minimum number of estimates requested for the compression
        - Minimum value of the standard deviation for outliers identification
        - Standard deviation scale factor for outliers identification

- For JASON-1:
  - Product data: None
  - Computed data:
    - From "ALT_PHY_MIS_02 - To compute the square of the off-nadir angle from the on-ground waveform-derived estimates":
        - Square of the off-nadir angle (derived from Ku-band data) and associated validity flag
  - Dynamic auxiliary data: None
  - Static auxiliary data:
    - POSEIDON-2 instrumental characterization data:
        - Number of elementary measurements per averaged measurement
    - Processing parameters:
        - Minimum number of estimates requested for the compression
        - Minimum value of the standard deviation for outliers identification
        - Standard deviation scale factor for outliers identification

Output data

For ENVISAT and for JASON-1:

- For the square off-nadir angle:
  - Compressed value (1 Hz)
  - Standard deviation
  - Updated quality information

Mathematical statement

The computation of the 1-Hz compressed estimate of the square of the off-nadir angle is computed by arithmetic averaging of the elementary estimates of the corresponding source packet.

- For ENVISAT, the set of elementary measurements to be compressed is restricted to the measurements identified in "ALT_COM_GEN_01 - To identify the elementary measurements to be compressed". The compression process is performed from the valid elementary estimates.
- For JASON-1, the compression process is performed from the valid elementary estimates.

For both cases, outliers are detected and rejected within the compression process. The outliers detection is based on the comparison of elementary residuals (estimate - model) with the value of the standard deviation of the elementary estimates scaled by a constant. To account for some special cases (low noise level), this detection is performed only if the standard deviation exceeds a predefined threshold. The compressed estimate will be valid

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only if the final number of selected elementary estimates exceeds the minimum requested value. The updated corresponding quality information (number of valid estimates, maps of valid points, validity of the compressed estimate) are provided on output

ALGORITHM SPECIFICATION

For each averaged measurement, the editing and compression of the elementary estimates of the square of the off-nadir angle is specified hereafter.

Input data

- Square of the off-nadir angle parameters:
  - Elementary estimates : Sq_Off_Nad [0:Ne -1] (degree^2)
  - Map of elementary estimates to be compressed (1) (4) : Map_Comp [0:Ne-1] (/)
  - Validity flags (2) : Sq_Off_Nad_Val_Flag [0:Ne -1] (/)
- Instrumental characterization data:
  - Number of elementary estimates per averaged measurement : Ne (/)
- Editing and compression parameters (3):
  - Minimum number of estimates requested for the compression : Min_Pts_Sq_Off_Nad (/)
  - Minimum value of the standard deviation for outliers identification : Min_Std_Sq_Off_Nad (degree^2)
  - Standard deviation scale factor for outliers identification : Scale_Sq_Off_Nad (/)

Output data

- The following parameters for the square of the off-nadir angle:
  - Compressed estimate : Sq_Off_Nad_Mean (degree^2)
  - Standard deviation : Sq_Off_Nad_Std (degree^2)
  - Map of valid estimates (4) : Sq_Off_Nad_Map [0:Ne-1] (/)
  - Number of valid estimates : Sq_Off_Nad_Nval (/)
  - Validity of the compressed estimate (2) : Sq_Off_Nad_Mean_Val_Flag (/)
- Execution status

---

(1) Not requested for JASON-1

(2) 2 states: "valid" or "invalid"

(3) For ENVISAT, values to be selected according to the processed band and the emitted bandwidth (Ku bandwidth identifier)

(4) 2 states for each point of the map: "valid" or "invalid"

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Processing

- The above-mentioned parameters are computed using mechanism "GEN_MEC_COM_04 - Editing and compression" (AD11), with the following inputs:
  - Number of estimates to be compressed : Ne
  - Estimates : Sq_Off_Nad [0:Ne -1]
  - Map of estimates to be compressed : Map_Comp [0:Ne-1] (5)
  - Validity flags for the estimates : Sq_Off_Nad_Val_Flag [0:Ne -1]
  - Processing parameters:
    - Type of compression : set to "arithmetic averaging"
    - Minimum number of estimates requested for the compression : Min_Pts_Sq_Off_Nad
    - Minimum value of the standard deviation for outliers identification : Min_Std_Sq_Off_Nad
    - Standard deviation scale factor for outliers identification : Scale_Sq_Off_Nad
    - Center of the averaged measurement : not requested

COMMENTS

None

REFERENCES

None

(5) For JASON-1: set to "valid" for each of the Ne measurements

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ALT_PHY_SNR_02 - To compute the SNR from the on-ground estimates

DEFINITION, ACCURACY AND SPECIFICATION

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Checked by:	For the JASON-1 SWT D. HANCOCK E. RODRIGUEZ M. SROKOSZ For the JASON-1 Project P. VINCENT CNES S. DESAI JPL	
Approved by:	P. VINCENT CNES	

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HERITAGE

POSEIDON-1

FUNCTION

To compute the signal to noise ratio (Ku and C bands) from the 1-Hz averaged on-ground estimates of the amplitude and of the thermal noise level of the waveforms.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The signal to noise ratio is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Ku-band corrected AGC (1 Hz): AGC_{cKu}
  - C-band corrected AGC (1 Hz): AGC_{cC}
  - Altimeter configuration data
- Computed data:
  - From "ALT_COM_SNR_01 - To edit and compress the on-ground retracked amplitude of waveforms", for Ku and C bands:
    - Amplitude of the waveforms (P_u) and associated validity flag (1 Hz)
  - From "ALT_COM_SNR_02 - To edit and compress the on-ground retracked thermal noise level", for Ku and C bands:
    - Thermal noise level of the waveforms (P_n) and associated validity flag (1 Hz)
- Dynamic auxiliary data: None

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- Static auxiliary data:
  - Processing parameters:
    - Minimum value of AGC requested to set SNR to AGC in case of null thermal noise (Ku and C bands): AGC_{minKu} and AGC_{minC}
    - Bias between SNR and AGC (Ku and C bands): $Bias_{Ku}$ and $Bias_C$

Output data

- Ku-band signal to noise ratio (1 Hz)
- C-band signal to noise ratio (1 Hz)

Mathematical statement

For each band, the 1-Hz signal to noise ratio is computed by:

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

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).

ALGORITHM SPECIFICATION

For each averaged measurement, the computation of the Ku band or C band signal to noise ratio is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

Input data

- Corrected AGC [Ku/C] : AGC_Mean (dB)
- On-ground retracked amplitude and validity flag [Ku/C]:
  - Amplitude : Retrk_Amp_Mean (FFT power unit)
  - Validity flag [1] : Retrk_Amp_Mean_Val_Flag (/)
- On-ground retracked thermal noise level and validity flag [Ku/C]:
  - Thermal noise level : Retrk_Noise_Mean (FFT power unit)
  - Validity flag [1] : Retrk_Noise_Mean_Val_Flag (/)

[1] 2 states: "valid" or "invalid"

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- Processing parameters relative to the SNR derived from on-ground estimates [Ku/C] [(2)]:
  - Minimum value of AGC requested to set SNR to AGC in case of null thermal noise : AGC_Thresh (dB)
  - Bias between SNR and AGC : SNR_AGC_Bias (dB)

Output data

- Signal to noise ratio [Ku/C] : SNR (dB)
- Validity flag for the signal to noise ratio [Ku/C] [(1)] : SNR_Val_Flag (/)
- Execution status

Processing

- If the two following flags:
  - Amplitude validity flag (Retrk_Amp_Mean_Val_Flag)
  - Thermal noise level validity flag (Retrk_Noise_Mean_Val_Flag)

  are set to "valid", then:
  - SNR is computed as follows:
    - If Retrk_Noise_Mean > 0, then:

$$SNR = 10 * \log_{10}\left(\frac{Retrk_Amp_Mean}{Retrk_Noise_Mean}\right) \quad (1)$$

      Else:
      - If AGC_Mean > AGC_Thresh, then:

$$SNR = AGC_Mean + SNR_AGC_Bias \quad (2)$$

      - Else:

$$SNR = 10 * \log_{10}(Retrk_Amp_Mean) \quad (3)$$

  - The validity flag for the signal to noise ratio (SNR_Val_Flag) is set to "valid".
- Else (at least one of the two flags is set to "invalid"), then:
  - SNR is set to a default value
  - SNR_Val_Flag is set to "invalid"

ACCURACY

The signal to noise ratio is requested in the level 2 processing to access the modeled instrumental corrections tables. Its value is derived from the estimates of amplitudes of the waveform provided by the ocean retracking algorithm (the thermal noise level P_n is derived from an averaging of samples of the first plateau, while the

---

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

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amplitude P_u is derived from a fit of the waveform with a mean return power model). This parameter is thus consistent with the one used in the simulator to build the corrections tables.

See RD8 ("ALT_PHY_SNR_01 - To compute the SNR from the on-board estimates" - section "Accuracy") for the impact of the quantization of waveforms.

COMMENTS

None

REFERENCES

None

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ALT_COR_GEN_03 - To compute the modeled instrumental corrections on the on-ground retracked parameters

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
Checked by:	For the JASON-1 SWT G. HAYNE For the JASON-1 Project P. VINCENT CNES S. DESAI JPL	
Approved by:	P. VINCENT CNES	

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HERITAGE

POSEIDON-1

FUNCTION

To compute the 1-Hz modeled corrections of the instrumental errors on the Ku and C bands altimetric estimates (altimeter range, altimeter range rate, significant waveheight and backscatter coefficient), using correction tables depending on significant waveheight and signal to noise ratio.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The modeled corrections of the instrumental errors are relevant over ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Altimeter configuration data
- Computed data:
  - From "ALT_PHY_SNR_02 - To compute the SNR from the on-ground estimates":
    - Ku-band signal to noise ratio and associated validity flag (1 Hz)
    - C-band signal to noise ratio and associated validity flag (1 Hz)
  - From "ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH":
    - Ku-band significant waveheight and associated validity flag (1 Hz)
    - C-band significant waveheight and associated validity flag (1 Hz)
- Dynamic auxiliary data: None

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- Static auxiliary data:
  - Instrumental correction tables [(1)]:
    - Ku-band altimeter range correction table
    - C-band altimeter range correction tables (for 320 MHz and for 100 MHz)
    - Altimeter range rate correction table
    - Ku-band significant waveheight correction table
    - C-band significant waveheight correction tables (for 320 MHz and for 100 MHz)
    - Ku-band backscatter coefficient correction table
    - C-band backscatter coefficient correction tables (for 320 MHz and for 100 MHz)
  - Processing parameters:
    - Default value for the inputs of the correction tables

Output data

- Ku-band altimeter range modeled instrumental correction (1 Hz)
- C-band altimeter range modeled instrumental correction (1 Hz)
- Modeled instrumental correction on the altimeter range rate (1 Hz)
- Ku-band significant waveheight modeled instrumental correction (1 Hz)
- C-band significant waveheight modeled instrumental correction (1 Hz)
- Ku-band backscatter modeled instrumental coefficient correction (1 Hz)
- C-band backscatter modeled instrumental coefficient correction (1 Hz)

Mathematical statement

Principle

The principle is identical to the one described in RD8 "ALT_COR_GEN_02 - To compute the modeled instrumental corrections on the on-board retracked parameters", except that, regarding the altimeter range, the significant waveheight and the backscatter coefficient:

- 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 on-ground retracking processing have already been corrected for these effects (see RD8 "ALT_COR_WAV_01 - To correct the waveforms for the low-pass filtering effects")
- in order to be consistent with the IGDR processing, the simulator accounts for the on-ground retracking and not for the on-board retracking as it was done in the level 1b processing
- no mispointing correction on the backscatter coefficient is accounted for (because mispointing is managed through the on-ground retracking algorithm).

---

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

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Computation of the corrections

For each band, the processing consists of a bilinear interpolation of the corresponding input correction tables versus the significant waveheight and the signal to noise ratio, as defined in RD8 "ALT_COR_GEN_02 - To compute the modeled instrumental corrections on the on-board retracked parameters". 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.

ALGORITHM SPECIFICATION

For each parameter X (Ku-band altimeter range, C-band altimeter range, altimeter range rate, Ku-band significant waveheight, C-band significant waveheight, Ku-band backscatter coefficient and C-band backscatter coefficient), the 1-Hz modeled correction of the instrumental errors is computed using mechanism "GEN_MEC_COR_04 - Computation of a modeled instrumental correction" (AD11), with the following inputs:

- Significant waveheight and validity flag: [(1)]
  - Significant waveheight : SWH (m)
  - Validity flag for the significant waveheight : SWH_Val_Flag (/)
- Signal to noise ratio and validity flag: [(1)]
  - Signal to noise ratio : SNR (dB)
  - Validity flag for the signal to noise ratio : SNR_Val_Flag (/)
- Mispointing correction on the backscatter coefficient : set to "0" (unused)
- Default value for the inputs of the correction table:
  - SWH default value : SWH_Def (m)
  - SNR default value : SNR_Def (dB)
- Modeled instrumental correction table for X [(2)]:
  - SWH lower bound : Min_SWH (m)
  - SWH upper bound : Max_SWH (m)
  - SWH step : Step_SWH (m)
  - SNR lower bound : Min_SNR (dB)
  - SNR upper bound : Max_SNR (dB)
  - SNR step : Step_SNR (dB)

---

(1) Ku-band or C-band parameter according to the band of the processed parameter (X)

(2) The C-band altimeter range correction table, the C-band significant waveheight correction table and the C-band backscatter coefficient correction table will be selected according to the emitted bandwidth in C band (configuration data)

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– Correction table : Tab [0:N_SWH-1][0:N_SNR-1] (same unit as X)

with N_a=(Max_a-Min_a)/Step_a+1

The corresponding outputs consist of the correction and the execution status.

ACCURACY

TBD

COMMENT

Although the altimeter range rate estimate does not depend on the on-ground retracking (it is an on-board estimate provided by the tracking algorithm), the corresponding modeled instrumental correction computed in the level 1b processing must be updated in the IGDR processing, using the same input table, to account for the updated estimates of the significant waveheight and of the signal to noise ratio.

REFERENCES

None

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ALT_COR_RAN_08 - To compute the corrected on-ground retracked altimeter ranges

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To compute the Ku and C bands corrected on-ground retracked altimeter ranges.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The corrected parameters are relevant over ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Altimeter configuration data
- Computed data:
  - From "ALT_COM_RAN_05 - To edit and compress the on-ground retracked altimeter ranges", for Ku and C bands:
    - On-ground retracked altimeter range and associated validity flag (1 Hz)
  - From "ALT_COR_RAN_02 - To compute the Doppler correction", for Ku and C bands:
    - Doppler correction on the altimeter range (1 Hz)
  - From "ALT_COR_GEN_03 - To compute the modeled instrumental corrections on the on-ground retracked parameters", for Ku and C bands:
    - Altimeter range modeled instrumental correction (1 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Processing parameters:
    - Ku-band and C-band altimeter range system biases

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Output data

- Ku-band corrected on-ground retracked altimeter ranges (1 Hz)
- C-band corrected on-ground retracked altimeter ranges (1 Hz)

Mathematical statement

The 1-Hz estimates of the on-ground retracked altimeter range are already corrected through the 20-Hz tracker range estimates, for the USO frequency drift, the internal path correction and the distance antenna - COG, (see RD8). The three following corrections are added:

- the Doppler correction
- the modeled instrumental correction
- the system bias

ALGORITHM SPECIFICATION

The computation of the 1-Hz corrected on-ground retracked altimeter ranges (Ku-band or C-band) is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

Input data

- On-ground retracked altimeter range and validity flag [Ku/C]:
  - On-ground retracked altimeter range : Retrk_Range (m)
  - On-ground retracked altimeter range validity flag [1] : Retrk_Range_Val_Flag (/)
- Corrections on the on-ground retracked altimeter range:
  - Doppler correction [Ku/C] : Cor_Dop_Range (m)
  - Modeled instrumental correction [Ku/C] : Cor_Mod_Range (m)
  - System bias [Ku/C] [2] : Sys_Bias_Range (m)

Output data

- Corrected on-ground retracked altimeter range [Ku/C] : Retrk_Range_Cor (m)
- Execution status

---

[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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Processing

The corrected on-ground retracked altimeter range is computed using mechanism "GEN_MEC_COR_02 - Computation of a corrected parameter from its raw value and its corrections" (AD11), with the following inputs:

- Raw value : Retrk_Range
- Validity flag of the raw value : Retrk_Range_Val_Flag
- Number of corrections : 3
- Corrections: : Cor_Dop_Range
  Cor_Mod_Range
  Sys_Bias_Range

ACCURACY

TBD

COMMENTS

- The 20-Hz estimates of the on-ground retracked altimeter range will be represented in the output product as differences with respect to the corresponding 1-Hz estimate. As the instrumental corrections to be applied are constant over a 1-Hz measurement, the 20-Hz corrected values do not need to be computed.

REFERENCES

None

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ALT_COR_RAN_05 - To compute the corrected tracker range rates

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To compute the corrected tracker range rates.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The corrected parameters are relevant over ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Tracker range rate (raw value) and associated validity flag (1 Hz)
- Computed data:
  - From "ALT_COR_GEN_03 - To compute the modeled instrumental corrections on the on-ground retracked parameters":
    - Altimeter range rate modeled instrumental correction (1 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data: None

Output data

- Corrected tracker range rate (1 Hz)

Mathematical statement

The modeled instrumental correction is added to the input tracker range rate.

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ALGORITHM SPECIFICATION

The computation of the 1-Hz corrected tracker range rate is specified hereafter.

Input data

- Tracker range rate and validity flag:
  - Tracker range rate : Trk_Range_Rate (m/s)
  - Tracker range rate validity flag [1] : Trk_Range_Rate_Val_Flag (/)
- Corrections on the tracker range rate:
  - Modeled instrumental correction : Cor_Mod_Trk_Range_Rate (m/s)

Output data

- Corrected tracker range rate : Trk_Range_Rate_Cor (m/s)
- Execution status

Processing

The corrected tracker range rate is computed using mechanism "GEN_MEC_COR_02 - Computation of a corrected parameter from its raw value and its corrections" (AD11), with the following inputs:

- Raw value : Trk_Range_Rate
- Validity flag of the raw value : Trk_Range_Rate_Val_Flag
- Number of corrections : 1
- Corrections: : Cor_Mod_Trk_Range_Rate

ACCURACY

TBD

COMMENTS

None

[1] 2 states: "valid" or "invalid"

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REFERENCES

None

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ALT_COR_SWH_02 - To compute the corrected on-ground retracked significant waveheights

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J.P. DUMONT CLS	
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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To compute the Ku and C bands corrected on-ground retracked significant waveheights.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The corrected parameters are relevant over ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Altimeter configuration data
- Computed data:
  - From "ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH", for Ku and C bands:
    - On-ground retracked significant waveheight and associated validity flag (1 Hz)
  - From "ALT_COR_GEN_03 - To compute the modeled instrumental corrections on the on-ground retracked parameters", for Ku and C bands:
    - Significant waveheight modeled instrumental correction (1 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Processing parameters:
    - Ku-band and C-band significant waveheight system biases

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Output data

- Ku-band corrected on-ground retracked significant waveheight (1 Hz)
- C-band corrected on-ground retracked significant waveheight (1 Hz)

Mathematical statement

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

- the modeled instrumental correction
- the system bias

ALGORITHM SPECIFICATION

The computation of the 1-Hz corrected on-ground retracked significant waveheight (Ku-band or C-band) is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

Input data

- On-ground retracked significant waveheight and validity flag [Ku/C]:
  - On-ground retracked significant waveheight : SWH (m)
  - On-ground retracked significant waveheight validity flag [(1)] : SWH_Val_Flag (/)
- Corrections on the on-ground retracked significant waveheight:
  - Modeled instrumental correction [Ku/C] : Cor_Mod_SWH (m)
  - System bias [Ku/C] [(2)] : Sys_Bias_SWH (m)

Output data

- Corrected on-ground retracked significant waveheight : SWH_Cor (m)
- Execution status

Processing

The corrected on-ground retracked significant waveheight is computed using mechanism "GEN_MEC_COR_02 - Computation of a corrected parameter from its raw value and its corrections" (AD11), with the following inputs:

- Raw value : SWH

---

(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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- Validity flag of the raw value : SWH_Val_Flag
- Number of corrections : 2
- Corrections: : Cor_Mod_SWH
  Sys_Bias_SWH

ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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ALT_COR_BAC_02 - To compute the corrected on-ground retracked backscatter coefficients

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To compute the Ku and C bands corrected on-ground retracked backscatter coefficients.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The corrected parameters are relevant over ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - Altimeter configuration data
- Computed data:
  - From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients", for Ku and C bands:
    - On-ground retracked backscatter coefficient and associated validity flag (1 Hz)
  - From "ALT_COR_GEN_03 - To compute the modeled instrumental corrections on the on-ground retracked parameters", for Ku and C bands:
    - Backscatter modeled instrumental coefficient correction (1 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Processing parameters:
    - Ku-band and C-band backscatter coefficient system biases

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Output data

- Ku-band corrected on-ground retracked backscatter coefficients (1 Hz)
- C-band corrected on-ground retracked backscatter coefficients (1 Hz)

Mathematical statement

The 1-Hz estimates of the on-ground retracked backscatter coefficients are already corrected through the scaling factors for Sigma0 evaluation, for the AGC errors and the internal calibration (see RD8). The two following corrections are added:

- the modeled instrumental correction
- the system bias

ALGORITHM SPECIFICATION

The computation of the 1-Hz corrected on-ground retracked backscatter coefficients (Ku-band or C-band) is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

Input data

- On-ground retracked backscatter coefficient and validity flag [Ku/C]:
  - On-ground retracked backscatter coefficient : Retrk_Sigma0 (dB)
  - On-ground retracked backscatter coefficient validity flag [(1)] : Retrk_Sigma0_Val_Flag (/)
- Corrections on the on-ground retracked backscatter coefficient:
  - Modeled instrumental correction [Ku/C] : Cor_Mod_Sigma0 (dB)
  - System bias [Ku/C] [(2)] : Sys_Bias_Sigma0 (dB)

Output data

- Corrected on-ground retracked backscatter coefficient [Ku/C] : Retrk_Sigma0_Cor (dB)
- Execution status

---

(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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Processing

The corrected on-ground retracked backscatter coefficient is computed using mechanism "GEN_MEC_COR_02 - Computation of a corrected parameter from its raw value and its corrections" (AD11), with the following inputs:

- Raw value : Retrk_Sigma0
- Validity flag of the raw value : Retrk_Sigma0_Val_Flag
- Number of corrections : 2
- Corrections: : Cor_Mod_Sigma0
  Sys_Bias_Sigma0

ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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ALT_COR_RAN_09 - To update the Doppler correction on the altimeter range

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To update the Doppler correction on the altimeter range.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	/	See 3.1.4

- Surface type:

  The Doppler correction is relevant over ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - On-ground retracked altimeter range corrected for instrumental errors (1 Hz) and associated validity flag: Ku and C bands
  - Doppler correction on the altimeter range (1 Hz): Ku and C bands
- Computed data:
  - From "ALT_COR_RAN_02 - To compute the Doppler correction", for Ku and C bands:
    - Doppler correction on the altimeter range (1 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data: None

Output data

The following estimates with the Doppler correction updated:

- Ku-band corrected on-ground retracked altimeter ranges (1 Hz)
- C-band corrected on-ground retracked altimeter ranges (1 Hz)

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Mathematical statement

For each band, the product Doppler correction is removed from the altimeter range, and the computed Doppler correction is added.

ALGORITHM SPECIFICATION

For each averaged measurement, the update of the Doppler correction (for Ku band or C band) on the on-ground retracked altimeter range is specified hereafter.

Symbol [Ku/C] associated with a parameter or with a set of parameters means that this (set of) parameter(s) is defined twice (Ku-band and C-band value(s)).

Input data

- Altimeter range and validity flag [Ku/C]:
  - Altimeter range : Alt_Range (m)
  - Validity flag [1] : Alt_Range_Val_Flag (/)
- Doppler correction applied to the altimeter range [Ku/C] : Cor_Dop_Range_Old (m)
- Doppler correction to be applied to the altimeter range [Ku/C] : Cor_Dop_Range_New (m)

Output data

- Updated altimeter range [Ku/C] : Alt_Range_New (m)
- Execution status

Processing

The updated altimeter range (Alt_Range_New) is computed using mechanism "GEN_MEC_COR_02 - Computation of a corrected parameter from its raw value and its corrections" (AD11), with the following inputs:

- Raw value : Alt_Range
- Validity flag of the raw value : Alt_Range_Val_Flag
- Number of corrections : 2
- Corrections : - Cor_Dop_Range_Old and + Cor_Dop_Range_New

ACCURACY

TBD

[1] 2 states: "valid" or "invalid"

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COMMENTS

- The 20-Hz estimates of the on-ground retracked altimeter range will be represented in the output product as differences with respect to the corresponding 1-Hz estimate. As the Doppler correction is constant over a 1-Hz measurement, the 20-Hz updated values do not need to be computed.
- The update of the corrected altimeter range will be performed only if the improvement on the Doppler correction is significant with respect to the IGDR estimate (see "ALT_COR_RAN_02 - To compute the Doppler correction").

REFERENCES

None

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RAD_MAN_INT_01 - To interpolate radiometer data to altimeter time tags

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

The radiometer operates independently of the altimeter, and although the radiometer data rate is close to the altimeter rate (about 1/sec), they are asynchronous. In order to apply radiometer-derived corrections to the altimeter, the radiometer data must therefore be interpolated to the desired altimeter time. This algorithm acts as a synchronizer between the radiometer and the altimeter processing.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The interpolation of radiometer data to altimeter time will be performed for all surface types (over land and ocean).

ALGORITHM DEFINITION

Input data

- Product data:
  - For ENVISAT:
    - Radiometer time tag
    - Radiometer brightness temperatures (2 channels)
    - Radiometer brightness temperatures standard deviations (2 channels)
    - Radiometer surface type (percentage of land in the radiometer field of view)
    - Radiometer instrument flags
    - Radiometer measurement confidence data
  - For JASON-1:
    - Radiometer time tag
    - Radiometer main beam brightness temperatures (3 channels)
    - Radiometer averaged along-track brightness temperatures (3 channels)

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    - Radiometer antenna temperatures quality flags (3 channels)
    - Radiometer surface type (percentage of land in the radiometer field of view)
    - 1-Hz altimeter time tag
- Computed data:
  - For ENVISAT:
    - From "ALT_COM_TIM_01 - To compute the averaged time tags":
      - 1-Hz altimeter time tag
  - For ENVISAT and JASON-1:
    - From "GEN_ENV_SUR_01 - To determine the surface type "
      - Surface type: “open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, or “land” (1 Hz)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Processing parameters

Output data

- For ENVISAT:
  - Interpolated radiometer nadir brightness temperatures (2 channels)
  - Interpolated radiometer nadir brightness temperatures standard deviations (2 channels)
  - Interpolation quality flag
  - Radiometer surface type (percentage of land in the radiometer field of view), the closest to altimeter time
  - Radiometer instrument flags, the closest to altimeter time
  - Radiometer measurement confidence data, the closest to altimeter time
- For JASON-1:
  - Interpolated radiometer main beam brightness temperatures (3 channels)
  - Interpolated radiometer averaged along-track brightness temperatures (3 channels)
  - Interpolation quality flag
  - Radiometer antenna temperatures quality flags (3 channels), the closest to altimeter time
  - Radiometer surface type (percentage of land in the radiometer field of view), the closest to altimeter time

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Mathematical statement

The radiometer brightness temperatures (and also brightness temperatures standard deviations for ENVISAT) are computed at the altimeter time tag by linear interpolation of the two nearest valid bracketing radiometer measurements found within a maximum time interval of ± Dt_Int_Max_Rad s centered on the altimeter time.

If two radiometer measurements are not found within this time interval but if only one valid radiometer point is found within a maximum time interval of ± Dt_Ext_Max_Rad s centered on the altimeter time, the corresponding brightness temperatures are assigned to the altimeter time tag. The quality of the interpolation will be "good" if the linear interpolation is successful and if there is no gap between radiometer measurements, "interp" if interpolation is successful with a gap between the two radiometer measurements, "extrap", if extrapolation is used, and "fail" if both interpolation and extrapolation fail. For the various radiometer flags, no interpolation is performed: in each case, the radiometer flags from the closest radiometer measurement are simply assigned to the altimeter measurement. This flag assigning is performed at the algorithm output by the corresponding management algorithm, knowing the index corresponding to the closest radiometer measurement.

The valid radiometer measurements considered depend on the altimeter surface type:

- If the surface type seen by the altimeter is “open ocean or semi-enclosed seas”, or “enclosed seas or lakes”, in a first step only radiometer measurements having the radiometer land flag set to "ocean" are considered. If no ocean radiometer measurement is found within the above defined time spans, then radiometer measurements having the radiometer land flag set to "land" are considered in a second step.
- If the surface type seen by the altimeter is “continental ice”, or “land”, in a first step only radiometer measurements having the radiometer land flag set to "land" are considered. If no land radiometer measurement is found within the above defined time spans, then radiometer measurements having the radiometer land flag set to "ocean" are considered in a second step.

ALGORITHM SPECIFICATION

Input data

- The following time intervals:
  - Time interval for radiometer interpolation : Dt_Int_Max_Rad (s)
  - Time interval for radiometer extrapolation : Dt_Ext_Max_Rad (s)
  - Time interval between two successive radiometer meas. : Dt_No_Gap_Rad (s)
- Number of radiometer meas. for the whole radiometer sequence : N_mes (/)
- Number of radiometer parameters to be interpolated : N_param (/)
- Number of radiometer channels : N_channels (/)
- Radiometer time tags : Rad_Time_Tag[0:N_mes-1] (1)

(1) Seconds elapsed since Time_Ref

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- Radiometer data to be interpolated : Rad_Data [0:N_param-1][0:N_mes-1]
- Brightness temperatures quality flags : Rad_Valid [0:N_channels-1][0:N_mes-1]
- Radiometer surface type : Rad_Surf [0: N_mes-1] (percent)
- Altimeter time tag : Alt_Time_Tag_Mean[(1)]
- Altimeter surface type [(3)] : Alt_Surf

Output data

- Radiometer data interpolated to altimeter time : Rad_Data_Int [0:N_param-1]
- Interpolation quality flag : Qual_Int_Rad_To_Alt
- Index in the radiometer data set, of the radiometer measurement the closest to the altimeter measurement : Index_Rad
- Execution status

Processing

The processing consists, for the input altimeter measurement, of:

- If the altimeter surface type is set to “open ocean or semi-enclosed seas”, or “enclosed seas or lakes”:
  - Selecting, in the input radiometer data, the couple of radiometer measurements (j) and (j + 1) which satisfy the four following conditions:
    - The two radiometer measurements bracket the altimeter measurement in time : Rad_Time_Tag(j) ≤ Alt_Time_Tag_Mean ≤ Rad_Time_Tag(j+1)
    - The radiometer measurements are valid for all channels
    - The time span between the altimeter measurement and each radiometer measurement is minimum, and its absolute value is less than Dt_Int_Max_Rad
    - The radiometer surface type of each radiometer measurement denotes an ocean measurement (i.e., = 0)
  - If such bracketing couple exists:
    - Computing the weights of linear interpolation, using mechanism "GEN_MEC_INT_01 - Linear weighting", the input parameters of which are :
      - Xmin = Rad_Time_Tag(j)
      - Xmax = Rad_Time_Tag(j+1)
      - Xstep = Rad_Time_Tag(j+1) – Rad_Time_Tag(j)
      - X = Alt_Time_Tag_Mean

---

(2) Set to "ocean" or "land"

(1) Seconds elapsed since Time_Ref

(3) Set to “open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, or “land”

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and the output parameters of which are :

◊ Index_1 (unused)

◊ Index_2 (unused)

◊ W1 = w1

◊ W2 = w2

◊ The execution status

∗ For i = 0 to N_param-1:

Computing by linear interpolation in time the radiometer data at altimeter time, Rad_Data_Int(i), using mechanism "GEN_MEC_INT_02 - Linear interpolation",

the input parameters of which are :

⇒ X1 = Rad_Data(i,j)

⇒ X2 = Rad_Data(i,j+1)

⇒ W1 = w1

⇒ W2 = w2

and the output parameter of which is :

⇒ Rad_Data_Int(i).

⇒ The execution status

∗ Determining the index of the closest radiometer measurement of the couple, Index_Rad

– If no such bracketing couple of radiometer brightness temperatures exists:

∗ If radiometer measurements with radiometer surface type = 0 are valid for all channels either before, or after the altimeter measurement, but within ± Dt_Ext_Max_Rad of the altimeter time, then the interpolated radiometer data are simply the radiometer data of the closest ocean radiometer measurement (let Index_Rad be the index of this closest ocean measurement)

∗ If the previous ocean radiometer extrapolation failed, but if radiometer measurements with radiometer surface type > 0 (i.e., “land” radiometer measurements) are valid for all channels either before, or after the altimeter measurement, within ± Dt_Ext_Max_Rad of the altimeter time, then the interpolated radiometer data are simply the radiometer data of the closest land radiometer measurement (let Index_Rad be the index of this closest land measurement)

∗ If no valid radiometer measurement is available neither before, nor after the altimeter measurement within ± Dt_Ext_Max_Rad of the altimeter time, then the interpolated radiometer data are not computed

- If the altimeter surface type is set to “continental ice”, or “land”:

– Selecting, in the input radiometer data, the couple of radiometer measurements (j) and (j + 1) which satisfy the four following conditions:

∗ The two radiometer measurements bracket the altimeter measurement in time

∗ The radiometer measurements are valid for all channels

∗ The time span between the altimeter measurement and each radiometer measurement is minimum, and its absolute value is less than Dt_Int_Max_Rad

∗ The radiometer surface type of each radiometer measurement is > 0 (“land” radiometer measurement)

– If such bracketing couple exists:

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- Computing the weights of linear interpolation, using mechanism "GEN_MEC_INT_01 - Linear weighting", the input parameters of which are :
  - Xmin = Rad_Time_Tag(j)
  - Xmax = Rad_Time_Tag(j+1)
  - Xstep = Rad_Time_Tag(j+1) – Rad_Time_Tag(j)
  - X = Alt_Time_Tag_Mean

  and the output parameters of which are :
  - Index_1 (unused)
  - Index_2 (unused)
  - W1 = w1
  - W2 = w2
  - The execution status
- For i = 0 to N_param-1:

  Computing by linear interpolation in time the radiometer data at altimeter time, Rad_Data_Int(i), using mechanism "GEN_MEC_INT_02 - Linear interpolation",

  the input parameters of which are :
  - ⇒ X1 = Rad_Data(i,j)
  - ⇒ X2 = Rad_Data(i,j+1)
  - ⇒ W1 = w1
  - ⇒ W2 = w2

  and the output parameter of which is :
  - ⇒ Rad_Data_Int(i)
  - ⇒ the execution status
- Determining the index of the closest radiometer measurement, Index_Rad

– If no such bracketing couple of radiometer brightness temperatures exists:
- If radiometer measurements with radiometer surface type > 0 (“land” radiometer measurements) are valid for all channels either before, or after the altimeter measurement, but within ± Dt_Ext_Max_Rad of the altimeter time, then the interpolated radiometer data are simply the radiometer data of the closest land radiometer measurement (let Index_Rad be the index of this closest land measurement)
- If the previous land radiometer extrapolation failed, but if radiometer measurements with radiometer surface type = 0 (“ocean” radiometer measurements) are valid for all channels either before, or after the altimeter measurement, within ± Dt_Ext_Max_Rad of the altimeter time, then the interpolated radiometer data are simply the radiometer data of the closest ocean radiometer measurement (let Index_Rad be the index of this closest ocean measurement)
- If no valid radiometer measurement is available neither before, nor after the altimeter measurement within ± Dt_Ext_Max_Rad of the altimeter time, then the interpolated radiometer data are not computed

• Assigning the radiometer to altimeter interpolation quality flag, Qual_Int_Rad_To_Alt, to:

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- "good" if interpolation was successful with no gap between the two radiometer measurements (Time_Tag_Rad(j + 1) - Time_Tag_Rad(j) ≤ Dt_No_Gap_Rad)
- "interp" if interpolation was successful with a gap between the two radiometer measurements
- "extrap" if extrapolation was used
- "fail" if interpolation and extrapolation failed

ACCURACY

Experience with TOPEX data has shown that, in order to avoid out-of-bounds interpolation values, linear interpolation is preferred to cubic interpolation. Typical values for Dt_Int_Max_Rad and Dt_Ext_Max_Rad are 16 s and 8 s respectively. These time spans of ± 16 s and ± 8 s allow for the radiometer to altimeter correspondence to work in case of missing ocean radiometer measurements. Selecting only ocean radiometer points within these time spans for the interpolation to ocean altimetric points, will permit ocean altimeter measurements between small islands or at land/sea transitions to get a non land-contaminated radiometer measurement. An estimate of the wet tropospheric correction error induced by the interpolation of radiometer data in the worst case (i.e., interpolation at altimeter time from two equidistant radiometer data spaced by 32 s) has been performed using one 35-day ERS-2 cycle. The standard deviation of the difference between the interpolated value and the true value is 13 mm. In case of extrapolation, the same worst case feature is obtained with ± 8 s.

COMMENTS

None

REFERENCES

None

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RAD_PHY_GEN_01 - To compute the JMR geophysical parameters

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX (TMR)

FUNCTION

To compute the geophysical parameters (vapor-induced path delay, water vapor content, liquid water content, sea surface windspeed, Sigma0 atmospheric attenuations) from the JMR brightness temperatures.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The computation of the JMR geophysical parameters will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "RAD_MAN_INT_01 - To interpolate radiometer data to altimeter time tags "
    - Interpolated averaged along-track brightness temperatures, T_b, at each JMR frequency
    - Radiometer surface type (percentage of land in the radiometer field of view), the closest to altimeter time
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Retrieval coefficients relating sea surface wind speed to JMR brightness temperatures (4 coefficients, w_0 and $w(\nu_i)$ with i = 1 to 3). These coefficients are derived from regression of island radiosonde data computations combined with season and latitude dependent wind speed statistics.
  - Retrieval coefficients relating cloud liquid burden to JMR brightness temperatures (5 coefficients, l_o, $l(\nu_i)$ with i = 1 to 3, and l_{sq}). These coefficients are derived from regression of island radiosonde data computations.
  - Retrieval coefficients, dependent on wind speed and path delay range, relating the vapor-induced path delay to JMR brightness temperatures (B_0 and $B(\nu_i)$ (i = 1 to 3), 4 coefficients ∗ 5 wind speeds ∗ 5 path delays = 100 coefficients). These coefficients are derived from island radiosonde data computations.

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- Single coefficient relating the liquid-induced path delay to retrieved liquid burden (1 coefficient).
- Coefficients relating vapor-induced path delay to integrated vapor burden (3 coefficients, v_0, v_1, and v_2).
- Coefficients relating vapor-induced path delay and liquid burden to C and Ku band atmospheric attenuation (3 coefficients for each band = 6 coefficients, c_0, c_v, c_L, k_0, k_v and k_L).

Output data

- Wet tropospheric correction due to vapor and liquid (1 value)
- Sigma0 atmospheric attenuation at Ku and C band (2 values)
- Integrated vapor content
- Integrated liquid content (cloud burden)
- Sea surface wind speed

Mathematical statement

The wet troposphere correction algorithm requires the following computational steps. First wind speed is estimated in one step:

$$W = w_0 + \sum_{i=1}^{3} w(\nu_i).T_b(\nu_i) \quad \text{(in m/s)} \tag{1}$$

where ν_i are the three JMR frequencies (i = 1 to 3 corresponding to the 18.7 GHz, 23.8 GHz, and 34.0 GHz frequencies, respectively), and w_0 and $w(\nu_i)$ are the wind speed retrieval coefficients.

Next, the cloud liquid burden is estimated:

$$L_Z = l_0 + \sum_{i=1}^{3} l(\nu_i).T_b(\nu_i) + l_{sq}.[T_b(\nu_3)]^2 \quad \text{(in kg/m}^2\text{)} \tag{2}$$

where l_o, $l(\nu_i)$ with i = 1 to 3, and l_{sq} are cloud liquid retrieval coefficients.

Next a first estimate of the vapor-induced path delay correction is made using global (unstratified in path delay) coefficients which are dependent on the wind speed estimate:

$$PD^{(g)} = B_0^{(g)} + \sum_{i=1}^{3} B^{(g)}(\nu_i).\ln[280 - T_b(\nu_i)] \quad \text{(in cm)} \tag{3}$$

where $B_o^{(g)}$ and $B^{(g)}(\nu_i)$ (i =1 to 3) are determined by linear interpolation with respect to wind speed in the path delay retrieval coefficient tables.

Next, path delay values are computed using stratified coefficients for path delay ranges with center points which bracket the initial (global) path delay estimate:

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$$PD^{(1)} = B_0^{(1)} + \sum_{i=1}^{3} B^{(1)}(\nu_i).\ln[280 - T_b(\nu_i)] \quad (4)$$

$$PD^{(2)} = B_0^{(2)} + \sum_{i=1}^{3} B^{(2)}(\nu_i).\ln[280 - T_b(\nu_i)] \quad (5)$$

where $B_0^{(1)}$, $B^{(1)}(\nu_i)$, $B_0^{(2)}$, $B^{(2)}(\nu_i)$ (i = 1 to 3) are obtained by interpolation in wind speed in the appropriate path delay range rows of the path delay retrieval coefficient tables.

The final estimate for the vapor-induced path delay component is obtained by linear interpolation between $PD^{(1)}$ and $PD^{(2)}$. This linear interpolation assures that there will be no retrieval discontinuities across stratification boundaries. The final total wet path delay is found by adding the small liquid component to the vapor-induced component:

$$PD_w = PD^{(f)} + 0.00016.L_z \quad \text{(in cm)} \quad (6)$$

Integrated vapor content will be derived from its correlation with $PD^{(f)}$:

$$V_Z = \frac{PD^{(f)}}{v_0 + v_1.PD^{(f)} + v_2.PD^{(f)}.PD^{(f)}} \quad \text{(in cm)} \quad (7)$$

where v_0, v_1, and v_2, are obtained from a regression of radiosonde calculations of V_Z and $PD^{(f)}$.

The C and Ku band Sigma0 atmospheric attenuations are obtained from a linear combination of the $PD^{(f)}$ and L_Z results:

$$\tau_C = c_0 + c_v.PD^{(f)} + c_L.L_Z \quad (8)$$

$$\tau_K = k_0 + k_v.PD^{(f)} + k_L.L_Z \quad (9)$$

where the coefficients c_0, c_v, c_L, k_0, k_v and k_L, are computed from radiosonde correlations of attenuation with $PD^{(f)}$ and L_Z.

When the JMR brightness temperatures are contaminated by land, the C and Ku band Sigma0 atmospheric attenuations are computed using climatological values for path delay and cloud liquid water content.

When the JMR brightness temperatures are not available, the algorithm only computes the C and Ku band Sigma0 atmospheric attenuations, using climatological values for path delay and cloud liquid water content.

ALGORITHM SPECIFICATION

Input data

- Interpolated averaged along-track brightness temperatures: JMR_TB18_Int, JMR_TB23_Int, JMR_TB34_Int (K)
- Radiometer surface type, the closest to altimeter time : Rad_Surf (percent, = 0 over free ocean)

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- Retrieval coefficients relating sea surface wind speed to JMR brightness temperatures: Rad_Wind_Coef[0:3] (m/s for index 0, m/s/K for indexes 1 to 3)
- Retrieval coefficients relating cloud liquid burden to JMR brightness temperatures: Cloud_Liq_Coef[0:4] (1)
- The following tables for computing the global retrieval coefficients (representative of the whole path delay range) as function of :
  - Index J: sea surface wind speed ; J = 0 to 4 for wind speed values = 0, 7, 14, 21 and 28 m/s respectively.
    - The table TAB_B0_Glob[J] for global retrieval coefficient B0 (m)
    - The table TAB_B1_Glob[J] for global retrieval coefficient B1 (m/K)
    - The table TAB_B2_Glob[J] for global retrieval coefficient B2 (m/K)
    - The table TAB_B3_Glob[J] for global retrieval coefficient B3 (m/K)
- The following tables for computing the stratified retrieval coefficients (stratified in path delay), as function of:
  - Index I: path delay range ; I = 0 to 3 for path delay ranges [0, 10 cm], [10, 20 cm], [20, 30 cm] and > 30 cm respectively
  - Index J: sea surface wind speed ; J = 0 to 4 for wind speed values = 0, 7, 14, 21 and 28 m/s respectively.
    - The table TAB_B0_Stra[I][J] for stratified retrieval coefficient B0 (m)
    - The table TAB_B1_Stra[I][J] for stratified retrieval coefficient B1 (m/K)
    - The table TAB_B2_Stra[I][J] for stratified retrieval coefficient B2 (m/K)
    - The table TAB_B3_Stra[I][J] for stratified retrieval coefficient B3 (m/K)
- First tabulated wind speed value : W_first (m/s)
- Last tabulated wind speed value : W_last (m/s)
- Table step in wind speed : W_step (m/s)
- First tabulated path delay range center value : PD_first (m)
- Last tabulated path delay range center value : PD_last (m)
- Table step in path delay range : PD_step (m)
- Coefficient relating the liquid-induced path delay to retrieved liquid burden : PD_Liq_Coef (m/(kg/m^2))
- Regression coefficients relating vapor-induced path delay to integrated vapor burden : Vap_Cont_Coef[0:2] (2)
- Coefficients relating vapor-induced path delay and liquid burden to Ku-band sigma0 atmospheric attenuation: Att_Sigma0_Ku_Coef[0:2] (3)
- Coefficients relating vapor-induced path delay and liquid burden to C-band sigma0 atmospheric attenuation: Att_Sigma0_C_Coef[0:2] (3)
- Climatological value for water vapor path delay : PD_Clim (m)

---

(1) kg/m^2 for index 0, (kg/m^2)/K for indexes 1 to 3, and [(kg/m^2)/K^2] for index 4

(2) m/(kg/m^2) for index 0, 1/(kg/m^2) for index 1 and 1/[m.(kg/m^2)] for index 2

(3) dB for index 0, dB/m for index 1, dB/(kg/m^2) for index 2

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- Climatological value for cloud liquid water content : LWP_Clim (kg/m^2)
- Radiometer to altimeter interpolation quality flag : Qual_Int_Rad_To_Alt

Output data

- Wet tropospheric correction due to vapor and liquid (1 value) : PD_Total (m)
- Sigma0 atmospheric attenuation at Ku-band : Att_Sigma0_Ku (dB)
- Sigma0 atmospheric attenuation at C-band : Att_Sigma0_C (dB)
- Integrated vapor content : Vap_Cont (kg/m^2)
- Integrated liquid content (cloud burden) : Cloud_Liq_Burd (kg/m^2)
- Sea surface wind speed : Rad_Wind (m/s)
- Execution status

Processing

If Qual_Int_Rad_To_Alt is not set to "fail", and none of the interpolated averaged along-track brightness temperatures is > 279.9 K, then :

- Compute the sea surface wind speed, Rad_Wind:
  - Rad_Wind = Rad_Wind_Coef(0) + Rad_Wind_Coef(1) ∗ JMR_TB18_Int
    + Rad_Wind_Coef(2) ∗ JMR_TB23_Int
    + Rad_Wind_Coef(3) ∗ JMR_TB34_Int (1)
- Compute the cloud liquid burden, Cloud_Liq_Burd:
  - Cloud_Liq_Burd = Cloud_Liq_Coef(0) + Cloud_Liq_Coef(1) ∗ JMR_TB18_Int
    + Cloud_Liq_Coef(2) ∗ JMR_TB23_Int
    + Cloud_Liq_Coef(3) ∗ JMR_TB34_Int
    + Cloud_Liq_Coef(4) ∗ (JMR_TB34_Int)^2 (2)
- Compute the total (vapor-induced and liquid-induced) path delay, PD_Total:
  - Computing the first estimate of vapor-induced path delay, PD_Global, using global retrieval coefficients:
    - Computing the weights of linear interpolation in windspeed, using mechanism "GEN_MEC_INT_01 - Linear weighting",

      the input parameters of which are :
      - ◊ Xmin = W_first
      - ◊ Xmax = W_last
      - ◊ Xstep = W_step

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◊ X = Rad_Wind

and the output parameters of which are :

◊ Index_1 = J1

◊ Index_2 = J2

◊ W1 = w1_WS

◊ W2 = w2_WS

◊ The execution status

∗ Computing PD_Global, thanks to the mechanism “GEN_MEC_COR_05 – Calculation of a path delay value”,

the input parameters of which are :

◊ Val1_TAB_B0 = TAB_B0_Glob(J1)

◊ Val1_TAB_B1 = TAB_B1_Glob(J1)

◊ Val1_TAB_B2 = TAB_B2_Glob(J1)

◊ Val1_TAB_B3 = TAB_B3_Glob(J1)

◊ Val2_TAB_B0 = TAB_B0_Glob(J2)

◊ Val2_TAB_B1 = TAB_B1_Glob(J2)

◊ Val2_TAB_B2 = TAB_B2_Glob(J2)

◊ Val2_TAB_B3 = TAB_B3_Glob(J2)

◊ W1 = w1_WS

◊ W2 = w2_WS

◊ TB1 = JMR_TB18_Int

◊ TB2 = JMR_TB23_Int

◊ TB3 = JMR_TB34_Int

and the output parameter of which are :

◊ Path_Delay = PD_Global

◊ The execution status

– Computing the final estimate of vapor-induced path delay, PD_Final, using stratified retrieval coefficients :

∗ Computing the weights of linear interpolation in path delay, using mechanism “GEN_MEC_INT_01 - Linear weighting",

the input parameters of which are :

◊ Xmin = PD_first

◊ Xmax = PD_last

◊ Xstep = PD_step

◊ X = PD_Global

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and the output parameters of which are :

◊ Index_1 = I1

◊ Index_2 = I2

◊ W1 = w1_PD

◊ W2 = w2_PD

◊ The execution status

∗ If w1_PD > 0, then :

◊ Computing the path delay value PD1 corresponding to the index I1, thanks to the mechanism "GEN_MEC_COR_05 – Calculation of a path delay value",

the input parameters of which are :

⇒ Val1_TAB_B0 = TAB_B0_Stra(I1,J1)

⇒ Val1_TAB_B1 = TAB_B1_Stra(I1,J1)

⇒ Val1_TAB_B2 = TAB_B2_Stra(I1,J1)

⇒ Val1_TAB_B3 = TAB_B3_Stra(I1,J1)

⇒ Val2_TAB_B0 = TAB_B0_Stra(I1,J2)

⇒ Val2_TAB_B1 = TAB_B1_Stra(I1,J2)

⇒ Val2_TAB_B2 = TAB_B2_Stra(I1,J2)

⇒ Val2_TAB_B3 = TAB_B3_Stra(I1,J2)

⇒ W1 = w1_WS

⇒ W2 = w2_WS

⇒ TB1 = JMR_TB18_Int

⇒ TB2 = JMR_TB23_Int

⇒ TB3 = JMR_TB34_Int

and the output parameter of which are :

⇒ Path_Delay = PD1

⇒ The execution status

∗ Else (if w1_PD = 0) :

◊ PD1 = 0 (3)

∗ If w2_PD > 0, then :

◊ Computing the path delay value PD2 corresponding to the index I2, thanks to the mechanism "GEN_MEC_COR_05 – Calculation of a path delay value",

the input parameters of which are :

⇒ Val1_TAB_B0 = TAB_B0_Stra(I2,J1)

⇒ Val1_TAB_B1 = TAB_B1_Stra(I2,J1)

⇒ Val1_TAB_B2 = TAB_B2_Stra(I2,J1)

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⇒ Val1_TAB_B3 = TAB_B3_Stra(I2,J1)

⇒ Val2_TAB_B0 = TAB_B0_Stra(I2,J2)

⇒ Val2_TAB_B1 = TAB_B1_Stra(I2,J2)

⇒ Val2_TAB_B2 = TAB_B2_Stra(I2,J2)

⇒ Val2_TAB_B3 = TAB_B3_Stra(I2,J2)

⇒ W1 = w1_WS

⇒ W2 = w2_WS

⇒ TB1 = JMR_TB18_Int

⇒ TB2 = JMR_TB23_Int

⇒ TB3 = JMR_TB34_Int

and the output parameter of which are :

⇒ Path_Delay = PD2

⇒ The execution status

∗ Else (if w2_PD = 0) :

◊ PD2 = 0 (4)

∗ Computing by linear interpolation in path delay PD_Final, using mechanism “GEN_MEC_INT_02 - Linear interpolation",

the input parameters of which are :

◊ X1 = PD1

◊ X2 = PD2

◊ W1 = w1_PD

◊ W2 = w2_PD

and the output parameters of which are :

◊ PD_Final

◊ the execution status

– Adding the liquid-induced path delay contribution to derive PD_Total:

∗ LWP = Cloud_Liq_Burd (5)

∗ If LWP < 0, then LWP = 0 (6)

∗ PD_Total = PD_Final + PD_Liq_Coef ∗ LWP (7)

- Compute the integrated water vapor content, Vap_Cont:

– PDF = PD_Final (8)

– If PDF < 0, then PDF = 0 (9)

– Coef_PD_To_Vap = Vap_Cont_Coef(0) + Vap(Cont_Coef(1) ∗ PDF + Vap_Cont_Coef(2) ∗ $(PDF)^2$(10)

– Vap_Cont = PD_Final / Coef_PD_To_Vap (11)

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- Compute the C-band and Ku-band sigma0 atmospheric attenuations:
  - If Rad_Surf = 0 (ocean radiometer measurement), then :
    - Att_Sigma0_C = Att_Sigma0_C_Coef(0) + Att_Sigma0_C_Coef(1) ∗ PDF + Att_Sigma0_C_Coef(2) ∗ LWP (12)
    - Att_Sigma0_Ku = Att_Sigma0_Ku_Coef(0) + Att_Sigma0_Ku_Coef(1) ∗ PDF + Att_Sigma0_Ku_Coef(2) ∗ LWP (13)
  - Else
    - Att_Sigma0_C = Att_Sigma0_C_Coef(0) + Att_Sigma0_C_Coef(1) ∗ PD_Clim + Att_Sigma0_C_Coef(2) ∗ LWP_Clim (14)
    - Att_Sigma0_Ku = Att_Sigma0_Ku_Coef(0) + Att_Sigma0_Ku_Coef(1) ∗ PD_Clim + Att_Sigma0_Ku_Coef(2) ∗ LWP_Clim (15)
- PD_Total = PD_Total x (-1) (16)

Else, if Qual_Int_Rad_To_Alt is set to "fail", or if one of the interpolated averaged along-track brightness temperatures is > 279.9 K, then :

- Compute the C-band and Ku-band sigma0 atmospheric attenuations:
  - Att_Sigma0_C = Att_Sigma0_C_Coef(0) + Att_Sigma0_C_Coef(1) ∗ PD_Clim + Att_Sigma0_C_Coef(2) ∗ LWP_Clim (17)
  - Att_Sigma0_Ku = Att_Sigma0_Ku_Coef(0) + Att_Sigma0_Ku_Coef(1) ∗ PD_Clim + Att_Sigma0_Ku_Coef(2) ∗ LWP_Clim (18)

ACCURACY

Recent improvements in our knowledge of the emission properties of atmospheric water vapor (e.g. Cruz Pol et al., 1998), coupled with the anticipated 0.9 JMR brightness temperature accuracy, indicate that the global rms performance for JMR path delay retrieval will be ≤ 1.2 cm. Accuracies for other geophysical parameters are TBD.

COMMENTS

The formulation of the JMR wet troposphere algorithm and related geophysical parameters closely follows that of the TOPEX Microwave Radiometer (Keihm et al., 1995). The path delay has been multiplied by (-1) to be added to the altimeter range. Positive path delay values, as well as negative water vapor content, cloud liquid water content and radiometer wind speed may be output by this algorithm. Setting or not these values to zero for their inclusion in the user products may be discussed by the SWT.

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REFERENCES

- Cruz Pol, S. L., C. S. Ruf, and S. J. Keihm, Improved 20-32 GHz atmospheric absorption model. Radio Science, in press, 1998.
- Keihm, S. J., M. A. Janssen, and C. S. Ruf, TOPEX/POSEIDON microwave radiometer (TMR): III. Wet troposphere range correction algorithm and pre-launch error budget, IEEE Trans. Geosci. Remote Sensing, 33, 147-161, Jan, 1995.

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RAD_PHY_ATT_01 - To compute the RA-2 sigma0 atmospheric attenuations

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J. STUM CLS	
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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To compute the RA-2 backscatter coefficient (Sigma0) atmospheric attenuation in both bands.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the sigma0 atmospheric attenuations will be performed for all surface types (over land and ocean), although it is mainly relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "RAD_MAN_INT_01 - To interpolate radiometer data to altimeter time tags":
    - Interpolated radiometer brightness temperatures
    - Radiometer land flag, the closest to altimeter time
  - From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients":
    - Ku-band ocean backscatter coefficient
    - S-band ocean backscatter coefficient
    - Ku-band ocean backscatter coefficient validity flag
    - S-band ocean backscatter coefficient validity flag
- Dynamic data: None
- Static auxiliary data:
  - Processing parameters

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Output data

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

Mathematical statement

If the MWR 23.8 GHz and 36.5 GHz brightness temperatures (TB23 and TB36) are available (this should be the nominal case), and (of course) if the sigma0 is valid, the backscatter coefficient two-way atmospheric attenuations are computed in dB by (Obligis, 2001) :

$$Att_Sigma0_Ku = d_0 + d_1.Log_e(280 - TB23) + d_2.Log_e(280 - TB36) + d_3 \cdot \frac{1}{(Sigma0_Ku)^2} \quad (1)$$

$$Att_Sigma0_S = e_0 + e_1.Log_e(280 - TB23) + e_2.Log_e(280 - TB36) + e_3 \cdot \frac{1}{(Sigma0_S)^2} \quad (2)$$

Else, if the MWR 23.8 GHz and 36.5 GHz brightness temperatures (TB23 and TB36) are not available, the backscatter coefficient two-way atmospheric attenuations are computed (in dB) by:

$$Att_sigma0 = 2.\tau_c \quad (3)$$

where τ_c is the opacity in dB, given by:

$$\tau_c = \gamma_0 + \gamma_P.Vap_Clim + \gamma_L.Cloud_Liq_Clim \quad (4)$$

with: γ_0 = 0.042 dB (Ku-band), 0.038 dB (S-band)
γ_p = 0.023 dB/g.cm^{-2} (Ku-band), 0.00092 dB/g.cm^{-2} (S-band)
γ_L = 0.145 dB/kg.m^{-2} (Ku-band), 0.00863 dB/kg.m^{-2} (S-band)

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}. First proposal for these values is Vap_Clim = 2 g.cm^{-2} and Cloud_Liq_Clim = 0 kg.m^{-2}.

EMBEDEMBEDγ_0, γ_p and γ_L have been calculated 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.

ALGORITHM SPECIFICATION

Input data

- Interpolated MWR 23.8 GHz brightness temperature : MWR_TB23_Int (K)
- Interpolated MWR 36.5 GHz brightness temperature : MWR_TB36_Int (K)
- MWR land flag, the closest to RA-2 time : MWR_Surf_Clos (/)
- Ku-band backscatter coefficient : Sigma0_Ku (dB)

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- S-band backscatter coefficient : Sigma0_S (dB)
- Ku-band backscatter coefficient validity flag : Flag_Valid_Sigma0_Ku (/)
- S-band backscatter coefficient validity flag : Flag_Valid_Sigma0_S (/)
- Attenuation coefficients for Ku-band:
  - Oxygen attenuation : Att_Oxy_Ku (dB)
  - Attenuation coefficient for water vapor : Coeff_Att_Vap_Ku (dB/kg.m^{-2})
  - Attenuation coefficient for liquid water : Coef_Att_Liq_Ku (dB/kg.m^{-2})
- Attenuation coefficients for S-band:
  - Oxygen attenuation : Att_Oxy_S (dB)
  - Attenuation coefficient for water vapor : Coeff_Att_Vap_S (dB/kg.m^{-2})
  - Attenuation coefficient for liquid water : Coef_Att_Liq_S (dB/kg.m^{-2})
- Retrieval coefficients for Ku-band sigma0 attenuation : Coef_d0 (dB), Coef_d1 (dB/K), Coef_d2 (dB/K), Coef_d3 (dB^3)
- Retrieval coefficients for S-band sigma0 attenuation : Coef_e0 (dB), Coef_e1 (dB/K), Coef_e2 (dB/K), Coef_e3 (dB^3)
- Climatological value for water vapor content : V_Clim (kg/m^2)
- Climatological value for cloud liquid water content : L_Clim (kg/m^2)
- Radiometer to altimeter interpolation quality flag : Qual_Int_Rad_To_Alt
- Processing mode [(1)] : Proc_Mode

Output data

- Backscatter coefficient two-way atmospheric attenuation for Ku band : Att_Sigma0_Ku (dB)
- Backscatter coefficient two-way atmospheric attenuation for S band : Att_Sigma0_S (dB)
- Execution status

Processing

- If the processing mode is set to "RA2 + MWR", the processing consists of:
  - If the radiometer to altimeter interpolation quality flag is not set to "fail", and if the MWR land flag the closest to altimeter time is set to "ocean", and if both input brightness temperatures, MWR_TB23_Int and MWR_TB36_Int, are < 279.9, and if both backscatter coefficient validity flags Flag_Valid_Sigma0_Ku and Flag_Valid_Sigma0_S are set to “valid”, then computing the Ku-band and S-band two-way atmospheric attenuation from the input brightness temperatures TB23_Int and TB36_Int and from sigma0s:

(1) Set to "RA2" or "RA2+MWR"

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- Att_Sigma0_Ku = Coeff_d_0 + Coeff_d_1 ∗ Log_e(280 – MWR_TB23_Int)

$$+ \text{Coeff_d}_2 * \text{Log}_e(280 - \text{MWR_TB36_Int}) \quad (1)$$

$$+ \text{Coeff_d3} * \frac{1}{(\text{Sigma0_Ku})^2}$$

- Att_Sigma0_S = Coeff_e_0 + Coeff_e_1 ∗ Log_e(280 – MWR_TB23_Int)

$$+ \text{Coeff_e}_2 * \text{Log}_e(280 - \text{MWR_TB36_Int}) \quad (2)$$

$$+ \text{Coeff_e3} * \frac{1}{(\text{Sigma0_S})^2}$$

– Else if the radiometer to altimeter interpolation quality flag is set to "fail", or if the MWR land flag the closest to altimeter time is set to "land", or if one of the input brightness temperatures is > 279.9, or if one of the backscatter coefficient validity flags is set to “invalid”, then:

  – Computing the Ku-band opacity, Tau_Ku, and the S-band opacity, Tau_S in dB:

  - Tau_Ku = Att_Oxy_Ku + Coeff_Att_Vap_Ku ∗ V_Clim + Coef_Att_Liq_Ku ∗ L_Clim (3)
  - Tau_S = Att_Oxy_S + Coeff_Att_Vap_S ∗ V_Clim + Coef_Att_Liq_S ∗ L_Clim (4)

Computing the Ku-band two-way atmospheric attenuation correction, Att_Sigma0_Ku, in dB, and the S-band two-way atmospheric attenuation correction, Att_Sigma0_S, in dB:

- Att_Sigma0_Ku = 2 ∗ Tau_Ku (5)
- Att_Sigma0_S = 2 ∗ Tau_S (6)

- If the processing mode is set to "RA2", the processing starts from (3)

ACCURACY

TBD

COMMENTS

None

REFERENCES

- In flight calibration/validation of the Envisat MWR. Estelle Obligis, Report of WP3000 of ESA contract N° 13681/99/NL/GD, CLS/DOS/NT/01.378, 30 March 2001.
- Ulaby, F.T., R.K. Moore and A.K. Fung, Microwave Remote Sensing, Volume 1, Addison-Wesley Publishing Company, Reading, Massachusetts, 1981

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ALT_PHY_WIN_01 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Witter and Chelton, 1991)

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J. STUM CLS	
Checked by:	For the JASON-1 SWT D. CHELTON L. EYMARD For the JASON-1 Project P. VINCENT CNES S. DESAI JPL For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
Approved by:	P. VINCENT CNES	

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HERITAGE

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

FUNCTION

To correct the backscatter coefficients for atmospheric attenuation and to compute the altimeter wind speed from the corrected Ku-band backscatter coefficient, using the modified Chelton and Wentz algorithm (Witter and Chelton, 1991)

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the 10-meter altimeter wind speed will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients":
    - Ku-band ocean backscatter coefficient
    - S-band ocean backscatter coefficient
    - Ku-band ocean backscatter coefficient validity flag
    - S-band ocean backscatter coefficient validity flag
  - From "RAD_PHY_ATT_01 - To compute the RA-2 sigma0 atmospheric attenuations":
    - Ku-band backscatter coefficient atmospheric attenuation
    - S-band backscatter coefficient atmospheric attenuation

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- Dynamic auxiliary data: None
- Static auxiliary data:
  - Backscatter coefficient to wind speed conversion (look-up table)

Output data

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

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 the Ku-band corrected backscatter coefficient, according to the modified Chelton and Wentz algorithm (Witter and Chelton, 1991).

ALGORITHM SPECIFICATION

Input data

- Ku-band backscatter coefficient : Sigma0_Ku (dB)
- Auxiliary band backscatter coefficient : Sigma0_Aux (dB)
- Ku-band backscatter coefficient atmospheric attenuation : Att_Sigma0_Ku (dB)
- Auxiliary band backscatter coefficient atmospheric attenuation : Att_Sigma0_Aux (dB)
- Ku-band backscatter coefficient validity flag : Flag_Valid_Sigma0_Ku (/)
- Auxiliary band backscatter coefficient validity flag : Flag_Valid_Sigma0_Aux (/)
- Number of tabulated backscatter coefficient values of the wind table : Wind_Nb_Sigma0 (/)

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- Wind table : Wind[0:Wind_Nb_Sigma0-1] (m/s)
- Minimum tabulated value of backscatter coefficient : Wind_Sigma0_Min (dB)
- Maximum tabulated value of backscatter coefficient : Wind_Sigma0_Max (dB)
- Table step in backscatter coefficient : Wind_Sigma0_Step (dB)

Output data

- Ku-band corrected ocean backscatter coefficient : Sigma0_Ku_Corr (dB)
- Auxiliary band corrected ocean backscatter coefficient : Sigma0_Aux_Corr (dB)
- Altimeter windspeed : Alt_Wind (m/s)
- Execution status

Processing

The processing consists of:

- Computing, if Flag_Valid Sigma0_Ku is set to "valid", the corrected Ku-band ocean backscatter coefficient (Sigma0_Ku_Corr), and if Flag_Valid_Sigma0_Aux is set to "valid", the corrected auxiliary band ocean backscatter coefficient (Sigma0_Aux_Corr):
  - Sigma0_Ku_Corr = Sigma0_Ku + Att_Sigma0_Ku (1)
  - Sigma0_Aux_Corr = Sigma0_Aux + Att_Sigma0_Aux (2)
- Computing, if Flag_Valid_Sigma0_Ku is set to "valid", the altimeter wind speed:
  - Sigma0_Ku_Corr_In = Sigma0_Ku_Corr (3)
  - Computing the weights of linear interpolation in sigma0_Ku, using mechanism “GEN_MEC_INT_01 - Linear weighting",

    the input parameters of which are :
    - Xmin = Wind_Sigma0_Min
    - Xmax = Wind_Sigma0_Max
    - Xstep = Wind_Sigma0_Step
    - X = Sigma0_Ku_Corr_In

    and the output parameters of which are :
    - Index_1 = I1
    - Index_2 = I2
    - W1 = w1
    - W2 = w2
    - The execution status

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- Computing the altimeter wind speed Alt_Wind by linear interpolation in the input wind table Wind, using mechanism "GEN_MEC_INT_02 - Linear interpolation",

  the input parameters of which are :

  - X1 = Wind(I1)
  - X2 = Wind(I2)
  - W1 = w1
  - W2 = w2

  and the output parameter of which is :

  - Alt_Wind
  - the execution status

ACCURACY

The derived wind speed is considered to be accurate to the 2 m/s level.

COMMENTS

None

REFERENCES

- Witter, D.L., and D.B. Chelton: A Geosat altimeter wind speed algorithm and a method for altimeter wind speed algorithm development, J. Geophys.Res., 96, 8853-8860, 1991

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ALT_PHY_WIN_02 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Gourrion et al., 2000)

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J. STUM CLS	
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Approved by:	P. VINCENT CNES	

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HERITAGE

None

FUNCTION

To correct the backscatter coefficients for atmospheric attenuation and to compute the altimeter wind speed from the corrected Ku-band backscatter coefficient, using the Gourrion et al. (2000) algorithm.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The computation of the 10-meter altimeter wind speed will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - For JASON-1:
    - From "ALT_COR_BAC_02 - To compute the corrected on-ground retracked backscatter coefficients":
      - Ku-band ocean backscatter coefficient
      - C-band ocean backscatter coefficient
    - From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients":
      - Ku-band ocean backscatter coefficient validity flag
      - C-band ocean backscatter coefficient validity flag
    - From "RAD_PHY_GEN_01 - To compute the JMR geophysical parameters":
      - Ku-band backscatter coefficient atmospheric attenuation
      - C-band backscatter coefficient atmospheric attenuation
    - From "ALT_COR_SWH_02 - To compute the corrected on-ground retracked significant waveheights":

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- ◊ Ku-band significant waveheight (SWH_Ku)
- ∗ From "ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH":
  - ◊ Ku-band ocean significant waveheight validity flag

- Dynamic auxiliary data: None

Output data

For JASON-1:

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

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 the Ku-band corrected backscatter coefficient, according to Gourrion et al. (2000).

ALGORITHM SPECIFICATION

Input data

- Ku-band backscatter coefficient : Sigma0_Ku (dB)
- Auxiliary band backscatter coefficient : Sigma0_Aux (dB)
- Ku-band backscatter coefficient atmospheric attenuation : Att_Sigma0_Ku (dB)
- Auxiliary band backscatter coefficient atmospheric attenuation : Att_Sigma0_Aux (dB)
- Ku-band backscatter coefficient validity flag : Flag_Valid_Sigma0_Ku (/)
- Auxiliary band backscatter coefficient validity flag : Flag_Valid_Sigma0_Aux (/)
- Significant waveheight for Ku-band : SWH_Ku (m)
- Ku-band significant waveheight validity flag : Flag_Valid_SWH_Ku[(1)] (/)
- The following values of the parameters for wind speed calculation :
  - m_Ku = 0.0690915
  - b_Ku = - 0.3433598
  - m_SWH = 0.0637450
  - b_SWH = 0.0872510
  - W_First_11 = - 33.9506170
  - W_First_12 = - 11.0339400

---

(1) Two states : “valid”, or “invalid”

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- W_First_21 = - 3.9342847
- W_First_22 = - 0.0583444
- B_First_1 = 18.0637810
- B_First_2 = - 0.3722814
- W_Second_1 = 0.5401201
- W_Second_2 = 10.4048140
- B_Second = - 2.2838729
- b_Wind = 0.1
- m_Wind = 0.0284394

Output data

- Ku-band corrected ocean backscatter coefficient : Sigma0_Ku_Corr (dB)
- Auxiliary band corrected ocean backscatter coefficient : Sigma0_Aux_Corr (dB)
- Altimeter windspeed : Alt_Wind (m/s)
- Execution status

Processing

The processing consists of:

- Computing, if Flag_Valid Sigma0_Ku is set to "valid", the corrected Ku-band ocean backscatter coefficient (Sigma0_Ku_Corr), and if Flag_Valid_Sigma0_Aux is set to "valid", the corrected auxiliary band ocean backscatter coefficient (Sigma0_Aux_Corr):
  - Sigma0_Ku_Corr = Sigma0_Ku + Att_Sigma0_Ku (1)
  - Sigma0_Aux_Corr = Sigma0_Aux + Att_Sigma0_Aux (2)
- Computing, if Flag_Valid_Sigma0_Ku is set to "valid", the altimeter wind speed:
  - P1 = m_Ku ∗ Sigma0_Ku_Corr + b_Ku (3)
  - P2 = m_SWH ∗ SWH_Ku + b_SWH (4)
  - E1 = W_First_11∗P1 + W_First_12∗P2 + B_First_1 (5)
  - E2 = W_First_21∗P1 + W_First_22∗P2 + B_First_2 (6)
  - $X1 = \frac{1}{1+\exp(-E1)}$ (7)
  - $X2 = \frac{1}{1+\exp(-E2)}$ (8)
  - E = W_Second_1∗X1 + W_Second_2∗X2 + B_Second (9)
  - $U = \frac{1}{1+\exp(-E)}$ (10)

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– $\text{Alt_Wind} = \dfrac{\text{U} - \text{b_Wind}}{\text{m_Wind}}$ (11)

ACCURACY

The derived wind speed is considered to be accurate to the 2 m/s level.

COMMENTS

None

REFERENCES

- Gourrion, J., D. Vandemark, S. Bailey and B. Chapron, 2000 : Satellite altimeter models for surface wind speed developed using ocean satellite crossovers. Report number IFREMER-DROOS-2000-02, May 17th, 2000. Available from http://www.ifremer.fr/droos/Perso/gourrion/rapport/rapport.html

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ALT_PHY_GEN_02 - To compute the rain flag

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON

FUNCTION

To compute the rain flag from Ku-band and Auxiliary band altimeter backscatter coefficients.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the rain flag will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:

  For Jason-1 :

  – From "ALT_COR_BAC_02 - To compute the corrected on-ground retracked backscatter coefficients":
    - Ku-band ocean backscatter coefficient
    - C-band ocean backscatter coefficient

  – From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients":
    - Ku-band ocean backscatter coefficient validity flag
    - C-band ocean backscatter coefficient validity flag

  – From "RAD_PHY_GEN_01 - To compute the JMR geophysical parameters":
    - Integrated liquid water content

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For Envisat :

- From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients":
  - Ku-band ocean backscatter coefficient
  - S-band ocean backscatter coefficient
  - Ku-band ocean backscatter coefficient validity flag
  - S-band ocean backscatter coefficient validity flag
- From “RAD_PHY_GEN_02 - To compute the MWR geophysical parameters at RA-2 time tag” :
  - Integrated liquid water content

For Jason-1 and Envisat :

- From “RAD_MAN_INT_01 - To interpolate radiometer data to altimeter time tags ”
  - Radiometer surface type (percentage of land in the radiometer field of view), the closest to altimeter time
  - Radiometer interpolation quality flag

- Dynamic auxiliary data: None
- Static auxiliary data:
  - Table providing, for an input value of Auxiliary band backscatter coefficient, the expected Ku-band backscatter coefficient with its associated uncertainty.
  - Processing parameters

Output data

- Rain flag
- Rain attenuation

Mathematical statement

The expected Ku-band backscatter coefficient and its associated uncertainty are determined by linear interpolation in the input table, as function of the Auxiliary band (Aux = C for Jason-1, = S for Envisat) backscatter coefficient. The rain flag is set if both the difference between the expected Ku-band backscatter coefficient and the measured Ku-band backscatter coefficient exceeds a value (which depends on the uncertainty in the expected Ku-band backscatter coefficient), and the integrated liquid water content from the radiometer exceeds some given threshold Lmax.

The input Ku-band and Auxiliary band backscatter coefficients to be used are not corrected for atmospheric attenuation. Check of the radiometer surface type is performed to only use ocean radiometer measurements.

ALGORITHM SPECIFICATION

Input data

- Ku-band backscatter coefficient : Sigma0_Ku (dB)
- Auxiliary band backscatter coefficient : Sigma0_Aux (dB)

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- Ku-band backscatter coefficient validity flag : Flag_Valid_Sigma0_Ku[(1)] (/)
- Auxiliary band backscatter coefficient validity flag : Flag_Valid_Sigma0_Aux[(1)] (/)
- Number of tabulated Auxiliary band backscatter coefficient values : Exp_Sigma0Ku_Nb_Sigma0 (/)
- Expected Ku-band sigma0 table :Exp_Sigma0Ku[0:1][0: Exp_Sigma0Ku_Nb_Sigma0 -1] (dB)
- Minimum tabulated value of Auxiliary band sigma0 : Exp_Sigma0Ku_Sigma0_Min (dB)
- Maximum tabulated value of Auxiliary band sigma0 : Exp_Sigma0Ku_Sigma0_Max (dB)
- Table step for Auxiliary band sigma0 : Exp_Sigma0Ku_Sigma0_Step (dB)
- Radiometer interpolation quality flag : Qual_Int_Rad_To_Alt (/)
- Integrated liquid content (cloud burden) : Cloud_Liq_Burd (kg/m^2)
- Radiometer surface type, the closest to altimeter time : Rad_Surf (percent, = 0 over free ocean)
- Rain flag coefficient : Rain_Coef
- Liquid content threshold : Rain_Cloud_Liq (kg/m^2)
- Delta sigma0 difference threshold : Rain_Delta_Sigma0 (dB)

Output data

- Rain flag : Rain_Flag[(2)] (/)
- Rain attenuation : Rain_Att (dB)
- Execution status

Processing

The processing consists of:

- If Flag_Valid_Sigma0_Ku is set to "valid" and if Qual_Int_Rad_To_Alt is not set to “fail”, and if Rad_Surf = 0 (“ocean” radiometer measurement), then :
  - The rain flag is initialized to “no rain”
- Else :
  - The rain flag is set to “rain”
- If Flag_Valid_Sigma0_Ku is set to "valid", and if Qual_Int_Rad_To_Alt is not set to “fail”, and if Rad_Surf = 0 (“ocean” radiometer measurement), then computing the rain flag and the rain attenuation:
  - Sigma0_Aux_In = Sigma0_Aux (1)

(1) Two states : “valid”, or “invalid”

(1) Two states : “valid”, or “invalid”

(2) Two states : “rain”, or “no rain”

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- Computing the weights of linear interpolation in Sigma0_Aux, using mechanism “GEN_MEC_INT_01 - Linear weighting",

  the input parameters of which are :

  * Xmin = Exp_Sigma0Ku_Sigma0_Min
  * Xmax = Exp_Sigma0Ku_Sigma0_Max
  * Xstep = Exp_Sigma0Ku_Sigma0_Step
  * X = Sigma0_Aux_In

  and the output parameters of which are :

  * Index_1 = I1
  * Index_2 = I2
  * W1 = w1
  * W2 = w2
  * The execution status

- Computing the expected Ku-band sigma0, Exp_Sigma0_Ku, by linear interpolation in the input table Exp_Sigma0Ku, using mechanism "GEN_MEC_INT_02 - Linear interpolation",

  the input parameters of which are :

  * X1 = Exp_Sigma0Ku(0,I1)
  * X2 = Exp_Sigma0Ku(0,I2)
  * W1 = w1
  * W2 = w2

  and the output parameter of which are :

  * Exp_Sigma0_Ku
  * the execution status

- Computing the uncertainty on expected Ku-band Sigma0, RMS_Exp_Sigma0_Ku, by linear interpolation in the input table Exp_Sigma0Ku, using mechanism "GEN_MEC_INT_02 - Linear interpolation",

  the input parameters of which are :

  * X1 = Exp_Sigma0Ku(1,I1)
  * X2 = Exp_Sigma0Ku(1,I2)
  * W1 = w1
  * W2 = w2

  and the output parameter of which are :

  * RMS_Exp_Sigma0_Ku
  * the execution status

- Rain_Att = Exp_Sigma0_Ku – Sigma0_Ku (2)

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– If { [(Exp_Sigma0_Ku – Sigma0_Ku) > MIN(Rain_Coef∗RMS_Exp_Sigma0_Ku, Rain_Delta_Sigma0)] AND [Cloud_Liq_Burd > Rain_Cloud_Liq] }, then :

∗ Rain_Flag is set to “rain”.

ACCURACY

This rain flag is believed to be more accurate than the previous rain flag from TOPEX/POSEIDON TMR (see Tournadre and Morland, 1998).

COMMENTS

For Jason-1, initial values for Rain_Coef, Rain_Cloud_Liq and Rain_Delta_Sigma0 are 1.8, 0.2 kg/m2 and 0.5 dB respectively. For Envisat, initial values for Rain_Coef, Rain_Cloud_Liq and Rain_Delta_Sigma0 are 1.8, 0.2 kg/m2 and 0.5 dB respectively.

REFERENCES

- Tournadre, J., and J.C. Morland, The effects of rain on TOPEX/POSEIDON Altimeter data, IEEE Trans. Geosci. Remote Sensing, vol. 35, pp 1117-1135, 1998.

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GEN_ENV_SUR_02 - To compute the ice flag

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON

FUNCTION

To compute the ice flag from climatologic estimates of the latitudinal boundary of the ice shelf, and from altimeter windspeed.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The computation of the ice flag will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - 1-Hz altimeter time tag
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Latitude of the measurement (1 Hz)
    - Longitude of the measurement (1 Hz)
  - From "ALT_PHY_WIN_02 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Gourrion et al., 2000)" :
    - 10 meter altimeter windspeed
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Table providing as function of altimeter longitude the 12 values of ice shelf latitude boundary (one value per month) for northern and southern hemisphere.
  - Processing parameters

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Output data

- Ice flag

Mathematical statement

Given the month, the latitude and the longitude of the altimeter measurement, a check is made on the input climatological table if ice is expected for this location and time. If ice is expected, then if the altimeter windspeed is less than 1 m/s, the ice flag is set.

ALGORITHM SPECIFICATION

Input data

- The month of the altimeter measurement : Month (months)
- The location of the altimeter measurement:
  - Latitude : Alt_Lat_Mean (degree)
  - Longitude : Alt_Lon_Mean (degree)
- Altimeter windspeed : Alt_Wind (m/s)
- Ice latitude boundary table : Ice_Bound[0:1][0:11][0: 35] (degree)

Output data

- Ice flag : Ice_Flag[1] (/)
- Execution status

Processing

- If Alt_Lat_Mean < 0, then:
  - I = 0 (1)

  Else:
  - I = 1 (2)
- J = Month – 1 (3)
- K = INT(Alt_Lon_Mean/10.) (4)
- Lat_Ice_Bound = Ice_Bound(I,J,K) (5)
- If ABS(Alt_Lat_Mean) ≤ ABS(Lat_Ice_Bound), then:
  - Ice_Flag is set to “no ice” (6)
- Else :
  - If Alt_Wind is set to its default value, then :

---

[1] Two states : “ice”, or “no ice”

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- ∗ Ice_Flag is set to “ice” (7)
- – Else :
  - ∗ If Alt_Wind < 1, then :
    - ◊ Ice_Flag is set to “ice” (8)
  - ∗ Else :
    - ◊ Ice_Flag is set to “no ice” (9)

ACCURACY

TBD

COMMENTS

None

REFERENCES

None

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RAD_PHY_GEN_02 - To compute the MWR geophysical parameters at RA-2 time tag

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

ERS-1, ERS-2

FUNCTION

To compute the MWR geophysical parameters (wet tropospheric correction, water vapor and cloud liquid water contents) at RA-2 time tag.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the MWR geophysical parameters will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "RAD_MAN_INT_01 - To interpolate radiometer data to altimeter time tags":
    - Interpolated MWR brightness temperatures
  - From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients":
    - Ku-band ocean backscatter coefficient
    - Ku-band ocean backscatter coefficient validity flag

REFMERGEFORMATREFMERGEFORMATDynamic auxiliary data: None

- Static auxiliary data:
  - Processing parameters

Output data

- Radiometer wet tropospheric correction: Wet_H_Rad

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- Water vapor content: Vap_cont
- Cloud liquid water content: Cloud_Liq

Mathematical statement

The radiometer wet tropospheric correction (Wet_H_Rad), the water vapor content (Vap_Cont) and the cloud liquid water content (Cloud_Liq) are given by:

$$Wet_H_Rad = a_0 + a_1.Log_e(280 - TB23) + a_2.Log_e(280 - TB36) + a_3.\frac{1}{Sigma0_Ku} \quad (1)$$

$$Cloud_Liq = b_0 + b_1.Log_e(280 - TB23) + b_2.Log_e(280 - TB36) + b_3.\frac{1}{Sigma0_Ku} \quad (2)$$

$$Vap_Cont = c_0 + c_1.Log_e(280 - TB23) + c_2.Log_e(280 - TB36) + c_3.\frac{1}{Sigma0_Ku} \quad (3)$$

where TB23 and TB36 are the 23.8 GHz and 36.5 GHz interpolated brightness temperatures (in K), Sigma0_Ku is the altimeter Ku-band backscatter coefficient (in dB), and where a_i, b_i and c_i are retrieval coefficients.

ALGORITHM SPECIFICATION

Input data

- Interpolated MWR 23.8 GHz brightness temperature : MWR_TB23_Int (K)
- Interpolated MWR 36.5 GHz brightness temperature : MWR_TB36_Int (K)
- Ku-band backscatter coefficient : Sigma0_Ku (dB)
- MWR to RA-2 interpolation quality flag : Rad_To_Alt_Qual_Interp
- Ku-band backscatter coefficient validity flag : Flag_Valid_Sigma0_Ku[(1)] (/)
- Retrieval coefficients for water vapor : Coef_c0 (kg/m^2)
  Coef_c1 ((kg/m^2)/K)
  Coef_c2 ((kg/m^2)/K)
  Coef_c3 (kg/(dB))
- Retrieval coefficients for liquid water : Coef_b0 (kg/m^2)
  Coef_b1 ((kg/m^2)/K)
  Coef_b2 ((kg/m^2)/K)
  Coef_b3 (kg/(dB))

(1) Two states : “valid”, or “invalid”

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- Retrieval coefficients for wet tropospheric correction : Coef_a0 (m)
  Coef_a1(m/K)
  Coef_a2(m/K)
  Coef_a3(m/(dB))
- The Sigma0_Ku value corresponding to the windspeed climatological value : Sigma0_Ku_Clim (dB)
- Processing mode : Proc_Mode (/)

Output data

- MWR wet tropospheric correction : Wet_H_Rad (m)
- Water vapor content : Vap_cont (kg/m^2)
- Cloud liquid water content : Cloud_Liq (kg/m^2)
- Execution status

Processing

- If the processing mode is not set to "RA-2 + MWR", or if the MWR to RA-2 interpolation quality flag is set to "fail", or if one of the input brightness temperatures is > 279.9, then the processing is not performed.
- Else, the processing consists of computing the MWR wet tropospheric correction Wet_Hrad, the MWR water vapor content Vap_Cont, the MWR liquid water content Cloud_Liq, from the input brightness temperatures MWR_TB23_Int and MWR_TB36_Int, and from the input RA-2 Ku-band backscatter coefficient, Sigma0_Ku :
  - If Flag_Valid_Sigma0_Ku is set to "invalid", then:
    - Sigma0_Ku_In = Sigma0_Ku_Clim (1)

    Else:
    - Sigma0_Ku_In = Sigma0_Ku (2)
  - Wet_Hrad = Coeff_a_0 + Coeff_a_1 ∗ $\mathrm{Log_e}$(280 – MWR_TB23_Int) + Coeff_a_2 ∗ $\mathrm{Log_e}$(280 – MWR_TB36_Int)

$$+ \text{Coeff_a}_3 * \frac{1}{(\text{Sigma0_Ku_In})^2} \quad (3)$$

  - If Wet_Hrad ≥ - 0.08 m, then (correction in case of dry atmosphere) :
    - Wet_Hrad = 1.25∗Wet_Hrad + 0.02 (4)
  - Vap_Cont = Coeff_c_0 + Coeff_c_1 ∗ $\mathrm{Log_e}$(280 – MWR_TB23_Int) + Coeff_c_2 ∗ $\mathrm{Log_e}$(280 – MWR_TB36_Int)

$$+ \text{Coeff_c}_3 * \frac{1}{(\text{Sigma0_Ku_In})^2} \quad (5)$$

  - Cloud_Liq = Coeff_b_0 + Coeff_b_1 ∗ $\mathrm{Log_e}$(280 - TB23_Int) + Coeff_b_2 ∗ $\mathrm{Log_e}$(280 - TB36_Int)

$$+ \text{Coeff_b}_3 * \frac{1}{(\text{Sigma0_Ku_In})^2} \quad (6)$$

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ACCURACY

In the above three equations, the correction term due to wind speed is small (for example, a_3 is about 1.3 mm per m/s). The radiometer wet tropospheric correction accuracy is about 1 to 2 cm, and the water vapor content accuracy is about 0.3 g/cm^2. The cloud liquid water accuracy has never been assessed, due to the lack of comparison data.

COMMENTS

None

REFERENCES

- In flight calibration/validation of the Envisat MWR. Estelle Obligis, Report of WP3000 of ESA contract N° 13681/99/NL/GD, CLS/DOS/NT/01.378, 30 March 2001.

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GEN_COR_RAN_01 - To compute the 10 meter wind vector, and the wet and dry tropospheric corrections from ECMWF model

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To compute at the altimeter time tag and location the 10 meter wind vector components U (zonal component) and V (meridian component), the wet and dry tropospheric corrections due to gases of the troposphere, and the surface pressure and mean sea surface pressure from the ECMWF meteorological model fields.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the ECMWF model derived parameters will be performed for all surface types (over land and ocean).

ALGORITHM DEFINITION

Input data

- Product data:
  - For JASON-1:
    - 1-Hz altimeter time tag
- Computed data:
  - For ENVISAT:
    - From "ALT_COM_TIM_01 - To compute the averaged time tags":
      - 1-Hz altimeter time tag
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement (1 Hz)
      - Longitude of the measurement (1 Hz)

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- From "GEN_ENV_SUR_01 - To determine the surface type":
  - Surface type ("open ocean or semi-enclosed seas", "enclosed seas or lakes", "continental ice", or "land")

- Dynamic auxiliary data:
  - Meteorological data: U and V components of the 10 meter wind vector, dry tropospheric correction, wet tropospheric correction, surface pressure and mean sea surface pressure. For each of these 6 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, nonregular in longitude).
  - Map of the altitude of meteorological grid points (on the same geographical grid as for the meteorological data).
  - Table providing the latitudes of the model grid points
  - Table providing the number of grid points in longitude for each model latitude
- Static auxiliary data:
  - None

Output data

For ENVISAT and JASON-1, at the altimeter measurement time tag and location:

- U-component of the 10 meter model wind vector.
- V-component of the 10 meter model wind vector.
- Dry tropospheric correction: δh_{dry}
- Model wet tropospheric correction: δh_{wet}
- Surface pressure
- Mean sea surface pressure

Mathematical statement

The wet and dry tropospheric corrections, 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 nonregular in longitude (the number of grid points in longitude increases towards lower latitudes). 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 (to avoid wrong tropospheric correction to be computed over ocean due to a grid point over high land altitude). 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, whatever their altitude is. Hereafter are detailed the mathematical statement used at Météo-France to compute the surface pressure map and the wet tropospheric correction map. The input data for computing these maps at Météo-France are the model surface pressure, and the specific humidity and temperature profiles from the vertical levels of the ECMWF model in its most recent version.

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

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:

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

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:

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

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

$$N(z) = 77.6\, \frac{P_d}{T} + 72\, \frac{e}{T} + 3.75\, 10^5\, \frac{e}{T^2} \tag{3}$$

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:

$$\text{For dry air: } \frac{P_d}{\tilde{n}_d} = \frac{RT}{M_d} \tag{4}$$

$$\text{For water vapor: } \frac{e}{\tilde{n}_w} = \frac{RT}{M_w} \tag{5}$$

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:

$$N(z) = 77.6\, R \frac{\tilde{n}_d}{M_d} + 72\, R\, \frac{\tilde{n}_w}{M_w} + 3.75\, 10^5\, \frac{e}{T^2} \tag{6}$$

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

$$\rho = \rho_d + \rho_w \tag{7}$$

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

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$$N(z) = 77.6\ R\frac{\tilde{n}}{M_d} + (72 - 77.6\ \frac{M_w}{M_d})\ R\ \frac{\tilde{n}_w}{M_w} + 3.75\ 10^5\ \frac{e}{T^2} \tag{8}$$

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

$$N(z) = 77.6\ R\frac{\tilde{n}}{M_d} + (72 - 77.6\ \frac{M_w}{M_d})\ \frac{e}{T} + 3.75\ 10^5\ \frac{e}{T^2} \tag{9}$$

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

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

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

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

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

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

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:

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

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:

$$\delta h_{dry} = 77.6\ 10^{-6}\ \frac{R}{M_d}\int_{0}^{Psurf}\frac{1}{g}dP \tag{15}$$

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The dry tropospheric correction map given by Météo-France is computed from (15).

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

$$g = g_0 . [1 - 0.0026 \cos(2\phi) - 0.00031 z] \tag{16}$$

where ϕ is the latitude, z is altitude in km, and g_0 = 9.80665 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/s^2 constant with altitude. This leads to the final expression for δh_{dry}:

$$\delta h_{dry} = -2.277\, P_{surf} . [1 + 0.0026 \cos(2\phi)] \tag{17}$$

(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°).

Calculation of the surface pressure map at Météo-France

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 at Météo-France from P_{sol} using (18):

$$P_{surf} = P_{sol} . \left(\frac{T_{sol} + \tilde{a}(H - H_{sol})}{T_{sol}} \right)^{-\frac{M_a g}{R \tilde{a}}} \tag{18}$$

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:

$$T_{sol} = T_{lev} . \left(1 + \frac{R\tilde{a}}{M_a\, g} \left(\frac{P_{sol}}{P_{lev}} - 1 \right) \right) \tag{19}$$

Calculation of the wet tropospheric correction map at Météo-France:

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

$$q = \frac{\tilde{n}_w}{\tilde{n}_d + \tilde{n}_w} \tag{20}$$

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

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

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 an 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}:

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

The wet tropospheric correction map given by Météo-France is computed from (22), where EMBEDEMBEDthe 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.

ALGORITHM SPECIFICATION

Warning: The preparation of Meteo data is considered as part of "data management" algorithms (see section 1). It is specified in RD12.

Input data

- UTC Time of the altimeter measurement : Alt_Time_Tag_Mean (seconds elapsed since 01/01/1950 0 h.)
- Location of the altimeter measurement:
  - Latitude : Alt_Lat_Mean (degree)
  - Longitude : Alt_Lon_Mean (degree)
- Altimeter surface type [(1)] : Alt_Surf_Type (/)

[(1)] 4 states (“open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, “land”).

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- For I = 0 to 1 (i.e. for the former and for the later grids):
  - Number of grid points : Nb_Pts(I) (/)
  - Number of model latitudes : Nb_Lat(I) (/)
  - Longitude of the first grid point : Lon_First(I) (degrees)
  - Table providing the latitudes of the model grid points : Tab_Lat(I)(0:Nb_Lat(I)-1) (/)
  - Table providing the number of grid points in longitude for each model latitude: Tab_Nb_Lon(I)(0:Nb_Lat(I)-1) (/)
  - Altitude of ECMWF grid points : Grid_Alt(I)(0:Nb_Pts(I)-1) (m)
  - Date of the ECMWF grid : Date_Grid(I) (seconds elapsed since 01/01/1950 0 h.)
  - ECMWF model mean sea surface pressure data, Mean_SSP(I) (Pa)
  - ECMWF model grid data, ECMWF(I,J,K), with J = 0 for the U-component of the model surface wind (units = m/s), J = 1 for the V-component of the model surface wind (units = m/s), J = 2 for the dry tropospheric correction (units = m), J = 3 for the wet tropospheric correction (units = m), and J = 4 for the surface pressure (units = Pa), and with K = 0 to Nb_Pts(I)-1.

Output data

- U-component interpolated under the satellite track : U_Comp_Int (m/s)
- V-component interpolated under the satellite track : V_Comp_Int (m/s)
- Dry tropospheric correction : Dry_Tropo (m)
- Wet tropospheric correction : Wet_Tropo (m)
- Surface pressure : P_{surf} (Pa)
- Mean sea surface pressure : P_{bar} (Pa)
- Number of points used in the bilinear interpolation : Nb_points_used (/)
- Execution status

Processing

- For I = 0 to 1 (i.e. for the former and for the later grids):
  - Computing the indexes which identify in the input vectors the four grid points surrounding the altimeter point, using mechanism “GEN_MEC_GRI_02 - Meteo cell identification”,

    the input parameters of which being:
    - The latitude of the altimeter measurement : Alt_Lat_Mean (degree)
    - The longitude of the altimeter measurement : Alt_Lon_Mean (degree)
    - The longitude of the first grid point : Lon_First(I) (degrees)
    - The number of model latitudes : Nb_Lat(I)
    - The table providing the latitudes of the model grid points : Tab_Lat(I)(0:Nb_Lat(I)-1)
    - The table providing the number of grid points in longitude for each model latitude: Tab_Nb_Lon(I)(0:Nb_Lat(I)-1)

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and the output parameters of which being:

- The cell vector, C(0:3), made of the four indexes which identify the four grid points surrounding the altimeter point.
- The weight vector, W(0:3), made of the weights of these four grid points in the bilinear interpolation at the altimeter point.
- The execution status

– Nb_points_used = 4 (1)

– For K = 0 to 3: W_Grid(K) = W(K) (2)

– If the altimeter surface type is set to “open ocean or semi-enclosed seas”, eliminating the grid points over non ocean surface (by checking if the grid point altitude above mean sea level is > 0) by setting their weights to 0:

- For K = 0 to 3, if Grid_Alt(I)(C(K)) > 0, then:
  - W_Grid(K) = 0 (3)
  - Nb_points_used = Nb_points_used – 1 (4)
- If Nb_points_used = 0, then (i.e., if all grid points are on land, keeping all the grid points):
  - For K = 0 to 3: W_Grid(K) = W(K) (5)

– For J = 0 to 4 (i.e. for the U-component of wind, for the V-component of wind, for the dry tropospheric correction, for the wet tropospheric correction, and for the surface pressure):

Computing the ECMWF data at altimeter location by bilinear interpolation, using mechanism “GEN_MEC_INT_03 - Bilinear interpolation”,

the input parameters of which being:

- VAL_LL = ECMWF(I,J,C(0))
- VAL_LR = ECMWF(I,J,C(1))
- VAL_UL = ECMWF(I,J,C(2))
- VAL_UR = ECMWF(I,J,C(3))
- W_LL = W_Grid(0)
- W_LR = W_Grid(1)
- W_UL = W_Grid(2)
- W_UR = W_Grid(3)
- NIL = 0

and the output parameters of which being:

- The parameter interpolated in space at altimeter measurement ECMWF_Int_Space(I,J)
- The number of valid cell points used by the interpolation (unused)
- The execution status

- Computing the weights of linear interpolation in time, using mechanism "GEN_MEC_INT_01 - Linear weighting",

the input parameters of which are :

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- Xmin = Date_Grid(0)
- Xmax = Date_Grid(1)
- Xstep = Date_Grid(1) – Date_Grid(0)
- X = Alt_Time_Tag_Mean

and the output parameters of which are :

- Index_1 (unused)
- Index_2 (unused)
- W1 = w1
- W2 = w2
- The execution status

- For J = 0 to 4 (i.e. for the U-component of wind, for the V-component of wind, for the dry tropospheric correction, for the wet tropospheric correction and for the surface pressure):

  Computing by linear interpolation in time the parameters at altimeter time, using mechanism “GEN_MEC_INT_02 - Linear interpolation”,

  the input parameters of which being:

  - X1 = ECMWF_Int_Space(0,J)
  - X2 = ECMWF_Int_Space(1,J)
  - W1 = w1
  - W2 = w2

  and the output parameters of which is:

  - ECMWF_Int_Space_Time(J)
  - The execution status

- Computing by linear interpolation in time the mean sea surface pressure at altimeter time, using mechanism “GEN_MEC_INT_02 - Linear interpolation”,

  the input parameters of which being:

  - X1 = Mean_SSP(0)
  - X2 = Mean_SSP(1)
  - W1 = w1
  - W2 = w2

  and the output parameters of which is:

  - P_{bar}
  - The execution status

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ACCURACY

The best accuracy for wind vector varies from about 2 m/s in modulus and 20° in direction in the northern Atlantic to more than 5 m/s in modulus and 40° in direction in the southern Pacific. The error introduced by space and time interpolation under the satellite track is probably small compared with the intrinsic inaccuracy of the wind vector.

The accuracy of the dry tropospheric correction primarily depends on the accuracy of the surface pressure. The best accuracy for surface pressure is achieved for analyzed fields. Typical errors vary from 1 hPa in northern Atlantic to more than 10 hPa in southern Pacific. A 1 hPa error on pressure translates to a 2 mm error on the dry tropospheric correction. The error introduced by space and time interpolation under the satellite track is probably small compared with the intrinsic inaccuracy of the surface pressure. For land surfaces, additional error is induced by the calculation of the surface pressure from the upper level pressure, due to assumptions on the mean virtual temperature of the atmospheric layer between the surface and the first upper level above the ground surface, and due to inaccurate knowledge of the TerrainBase digital elevation model (DEM) used for computing the altitude of the grid points above mean sea level. This additional error may be as large as the intrinsic error of the upper level pressure.

The mean standard deviation of the difference between radiometer-derived and model-derived wet tropospheric corrections is about 3 cm. This is a mean value over the global ocean. Larger model errors are found in the tropics (up to 10-cm errors) and smaller ones in high latitudes.

COMMENTS

The mean sea surface pressure is recorded in the output product header. It is used together with the surface pressure for the inverted barometer height calculation.

REFERENCES

- Bean, B. R., and E. J. Dutton, Radio Meteorology, U.S. NBS Monogr., 92, March 1966.
- Saastamoinen, J., 1972: Atmospheric correction for the troposphere and stratosphere in radio ranging of satellites, Geophys. Monogr., 15, American Geophysical Union, Washington D.C.

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GEN_ENV_MET_02 - To compute the inverted barometer effect

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON

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.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the inverted barometer effect will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - For JASON-1 and ENVISAT:
    - From "GEN_COR_RAN_01 - To compute the 10 meter wind vector, and the wet and dry tropospheric corrections from ECMWF model":
      - Surface atmospheric pressure p
      - Mean sea surface atmospheric pressure over the global oceans $\overline{p}$
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Parameter b

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Output data

- Inverted barometer height: H_Baro

Mathematical statement

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

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

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.

ALGORITHM SPECIFICATION

Input data

- Surface atmospheric pressure : P_{surf} (Pa)
- Parameter b : Coef_b (m/Pa)
- Global mean sea level atmospheric pressure : P_{bar} (Pa)

Output data

- Inverted barometer height : Inv_Baro (m)
- Execution status

Processing

$$Inv_Baro = - Coef_b * (P_{surf} - P_{bar}) \quad (1)$$

ACCURACY

Extensive modeling work by Ponte et al. (1991) confirms that over most open ocean regions the ocean response to atmospheric pressure forcing is mostly static. Typical deviations from the inverted barometer response are in the range of 1 to 3 cm rms, with most of the variance occurring at high frequencies. The Inverted barometer correction is not reliable for pressure variations with very short periods (< 2 days) and in coastal regions.

This inverted barometer height calculation uses a non constant mean reference sea surface pressure. As stated by Dorandeu and Le Traon (1999), this improved inverted barometer height correction reduces the standard deviation of mean sea level variations (relative to an annual cycle and slope) by more than 20% when compared with the standard inverted barometer height correction (i.e. with constant reference pressure) and no correction at all. It also slightly reduces the variance of sea surface height differences at altimeter crossover points, and the impact of the improved correction on the mean sea level annual cycle and slope is also significant.

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COMMENTS

None

REFERENCES

- Ponte, R.M., D.A. Salstein and R.D. Rosen, Sea level response to pressure forcing in a barotropic numerical model. J. Phys. Oceanog., 21, 1043-1057, 1991
- Dorandeu, J., and P.Y. Le Traon, Effects of global mean atmospheric pressure variations on mean sea level changes from TOPEX/POSEIDON, accepted for publication in J. Atmos. Ocean. Technology, 1999.

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ALT_COR_RAN_10 - To compute the sea state biases

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON, ERS-1, ERS-2

FUNCTION

To compute the sea state bias in the main frequency band (Ku band) and in the auxiliary frequency band (C or S band). The sea state bias is the difference between the apparent sea level as "seen" by an altimeter and the actual mean sea level.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the sea state bias will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - For ENVISAT:
    - From "ALT_COM_SWH_01 - To edit and compress the on-ground retracked significant waveheights":
      - Ku-band significant waveheight (SWH_Ku)
      - Ku-band ocean significant waveheight validity flag
    - From "ALT_PHY_WIN_01 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Witter and Chelton, 1991)" :
      - Wind speed corrected for atmospheric attenuation (W)
  - For JASON-1:
    - From "ALT_COR_SWH_02 - To compute the corrected on-ground retracked significant waveheights":
      - Ku-band significant waveheight (SWH_Ku)
    -

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- From "ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH":
  - Ku-band ocean significant waveheight validity flag
- From "ALT_PHY_WIN_02 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Gourrion et al., 2000)" :
  - Wind speed corrected for atmospheric attenuation (W)

REFMERGEFORMATDynamic auxiliary data: None

- Static data:
  - Sea state bias table.

Output data

For ENVISAT and JASON-1:

- Sea state bias in main band: SSB_Ku
- Sea state bias in auxiliary band: SSB_Aux (Aux = S for ENVISAT, Aux = C for JASON-1)

Mathematical statement

EMBEDAs a first algorithm version, the SSB will be bilinearly interpolated from a table that is provided as a function of SWH_Ku and W, with same values for Ku-band and auxiliary band.

For JASON-1, the SSB table will be derived from the non parametric estimate by Gaspar and Florens (1998), using TOPEX data from cycles 21 to 131.

For ENVISAT, the table will be derived from the BM3 model by Gaspar and Ogor (1996) used for ERS-2 OPR altimeter data.

ALGORITHM SPECIFICATION

Input data

- Significant waveheight for Ku-band : SWH_Ku (m)
- Ku-band significant waveheight validity flag : Flag_Valid_SWH_Ku[1] (/)
- Altimeter windspeed : Alt_Wind (m/s)
- Number of table points of the SSB table in the SWH axis : SSB_Nb_SWH (/)
- Number of table points of the SSB table in the Wind axis : SSB_Nb_Wind (/)
- Table for the calculation of SSB : SSB[I][0:SSB_Nb_SWH-1][0:SSB_Nb_Wind-1] (m), with I = 0 for Ku-band, and I = 1 for auxiliary band.
- SWH step in SSB table : SSB_SWH_Step (m)

---

[1] Two states : "valid", or "invalid"

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- First tabulated SWH in SSB table : SSB_SWH_First (m)
- Wind step in SSB table : SSB_Wind_Step (m/s)
- First tabulated wind in SSB table : SSB_Wind_First (m/s)
- SSB default value : SSB_Def_Value (/)

Output data

- SSB for Ku-band : SSB_Ku (m)
- SSB for auxiliary-band : SSB_Aux (m)
- Execution status

Processing

- If the Ku-band significant waveheight validity flag is set to "valid", the processing consists of:

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- Computing the indexes of the four surrounding grid points in the SSB table, using mechanism "GEN_MEC_GRI_01 -Cell identification",

  the input parameters of which being:

  - X = SWH_Ku
  - Y = Alt_Wind
  - DX = SSB_SWH_Step
  - DY = SSB_Wind_Step
  - XFIR = SSB_SWH_First
  - YFIR = SSB_Wind_First
  - Nb_PtX = SSB_Nb_SWH
  - Nb_PtY = SSB_Nb_Wind
  - XCYC = 0
  - YCYC = 0
  - XCUT = 1
  - YCUT = 1

  and the output parameters of which being:

  - the indexes of the four grid points surrounding the (SWH_Ku, Alt_Wind) point: I_L, I_R, J_L, J_U
  - the weights of these four points: W_LL, W_LR, W_UL, W_UR
  - the execution status

- Computing the SSB correction for Ku-band at measurement (SWH_Ku, Alt_Wind) by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

  the input parameters of which being:

  - VAL_LL = SSB(0,I_L,J_L)
  - VAL_LR = SSB(0,I_R,J_L)
  - VAL_UL = SSB(0,I_L,J_U)
  - VAL_UR = SSB(0,I_R,J_U)
  - W_LL
  - W_LR
  - W_UL
  - W_UR
  - NIL = SSB_Ku_Def_Value

  and the output parameters of which being:

  - SSB_Ku
  - The number of valid cell points used by the interpolation (unused)
  - The execution status

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– Computing the SSB correction for auxiliary-band at measurement (SWH_Ku, Alt_Wind) by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

the input parameters of which being:

* VAL_LL = SSB(1,I_L,J_L)
* VAL_LR = SSB(1,I_R,J_L)
* VAL_UL = SSB(1,I_L,J_U)
* VAL_UR = SSB(1,I_R,J_U)
* W_LL
* W_LR
* W_UL
* W_UR
* NIL = SSB_Aux_Def_Value

and the output parameters of which being:

* SSB_Aux
* The number of valid cell points used by the interpolation (unused)
* The execution status

ACCURACY

The underlying physics of the sea state bias is not completely understood. The estimated global RMS accuracy is about 2 cm.

COMMENTS

NoneREFMERGEFORMAT

REFERENCES

- Gaspar, P., and J.P. Florens, 1998 : Estimation of the sea state bias in radar altimeter measurements of sea level : Results from a new nonparametric method.J. Geophys. Res, Vol 103, NO. C8, 15803-15814.
- Gaspar, P., and F. Ogor, 1996: Estimation and analysis of the Sea State Bias of the new ERS-1 and ERS-2 altimetric data (OPR version 6). Report of task 2 of IFREMER Contract n° 96/2.246002/C.

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ALT_COR_RAN_11 - To compute the composite sea state bias

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

None

FUNCTION

To compute the composite sea state bias.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	/	/
JASON-1	Yes	/

- Surface type:

  The computation of the composite sea state bias will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "ALT_COR_SWH_02 - To compute the corrected on-ground retracked significant waveheights":
    - Ku-band significant waveheight (SWH_Ku)
    - C-band significant waveheight (SWH_C)
  - From "ALT_COM_SWH_02 - To edit and compress the on-ground retracked composite Sigma and to derive SWH":
    - Ku-band ocean significant waveheight validity flag
    - C-band ocean significant waveheight validity flag
  - From "ALT_PHY_WIN_02 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Gourrion et al., 2000)" :
    - Ku-band backscatter coefficient corrected for atmospheric attenuation (σ_0_Ku)
    - C-band backscatter coefficient corrected for atmospheric attenuation (σ_0_S/C)
    - Wind speed corrected for atmospheric attenuation (W)

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- From "GEN_COR_RAN_01 - To compute the 10 meter wind vector, and the wet and dry tropospheric corrections from ECMWF model":
  - U-component of the 10 meter model wind vector (zonal component)
  - V-component of the 10 meter model wind vector (meridian component)
- Dynamic auxiliary data: None
- Static data:
  - Composite SSB table

Output data

- Composite sea state bias: SSB_comp

Mathematical statement

The composite sea state bias is computed (in mm) by:

$$SSB_comp = h(c_i, SWH_Ku, \sigma_0_Ku, SWH_C, \sigma_0_C, U, V, W) \quad (1)$$

where h is a function provided either under analytical form or under tabulated form. As a first algorithm version, the composite SSB will be bilinearly interpolated from a table that is provided as a function of SWH_Ku and W.

ALGORITHM SPECIFICATION

Input data

- Significant waveheight for Ku-band : Mean_SWH_Ocean_Ku (m)
- Ku-band significant waveheight validity flag : Flag_Valid_SWH_Ku (/)
- Interpolated model wind vector components : Ucomp_Int and Vcomp_Int (m/s)
- Ku-band corrected ocean backscatter coefficient : Sigma0_Ku_Corr (dB)
- Auxiliary band corrected ocean backscatter coefficient : Sigma0_Aux_Corr (dB)
- Altimeter windspeed : Alt_Wind (m/s)
- Number of table points of the SSB_Comp table in the SWH axis : SSB_Comp_Nb_SWH (/)
- Number of table points of the SSB_Comp table in the Wind axis : SSB_Comp_Nb_Wind (/)
- Table for the calculation of SSB_Comp: SSB_Comp[0:SSB_Comp_Nb_SWH-1][0:SSB_Comp_Nb_Wind-1] (m)
- SWH step in SSB_Comp table : SSB_Comp_SWH_Step (m)
- First tabulated SWH in SSB_Comp table : SSB_Comp_SWH_First (m)
- Wind step in SSB_Comp table : SSB_Comp_Wind_Step (m/s)
- First tabulated wind in SSB_Comp table : SSB_Comp_Wind_First (m/s)
- SSB_Comp default value : SSB_Comp_Def_Value (/)

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Output data

- Composite SSB : SSB_Comp (m)
- Execution status

Processing

- If the Ku-band significant waveheight validity flag is set to "valid", the processing consists of:
  - Computing the indexes of the four surrounding grid points in the SSB_Comp table, using mechanism "GEN_MEC_GRI_01 - Cell identification",

    the input parameters of which being:

    * X = SWH_Ku
    * Y = Alt_Wind
    * DX = SSB_Comp_SWH_Step
    * DY = SSB_Comp_Wind_Step
    * XFIR = SSB_Comp_SWH_First
    * YFIR = SSB_Comp_Wind_First
    * Nb_PtX = SSB_Comp_Nb_SWH
    * Nb_PtY = SSB_Comp_Nb_Wind
    * XCYC = 0
    * YCYC = 0
    * XCUT = 1
    * YCUT = 1

    and the output parameters of which being:

    * the indexes of the four grid points surrounding the (SWH_Ku, Alt_Wind) point: I_L, I_R, J_L, J_U
    * the weights of these four points: W_LL, W_LR, W_UL, W_UR
    * the execution status
  - Computing the composite SSB correction at measurement (SWH_Ku, Alt_Wind) by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

    the input parameters of which being:

    * VAL_LL = SSB_Comp(I_L,J_L)
    * VAL_LR = SSB_Comp(I_R,J_L)
    * VAL_UL = SSB_Comp(I_L,J_U)
    * VAL_UR = SSB_Comp(I_R,J_U)
    * W_LL
    * W_LR

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* W_UL
* W_UR
* NIL = SSB_Comp_Def_Value

and the output parameters of which being:

* SSB_Comp
* The number of valid cell points used by the interpolation (unused)
* The execution status

ACCURACY

As for the sea state bias, the estimated global RMS accuracy of the composite sea state bias is about 2 cm.

COMMENTS

The computation of the composite sea state bias has been proposed by Gaspar et al. (1997) in a report study dealing with the improvement of sea state bias estimation techniques. A brief recall of the physical background of the composite sea state bias will be done here.

The classical equation for retrieving the sea surface height (SSH) from the altimeter system is the following (the frequency-independent corrections are omitted here for clarity):

$$SSH = H - [R_Ku + SSB_Ku + Iono_Alt_Ku] \quad (1)$$

Where H is the satellite orbit height, R_Ku is the Ku-band altimeter range, SSB_Ku is the Ku-band sea state bias, and Iono_Alt_Ku is the Ku-band ionospheric correction.

This equation implies the computation of the ionospheric correction, Iono_Alt_Ku. This is done by forming the difference between Ku- and C-band ranges, each being corrected for the corresponding Ku- and C-band sea state bias:

$$Iono_Alt_Ku = \delta f_{Ku}.[(R_Ku + SSB_Ku) - (R_C + SSB_C)] \quad (2)$$

with:

$$\delta f_{Ku} = \frac{f_C^2}{f_Ku^2 - f_C^2} \approx 0.1798 \text{ for JASON-1} \quad (3)$$

The computation of the ionospheric correction implies the knowledge of the Ku- and C-band sea state biases. These sea state biases are usually determined from SSH crossover minimization, and thus themselves depend on the ionospheric correction. Another formulation for SSH which is independent of ionospheric correction can be obtained by introducing (2) into (1):

$$SSH = H - [(1 + \delta f_{Ku})R_Ku - \delta f_{Ku}\, R_C] - SSB_comp \quad (4)$$

where:

$$SSB_comp = [(1 + \delta f_{Ku})SSB_Ku - \delta f_{Ku}\, SSB_C] \quad (5)$$

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In (4), the SSH is derived from a simple linear combination of the Ku- and C-band range measurements without any need to determine the ionospheric correction. The chief advantage of (4) is that it relies on the determination of a single SSB: the composite SSB, that can be determined using a classical crossover minimization approach, as is usually done for Ku-band SSB. The disadvantage of (4) is that it makes direct use of noisy C-band range measurements: their filtering should be studied (as was the case for the dual-frequency ionospheric correction derived from (2)). The most accurate method of computing the SSH, between (1) and (4), will be under investigation during the in flight data assessment period.

REFERENCES

- Gaspar, P., J.P. Florens, F. Ogor-Mertz, et D. Bouniol: Etude d'amélioration des techniques d'estimation du biais d'état de mer du radar altimètre. Contrat n° 856/CNES/96/0618/00 (Bon de commande n° 4). CLS/DOS/NT/97.055, Décembre 1997. CLS technical note (in french), available from P. Gaspar, CLS, 8-10 rue Hermès, Parc Technologique de Canal, 31526 Ramonville Cedex.

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ALT_COR_RAN_12 - To compute the dual-frequency ionospheric corrections

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON

FUNCTION

To combine the altimeter ranges in the main frequency band (Ku band) and in the auxiliary frequency band (C or S band), so as to derive the Ku-band ionospheric correction and the auxiliary band ionospheric correction (C or S band). The altimeter ranges are first corrected for sea state bias before being combined.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	See 3.1.4

- Surface type:

  The computation of the dual frequency ionospheric correction will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data (See section "Comments" for JASON-1 GDR processing)

- Product data: None
- Computed data:
  - For ENVISAT:
    - From "ALT_COM_RAN_05 - To edit and compress the on-ground retracked altimeter ranges":
      - Ku-band ocean altimeter range
      - S-band ocean altimeter range
      - Ku-band ocean altimeter range validity flag
      - S-band ocean altimeter range validity flag
  - For JASON-1:
    - From "ALT_COR_RAN_08 - To compute the corrected on-ground retracked altimeter ranges":
      - Ku-band altimeter range
      - C-band altimeter range

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  - From "ALT_COM_RAN_05 - To edit and compress the on-ground retracked altimeter ranges":
    - Ku-band ocean altimeter range validity flag
    - C-band ocean altimeter range validity flag
  - For ENVISAT and JASON-1:
    - From "ALT_COR_RAN_10 - To compute the sea state biases":
    - Ku-band sea state bias correction
    - S/C-band sea state bias correction
- Dynamic data: None
- Static auxiliary data:
  - Processing parameters
  - Altimeter instrumental characterization data (main and auxiliary band emitted frequency for ENVISAT and for JASON-1)

Output data

- For ENVISAT:
  - Ku-band ionospheric correction: Iono_Alt_Ku
  - S-band ionospheric correction: Iono_Alt_S
- For JASON-1:
  - Ku-band ionospheric correction: Iono_Alt_Ku
  - C-band ionospheric correction: Iono_Alt_C

Mathematical statement

The following formulae assume input parameters in mm.

The Ku band and auxiliary band sea state bias corrections are first added to the input Ku band and auxiliary (S for ENVISAT and C for JASON-1) band altimeter ranges to correct them, because these corrections may be different for the two frequencies. Let R_{Ku} 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:

$$R = R_{Ku} + Iono_Alt_Ku \quad (1)$$

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

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

$$Iono_Alt_Ku = -40300.\frac{TEC}{f_Ku^2} \quad \text{(Ku band)} \tag{2}$$

$$Iono_Alt_Aux = -40300.\frac{TEC}{f_Aux^2} \quad \text{(Auxiliary band)}$$

where f_Ku and f_Aux are the emitted frequencies (in Hz, with Aux=S for ENVISAT and Aux=C for JASON-1), and where TEC is the columnar total electron content of the ionosphere, expressed in electrons/m^2.

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

$$\begin{aligned} Iono_Alt_Ku &= \delta f_{Ku}.(R_{Ku} - R_{Aux}) \\ Iono_Alt_Aux &= \delta f_{Aux}.(R_{Ku} - R_{Aux}) \end{aligned} \tag{3}$$

with:

$$\delta f_{Ku} = \frac{f_Aux^2}{f_Ku^2 - f_Aux^2} \approx 0.0588 \text{ for ENVISAT, } 0.1798 \text{ for JASON-1} \tag{4}$$

$$\delta f_{Aux} = \frac{f_Ku^2}{f_Ku^2 - f_Aux^2} \approx 1.0588 \text{ for ENVISAT, } 1.1798 \text{ for JASON-1}$$

ALGORITHM SPECIFICATION

Input data

- Range for Ku-band : Mean_Range_Ocean_Ku (m)
- Range for auxiliary-band : Mean_Range_Ocean_Aux (m)
- Ku-band radar frequency : F_Ku (Hz)
- Auxiliary-band radar frequency : F_Aux (Hz)
- SSB correction for Ku-band : SSB_Ku (m)
- SSB correction for auxiliary-band : SSB_Aux (m)
- Ku-band altimeter range validity flag : Flag_Valid_Range_Ku[(1)] (/)
- Auxiliary-band altimeter range validity flag : Flag_Valid_Range_Aux[(1)] (/)

(1) Two states : “valid”, or “invalid”

(1) Two states : “valid”, or “invalid”

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Output data

- Altimeter-derived ionospheric correction for Ku-band : Iono_Alt_Ku (m)
- Altimeter-derived ionospheric correction for auxiliary-band : Iono_Alt_Aux (m)
- Altimeter-derived total electron content : TEC_Alt (e^-/m^2)
- Execution status

Processing

- If the Ku-band and auxiliary-band altimeter range validity flags are set to "valid", then:
  - Correcting the altimeter ranges for SSB:

$$Rc_Ku = Mean_Range_Ocean_Ku + SSB_Ku \quad (1)$$

$$Rc_Aux = Mean_Range_Ocean_Aux + SSB_Aux \quad (2)$$

  - Computing the RA-2 ionospheric corrections and total electron content:

$$Delta_freq_Ku = \frac{Freq_Aux^2}{Freq_Ku^2 - Freq_Aux^2} \quad (3)$$

$$Delta_freq_Aux = \frac{Freq_Ku^2}{Freq_Ku^2 - Freq_Aux^2} \quad (4)$$

$$Iono_Alt_Ku = Delta_Freq_Ku * (Rc_Ku - Rc_Aux) \quad (5)$$

$$Iono_Alt_Aux = Delta_Freq_Aux * (Rc_Ku - Rc_Aux) \quad (6)$$

$$TEC_Alt = Iono_Alt_Ku * \frac{Freq_Ku^2}{-40.3} \quad (7)$$

- Else: No calculation is performed

ACCURACY

From equation (3) of the mathematical statement, one can derive the standard deviation of Ku band and auxiliary band ionospheric corrections σ(Iono_Alt_Ku) and σ(Iono_Alt_Aux):

$$\sigma(Iono_Alt_Ku) = \delta f_{Ku} \cdot \sqrt{\sigma^2(R_{Ku}) + \sigma^2(R_{Aux})}$$

$$\sigma(Iono_Alt_Aux) = \delta f_{Aux} \cdot \sqrt{\sigma^2(R_{Ku}) + \sigma^2(R_{Aux})}$$

where $\sigma(R_{Ku})$ and $\sigma(R_{aux})$ are respectively the 1-Hz range standard deviation for Ku band and auxiliary band.

The tables below give for JASON-1 and ENVISAT the values of σ(Iono_Alt_Ku) and σ(Iono_Alt_Aux), assuming probable values for Ku band and auxiliary band 1-Hz range standard deviations $\sigma(R_{Ku})$ and $\sigma(R_{Aux})$ as function of waveheight SWH.

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For JASON-1 :

SWH (m)	$\sigma(R_{Ku})$ (cm)	$\sigma(R_C)$ (cm)	σ(Iono_Alt_Ku) (cm)	σ(Iono_Alt_C) (cm)
2	1.21	3.42	0.65	4.26
4	1.59	4.56	0.87	5.71
8	2.35	6.26	1.20	7.87

For ENVISAT :

SWH (m)	$\sigma(R_{Ku})$ (cm)	$\sigma(R_S)$ (cm)	σ(Iono_Alt_Ku) (cm)	σ(Iono_Alt_S) (cm)
2	1.5	4.5	0.3	5.0
4	3.3	10	0.6	11.1
8	5.5	16.5	1.0	18.4

These values represent the expected noise in the retrieved ionospheric corrections, given the noise in the input altimeter ranges.

The range combination algorithm assumes that the other range corrections are independent of the altimeter frequency. For the TOPEX altimeter, the ionospheric correction for the Ku band is given by equation (8) in Imel's paper (Imel, 1994):

$$\Delta r_{ion} = \delta f.[(R_c - b_c) - (R_{Ku} - b_{Ku})] \text{ , with } \delta f = \frac{f_c^2}{f_{Ku}^2 - f_c^2} \approx 0.179 \text{ for TOPEX}$$

In the above equation, Δr_{ion} is the derived ionospheric correction, R_C and R_{Ku} are the measured C and Ku ranges respectively, b_C and b_{Ku} represent all the other potentially frequency-dependent corrections. The above equation shows that an error of 5.5 cm on the difference b_C - b_{Ku} leads to a 1-cm error on the derived ionospheric correction. For the ENVISAT altimeter, the situation is better because the gap between the two bands is larger: an error of 17 cm on the difference b_S - b_{Ku} leads to a 1-cm error on the derived ionospheric correction. Such errors on the difference b_S - b_{Ku} could be due to errors on the absolute range bias difference between the two bands, or due to inaccuracies in the sea state bias parameterization for one of the frequencies.

COMMENTS

Regarding the JASON-1 GDR processing, the update of the dual frequency correction will be performed only if the Doppler correction is updated in the GDR processing. In this case, the input altimeter ranges will be issued from "ALT_COR_RAN_09 - To update the Doppler correction on the altimeter range".

The total electron content, TEC_Alt, is output in e^-/m^2. In the user product, it will be expressed in 10^{-1} TEC units (1 TEC unit = 10^{16} e^-/m^2).

REFERENCES

- Imel, D., Evaluation of the TOPEX/POSEIDON dual-frequency ionosphere correction, J. Geophys. Res., 99, 24,895-24,906, 1994.

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GEN_COR_RAN_03 - To compute the DORIS-derived ionospheric corrections

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON

FUNCTION

To compute the ionospheric corrections from DORIS-derived TEC maps.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	If not done in the IGDR processing

- Surface type:

  The computation of the DORIS ionospheric correction will be performed for all surface types (over land and ocean).

ALGORITHM DEFINITION

Input data

- Product data:
  - For ENVISAT and JASON-1:
    - Pass number of the measurement (indicating if the pass is ascending or descending)
- Computed data:
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement
      - Longitude of the measurement
- Dynamic auxiliary data:
  - DORIS-derived TEC maps (one map for ascending passes, and one map for descending passes)
- Static auxiliary data:
  - Altimeter instrumental characterization data (main and auxiliary band emitted frequency for ENVISAT and for JASON-1)

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Output data

- For ENVISAT:
  - Ku-band DORIS-derived ionospheric correction: Iono_Dor_Ku
  - S-band DORIS-derived ionospheric correction: Iono_Dor_S
- For JASON-1:
  - Ku-band DORIS-derived ionospheric correction: Iono_Dor_Ku
  - C-band DORIS-derived ionospheric correction: Iono_Dor_C

Mathematical statement

The TEC from DORIS maps is interpolated bilinearly in latitude and longitude at the altimeter measurement. It is then used in the two following equations to derive the ionospheric corrections (in mm):

$$\begin{aligned} Iono_Dor_Ku &= -40300.\frac{TEC}{f_Ku^2} \\ Iono_Dor_Aux &= -40300.\frac{TEC}{f_Aux^2} \end{aligned} \qquad (1)$$

where f_Ku and f_Aux are the emitted frequencies (in Hz), with Aux = C for JASON-1, and Aux = S for ENVISAT), and where TEC is the columnar total electron content of the ionosphere, expressed in electrons/m^2.

ALGORITHM SPECIFICATION

Warning: The selection of the appropriate DORIS TEC map according to the pass number of the measurement is considered as part of "data management" algorithms (see section 1). It is specified in RD12.

Input data

- Pass number of the measurement : Pass_Nb (/)
- Location of the measurement:
  - Longitude : Lon (degree)
  - Latitude : Lat (degree)
- The Ku-band radar frequency : F_Ku (Hz)
- The auxiliary-band radar frequency : F_Aux (Hz)
- The DORIS TEC map:
  - Longitude of first grid point : Lon_First (degree)
  - Grid step in longitude : Step_Lon (degree)
  - Number of points in longitude : Nb_Pts_Lon (/)
  - Latitude of first grid point : Lat_First (degree)
  - Grid step in latitude : Step_Lat (degree)

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- Number of points in latitude : Nb_Pts_Lat (/)
- TEC values : DORIS_TEC[0:Nb_Pts_Lon-1][0:Nb_Pts_Lat-1] (10^{15} e^-/m^2)
- Default value in TEC map : Def_Value (/)
- List of pass number covered by the TEC map : Pass_Nb_List[0:N-1] (/)
- Modified equatorial longitude of the passes : Mod_Lon_Eq[0:N-1] (degrees)

Output data

- DORIS-derived ionospheric correction for Ku-band : Iono_Dor_Ku (m)
- DORIS-derived ionospheric correction for auxiliary-band : Iono_Dor_Aux (m)
- Execution status

Processing

- Translation of the measurement longitude to match the TEC map coverage :
  - Selection of the index i of the array Pass_Nb_List corresponding to the pass number of the measurement

    Pass_Nb_List(i) = Pass_Nb
  - Selection of the modified equatorial longitude corresponding to the pass :

    Lon_Eq = Mod_Lon_Eq(i)
  - Translation of the measurement longitude (Lon) to match the equatorial longitude (Lon_Eq)

```
Lon_Mod = Lon
While  ( | Lon_Mod-Lon_Eq| ≥ 180)
        If ( Lon_Mod < Lon_Eq ) then
                Lon_Mod = Lon_Mod + 360
        If ( Lon_Mod > Lon_Eq ) then
                Lon_Mod = Lon_Mod - 360
```

- Computing the indexes of the four surrounding grid points in the map, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

  the input parameters being:
  - X = Lon_Mod
  - Y = Lat
  - DX = Step_Lon
  - DY = Step_Lat
  - XFIR = Lon_First
  - YFIR = Lat_First
  - Nb_Ptx = Nb_Pts_Lon
  - Nb_Pty = Nb_Pts_Lat

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- Xcyc = 0
- Ycyc = 0
- Xcut = 0
- Ycut = 0

and the output parameters of which being:

- The indexes of the four grid corners surrounding the (Lon_Mod,Lat) point: Ileft,Iright,Jlow,Jup
- The weights of these corners: W_LL, W_LR, W_UL, W_UR
- The execution status.

- Computing the TEC at (Lon,Lat) by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

  the input parameters of which being:

  - VAL_LL = DORIS_TEC(Ileft, Jlow)
  - VAL_LR = DORIS_TEC(Iright, Jlow)
  - VAL_UL = DORIS_TEC(Ileft, Jup)
  - VAL_UR = DORIS_TEC(Iright, Jup)
  - W_LL
  - W_LR
  - W_UL
  - W_UR
  - NIL = Def_Value

  and the output parameters of which being:

  - TEC_Dor
  - Nb_Pts_Valid (unused)
  - The execution status

- Computing the Ku-band and auxiliary band DORIS ionospheric corrections :

$$\text{Iono_Dor_Ku} = -40.3\,10^{15}.\frac{\text{TEC}}{\text{F_Ku}^2} \tag{1}$$

$$\text{Iono_Dor_Aux} = -40.3\,10^{15}.\frac{\text{TEC}}{\text{F_Aux}^2} \tag{2}$$

ACCURACY

Comparison with the TOPEX dual-frequency altimeter estimates show that the global mean difference between the two ionospheric corrections (TOPEX and DORIS) is about 1 cm, with a standard deviation less than 2 cm (Le Traon et al., 1996).

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COMMENTS

None

REFERENCES

- Le Traon, P.Y., J.P. Dumont, J. Stum, O.Z. Zanife, J. Dorandeu, P. Gaspar, T. Engelis, C. Le Provost, F. Remy, B. Legresy and S. Barstow, 1996. Multi-mission altimeter inter-calibration study, CLS/ESTEC contract number 11583/95/NL/CN.

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GEN_COR_RAN_02 - To compute the Bent model ionospheric corrections

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J. STUM CLS	
Checked by:	For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
Approved by:	P. VINCENT CNES	

Document ref:	SMM-ST-M2-EA-11005-CN	18th October, 2001	Issue: 3	Update: 3

Algorithm change record	creation	date	Issue:	Update:
	CCM			

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HERITAGE

ERS-1, ERS-2

FUNCTION

To compute the ionospheric path delays for Ku and auxiliary bands due to free electrons of the ionosphere.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the Bent ionospheric correction will be performed for all surface types (over land and ocean).

ALGORITHM DEFINITION

Input data

- Product data:
  - RF subsystem identifier
- Computed data:
  - From "ALT_COM_TIM_01 - To compute the averaged time tags":
    - 1-Hz altimeter time tag
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Latitude of the measurement
    - Longitude of the measurement
- Dynamic auxiliary data:
  - Solar activity data: two monthly sunspot numbers bracketing the time of measurement. (These sunspot numbers should be the observed 12-month running average of the monthly sunspot number. As the observed 12-month running average is available only 6 months after the month of measurement, predicted values are used).

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- Static auxiliary data:
  - Processing parameters:
    - Two monthly coefficients datasets corresponding to the months of the two sunspot numbers (these coefficient datasets are extracted from an input file containing the 12 datasets of coefficients).
    - Tables of parameters
  - RA2 instrumental characterization data

Output data

- Ku-band Bent model ionospheric correction: Iono_Mod_Ku
- S-band Bent model ionospheric correction: Iono_Mod_S
- Sunspot number interpolated to the altimeter time tag

Mathematical statement

The ionospheric corrections are obtained (in mm) by using the first order expansion of the refraction index:

$$\begin{aligned} Iono_Mod_Ku &= -40300.\frac{TEC}{f_Ku^2} \\ Iono_Mod_Aux &= -40300.\frac{TEC}{f_Aux^2} \end{aligned} \qquad (1)$$

where f_Ku and f_Aux are the emitted frequencies (in Hz), with Aux = S (for ENVISAT), and where TEC is the columnar total electron content of the ionosphere, expressed in e^-/m^2. TEC is computed for each altimeter measurement from the Bent model (Llewellyn and Bent, 1973).

ALGORITHM SPECIFICATION

Input data

- TBD

Output data

- TBD
- Execution status

Processing

TBD

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ACCURACY

The ionospheric correction retrieved with the Bent model is accurate to the 2-cm level for low solar activities, but errors as high as 10 cm may occur in high solar activities during the day near the geomagnetic equator.

COMMENTS

None

REFERENCES

- Llewellyn, S.K. and R.B. Bent, 1973: Documentation and description of the Bent ionospheric model, AFCRL-TR-73-0657

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GEN_ENV_TID_05 - To compute the diurnal and semidiurnal elastic ocean tide height and the loading tide height (orthotide algorithm)

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J. STUM CLS	
Checked by:	For the JASON-1 SWT R. RAY E. SCHRAMA For the JASON-1 Project P. VINCENT CNES S. DESAI JPL For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
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Document ref:	SMM-ST-M2-EA-11005-CN	18th October, 2001	Issue: 3	Update: 3

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	CCM			

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HERITAGE

TOPEX/POSEIDON

FUNCTION

To compute the sum total of the diurnal and semidiurnal elastic ocean tide height (i.e., the sum total of the ocean tide height and the respective load tide height over the oceans), and the respective load tide height, from the orthotide algorithm.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the diurnal and semi-diurnal elastic ocean tide height and the respective load tide height from the orthotide algorithm will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - For JASON-1:
    - 1-Hz altimeter time tag
- Computed data:
  - For ENVISAT:
    - From "ALT_COM_TIM_01 - To compute the averaged time tags":
      - 1-Hz altimeter time tag
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement
      - Longitude of the measurement

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- Dynamic auxiliary data: None
- Static auxiliary data:
  - Elastic ocean tide orthoweights map (geographical grid providing at each grid point 6 weighting factors U and 6 weighting factors V).
  - Load tide orthoweights map (geographical grid providing at each grid point 6 weighting factors U and 6 weighting factors V).
  - Processing parameters

Output data

- Sum of total diurnal and semidiurnal elastic ocean tide height (orthotide algorithm)
- Height of the tidal loading (orthotide algorithm)

Mathematical statement

The diurnal and semidiurnal elastic ocean tide, and the corresponding load tide, are computed from the model developed at the University of Texas (Eanes and Bettadpur, 1996). This model uses the formulation described by Cartwright and Ray (1990). This formulation is based on orthotide functions. The computed ocean and load tides are composed of the 30 largest spectral lines within both the diurnal and semidiurnal bands, sufficient for representing all major constituents including nodal modulations. The model is based on empirical determination of orthoweights maps, derived from the TOPEX mission, as adjustments to a FES hydrodynamic model.

For the Mediterranean sea, the tide solution from the model by Vincent and Canceil (1993) is incorporated in the input orthoweights map.

ALGORITHM SPECIFICATION

Input data

- Time of the altimeter measurement : Day_1900 (days elapsed since 1/1/1900 at 0h)
- Location of the altimeter measurement:
  - Latitude : Alt_Lat_Mean (degree)
  - Longitude : Alt_Lon_Mean (degree)
- For the diurnal and semi-diurnal elastic ocean tide:
  - Number of grid points of the orthoweights coefficients map in the longitude axis : Ortho_Nb_Lon (/)
  - Number of grid points of the orthoweights coefficients map in the latitude axis : Ortho_Nb_Lat (/)
  - Orthoweights coefficients map : Ortho_Map[0:11][0:Ortho_Nb_Lon-1][0:Ortho_Nb_Lat-1] (10^{-6} m)[1]
  - Orthoweights coefficients map longitude step : Ortho_Lon_Step (degree)

---

[1] The orthoweights coefficients have to be converted from microns to meters, excepted those which are set to a default value.

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- Orthoweights coefficients map first longitude : Ortho_Lon_First (degree)
- Orthoweights coefficients map latitude step : Ortho_Lat_Step (degree)
- Orthoweights coefficients map first latitude : Ortho_Lat_First (degree)
- Orthoweights coefficients map default value : Ortho_Def_Value (/)

- For the load tide:
  - Number of grid points of the orthoweights coefficients map in the longitude axis: Load_Ortho_Nb_Lon (/)
  - Number of grid points of the orthoweights coefficients map in the latitude axis : Load_Ortho_Nb_Lat (/)
  - Orthoweights coefficients map : Load_Ortho_Map[0:11][0:Load1_Nb_Lon-1][0:Load1_Nb_Lat-1] (10^{-6} m)(1)
  - Orthoweights coefficients map longitude step : Load_Ortho_Lon_Step (degree)
  - Orthoweights coefficients map first longitude : Load_Ortho_Lon_First (degree)
  - Orthoweights coefficients map latitude step : Load_Ortho_Lat_Step (degree)
  - Orthoweights coefficients map first latitude : Load_Ortho_Lat_First (degree)
  - The Orthoweights coefficients map default value : Load_Ortho_Def_Value (/)
- The frequencies Freq[0:3] in degree per day, and the phases Pha0[0:3] at 0h on 1/1/1900 in degree, for i = 0 to 3, of four astronomical variables, respectively the mean longitude of the moon, the mean longitude of the sun, the mean longitude of the lunar perigee, and the negative of the mean longitude of the lunar ascending node.

i	Freq	Pha0
0	13.17639648	277.0256206
1	0.98564736	280.1895015
2	0.11140353	334.3837214
3	0.05295377	- 259.1560563

- The potential coefficients $U_{00}(k)$, $U_{20}(k)$, $U_{21}(k)$, $U_{40}(k)$, $U_{41}(k)$, and $V_{41}(k)$, for each tidal species k = 0 to 1

k	U_{00}	U_{20}	U_{21}	U_{40}	U_{41}	V_{41}
0	0.0298	0.1408	0.0805	0.6002	0.3025	0.1517
1	0.0200	0.0905	0.0638	0.3476	0.1645	0.0923

- The Doodson numbers:
  - Doodson indexes DOOD_IND[0:3][0:29][0:1], for each astronomical variable i = 0 to 3, for each tidal constituent j = 0 to 29, and for each tidal species k = 0 to 1
  - Doodson amplitudes DOOD_AMP[0:29][0:1], for each tidal constituent j = 0 to 29, and for each tidal species k = 0 to 1
  - Doodson phases DOOD_PHA[0:29][0:1] in degree, for each tidal constituent j = 0 to 29, and for each tidal species k = 0 to 1

DOOD_IND (0,j,k)	DOOD_IND (1,j,k)	DOOD_IND (2,j,k)	DOOD_IND (3,j,k)	DOOD_AMP (j,k)	DOOD_PHA (j,k)	j	k
-3	0	2	0	0.00663	90.	0	0
-3	2	0	0	0.00802	90.	1	0
-2	0	1	-1	0.00947	90.	2	0
-2	0	1	0	0.05019	90.	3	0
-2	2	-1	-1	0.00180	90.	4	0
-2	2	-1	0	0.00954	90.	5	0
-1	0	0	-2	0.00152	270.	6	0
-1	0	0	-1	0.04946	90.	7	0

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-1	0	0	0	0.26218	90.	8	0
-1	0	2	0	0.00171	270.	9	0
-1	2	0	0	0.00343	270.	10	0
0	0	-1	0	0.00741	270.	11	0
0	0	1	0	0.02062	270.	12	0
0	0	1	1	0.00414	270.	13	0
0	2	-1	0	0.00394	270.	14	0
1	-3	0	0	0.00713	13.	15	0
1	-2	0	-1	0.00137	270.	16	0
1	-2	0	0	0.12200	90.	17	0
1	0	0	-1	0.00730	90.	18	0
1	0	0	0	0.36874	270.	19	0
1	0	0	1	0.05002	270.	20	0
1	1	0	0	0.00293	-13.	21	0
1	2	0	0	0.00524	270.	22	0
2	-2	1	0	0.00395	270.	23	0
2	0	-1	0	0.02061	270.	24	0
2	0	-1	1	0.00409	270.	25	0
3	-2	0	0	0.00342	270.	26	0
3	0	-2	0	0.00169	270.	27	0
3	0	0	0	0.01128	270.	28	0
3	0	0	1	0.00723	270.	29	0
-3	0	3	0	0.00180	0.	0	1
-3	2	1	0	0.00467	0.	1	1
-2	0	2	0	0.01601	0.	2	1
-2	2	0	0	0.01932	0.	3	1
-2	3	0	0	0.00130	77.	4	1
-1	-1	1	0	0.00102	103.	5	1
-1	0	1	-1	0.00451	180.	6	1
-1	0	1	0	0.12100	0.	7	1
-1	1	1	0	0.00113	77.	8	1
-1	2	-1	0	0.02298	0.	9	1
-1	3	-1	0	0.00106	77.	10	1
0	-2	2	0	0.00190	180.	11	1
0	-1	0	0	0.00218	103.	12	1
0	0	0	-1	0.02358	180.	13	1
0	0	0	0	0.63194	0.	14	1
0	1	0	0	0.00193	77.	15	1
1	-2	1	0	0.00466	180.	16	1
1	0	-1	0	0.01786	180.	17	1
1	0	1	0	0.00447	0.	18	1
1	0	1	1	0.00197	0.	19	1
2	-3	0	0	0.01718	283.	20	1
2	-2	0	0	0.29402	0.	21	1
2	-1	0	0	0.00305	262.	22	1
2	0	0	-1	0.00102	180.	23	1
2	0	0	0	0.07994	0.	24	1
2	0	0	1	0.02382	0.	25	1
2	0	0	2	0.00259	0.	26	1
3	-2	1	0	0.00086	0.	27	1
3	0	-1	0	0.00447	0.	28	1
3	0	-1	1	0.00195	0.	29	1

Output data

- Sum of total diurnal and semidiurnal elastic ocean tide height (orthotide algorithm) : H_Ortho(m)
- Number of cell points used by interpolation : Nb_Pts_Valid_H_Ortho (∈ [0,4]) (/)
- Loading tide height (orthotide algorithm) : H_Load_Ortho(m)
- Number of cell points used by interpolation : Nb_Pts_Valid_H_Load_Ortho (∈ [0,4]) (/)

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- Execution status

Processing

- Computing the mean longitude of the moon in degree, Pha(0), on measurement time Day_1900:

  Pha(0) = value modulo 360 of [Pha0(0) + Freq(0) ∗ Day_1900] (1)

- Computing the mean longitude of the sun in degree, Pha(1), on measurement time Day_1900:

  Pha(1) = value modulo 360 of [Pha0(1) + Freq(1) ∗ Day_1900] (2)

- Computing the mean longitude of the lunar perigee in degree, Pha(2), on measurement time Day_1900:

  Pha(2) = value modulo 360 of [Pha0(2) + Freq(2) ∗ Day_1900] (3)

- Computing the negative of the mean longitude of the lunar ascending node in degree, Pha(3), on measurement time Day_1900:

  Pha(3) = value modulo 360 of [Pha0(3) + Freq(3) ∗ Day_1900] (4)

- Computing the mean lunar time angle in degree, Moon_Angle, on measurement time:

  Frac_Day = Day_1900 – INT(Day_1900) (5)

  Moon_Angle = 360 ∗ Frac_Day – Pha(0) + Pha(1) (6)

- Computing the moon frequency, Moon_Freq, in degree per day:

  Moon_Freq = 360 – Freq(0) + Freq(1) (7)

- For each tidal species (k = 0 to 1), computing the individual orthotides P and Q:
  - Theta0(k) = (k+1) ∗ Moon_Freq (8)
  - Psi0(k) = (k+1) ∗ Moon_Angle (9)
  - For each tidal constituent (j = 0 to 29):
    - $\text{Theta} = \text{Theta0(k)} + \sum_{i=0}^{3} \text{DOOD_IND}(i,j,k) * \text{Freq}(i)$ (10)
    - Omega_T = 2 ∗ Theta ∗ (π/180) (11)
    - CT = 2 cos (Omega_T) (12)
    - ST = 2 sin (Omega_T) (13)
    - $\text{Psi} = \text{Psi0(k)} + \text{DOOD_PHA(j,k)} + \sum_{i=0}^{3} \text{DOOD_IND}(i,j,k) * \text{Pha}(i)$ (14)
    - Psir= Psi ∗ (π/180) (15)
    - CR(j,k) = 100 ∗ DOOD_AMP(j,k) ∗ cos (Psir) (16)
    - SR(j,k) = 100 ∗ DOOD_AMP(j,k) ∗ sin (Psir) (17)
    - CRCT(j,k) = CR(j,k) ∗ CT (18)
    - CRST(j,k) = CR(j,k) ∗ ST (19)
    - SRCT(j,k) = SR(j,k) ∗ CT (20)

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$* \quad SRST(j,k) = SR(j,k) * ST$ (21)

– $AT(0,k) = \sum_{j=0}^{29} CR(j,k)$ (22)

– $BT(0,k) = \sum_{j=0}^{29} - SR(j,k)$ (23)

– $AT(1,k) = \sum_{j=0}^{29} CRCT(j,k)$ (24)

– $BT(1,k) = \sum_{j=0}^{29} - SRCT(j,k)$ (25)

– $AT(2,k) = \sum_{j=0}^{29} CRST(j,k)$ (26)

– $BT(2,k) = \sum_{j=0}^{29} - SRST(j,k)$ (27)

– $P(0,k) = U_{00}(k) * AT(0,k)$ (28)

– $Q(0,k) = U_{00}(k) * BT(0,k)$ (29)

– $P(1,k) = U_{20}(k) * AT(0,k) - U_{21}(k) * AT(1,k)$ (30)

– $Q(1,k) = U_{20}(k) * BT(0,k) - U_{21}(k) * BT(1,k)$ (31)

– $P(2,k) = U_{40}(k) * AT(0,k) - U_{41}(k) * AT(1,k) + V_{41}(k) * AT(2,k)$ (32)

– $Q(2,k) = U_{40}(k) * BT(0,k) - U_{41}(k) * BT(1,k) + V_{41}(k) * BT(2,k)$ (33)

For the elastic ocean tide:

- Computing the indexes of the four surrounding grid points in the orthoweights coefficients map, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

  the input parameters being:

  – X = Alt_Lon_Mean
  – Y = Alt_Lat_Mean
  – DX = Ortho_Lon_Step
  – DY = Ortho_Lat_Step
  – XFIR = Ortho_Lon_First
  – YFIR = Ortho_Lat_First
  – Nb_Ptx = Ortho_Nb_Lon

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- Nb_Pty = Ortho_Nb_Lat
- Xcyc = 360
- Ycyc = 0
- Xcut = 0
- Ycut = 0

and the output parameters of which being:

- The indexes of the four grid corners surrounding the (Lon,Lat) point: I_Left,I_Right,J_Low,J_Up
- The weights of these corners: W_LL, W_LR, W_UL, W_UR
- The execution status

- For each tidal species (k = 0 to 1) and for each of the three orthoweights coefficients (for l = 0 to 2):
  - $n = l + 3k$ (34)
  - Computing the orthoweight U(l,k) at the (Lon, Lat) point by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

    the input parameters of which being:
    - VAL_LL = Ortho_Map(n,I_Left,J_Low)
    - VAL_LR = Ortho_Map(n,I_Right,J_Low)
    - VAL_UL = Ortho_Map(n,I_Left,J_Up)
    - VAL_UR = Ortho_Map(n,I_Right,J_Up)
    - W_LL
    - W_LR
    - W_UL
    - W_UR
    - NIL = Ortho_Def_Value

    and the output parameters of which being:
    - U(l,k)
    - Nb_Pts_Valid_H_Ocean1
    - The execution status
  - If n = 0, then :
    - If Nb_Pts_Valid_H_Ocean1 = 0 (the four grid points are set to their default values), then the elastic ocean tide height H_Ocean1 is returned set to its default value.
  - $m = l + 3k + 6$ (35)
  - Computing the orthoweight V(l,k) at the (Lon, Lat) point by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

    the input parameters of which being:
    - VAL_LL = Ortho_Map(m,I_Left,J_Low)

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- VAL_LR = Ortho_Map(m,I_Right,J_Low)
- VAL_UL = Ortho_Map(m,I_Left,J_Up)
- VAL_UR = Ortho_Map(m,I_Right,J_Up)
- W_LL
- W_LR
- W_UL
- W_UR
- NIL = Ortho_Def_Value

and the output parameters of which being:

- V(I,k)
- Nb_Pts_Valid_H_Ortho
- The execution status

- Computing the elastic ocean tide height (H_Ortho):

$$H_Ortho = \sum_{k=0}^{1}\sum_{l=0}^{2}\left[U(l,k)*P(l,k)+V(l,k)*Q(l,k)\right] \quad (36)$$

For the load tide:

- Computing the indexes of the four surrounding grid points in the orthoweights coefficients map, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

  the input parameters being:

  - X = Alt_Lon_Mean
  - Y = Alt_Lat_Mean
  - DX = Load_Ortho_Lon_Step
  - DY = Load_Ortho_Lat_Step
  - XFIR = Load_Ortho_Lon_First
  - YFIR = Load_Ortho_Lat_First
  - Nb_Ptx = Load_Ortho_Nb_Lon
  - Nb_Pty = Load_Ortho_Nb_Lat
  - Xcyc = 360
  - Ycyc = 0
  - Xcut = 0
  - Ycut = 0

  and the output parameters of which being:

  - The indexes of the four grid corners surrounding the (Lon,Lat) point: I_Left,I_Right,J_Low,J_Up
  - The weights of these corners: W_LL, W_LR, W_UL, W_UR

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- The execution status.

- For each tidal species (k = 0 to 1), and for each of the three orthoweights coefficients (for l = 0 to 2):
  - n = l + 3k (37)
  - Computing the orthoweight U(l,k) at the (Lon, Lat) point by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

    the input parameters of which being:
    - VAL_LL = Load_Ortho_Map(n,I_Left,J_Low)
    - VAL_LR = Load_Ortho_Map(n,I_Right,J_Low)
    - VAL_UL = Load_Ortho_Map(n,I_Left,J_Up)
    - VAL_UR = Load_Ortho_Map(n,I_Right,J_Up)
    - W_LL
    - W_LR
    - W_UL
    - W_UR
    - NIL = Load_Ortho_Def_Value

    and the output parameters of which being:
    - U(l,k)
    - Nb_Pts_Valid_H_Load_Ortho
    - The execution status
  - If n = 0, then :
    - If Nb_Pts_Valid_H_Load_Ortho = 0 (the four grid points are set to their default values), then the height of the tidal loading H_Load_Ortho is returned set to its default value.
  - m = l + 3k + 6 (38)
  - Computing the orthoweight V(l,k) at the (Lon, Lat) point by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

    the input parameters of which being:
    - VAL_LL = Load_Ortho_Map(m,I_Left,J_Low)
    - VAL_LR = Load_Ortho_Map(m,I_Right,J_Low)
    - VAL_UL = Load_Ortho_Map(m,I_Left,J_Up)
    - VAL_UR = Load_Ortho_Map(m,I_Right,J_Up)
    - W_LL
    - W_LR
    - W_UL
    - W_UR
    - NIL = Load_Ortho_Def_Value

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and the output parameters of which being:

* V(l,k)
* Nb_Pts_Valid (unused)
* The execution status

- Computing the height of the tidal loading (H_Load_Ortho):

$$H_Load_Ortho = \sum_{k=0}^{1}\sum_{l=0}^{2}\left[U(l,k)*P(l,k)+V(l,k)*Q(l,k)\right] \quad (39)$$

ACCURACY

The comparison by Le Provost et al. (1996) of the tide model prediction with tide gauge observations from 59 sites distributed over the world ocean showed that the overall RMS difference is 3.48 cm for CSR model (3.86 cm for FES model). The load tide algorithm gives results in close agreement with the load tide algorithm from harmonic components described hereafter.

The choice of the model will be done according to the SWT recommendations.

COMMENTS

The present algorithm must be implemented in such a way that the elastic ocean tide alone, or the load tide alone, can be computed.

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GEN_ENV_TID_02 - To compute the diurnal and semidiurnal elastic ocean tide height and the load tide height (solution 2)

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J. STUM CLS	
Checked by:	For the JASON-1 SWT R. RAY E. SCHRAMA For the JASON-1 Project P. VINCENT CNES S. DESAI JPL For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
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Algorithm change record	creation	date	Issue:	Update:
	CCM			

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HERITAGE

TOPEX/POSEIDON, ERS-1, ERS-2

FUNCTION

- To compute the sum total of the diurnal and semidiurnal ocean tide from the harmonic components algorithm (using Grenoble hydrodynamical 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 that is provided in output.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the diurnal and semi-diurnal ocean tide height and of the load tide height from the solution 2 algorithm will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only for the ocean tide height.

ALGORITHM DEFINITION

Input data

- Product data:
  - For JASON-1:
    - 1-Hz altimeter time tag

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- Computed data:
  - For ENVISAT:
    - From "ALT_COM_TIM_01 - To compute the averaged time tags":
      - 1-Hz altimeter time tag
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement
      - Longitude of the measurement
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Harmonic coefficients maps of the principal tidal waves.
  - Load tide harmonic coefficients maps of the principal tidal waves.

Output data

- Diurnal and semi-diurnal elastic ocean tide height (solution 2)
- Height of the tidal loading (solution 2)

Mathematical statement

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

$$h_i = F_i.[A_i(\phi,\mu).\cos(\psi_i) + B_i(\phi,\mu).\sin(\psi_i)] \quad (i=1,N) \qquad (2)$$

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

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$A_i(\phi,\mu)$ 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 FES99 model by Lefèvre et al. (1999). Harmonic coefficients A and B are tidal amplitude x cos(phase) and tidal amplitude x sin(phase) respectively. N = 27 tidal constituents are used. Among these 27 tidal constituents, 8 principal ones are given in input amplitudes and phases maps, the 19 remaining ones are computed by admittance from the principal constituents 1 to 8, using processing parameters.

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

$$h_i = F_i.[C_i(\phi,\mu).\cos(\psi_i) + D_i(\phi,\mu).\sin(\psi_i)] \quad (i=1,N) \qquad (2)$$

$C_i(\phi,\mu)$ 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 (1990): 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 FES99 model.

ALGORITHM SPECIFICATION

Input data

- Time of the altimeter measurement : Day_1900 (days elapsed since 1/1/1900 at 0h)
- Location of the altimeter measurement:
  - Latitude : Alt_Lat_Mean (degree)
  - Longitude : Alt_Lon_Mean (degree)
- The frequencies Freq[0:4] in degree per day, and the phases Pha0[0:4] at 0h on 1/1/1900 in degree, for i = 0 to 4, 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.

i	Freq	Pha0
0	13.17639648	277.0256206
1	0.98564736	280.1895015
2	0.11140353	334.3837214
3	0.05295377	- 259.1560563
4	0.00004706	281.2208568

- The frequencies of the 27 tidal waves, Sigma[0:26], j = 0 to 26, in 10^{-4} radian per second

Sigma	j	Wave
1.40519	0	M2
1.45444	1	S2
1.37878	2	N2
1.45842	3	K2
0.72921	4	K1
0.67598	5	O1
1.35240	6	2N2
0.64959	7	Q1
1.43158	8	L2
1.45245	9	T2
0.72523	10	P1
1.38233	11	NU2

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1.35594	12	MU2
1.32954	13	EPS2
1.42804	14	LAMBDA2
1.48481	15	ETA2
0.62319	16	2Q1
0.62672	17	SIGMA1
0.65311	18	RHO1
0.70281	19	M11
0.70281	20	M12
0.70635	21	KHI1
0.72323	22	PI1
0.73319	23	PHI1
0.75207	24	THETA1
0.75560	25	J1
0.78244	26	OO1

- For the diurnal and semi-diurnal ocean tide:
  - Number of grid points of the harmonic coefficients map in the longitude axis : Ocean2_Nb_Lon (/)
  - Number of grid points of the harmonic coefficients map in the latitude axis : Ocean2_Nb_Lat (/)
  - Harmonic coefficients map: Ocean2_Map[0:1][0:7][0:Ocean2_Nb_Lon-1][0:Ocean2_Nb_Lat-1] (10^{-4} m)(1)
  - Harmonic coefficients map longitude step : Ocean2_Lon_Step (degree)
  - Harmonic coefficients map first longitude : Ocean2_Lon_First (degree)
  - Harmonic coefficients map latitude step : Ocean2_Lat_Step (degree)
  - Harmonic coefficients map first latitude : Ocean2_Lat_First (degree)
  - Harmonic coefficients map default value : Ocean2_Def_Value (/)
- For the load tide height:
  - Number of grid points of the harmonic coefficients map in the longitude axis : Load2_Nb_Lon (/)
  - Number of grid points of the harmonic coefficients map in the latitude axis : Load2_Nb_Lat (/)
  - Harmonic coefficients map : Load2_Map[0:1][0:7][0:Load2_Nb_Lon-1][0:Load2_Nb_Lat-1] (10^{-4} m)(1)
  - Harmonic coefficients map longitude step : Load2_Lon_Step (degree)
  - Harmonic coefficients map first longitude : Load2_Lon_First (degree)
  - Harmonic coefficients map latitude step : Load2_Lat_Step (degree)
  - Harmonic coefficients map first latitude : Load2_Lat_First (degree)
  - Harmonic coefficients map default value : Load2_Def_Value (/)
- The admittance parameters, containing for j = 8 to 26:
  - The admittance coefficients a[8:26], b[8:26], c[8:26] used to compute the harmonic coefficients of tidal waves number j = 8 to 26 from linear combination of the main tidal waves (tidal waves number 0 to 7)
  - The indexes j_a[8:26], j_b[8:26], j_c[8:26] used to identify on which main tidal waves the admittance coefficients have to be applied

(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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a	j_a	Wave	b	j_b	Wave	c	j_c	Wave	j	Wave
+7.7137783E-02	3	K2	-5.1653463E-02	2	N2	+2.7869917E-02	0	M2	8	L2
+0.1804801E+00	3	K2	-2.0101206E-02	2	N2	+8.3315177E-03	0	M2	9	T2
-0.2387672E+00	7	Q1	+0.1038588E+00	5	O1	+0.2892815E+00	4	K1	10	P1
-6.1046719E-03	3	K2	+0.1568788E+00	2	N2	+6.7556924E-03	0	M2	11	NU2
+6.9440007E-02	3	K2	+0.3515356E+00	2	N2	-4.6278324E-02	0	M2	12	MU2
+0.5328500E+00	6	2N2	-0.3304000E-01	2	N2	+0.0000000E+00	0	M2	13	EPS2
+1.6503554E-02	3	K2	-1.3307810E-02	2	N2	+7.7533796E-03	0	M2	14	LAMBDA2
-0.3492500E-02	0	M2	+0.8317070E-01	3	K2	+0.0000000E+00	0	M2	15	ETA2
+0.2630000E+00	7	Q1	-0.2520000E-01	5	O1	+0.0000000E+00	0	M2	16	2Q1
+0.2970000E+00	7	Q1	-0.2640000E-01	5	O1	+0.0000000E+00	0	M2	17	SIGMA1
+0.1640000E+00	7	Q1	+0.4800000E-02	5	O1	+0.0000000E+00	0	M2	18	RHO1
+0.1400000E-01	5	O1	+0.1010000E-01	4	K1	+0.0000000E+00	0	M2	19	M11
+0.3890000E-01	5	O1	+0.2820000E-01	4	K1	+0.0000000E+00	0	M2	20	M12
+0.6400000E-02	5	O1	+0.6000000E-02	4	K1	+0.0000000E+00	0	M2	21	KHI1
+0.3000000E-02	5	O1	+0.1710000E-01	4	K1	+0.0000000E+00	0	M2	22	PI1
-0.1500000E-02	5	O1	+0.1520000E-01	4	K1	+0.0000000E+00	0	M2	23	PHI1
-0.6500000E-02	5	O1	+0.1550000E-01	4	K1	+0.0000000E+00	0	M2	24	THETA1
-0.3890000E-01	5	O1	+0.8360000E-01	4	K1	+0.0000000E+00	0	M2	25	J1
-0.4310000E-01	5	O1	+0.6130000E-01	4	K1	+0.0000000E+00	0	M2	26	OO1

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Output data

- Diurnal and semi-diurnal elastic ocean tide height [1] : H_Ocean2 (m)
- Number of cell points used by interpolation : Nb_Pts_Valid_H_Ocean2 ($\in$ [0,4]) (/)
- Height of the tidal loading [1] : H_Load2 (m)
- Execution status

Processing

- Computing the day of measurement at 0h, Day_1900_0h, and the number of seconds in the day, Sec_Day:

  Day_1900_0h = INT(Day_1900) (1)

  Sec_Day = (Day_1900 - Day_1900_0h) x 86400. (2)

- Computing the mean longitude of the moon in radian, s, at 0h on measurement time Day_1900_0h:

  s = {value modulo 360 of [Pha0(0) + Freq(0) $*$ Day_1900_0h]} $*$ (π/180) (3)

- Computing the mean longitude of the sun in radian, h, at 0h on measurement time Day_1900_0h:

  h = {value modulo 360 of [Pha0(1) + Freq(1) $*$ Day_1900_0h]} $*$ (π/180) (4)

- Computing the mean longitude of the lunar perigee in radian, p, at 0h on measurement time Day_1900_0h:

  p = {value modulo 360 of [Pha0(2) + Freq(2) $*$ Day_1900_0h]} $*$ (π/180) (5)

- Computing the mean longitude of the lunar ascending node in radian, N, at 0h on measurement time Day_1900_0h:

  N = - {value modulo 360 of [Pha0(3) + Freq(3) $*$ Day_1900_0h]} $*$ (π/180) (6)

- Computing the mean longitude of the solar perigee in radian, ps, at 0h on measurement time day, Day_1900_0h:

  ps = {value modulo 360 of [Pha0(4) + Freq(4) $*$ Day_1900_0h]} $*$ (π/180) (7)

- Computing the phases at 0h of the 27 tidal waves, X[0:26], j = 0, 26, from s, h, p, and ps:
  - j = 0: wave M2: X(0) = 2h - 2s (8)
  - j = 1: wave S2: X(1) = 0 (9)
  - j = 2: wave N2: X(2) = 2h - 3s + p (10)
  - j = 3: wave K2: X(3) = 2h (11)
  - j = 4: wave K1: X(4) = h + π/2 (12)
  - j = 5: wave O1: X(5) = h - 2s - π/2 (13)
  - j = 6: wave 2N2: X(6) = 2h - 4s + 2p (14)

---

[1] Solution 2

[1] Solution 2

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- j = 7: wave Q1: $X(7) = h - 3s + p - \pi/2$ (15)
- j = 8: wave L2: $X(8) = 2h - s - p - \pi$ (16)
- j = 9: wave T2: $X(9) = -h + ps$ (17)
- j = 10: wave P1: $X(10) = -h - \pi/2$ (18)
- j = 11: wave NU2: $X(11) = 4h - 3s - p$ (19)
- j = 12: wave MU2: $X(12) = 4h - 4s$ (20)
- j = 13: wave EPS2: $X(13) = 4h - 5s + p$ (21)
- j = 14: wave LDA2: $X(14) = -s + p - \pi$ (22)
- j = 15: wave ETA2: $X(15) = 2h + s - p$ (23)
- j = 16: wave 2Q1: $X(16) = h - 4s + 2p - \pi/2$ (24)
- j = 17: wave SIG1: $X(17) = 3h - 4s - \pi/2$ (25)
- j = 18: wave RHO1: $X(18) = 3h - 3s - p - \pi/2$ (26)
- j = 19: wave M11: $X(19) = h - s + p + \pi/2$ (27)
- j = 20: wave M12: $X(20) = h - s - p + \pi/2$ (28)
- j = 21: wave KHI1: $X(21) = 3h - s - p + \pi/2$ (29)
- j = 22: wave PI1: $X(22) = -2h + ps - \pi/2$ (30)
- j = 23: wave PHI1: $X(23) = 3h + \pi/2$ (31)
- j = 24: wave TTA1: $X(24) = -h + s + p + \pi/2$ (32)
- j = 25: wave J1: $X(25) = h + s - p + \pi/2$ (33)
- j = 26: wave OO1: $X(26) = h + 2s + \pi/2$ (34)

- Computing the nodal coefficients, I, n, theta, n', n", R, Ra, from N and p:
  - $t_n = tg(N/2)$ (35)
  - $at_1 = Arc\ tg(1.01883 * t_n)$ (36)
  - $at_2 = Arc\ tg(0.64412 * t_n)$ (37)
  - $COSI = 0.913694997 - 0.035692561 * \cos(N)$ (38)
  - $I = Arc\ \cos(COSI)$ (39)
  - $t_i = tg(I/2)$ (40)
  - $n = at_1 - at_2$ (41)
  - $theta = N - at_1 - at_2$ (42)
  - If $N > \pi$, then $theta = theta - 2\pi$ (43)
  - $TGNP = [\sin(2I) * \sin(n)] / [\sin(2I) * \cos(n) + 0.3347]$ (44)
  - $n' = Arc\ tg(TGNP)$ (45)

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- TGNS = $[\sin^2(I) * \sin(2n)] / [\sin^2(I) * \cos(2n) + 0.0727]$ (46)
- n" = 0.5 ∗ Arc tg(TGNS) (47)
- TGR = $\{ \sin[2(p - theta)] \} / \{ [1/(6t_i^2)] - \cos[2(p - theta)] \}$ (48)
- R = Arc tg(TGR) (49)
- Ra = $(1 - 12t_i^2 * \cos[2(p - theta)] + 36t_i^4)^{-1/2}$ (50)

- Computing the phase nodal corrections at 0h of the 27 tidal waves, U[0:26], j = 0, 26:
  - j = 0: wave M2: U(0) = 2 ∗ theta – 2 ∗ n (51)
  - j = 1: wave S2: U(1) = 0 (52)
  - j = 2: wave N2: U(2) = 2 ∗ theta – 2 ∗ n (53)
  - j = 3: wave K2: U(3) = - 2n" (54)
  - j = 4: wave K1: U(4) = - n' (55)
  - j = 5: wave O1: U(5) = 2 ∗ theta – n (56)
  - j = 6: wave 2N2: U(6) = 2 ∗ theta – 2 ∗ n (57)
  - j = 7: wave Q1: U(7) = 2 ∗ theta – n (58)
  - j = 8: wave L2: U(8) = 2 ∗ theta – 2 ∗ n – R (59)
  - j = 9: wave T2: U(9) = 0 (60)
  - j = 10: wave P1: U(10) = 0 (61)
  - j = 11: wave NU2: U(11) = 2 ∗ theta – 2 ∗ n (62)
  - j = 12: wave MU2: U(12) = 2 * theta – 2 * n (63)
  - j = 13: wave EPS2: U(13) = 0 (64)
  - j = 14: wave LDA2: U(14) = 2 * theta – 2 * n (65)
  - j = 15: wave ETA2: U(15) = - 2n (66)
  - j = 16: wave 2Q1: U(16) = 2 * theta – n (67)
  - j = 17: wave SIG1: U(17) = 2 * theta – n (68)
  - j = 18: wave RHO1: U(18) = 2 * theta – n (69)
  - j = 19: wave M11: U(19) = - n (70)
  - j = 20: wave M12: U(20) = 2 * theta – n (71)
  - j = 21: wave KHI1: U(21) = - n (72)
  - j = 22: wave PI1: U(22) = 0 (73)
  - j = 23: wave PHI1: U(23) = 0 (74)
  - j = 24: wave TTA1: U(24) = - n (75)
  - j = 25: wave J1: U(25) = - n (76)
  - j = 26: wave OO1: U(26) = - 2 * theta – n (77)

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- Computing the amplitude nodal correction coefficients F[0:26] , j = 0, 26 for the 27 tidal waves:
  - j = 0: wave M2: $F(0) = (\cos^4(I/2)) / 0.9154$ (78)
  - j = 1: wave S2: $F(1) = 1$ (79)
  - j = 2: wave N2: $F(2) = (\cos^4(I/2)) / 0.9154$ (80)
  - j = 3: wave K2: $F(3) = (19.0444 * \sin^4(I) + 2.7702 * \sin^2(I) * \cos(2n) + 0.0981)^{1/2}$ (81)
  - j = 4: wave K1: $F(4) = (0.8965 * \sin^2(2I) + 0.6001 * \sin(2I) * \cos(n) + 0.1006)^{1/2}$ (82)
  - j = 5: wave O1: $F(5) = \sin(I) * (\cos^2(I/2)) / 0.38$ (83)
  - j = 6: wave 2N2: $F(6) = (\cos^4(I/2)) / 0.9154$ (84)
  - j = 7: wave Q1: $F(7) = \sin(I) * (\cos^2(I/2)) / 0.38$ (85)
  - j = 8: wave L2: $F(8) = (\cos^4(I/2)) / (0.9154 * Ra)$ (86)
  - j = 9: wave T2: $F(9) = 1$ (87)
  - j = 10: wave P1: $F(10) = 1$ (88)
  - j = 11: wave NU2: $F(11) = (\cos^4(I/2)) / 0.9154$ (89)
  - j = 12: wave MU2: $F(12) = (\cos^4(I/2)) / 0.9154$ (90)
  - j = 13: wave EPS2: $F(13) = 1$ (91)
  - j = 14: wave LDA2: $F(14) = (\cos^4(I/2)) / 0.9154$ (92)
  - j = 15: wave ETA2: $F(15) = (\sin^2(I)) / 0.1565$ (93)
  - j = 16: wave 2Q1: $F(16) = (\sin(I) * \cos^2(I/2)) / 0.38$ (94)
  - j = 17: wave SIG1: $F(17) = (\sin(I) * \cos^2(I/2)) / 0.38$ (95)
  - j = 18: wave RHO1: $F(18) = (\sin(I) * \cos^2(I/2)) / 0.38$ (96)
  - j = 19: wave M11: $F(19) = (\sin(2I)) / 0.7214$ (97)
  - j = 20: wave M12: $F(20) = (\sin(I) * \cos^2(I/2)) / 0.38$ (98)
  - j = 21: wave KHI1: $F(21) = (\sin(2I)) / 0.7214$ (99)
  - j = 22: wave PI1: $F(22) = 1$ (100)
  - j = 23: wave PHI1: $F(23) = 1$ (101)
  - j = 24: wave TTA1: $F(24) = (\sin(2I)) / 0.7214$ (102)
  - j = 25: wave J1: $F(25) = (\sin(2I)) / 0.7214$ (103)
  - j = 26: wave OO1: $F(26) = (\sin(I) * \sin^2(I/2)) / 0.0164$ (104)
- For each of the 27 tidal waves (for j = 0 to 26), computing the tidal wave phase, Psi(j), at altimeter time:

  $Psi(j) = \text{value modulo } 2\pi \text{ of } [Sigma(j) * 10^{-4} * Sec_Day + X(j) + U(j)]$ (105)

  If $Psi(j) < 0$, then $Psi(j) = Psi(j) + 2\pi$ (106)

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For the diurnal and semi-diurnal ocean tide:

- Computing the indexes of the four surrounding grid points in the harmonic coefficients map, using mechanism "GEN_MEC_GRI_01 - Cell identification",

  the input parameters being:

  - X = Alt_Lon_Mean
  - Y = Alt_Lat_Mean
  - DX = Ocean2_Lon_Step
  - DY = Ocean2_Lat_Step
  - XFIR = Ocean2_Lon_First
  - YFIR = Ocean2_Lat_First
  - Nb_Ptx = Ocean2_Nb_Lon
  - Nb_Pty = Ocean2_Nb_Lat
  - Xcyc = 360
  - Ycyc = 0
  - Xcut = 0
  - Ycut = 0

  and the output parameters of which being:

  - The indexes of the four grid corners surrounding the (Lon,Lat) point: I_Left,I_Right,J_Low,J_Up
  - The weights of these corners: W_LL, W_LR, W_UL, W_UR
  - The execution status.

- For each of the 8 first tidal waves (for j = 0 to 7), and for each of the 2 kinds (first kind is tidal amplitude x cos(phase), second kind is tidal amplitude x sin(phase)) of ocean tide harmonic coefficient A (for i = 0 to 1):

  - Computing the ocean tide harmonic coefficient A(i,j) at the (Lon, Lat) point by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

    the input parameters of which being:

    * VAL_LL = Ocean2_Map(i, j, I_Left, J_Low)
    * VAL_LR = Ocean2_Map(i, j, I_Right, J_Low)
    * VAL_UL = Ocean2_Map(i, j, I_Left, J_Up)
    * VAL_UR = Ocean2_Map(i, j, I_Right, J_Up)
    * W_LL
    * W_LR
    * W_UL
    * W_UR
    * NIL = Ocean2_Def_Value

    and the output parameters of which being:

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  - A(i,j)
  - Nb_Pts_Valid_H_Ocean2
  - The execution status
- If (j = 0 and i = 0), then :
  - If Nb_Pts_Valid_H_Ocean2 = 0 (the four grid points are set to their default values), then the elastic ocean tide height H_Ocean2 is returned set to its default value.

- For each of the 19 remaining tidal waves (for j = 8 to 26), and for each of the 2 kinds of ocean tide harmonic coefficient A (for i = 0 to 1):
  - Computing the ocean tide harmonic coefficients A(i,j) at measurement (μ, ϕ) by linear combination of the coefficients A(i,j) obtained for j = 0 to 7, as defined by the admittance coefficients:

$$A(i,j) = a(j) * A(i, j_a(j)) + b(j) * A(i, j_b(j)) + c(j) * A(i, j_c(j)) \quad (107)$$

- For each of the 27 tidal waves (for j = 0 to 26), computing the ocean tide height h(j):

$$H(j) = F(j) * \{A(0,,j) * \cos(Psi(j)) + A(1,,j) * \sin(Psi(j))\} \quad (108)$$

- Compute the ocean tide height (H_Ocean2):

$$H_Ocean2 = \sum_{j=0}^{26} H(j) \quad (109)$$

For the load tide:

- Computing the indexes of the four surrounding grid points in the tidal loading harmonic coefficients map, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

  the input parameters being:
  - X = Alt_Lon_Mean
  - Y = Alt_Lat_Mean
  - DX = Load2_Lon_Step
  - DY = Load2_Lat_Step
  - XFIR = Load2_Lon_First
  - YFIR = Load2_Lat_First
  - Nb_Ptx = Load2_Nb_Lon
  - Nb_Pty = Load2_Nb_Lat
  - Xcyc = 360
  - Ycyc = 0
  - Xcut = 0
  - Ycut = 0

  and the output parameters of which being:
  - The indexes of the four grid corners surrounding the (Lon,Lat) point: I_Left,I_Right,J_Low,J_Up
  - The weights of these corners: W_LL, W_LR, W_UL, W_UR

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- The execution status.

- For each of the 8 first tidal waves (for j = 0 to 7), and for each of the 2 kinds of tidal loading harmonic coefficient B (for i = 0 to 1):
  - Computing the tidal loading harmonic coefficient B(i,j) at the (Lon, Lat) point by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

    the input parameters of which being:
    - VAL_LL = Load2_Map(i, j, I_Left, J_Low)
    - VAL_LR = Load2_Map(i,,j, I_Right, J_Low)
    - VAL_UL = Load2_Map(i, j, I_Left, J_Up)
    - VAL_UR = Load2_Map(i, j, I_Right, J_Up)
    - W_LL
    - W_LR
    - W_UL
    - W_UR
    - NIL = Load2_Def_Value

    and the output parameters of which being:
    - B(i,j)
    - Nb_Pts_Valid (unused)
    - The execution status

- For each of the 19 remaining tidal waves (for j = 8 to 26), and for each of the 2 kinds of tidal loading harmonic coefficient B (for i = 0 to 1):
  - Computing the tidal loading harmonic coefficients B(i,j) at measurement (μ, ϕ) by linear combination of the coefficients B(i,j) obtained for j = 0 to 7, as defined by the admittance coefficients:

$$B(i,j) = a(j) * B(i,j_a(j)) + b(j) * B(i,j_b(j)) + c(j) * B(i,j_c(j)) \quad (110)$$

- For each of the 27 tidal waves (for j = 0 to 26), computing the height of the tidal loading h(j):

$$H(j) = F(j) * \{B(0,,j) * \cos(Psi(j)) + B(1,,j) * \sin(Psi(j))\} \quad (111)$$

- Compute the height of the tidal loading (H_Load2):

$$H_Load2 = \sum_{j=0}^{26} H(j) \quad (112)$$

For the elastic ocean tide height :

- Adding the ocean tide height and the loading tide height :
  - H_Ocean2 = H_Ocean2 + H_Load2 (113)

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ACCURACY

The FES99 version of the Grenoble FES hydordynamical model is used (Lefèvre et al., 2000). 27 tidal constituents are used. Among these 27 tidal constituents, 8 principal ones are given in input amplitudes and phases maps (M2, S2, N2, K2, K1, O1, 2N2, Q1). the 19 remaining ones are computed by admittance from the principal constituents 1 to 8, using admittance coefficients. A comprehensive comparison study of the new tide models available before the JASON-1 and ENVISAT launch dates has been performed by Dorandeu et al. (2000).

For the load tide height, other methods have been used for Geosat and TOPEX/POSEIDON missions for the evaluation of the tidal loading. The Ray and Sanchez's method (1989) for the Cartwright and Ray tide model used a high-degree spherical harmonic method. The method of Francis and Mazzega is probably more accurate (no cut-off due to spherical harmonics expansion, no ocean to land discontinuities). Empirical determination of tidal loading was also derived from TOPEX/POSEIDON using the same method as for the ocean tide. This empirical solution and the Francis and Mazzegas's solution are very similar.

COMMENTS

- In the specification section, equations (3) to (104) are to be computed for the first processed altimeter measurement, and then only when the day of the altimeter measurement is changing.
- The present algorithm must be implemented in such a way that the diurnal and semi-diurnal ocean tide alone, or the load tide alone, can be computed.

REFERENCES

- Lefèvre, F., F. Lyard, C. Le Provost, and E.J.O. Schrama, FES99 : a tide finite element solution assimilating tide gauge and altimetric information, J. Atm. Oceano. Tech., submitted, 2000.
- Dorandeu, J., M. Ablain, F. Lefèvre and R. Ray (2000) : New tide models evaluation. Preliminary report. AVI-NT-011-0253-CLS, April 2000. Availbale on Internet at ftp://spike.cnes.fr/pub/poseidon/doc/tide.pdf

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GEN_ENV_TID_01 - To compute the diurnal and semidiurnal elastic ocean tide height and the load tide height (solution 1)

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON, ERS-1, ERS-2

FUNCTION

- To compute the sum total of the diurnal and semidiurnal ocean tide from the GOT99 harmonic components algorithm (using GOT99 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: GOT99 harmonic components).
- To add the ocean tide and the load tide to compute the elastic ocean tide that is provided in output.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the diurnal and semi-diurnal ocean tide height and of the load tide height from the GOT99 harmonic components algorithm will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only for the ocean tide height.

ALGORITHM DEFINITION

Input data

- Product data:
  - For JASON-1:
    - 1-Hz altimeter time tag

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- Computed data:
  - For ENVISAT:
    - From "ALT_COM_TIM_01 - To compute the averaged time tags":
      - 1-Hz altimeter time tag
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement
      - Longitude of the measurement
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Harmonic coefficients maps of the principal tidal waves.
  - Load tide harmonic coefficients maps of the principal tidal waves.

Output data

- Diurnal and semi-diurnal elastic ocean tide height (solution 1 = GOT99 harmonic components)
- Height of the tidal loading (solution 1 = GOT99 harmonic components)

Mathematical statement

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

$$h_i = F_i.[A_i(\phi,\mu).\cos(\psi_i) + B_i(\phi,\mu).\sin(\psi_i)] \quad (i=1,N) \tag{2}$$

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

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$A_i(\phi,\mu)$ 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 GOT99 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 h_i:

$$h_i = F_i.[C_i(\phi,\mu).\cos(\psi_i) + D_i(\phi,\mu).\sin(\psi_i)] \quad (i=1,N) \qquad (2)$$

$C_i(\phi,\mu)$ 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). The used ocean tide model is the GOT99 model. N = 25 tidal constituents were used. Among these 25 tidal constituents, 8 principal ones were given in input amplitudes and phases maps, the 17 remaining ones were computed by admittance from the principal constituents 1 to 8, using admittance coefficients.

ALGORITHM SPECIFICATION

Input data

- Time of the altimeter measurement : Day_1900 (days elapsed since 1/1/1900 at 0h)
- Location of the altimeter measurement:
  - Latitude : Alt_Lat_Mean (degree)
  - Longitude : Alt_Lon_Mean (degree)
- The frequencies Freq[0:4] in degree per day, and the phases Pha0[0:4] at 0h on 1/1/1900 in degree, for i = 0 to 4, 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.

i	Freq	Pha0
0	13.17639648	277.0256206
1	0.98564736	280.1895015
2	0.11140353	334.3837214
3	0.05295377	- 259.1560563
4	0.00004706	281.2208568

- The frequencies of the 25 tidal waves, Sigma[0:24], j = 0 to 24, in 10^{-4} radian per second

Sigma	j	Wave
1.40519	0	M2
1.45444	1	S2
1.37878	2	N2
1.45842	3	K2
0.72921	4	K1
0.67598	5	01
0.72523	6	P1
0.64959	7	Q1
1.43158	8	L2
1.45245	9	T2
1.35240	10	2N2
1.38233	11	NU2
1.35594	12	MU2
1.42804	13	LAMBDA2
0.62319	14	2Q1
0.62672	15	SIGMA1

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0.65311	16	RHO1
0.70281	17	M11
0.70281	18	M12
0.70635	19	KHI1
0.72323	20	PI1
0.73319	21	PHI1
0.75207	22	THETA1
0.75560	23	J1
0.78244	24	OO1

- For the diurnal and semi-diurnal ocean tide:
  - Number of grid points of the harmonic coefficients map in the longitude axis : Ocean1_Nb_Lon (/)
  - Number of grid points of the harmonic coefficients map in the latitude axis : Ocean1_Nb_Lat (/)
  - Harmonic coefficients map: Ocean1_Map[0:1][0:7][0:Ocean1_Nb_Lon-1][0:Ocean1_Nb_Lat-1] (10^{-4} m)(1)
  - Harmonic coefficients map longitude step : Ocean1_Lon_Step (degree)
  - Harmonic coefficients map first longitude : Ocean1_Lon_First (degree)
  - Harmonic coefficients map latitude step : Ocean1_Lat_Step (degree)
  - Harmonic coefficients map first latitude : Ocean1_Lat_First (degree)
  - Harmonic coefficients map default value : Ocean1_Def_Value (/)
- For the load tide height:
  - Number of grid points of the harmonic coefficients map in the longitude axis : Load1_Nb_Lon (/)
  - Number of grid points of the harmonic coefficients map in the latitude axis : Load1_Nb_Lat (/)
  - Harmonic coefficients map : Load1_Map[0:1][0:7][0:Load1_Nb_Lon-1][0:Load1_Nb_Lat-1] (10^{-4} m)(1)
  - Harmonic coefficients map longitude step : Load1_Lon_Step (degree)
  - Harmonic coefficients map first longitude : Load1_Lon_First (degree)
  - Harmonic coefficients map latitude step : Load1_Lat_Step (degree)
  - Harmonic coefficients map first latitude : Load1_Lat_First (degree)
  - Harmonic coefficients map default value : Load1_Def_Value (/)
- The admittance parameters, containing for j = 8 to 24:
  - The admittance coefficients a[8:24], b[8:24], c[8:24] used to compute the harmonic coefficients of tidal waves number j = 8 to 24 from linear combination of the main tidal waves (tidal waves number 0 to 7)
  - The indexes j_a[8:24], j_b[8:24], j_c[8:24] used to identify on which main tidal waves the admittance coefficients have to be applied

a	j_a	Wave	b	j_b	Wave	c	j_c	Wave	j	Wave
0.0326	1	S2	0	2	N2	0.0131	0	M2	8	L2
0.0585	1	S2	0	2	N2	0	0	M2	9	T2
0	1	S2	0.264	2	N2	-0.0253	0	M2	10	2N2
0	1	S2	0.165	2	N2	0.00487	0	M2	11	NU2
0	1	S2	0.298	2	N2	-0.0264	0	M2	12	MU2

(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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0.0074	1	S2	0	2	N2	0.004	0	M2	13	LAMBDA2
+0.2630000E+00	7	Q1	-0.2520000E-01	5	O1	+0.0000000E+00	0	M2	14	2Q1
+0.2970000E+00	7	Q1	-0.2640000E-01	5	O1	+0.0000000E+00	0	M2	15	SIGMA1
+0.1640000E+00	7	Q1	+0.4800000E-02	5	O1	+0.0000000E+00	0	M2	16	RHO1
+0.1400000E-01	5	O1	+0.1010000E-01	4	K1	+0.0000000E+00	0	M2	17	M11
+0.3890000E-01	5	O1	+0.2820000E-01	4	K1	+0.0000000E+00	0	M2	18	M12
+0.6400000E-02	5	O1	+0.6000000E-02	4	K1	+0.0000000E+00	0	M2	19	KHI1
+0.3000000E-02	5	O1	+0.1710000E-01	4	K1	+0.0000000E+00	0	M2	20	PI1
-0.1500000E-02	5	O1	+0.1520000E-01	4	K1	+0.0000000E+00	0	M2	21	PHI1
-0.6500000E-02	5	O1	+0.1550000E-01	4	K1	+0.0000000E+00	0	M2	22	THETA1
-0.3890000E-01	5	O1	+0.8360000E-01	4	K1	+0.0000000E+00	0	M2	23	J1
-0.4310000E-01	5	O1	+0.6130000E-01	4	K1	+0.0000000E+00	0	M2	24	OO1

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Output data

- Diurnal and semi-diurnal elastic ocean tide height [(1)] : H_Ocean1 (m)
- Number of cell points used by interpolation : Nb_Pts_Valid_H_Ocean1 (∈ [0,4]) (/)
- Height of the tidal loading [(1)] : H_Load1 (m)
- Execution status

Processing

- Computing the day of measurement at 0h, Day_1900_0h, and the number of seconds in the day, Sec_Day:

  Day_1900_0h = INT(Day_1900) (1)

  Sec_Day = (Day_1900 - Day_1900_0h) x 86400. (2)

- Computing the mean longitude of the moon in radian, s, at 0h on measurement time Day_1900_0h:

  s = {value modulo 360 of [Pha0(0) + Freq(0) ∗ Day_1900_0h]} ∗ (π/180) (3)

- Computing the mean longitude of the sun in radian, h, at 0h on measurement time Day_1900_0h:

  h = {value modulo 360 of [Pha0(1) + Freq(1) ∗ Day_1900_0h]} ∗ (π/180) (4)

- Computing the mean longitude of the lunar perigee in radian, p, at 0h on measurement time Day_1900_0h:

  p = {value modulo 360 of [Pha0(2) + Freq(2) ∗ Day_1900_0h]} ∗ (π/180) (5)

- Computing the mean longitude of the lunar ascending node in radian, N, at 0h on measurement time Day_1900_0h:

  N = - {value modulo 360 of [Pha0(3) + Freq(3) ∗ Day_1900_0h]} ∗ (π/180) (6)

- Computing the mean longitude of the solar perigee in radian, ps, at 0h on measurement time day, Day_1900_0h:

  ps = {value modulo 360 of [Pha0(4) + Freq(4) ∗ Day_1900_0h]} ∗ (π/180) (7)

- Computing the phases at 0h of the 25 tidal waves, X[0:24], j = 0, 24, from s, h, p, and ps:
  - j = 0: wave M2: X(0) = 2h - 2s (8)
  - j = 1: wave S2: X(1) = 0 (9)
  - j = 2: wave N2: X(2) = 2h - 3s + p (10)
  - j = 3: wave K2: X(3) = 2h (11)
  - j = 4: wave K1: X(4) = h + π/2 (12)
  - j = 5: wave O1: X(5) = h - 2s - π/2 (13)
  - j = 6: wave P1: X(6) = -h - π/2 (14)

---

(1) Solution 1

(1) Solution 2

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- j = 7: wave Q1: $X(7) = h - 3s + p - \pi/2$ (15)
- j = 8: wave L2: $X(8) = 2h - s - p - \pi$ (16)
- j = 9: wave T2: $X(9) = -h + ps$ (17)
- j = 10: wave 2N2: $X(10) = 2h - 4s + 2p$ (18)
- j = 11: wave NU2: $X(11) = 4h - 3s - p$ (19)
- j = 12: wave MU2: $X(12) = 4h - 4s$ (20)
- j = 13: wave LDA2: $X(13) = -s + p - \pi$ (21)
- j = 14: wave 2Q1: $X(14) = h - 4s + 2p - \pi/2$ (22)
- j = 15: wave SIG1: $X(15) = 3h - 4s - \pi/2$ (23)
- j = 16: wave RHO1: $X(16) = 3h - 3s - p - \pi/2$ (24)
- j = 17: wave M11: $X(17) = h - s + p + \pi/2$ (25)
- j = 18: wave M12: $X(18) = h - s - p + \pi/2$ (26)
- j = 19: wave KHI1: $X(19) = 3h - s - p + \pi/2$ (27)
- j = 20: wave PI1: $X(20) = -2h + ps - \pi/2$ (28)
- j = 21: wave PHI1: $X(21) = 3h + \pi/2$ (29)
- j = 22: wave TTA1: $X(22) = -h + s + p + \pi/2$ (30)
- j = 23: wave J1: $X(23) = h + s - p + \pi/2$ (31)
- j = 24: wave OO1: $X(24) = h + 2s + \pi/2$ (32)

- Computing the nodal coefficients, I, n, theta, n', n", R, Ra, from N and p:
  - $t_n = tg(N/2)$ (33)
  - $at_1 = Arc\ tg(1.01883 * t_n)$ (34)
  - $at_2 = Arc\ tg(0.64412 * t_n)$ (35)
  - $COSI = 0.913694997 - 0.035692561 * cos(N)$ (36)
  - $I = Arc\ cos(COSI)$ (37)
  - $t_i = tg(I/2)$ (38)
  - $n = at_1 - at_2$ (39)
  - $theta = N - at_1 - at_2$ (40)
  - If $N > \pi$, then $theta = theta - 2\pi$ (41)
  - $TGNP = [sin(2I) * sin(n)] / [sin(2I) * cos(n) + 0.3347]$ (42)
  - $n' = Arc\ tg(TGNP)$ (43)
  - $TGNS = [sin^2(I) * sin(2n)] / [sin^2(I) * cos(2n) + 0.0727]$ (44)
  - $n'' = 0.5 * Arc\ tg(TGNS)$ (45)

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- TGR = { sin[2(p -theta)] } / { [1/(6t_i^2)] - cos[2(p -theta)] } (46)
- R = Arc tg(TGR) (47)
- Ra = (1 - 12t_i^2 ∗ cos[2(p - theta)] + 36t_i^4)$^{-1/2}$ (48)

- Computing the phase nodal corrections at 0h of the 25 tidal waves, U[0:24], j = 0, 24:
  - j = 0: wave M2: U(0) = 2 ∗ theta – 2 ∗ n (49)
  - j = 1: wave S2: U(1) = 0 (50)
  - j = 2: wave N2: U(2) = 2 ∗ theta – 2 ∗ n (51)
  - j = 3: wave K2: U(3) = - 2n” (52)
  - j = 4: wave K1: U(4) = - n’ (53)
  - j = 5: wave O1: U(5) = 2 ∗ theta – n (54)
  - j = 6: wave P1: U(6) = 0 (55)
  - j = 7: wave Q1: U(7) = 2 ∗ theta – n (56)
  - j = 8: wave L2: U(8) = 2 ∗ theta – 2 ∗ n – R (57)
  - j = 9: wave T2: U(9) = 0 (58)
  - j = 10: wave 2N2: U(10) = 2 ∗ theta – 2 ∗ n (59)
  - j = 11: wave NU2: U(11) = 2 ∗ theta – 2 ∗ n (60)
  - j = 12: wave MU2: U(12) = 2 * theta – 2 * n (61)
  - j = 13: wave LDA2: U(13) = 2 * theta – 2 * n (62)
  - j = 14: wave 2Q1: U(14) = 2 * theta – n (63)
  - j = 15: wave SIG1: U(15) = 2 * theta – n (64)
  - j = 16: wave RHO1: U(16) = 2 * theta – n (65)
  - j = 17: wave M11: U(17) = - n (66)
  - j = 18: wave M12: U(18) = 2 * theta – n (67)
  - j = 19: wave KHI1: U(19) = - n (68)
  - j = 20: wave PI1: U(20) = 0 (69)
  - j = 21: wave PHI1: U(21) = 0 (70)
  - j = 22: wave TTA1: U(22) = - n (71)
  - j = 23: wave J1: U(23) = - n (72)
  - j = 24: wave OO1: U(24) = - 2 * theta – n (73)
- Computing the amplitude nodal correction coefficients F[0:24] , j = 0, 24 for the 25 tidal waves:
  - j = 0: wave M2: F(0) = ($\cos^4$(I/2)) / 0.9154 (74)
  - j = 1: wave S2: F(1) = 1 (75)
  - j = 2: wave N2: F(2) = ($\cos^4$(I/2)) / 0.9154 (76)

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- j = 3: wave K2: $F(3) = (19.0444 * \sin^4(I) + 2.7702 * \sin^2(I) * \cos(2n) + 0.0981)^{1/2}$ (77)
- j = 4: wave K1: $F(4) = (0.8965 * \sin^2(2I) + 0.6001 * \sin(2I) * \cos(n) + 0.1006)^{1/2}$ (78)
- j = 5: wave O1: $F(5) = \sin(I) * (\cos^2(I/2)) / 0.38$ (79)
- j = 6: wave P1: $F(6) = 1$ (80)
- j = 7: wave Q1: $F(7) = \sin(I) * (\cos^2(I/2)) / 0.38$ (81)
- j = 8: wave L2: $F(8) = (\cos^4(I/2)) / (0.9154 * Ra)$ (82)
- j = 9: wave T2: $F(9) = 1$ (83)
- j = 10: wave 2N2: $F(10) = (\cos^4(I/2)) / 0.9154$ (84)
- j = 11: wave NU2: $F(11) = (\cos^4(I/2)) / 0.9154$ (85)
- j = 12: wave MU2: $F(12) = (\cos^4(I/2)) / 0.9154$ (86)
- j = 13: wave LDA2: $F(13) = (\cos^4(I/2)) / 0.9154$ (87)
- j = 14: wave 2Q1: $F(14) = (\sin(I) * \cos^2(I/2)) / 0.38$ (88)
- j = 15: wave SIG1: $F(15) = (\sin(I) * \cos^2(I/2)) / 0.38$ (89)
- j = 16: wave RHO1: $F(16) = (\sin(I) * \cos^2(I/2)) / 0.38$ (90)
- j = 17: wave M11: $F(17) = (\sin(2I)) / 0.7214$ (91)
- j = 18: wave M12: $F(18) = (\sin(I) * \cos^2(I/2)) / 0.38$ (92)
- j = 19: wave KHI1: $F(19) = (\sin(2I)) / 0.7214$ (93)
- j = 20: wave PI1: $F(20) = 1$ (94)
- j = 21: wave PHI1: $F(21) = 1$ (95)
- j = 22: wave TTA1: $F(22) = (\sin(2I)) / 0.7214$ (96)
- j = 23: wave J1: $F(23) = (\sin(2I)) / 0.7214$ (97)
- j = 24: wave OO1: $F(24) = (\sin(I) * \sin^2(I/2)) / 0.0164$ (98)

- For each of the 25 tidal waves (for j = 0 to 24), computing the tidal wave phase, Psi(j), at altimeter time:

  $Psi(j) = \text{value modulo } 2\pi \text{ of } [Sigma(j) * 10^{-4} * Sec_Day + X(j) + U(j)]$ (99)

  If $Psi(j) < 0$, then $Psi(j) = Psi(j) + 2\pi$ (100)

For the diurnal and semi-diurnal ocean tide:

- Computing the indexes of the four surrounding grid points in the GOT99 harmonic coefficients map, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

  the input parameters being:

  - X = Alt_Lon_Mean
  - Y = Alt_Lat_Mean

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- DX = Ocean1_Lon_Step
- DY = Ocean1_Lat_Step
- XFIR = Ocean1_Lon_First
- YFIR = Ocean1_Lat_First
- Nb_Ptx = Ocean1_Nb_Lon
- Nb_Pty = Ocean1_Nb_Lat
- Xcyc = 360
- Ycyc = 0
- Xcut = 0
- Ycut = 0

and the output parameters of which being:

- The indexes of the four grid corners surrounding the (Lon,Lat) point: I_Left,I_Right,J_Low,J_Up
- The weights of these corners: W_LL, W_LR, W_UL, W_UR
- The execution status.

- For each of the 8 first tidal waves (for j = 0 to 7), and for each of the 2 kinds (first kind is tidal amplitude x cos(phase), second kind is tidal amplitude x sin(phase)) of ocean tide harmonic coefficient A (for i = 0 to 1):
  - Computing the ocean tide harmonic coefficient A(i,j) at the (Lon, Lat) point by bilinear interpolation, using mechanism “GEN_MEC_INT_03 - Bilinear interpolation”,

    ∗ the input parameters of which being:

    ∗ VAL_LL = Ocean1_Map(i, j, I_Left, J_Low)

    ∗ VAL_LR = Ocean1_Map(i, j, I_Right, J_Low)

    ∗ VAL_UL = Ocean1_Map(i, j, I_Left, J_Up)

    ∗ VAL_UR = Ocean1_Map(i, j, I_Right, J_Up)

    ∗ W_LL

    ∗ W_LR

    ∗ W_UL

    ∗ W_UR

    ∗ NIL = Ocean1_Def_Value

    and the output parameters of which being:

    ∗ A(i,j)

    ∗ Nb_Pts_Valid_H_Ocean1

    ∗ The execution status

  - If (j = 0 and i = 0), then :

    ∗ If Nb_Pts_Valid_H_Ocean1 = 0 (the four grid points are set to their default values), then the elastic ocean tide height H_Ocean1 is returned set to its default value.

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- For each of the 17 remaining tidal waves (for j = 8 to 24), and for each of the 2 kinds of ocean tide harmonic coefficient A (for i = 0 to 1):
  - Computing the ocean tide harmonic coefficients A(i,j) at measurement (μ, ϕ) by linear combination of the coefficients A(i,j) obtained for j = 0 to 7, as defined by the admittance coefficients:

$$A(i,j) = a(j) * A(i, j_a(j)) + b(j) * A(i, j_b(j)) + c(j) * A(i, j_c(j)) \quad (101)$$

- For each of the 25 tidal waves (for j = 0 to 24), computing the ocean tide height h(j):

$$H(j) = F(j) * \{A(0,,j) * \cos(Psi(j)) + A(1,,j) * \sin(Psi(j))\} \quad (102)$$

- Compute the ocean tide height (H_Ocean1):

$$H_Ocean1 = \sum_{j=0}^{24} H(j) \quad (103)$$

For the load tide:

- Computing the indexes of the four surrounding grid points in the tidal loading harmonic coefficients map, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

  the input parameters being:
  - X = Alt_Lon_Mean
  - Y = Alt_Lat_Mean
  - DX = Load1_Lon_Step
  - DY = Load1_Lat_Step
  - XFIR = Load1_Lon_First
  - YFIR = Load1_Lat_First
  - Nb_Ptx = Load1_Nb_Lon
  - Nb_Pty = Load1_Nb_Lat
  - Xcyc = 360
  - Ycyc = 0
  - Xcut = 0
  - Ycut = 0

  and the output parameters of which being:
  - The indexes of the four grid corners surrounding the (Lon,Lat) point: I_Left,I_Right,J_Low,J_Up
  - The weights of these corners: W_LL, W_LR, W_UL, W_UR
  - The execution status.
- For each of the 8 first tidal waves (for j = 0 to 7), and for each of the 2 kinds of tidal loading harmonic coefficient B (for i = 0 to 1):
  - Computing the tidal loading harmonic coefficient B(i,j) at the (Lon, Lat) point by bilinear interpolation, using mechanism “GEN_MEC_INT_03 - Bilinear interpolation”,

    the input parameters of which being:

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- VAL_LL = Load1_Map(i, j, I_Left, J_Low)
- VAL_LR = Load1_Map(i,,j, I_Right, J_Low)
- VAL_UL = Load1_Map(i, j, I_Left, J_Up)
- VAL_UR = Load1_Map(i, j, I_Right, J_Up)
- W_LL
- W_LR
- W_UL
- W_UR
- NIL = Load1_Def_Value

and the output parameters of which being:

- B(i,j)
- Nb_Pts_Valid (unused)
- The execution status

- For each of the 17 remaining tidal waves (for j = 8 to 24), and for each of the 2 kinds of tidal loading harmonic coefficient B (for i = 0 to 1):
  - Computing the tidal loading harmonic coefficients B(i,j) at measurement (μ, ϕ) by linear combination of the coefficients B(i,j) obtained for j = 0 to 7, as defined by the admittance coefficients:

$$B(i,j) = a(j) * B(i,j_a(j)) + b(j) * B(i,j_b(j)) + c(j) * B(i,j_c(j)) \quad (104)$$

- For each of the 25 tidal waves (for j = 0 to 24), computing the height of the tidal loading h(j):

$$H(j) = F(j) * \{B(0,,j) * \cos(Psi(j)) + B(1,,j) * \sin(Psi(j))\} \quad (105)$$

- Compute the height of the tidal loading (H_Load1):

$$H_Load1 = \sum_{j=0}^{24} H(j) \quad (106)$$

For the elastic ocean tide height :

- Adding the ocean tide height and the loading tide height :
  - H_Ocean1 = H_Ocean1 + H_Load1 (107)

ACCURACY

The ocean tide model GOT99.2, is essentially an update of the one described by E Schrama and R Ray in Journal of Geophysical Research, v.99, p 24799, 1994. The new solution is described in detail in Ray (1999). Solution GOT99.2 used 232 cycles of Topex and Poseidon data, and it solved (among other things) for 8 semidiurnal and diurnal tides (Q1,O1,P1,K1,N2,M2,S2,K2). The tides were computed as adjustments to the hydrodynamic model FES94.1. Outside the latitude limits of Topex (66 deg), the model defaults (by a taper) to FES94.1. A comprehensive comparison study of the new tide models available before the JASON-1 and ENVISAT launch dates has been performed by Dorandeu et al. (2000).

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COMMENTS

- In the specification section, equations (3) to (98) are to be computed for the first processed altimeter measurement, and then only when the day of the altimeter measurement is changing.
- The present algorithm must be implemented in such a way that the diurnal and semi-diurnal ocean tide alone or the load tide alone, can be computed

REFERENCES

- Ray, R., A Global Ocean Tide Model From TOPEX/Poseidon Altimetry/GOT99.2 - NASA/TM-1999-209478, pp. 58, Goddard Space Flight Center/NASA, Greenbelt, MD, 1999.
- Dorandeu, J., M. Ablain, F. Lefèvre and R. Ray (2000) : New tide models evaluation. Preliminary report. AVI-NT-011-0253-CLS, April 2000. Availbale on Internet at ftp://spike.cnes.fr/pub/poseidon/doc/tide.pdf

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GEN_ENV_TID_03 - To compute the solid earth and the equilibrium long period ocean tide heights

DEFINITION, ACCURACY AND SPECIFICATION

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	CCM			

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HERITAGE

TOPEX/POSEIDON

FUNCTION

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

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the solid earth tide height and of the equilibrium long period ocean tide height will be performed for all surface types (over land and ocean), although the computation of the equilibrium long period ocean tide height is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - For JASON-1:
    - 1-Hz altimeter time tag
- Computed data:
  - For ENVISAT:
    - From "ALT_COM_TIM_01 - To compute the averaged time tags":
      - 1-Hz altimeter time tag
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement
      - Longitude of the measurement
- Dynamic auxiliary data: None

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- Static auxiliary data:
  - Cartwright and Edden tables of tide potential amplitudes, frequencies ω_i and phases ϕ_i of the 6 astronomical variables at the reference epoch (22 May 1960 at 12H).
  - Processing parameters

Output data

- Height of the solid Earth tide: H_Solid
- Height of the equilibrium long period ocean tide: H_Equi

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:

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

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

$$\begin{aligned} V_n(s) &= g.c_n(s).\sum_{m=0}^{n} W_n^m.\cos[\omega(s).t + \phi(s) + m.\lambda] \leftarrow \text{for}(m+n) = \text{even} \\ V_n(s) &= g.c_n(s).\sum_{m=0}^{n} W_n^m.\sin[\omega(s).t + \phi(s) + m.\lambda] \leftarrow \text{for}(m+n) = \text{odd} \end{aligned} \tag{2}$$

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 $\omega_i.t + \phi_i$:

$$\omega(s).t + \phi(s) = \sum_{i=1}^{6} k_i(s).[\varpi_i.t + \phi_i] \tag{3}$$

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:

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$$H_Solid = H_2 . \frac{V_2}{g} + H_3 . \frac{V_3}{g} \tag{4}$$

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:

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

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

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

ALGORITHM SPECIFICATION

Input data

- Time of the altimeter measurement : Day_1900 (days elapsed since 1/1/1900 at 0h)
- Location of the altimeter measurement:
  - Latitude : Alt_Lat_MeanR (radian)
  - Longitude : Alt_Lon_MeanR (radian)
- The frequencies Freq[0:4] in degree per day, and the phases Pha0[0:4] at 0h on 1/1/1900 in degree, for i = 0 to 4, 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.
- Cartwright and Edden tables, containing:
  - Number of constituents for tide potential V_{20} : N_{20}
  - Number of constituents for tide potential V_{21} : N_{21}
  - Number of constituents for tide potential V_{22} : N_{22}
  - Number of constituents for tide potential V_{30} : N_{30}
  - Number of constituents for tide potential V_{31} : N_{31}
  - Number of constituents for tide potential V_{32} : N_{32}
  - Number of constituents for tide potential V_{33} : N_{33}
  - For each tide potential V_{nm}, sorted as defined above (V_{20}, then V_{21} , up to V_{33})

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∗ For each tidal constituent j = 0 to N_{nm} -1, (N_{20} for V_{20}, then N_{21} for V_{21}, up to N_{33} for V_{33}):

The linear coefficients $K_{nm}[i][j]$ (/) of the six astronomical variables i = 0 to 5, (respectively the lunar time angle, 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), and the constituent amplitude $AMP_{nm}[j]$ (m)

- Love numbers : H_2, K_2, H_3, K_3 (/)

Output data

- Height of the solid Earth tide : H_Solid (m)
- Height of the equilibrium long period ocean tide : H_Equi (m)
- Execution status

Processing

- Computing the mean longitude of the moon in degree, Pha(0), on measurement time Day_1900:

  Pha(0) = value modulo 360 of [Pha0(0) + Freq(0) ∗ Day_1900] (1)

- Computing the mean longitude of the sun in degree, Pha(1), on measurement time Day_1900:

  Pha(1) = value modulo 360 of [Pha0(1) + Freq(1) ∗ Day_1900] (2)

- Computing the mean longitude of the lunar perigee in degree, Pha(2), on measurement time Day_1900:

  Pha(2) = value modulo 360 of [Pha0(2) + Freq(2) ∗ Day_1900] (3)

- Computing the negative of the mean longitude of the lunar ascending node in degree, Pha(3), on measurement time Day_1900:

  Pha(3) = value modulo 360 of [Pha0(3) + Freq(3) ∗ Day_1900] (4)

- Computing the mean longitude of the solar perigee in degree, Pha(4), on measurement time, Day_1900:

  Pha(4) = value modulo 360 of [Pha0(4) + Freq(4) ∗ Day_1900] (5)

- Computing the mean lunar time angle in degree, Moon_Angle, on measurement time:

  Frac_Day = Day_1900 – INT(Day_1900) (6)

  Moon_Angle = 360 ∗ Frac_Day – Pha(0) + Pha(1) (7)

- Converting Pha(i) and Moon_Angle from degree to radian:

  For i = 0 to 4: Phar(i) = Pha(i) ∗ (π/180) (8)

  Moon_angle_rad = Moon_Angle ∗ (π/180) (9)

- Computing the height Z_{20} corresponding to the tide potential V_{20} (= g Z_{20}) of degree n = 2 and order m = 0 :

$$H_{20} = \sum_{j=1}^{N_{20}} [AMP_{20}(j-1) * \cos\left(\sum_{i=1}^{5} [K_{20}(i,j-1) * Phar(i-1)]\right)] \quad (10)$$

$$Z_{20} = H_{20} * \sqrt{5/4\pi} * [1.5 * \sin^2(Alt_Lat_MeanR) - 0.5] \quad (11)$$

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- Computing the height Z_{21} corresponding to the tide potential V_{21} (= g Z_{21}) of degree n = 2 and order m = 1 :

$$H_{21} = \sum_{j=1}^{N_{21}} [AMP_{21}(j-1) * \sin\left([\sum_{i=1}^{5} (K_{21}(i,j-1) * Phar(i-1))] + Moon_angle_rad + Alt_Lon_MeanR \right)] \quad (12)$$

$$Z_{21} = H_{21} * (-\sqrt{5/24\pi}) * 3 * \sin(Alt_Lat_MeanR) * \cos(Alt_Lat_MeanR) \quad (13)$$

- Computing the height Z_{22} corresponding to the tide potential V_{22} (= g Z_{22}) of degree n = 2 and order m = 2 :

$$H_{22} = \sum_{j=1}^{N_{22}} [AMP_{22}(j-1) * \cos\left([\sum_{i=1}^{5} (K_{22}(i,j-1) * Phar(i-1))] + 2 * (moon_angle_rad + Alt_Lon_MeanR) \right)] \quad (14)$$

$$Z_{22} = H_{22} * \sqrt{5/96\pi} * 3 * \cos^2(Alt_Lat_MeanR) \quad (15)$$

- Computing the height Z_{30} corresponding to the tide potential V_{30} (= g Z_{30}) of degree n = 3 and order m = 0 :

$$H_{30} = \sum_{j=1}^{N_{30}} [AMP_{30}(j-1) * \sin\left(\sum_{i=1}^{5} [K_{30}(i,j-1) * Phar(i-1)] \right)] \quad (16)$$

$$Z_{30} = H_{30} * \sqrt{7/4\pi} * [2.5 * \sin^2(Alt_Lat_MeanR) - 1.5] * \sin(Alt_Lat_MeanR) \quad (17)$$

- Computing the height Z_{31} corresponding to the tide potential V_{31} (= g Z_{31}) of degree n = 3 and order m = 1 :

$$H_{31} = \sum_{j=1}^{N_{31}} [AMP_{31}(j-1) * \cos\left[\left(\sum_{i=1}^{5} K_{31}(i,j) * Phar(i-1) \right) + Moon_angle_rad + Alt_Lon_MeanR \right]] \quad (18)$$

$$Z_{31} = H_{31} * (-\sqrt{7/48\pi}) * [5 * \sin^2(Alt_Lat_MeanR) - 1] * 1.5 * \cos(Alt_Lat_MeanR) \quad (19)$$

- Computing the height Z_{32} corresponding to the tide potential V_{32} (= g Z_{32}) of degree n = 3 and order m = 2 :

$$H_{32} = \sum_{j=1}^{N_{32}} [AMP_{32}(j-1) * \sin\left([\sum_{i=1}^{5} (K_{32}(i,j-1) * Phar(i-1))] + 2 * (Moon_angle_rad + Alt_Lon_MeanR) \right)] \quad (20)$$

$$Z_{32} = H_{32} * \sqrt{7/480\pi} * 15 * \cos^2(Alt_Lat_MeanR) * \sin(Alt_Lat_MeanR) \quad (21)$$

- Computing the height Z_{33} corresponding to the tide potential V_{33} (= g Z_{33}) of degree n = 3 and order m = 3 :

$$H_{33} = \sum_{j=1}^{N_{33}} [AMP_{33}(j-1) * \cos\left([\sum_{i=1}^{5} (K_{33}(i,j-1) * Phar(i-1))] + 3 * (Moon_angle_rad + Alt_Lon_MeanR) \right)] \quad (22)$$

$$Z_{33} = H_{33} * (-\sqrt{7/2880\pi}) * 15 * \cos^3(Alt_Lat_MeanR) \quad (23)$$

- Computing the solid earth tide height, H_Earth, in m:

$$H_Earth = H_2 * (Z_{20} + Z_{21} + Z_{22}) + H_3 * (Z_{30} + Z_{31} + Z_{32} + Z_{33}) \quad (24)$$

- Computing the equilibrium long period ocean tide height (H_Long), in m:

$$H_Long = (1 - H_2 + K_2) * Z_{20} + (1 - H_3 + K_3) * Z_{30} \quad (25)$$

ACCURACY

The accuracy of the solid earth tide height and of the height of the equilibrium long period ocean tide is better than 1 mm.

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COMMENTS

Propagation of Cartwright and Edden coefficient tides to the 2000's era is TBC.

REFERENCES

- Cartwright, D.E., and R.J. Tayler: New computations of the tide-generating potential, Geophys.J.R.Astr.Soc, v23, 45-74, 1971
- Cartwright, D.E., and A.C. Edden: Corrected tables of tidal harmonics, Geophys.J.R.Astr.Soc, v33, 253-264, 1973

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GEN_ENV_TID_04 - To compute the pole tide height

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

TOPEX/POSEIDON

FUNCTION

To compute the geocentric tide height due to polar motion.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	Yes

- Surface type:

  The computation of the pole tide height will be performed for all surface types (over land and ocean).

ALGORITHM DEFINITION

Input data

- Product data:
  - For JASON-1:
    - 1-Hz altimeter time tag
- Computed data:
  - For ENVISAT:
    - From "ALT_COM_TIM_01 - To compute the averaged time tags":
      - 1-Hz altimeter time tag
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement
      - Longitude of the measurement
    - From "GEN_ENV_SUR_01 - To determine the surface type":
      - Surface type (“open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, or “land”)

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- Dynamic auxiliary data:
  - Pole location data (arc second):
    - Date
    - x (along the 0° meridian)
    - y (along the 90°W meridian)
- Static auxiliary data:
  - Processing parameters :
    - Average pole position (arc second): x_avg, y_avg
    - Scaled amplitude factor: A

Output data

- Height of the pole tide: H_Pole
- Execution status

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:

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

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:

$$A = -\frac{\Omega^2 R^2}{2g}.\frac{\pi}{180 \times 3600}.(1+K_2) \text{ over ocean} \quad (2)$$

$$A = -\frac{\Omega^2 R^2}{2g}.\frac{\pi}{180 \times 3600}.H_2 \text{ over land} \quad (2)$$

where Ω is the nominal earth rotation angular velocity in radian/s, R is the earth radius in m, g is gravity in m/s^2, $\frac{\pi}{180 \times 3600}$ is a conversion factor from arc second to radian, H_2 and K_2 are Love numbers (H_2 = 0.609, K_2 = 0.302). Over ocean, A = -69.435 10^{-3}.

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ALGORITHM SPECIFICATION

Warning: The selection of the pole location (Xp, Yp) at altimeter measurement time tag is considered as a "data management" algorithm (see section 1). It is specified in RD12.

Input data

- Location of the altimeter measurement:
  - Latitude : Alt_Lat_MeanR (radian)
  - Longitude : Alt_Lon_MeanR (radian)
- Altimeter surface type [1] : Alt_Surf_Type (/)
- Selected pole location : Xp, Yp (arc second)
- Average pole co-ordinates : X_avg, Y_avg (arc second)
- Scaled amplitude factor over ocean : A_Ocean (m)
- Scaled amplitude factor over land : A_Land (m)

Output data

- Pole tide height : H_Pole (m)
- Execution status

Processing

If Alt_Surf_Type is set to “open oceans or semi-enclosed seas” or “enclosed seas or lakes”, then :

- A = A_Ocean

Else :

- A = A_Land

H_Pole = A∗sin(2∗Alt_Lat_MeanR)∗[(Xp - X_avg) ∗ cos(Alt_Lon_MeanR) - (Yp - Y_avg) ∗ sin(Alt_Lon_MeanR)] (1)

ACCURACY

IGDR processing uses predicted pole locations, whereas GDR processing will probably use true (measured) pole locations. The use of measured pole locations instead of predicted ones has probably little impact on the pole tide height accuracy.

A pole location accuracy of about 50 cm is needed to get a 1-mm accuracy on the pole tide height.

---

[1] 4 states (“open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, “land”).

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COMMENTS

- The pole tide height is recomputed in the JASON-1 GDR processing, using improved pole locations with respect to those used in the IGDR processing. Regarding this processing, the surface type must be considered as a "Product data".

REFERENCES

- Wahr, J.: J. Geophys. Res., Vol. 90, pp. 9363-9368, 1985.

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GEN_ENV_MSS_01 - To compute the mean sea surface height

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

ERS-1, ERS-2, TOPEX-POSEIDON

FUNCTION

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

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the mean sea surface height will be performed for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Latitude of the measurement
    - Longitude of the measurement
- Dynamic auxiliary data: None
- Static auxiliary data:
  - MSS (geographical grid)
  - Interpolation window size

Output data

- Height of the mean sea surface above the reference ellipsoid.

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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.

ALGORITHM SPECIFICATION

Warning : the units of the longitude and latitude of the measurement must be consistent with the units of the grid characteristics of the MSS map (minutes for Jason-1, degrees for Envisat).

Input data

- Location of the measurement:
  - Longitude : Lon
  - Latitude : Lat
- MSS map:
  - Longitude of first grid point : Lon_First
  - Grid step in longitude : Step_Lon
  - Number of points in longitude : Nb_Pts_Lon (/)
  - Latitude of first grid point : Lat_First (negative)
  - Grid step in latitude : Step_Lat (positive)
  - Number of points in latitude : Nb_Pts_Lat (/)
  - MSS model : MSS[0:Nb_Pts_Lon-1][0:Nb_Pts_Lat-1] (m)
  - Default value in Model : Def_Value (/)
  - Cycling value of the MSS : Xcyc (= 360 degrees, or = 360x 60 minutes)
- Number of grid points in longitude (and latitude) used for spline calculation : N_Window_MSS (/)

Output data

- Computed Mean Sea Surface : H_MSS (m)
- Number of cell points used by interpolation : Nb_Pts_Valid_MSS ($\in$ [0,N_Window$*$N_Window])
- Execution status

Processing

- H_MSS is set to its default value
- If Lat < Lat_First or Lat > Lat_First + (Nb_Pts_Lat – 1)$*$Step_Lat, then :

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- Exit

- Do while H_MSS is set to its default value AND N_Window_MSS ≥ 4
  - Computing the mean sea surface H_MSS at altimeter point by spline interpolation, using mechanism "GEN_MEC_INT_12 – Spline interpolation of grid values",

    The input parameters of which are :

    ∗ Lon

    ∗ Lat

    ∗ Lon_First

    ∗ Step_Lon

    ∗ Nb_Pts_Lon

    ∗ Lat_First

    ∗ Step_Lat

    ∗ Nb_Pts_Lat

    ∗ MSS[0:Nb_Pts_Lon-1][0:Nb_Pts_Lat-1]

    ∗ Def_Value

    ∗ Xcyc

    ∗ N_Window_MSS

    And the output parameters of which are :

    ∗ H_MSS

    ∗ The execution status
  - Nb_Pts_Valid_MSS = N_Window_MSS∗N_Window_MSS
  - N_Window_MSS = N_Window_MSS – 1

- If H_MSS is set to its default value, then :
  - Computing the indexes of the four surrounding grid points in the map, using mechanism "GEN_MEC_GRI_01 - Cell identification",

    the input parameters being:

    ∗ X = Lon

    ∗ Y = Lat

    ∗ DX = Step_Lon

    ∗ DY = Step_Lat

    ∗ XFIR = Lon_First

    ∗ YFIR = Lat_First

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* Nb_Ptx = Nb_Pts_Lon
* Nb_Pty = Nb_Pts_Lat
* Xcyc
* Ycyc = 0
* Xcut = 0
* Ycut = 0

and the output parameters of which being:

* The indexes of the four grid corners surrounding the (Lon,Lat) point: Ileft,Iright,Jlow,Jup
* The weights of these corners: W_LL, W_LR, W_UL, W_UR
* The execution status.

– Computing the mean sea surface at (Lon,Lat) by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

the input parameters of which being:

* VAL_LL = MSS(Ileft, Jlow)
* VAL_LR = MSS(Iright, Jlow)
* VAL_UL = MSS(Ileft, Jup)
* VAL_UR = MSS(Iright, Jup)
* W_LL
* W_LR
* W_UL
* W_UR
* NIL = Def_Value

and the output parameters of which being:

* H_MSS
* Nb_Pts_Valid_MSS
* The execution status

ACCURACY

The MSS to be used for Jason-1 is the GSFC00.1 mean sea surface. The MSS to be used for Envisat is the OSU95 mean sea surface.

GSFC00.1_MSS is a mean sea surface model in 2'x2' grid size between latitude ±80°. It was computed by combining satellite altimeter data of multi-missions. The data used are:

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6-years of T/P data (Cycles 11 to 232), multi-years of ERS-1/2 35-day repeat cycle (ERS-1 Phase C: Cycles 1 to 18; Phase G: Cycle 1 to 13; ERS-2: Cycle 1 to 29); Geosat ERM (Cycle 1 to 41); Geosat GM and ERS-1 168-day data. All altimeter data used are the GSFC's Pathfinder products [Koblinsky et al., 1999]. New environmental corrections were applied to the Pathfinder data. The standard invert barometer correction was applied [ibid., p.32, equation (9)]. The altimetric gravity anomaly and vertical component of the gravity gradient, namely GSFC00.1_DG and GSFC00.1_DGZ, were computed from GSFC00.1_MSS in 2'x2' grid by numerical evaluating of the inverse Stokes integral.

The mean sea surface GSFC00.1 is modeled by a 2-dimensional Fourier series in 2°x2° cells (1° x1° predication area plus 0.5° border). The Nyquist frequency was 1/11', which corresponds to the resolution of 21 km at the equator. The mean sea surface height along the oceanic study dedicated missions (TOPEX, GEOSAT ERM and ERS -1/2 35-day repeat missions) were averaged into mean tracks along the reference tracks. The mean sea surface heights of non-TOPEX missions were then adjusted to the 6-year mean of the TOPEX mean in 2° (0.5° border) latitude bands. Instead the sea surface height, the sea surface height differences (ssh(i+1)-ssh(i), i=1,2,...) of the GEOSAT GM and ERS-1 168-day data, combined with the adjusted mean sea surface heights, including the mean sea surface height of the TOPEX data, were used in the determination of the coefficients of the 2D Fourier series by the least squares adjustment. To stabilize solutions, a priori degree variance were adopted and the 2D Fourier were determined in such a way that the root mean squares of sea surface height differences and sea surface height slope differences were minimum. The error of the GSFC00.1 mean sea surface height was also provided for each 2' cells in the file STD00_MSS. The new technique is aimed to improve the quality of the mean sea surface, and solve the track pattern problem in GSFC98 MSS. The results show significant improvement in this respect.

Reference Frame of the GSFC00.1 MSS [from Koblinsky et al.]

Equatorial radius	6378136.3 m
Flatening	1/298.257
Potential	62636858.702 m**2/s**2
GMe	398600.4415 km**3/s**2

Invert Barometer Correction

The invert barometer correction (IB) applied to the Pathfinder data is:

IB =-9.948*(P-1013.3) millimeter

The IB corrected sea surface height is:

SSH(IB corrected)=SSH(T/P observation) - IB

If the new average pressure PA0 is used, the MSS can be convert to new mean pressure system by subtracting a constant DRP from GSFC00.1_MSS:

DRP= 9.948*(PA0-1013.3) millimeter

For example: If 1010.6 mbar mean pressure is used on Jason, a bias of -27 mm should be subtracted from GSFC00.1_MSS.

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COMMENTS

None

REFERENCES

None

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GEN_ENV_GEO_01 - To compute the geoid height

DEFINITION, ACCURACY AND SPECIFICATION

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HERITAGE

ERS-1, ERS-2, TOPEX-POSEIDON

FUNCTION

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

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the geoid height will be performed for all surface types (over land and ocean).

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
    - Latitude of the measurement
    - Longitude of the measurement
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Geoid (geographical grid)
  - Interpolation window size

Output data

- Height of the geoid.

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Mathematical statement

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

ALGORITHM SPECIFICATION

Input data

- Location of the measurement:
  - Longitude : Lon (degree ∈ [0,360[)
  - Latitude : Lat (degree)
- The geoid map:
  - Longitude of first grid point : Lon_First (degree ∈ [0,360[)
  - Grid step in longitude : Step_Lon (degree)
  - Number of points in longitude : Nb_Pts_Lon (/)
  - Latitude of first grid point : Lat_First (negative, degree)
  - Grid step in latitude : Step_Lat (positive, degree)
  - Number of points in latitude : Nb_Pts_Lat (/)
  - Geoid model : Geoid[0:Nb_Pts_Lon-1][0:Nb_Pts_Lat-1] (m)
  - Default value in Model : Def_Value (/)
- Number of grid points in longitude (and latitude) used for spline calculation : N_Window_Geoid (/)

Output data

- Computed geoid height : H_Geoid (m)
- Execution status

Processing

If N_Window_Geoid ≥ 4, then (spline interpolation):

- Computing the geoid height H_Geoid at altimeter point by spline interpolation, using mechanism "GEN_MEC_INT_12 – Spline interpolation of grid values",

  The input parameters of which are :
  - Lon
  - Lat
  - Lon_First
  - Step_Lon
  - Nb_Pts_Lon

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- Lat_First
- Step_Lat
- Nb_Pts_Lat
- Geoid[0:Nb_Pts_Lon-1][0:Nb_Pts_Lat-1]
- Def_Value
- Xcyc = 360
- N_Window_Geoid

And the output parameters of which are :

- H_Geoid
- The execution status

Else (bilinear interpolation) :

- Computing the indexes of the four surrounding grid points in the map, using mechanism “GEN_MEC_GRI_01 - Cell identification”,

  the input parameters being:

  - X = Lon
  - Y = Lat
  - DX = Step_Lon
  - DY = Step_Lat
  - XFIR = Lon_First
  - YFIR = Lat_First
  - Nb_Ptx = Nb_Pts_Lon
  - Nb_Pty = Nb_Pts_Lat
  - Xcyc = 360
  - Ycyc = 0
  - Xcut = 0
  - Ycut = 0

  and the output parameters of which being:

  - The indexes of the four grid corners surrounding the (Lon,Lat) point: Ileft,Iright,Jlow,Jup
  - The weights of these corners: W_LL, W_LR, W_UL, W_UR
  - The execution status.

- Computing the geoid height at (Lon,Lat) by bilinear interpolation, using mechanism “GEN_MEC_INT_03 - Bilinear interpolation”,

  the input parameters of which being:

  - VAL_LL = Geoid(Ileft, Jlow)
  - VAL_LR = Geoid(Iright, Jlow)

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- VAL_UL = Geoid(lleft, Jup)
- VAL_UR = Geoid(lright, Jup)
- W_LL
- W_LR
- W_UL
- W_UR
- NIL = Def_Value

and the output parameters of which being:

- H_Geoid = Interp_Value
- Nb_Pts_Valid (unused)
- The execution status

ACCURACY

The geoid model to be used for Jason-1 and Envisat is the EGM96 model (Lemoine et al., 1998)

COMMENTS

None

REFERENCES

Lemoine, F.G. et al., 1998 : The development of the joint NASA GSFC and NIMA Geopotential model EGM96, NASA/TP-1998-206861, 575 pp, July 1998

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31401 TOULOUSE CEDEX 4

GEN_ENV_BAT_01 - To compute the ocean depth / land elevation

DEFINITION, ACCURACY AND SPECIFICATION

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Checked by:	For the JASON-1 SWT D. CHAMBERS S. NEREM N. PAVLIS For the JASON-1 Project P. VINCENT CNES S. DESAI JPL For the F-PAC / ENVISAT Project J. BENVENISTE ESA P. VINCENT CNES	
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HERITAGE

TOPEX-POSEIDON

FUNCTION

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

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	Yes	/

- Surface type:

  The computation of the ocean depth/land elevation will be performed for all surface types (over land and ocean).

ALGORITHM DEFINITION

Input data

- Product data: None
- Computed data:
  - For ENVISAT and JASON-1:
    - From "LOS_ORB_GEN_01 - To compute altitude, orbital altitude rate and location":
      - Latitude of the measurement
      - Longitude of the measurement
    - From "GEN_ENV_SUR_01 - To determine the surface type":
      - Surface type (“open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, or “land”)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Bathymetry / topography file, from NGDC (TerrainBase).

Output data

- Ocean depth / land elevation.

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Mathematical statement

The ocean depth / land elevation is obtained by bilinear interpolation in space from the DTM2000.1 2'x2' grid 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.

ALGORITHM SPECIFICATION

Input data

- Location of the measurement:
  - Longitude : Lon (degree ∈ [0,360[)
  - Latitude : Lat (degree)
- The bathymetry/topography map:
  - Longitude of first grid point : Lon_First (minute ∈ [0,21600[)
  - Grid step in longitude : Step_Lon (minute)
  - Number of points in longitude : Nb_Pts_Lon (/)
  - Latitude of first grid point : Lat_First (minute)
  - Grid step in latitude : Step_Lat (minute)
  - Number of points in latitude : Nb_Pts_Lat (/)
  - Bathymetry model : Bathy[0:Nb_Pts_Lon-1][0:Nb_Pts_Lat-1] (m)
  - Default value in Model : Def_Value (/)
- Altimeter surface type [(1)] : Alt_Surf_Type (/)

Output data

- Ocean depth/land elevation : H_Depth (m)
- The number of cell points used by interpolation : Nb_Pts_Valid_Bathy (∈ [0,4])
- Execution status

Processing

- The input latitude (Lat) and longitude (Lon) are multiplied by 60 to be expressed in minutes.
- Computing the indexes of the four surrounding grid points in the map, using mechanism "GEN_MEC_GRI_01 - Cell identification",

---

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

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the input parameters being:

- X = Lon
- Y = Lat
- DX = Step_Lon
- DY = Step_Lat
- XFIR = Lon_First
- YFIR = Lat_First
- Nb_Ptx = Nb_Pts_Lon
- Nb_Pty = Nb_Pts_Lat
- Xcyc = 21600
- Ycyc = 0
- Xcut = 0
- Ycut = 0

and the output parameters of which being:

- The indexes of the four grid corners surrounding the (Lon,Lat) point: Ileft,Iright,Jlow,Jup
- The weights of these corners: W(0) = Wll; W(1) = Wlr; W(2) = Wul; W(3) = Wur
- The execution status.

- Set the cell points to account for in bilinear interpolation. Depends on the surface type:
  - DL(0) = Bathy(Ileft,Jlow)
  - DL(1) = Bathy(Iright,Jlow)
  - DL(2) = Bathy(Ileft,Jup)
  - DL(3) = Bathy(Iright,Jup)
  - If the surface type is set to “Open ocean or semi-enclosed seas”, then:
    - For i = 0 to 3 :

      If DL(i) < 0, then :

      Wp(i) = W(i)

      Else :

      Wp(i) =0
    - If (Wp(0) = 0) AND (Wp(1) = 0) AND (Wp(2) = 0) AND (Wp(3) = 0), then:

      For i = 0 to 3 :

      Wp(i) = W(i) (i.e., the four cell corners are taken in account)
  - Else :
    - For i = 0 to 3 :
      - Wp(i) = W(i)

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- Computing the ocean depth/land elevation at (Lon,Lat) by bilinear interpolation, using mechanism "GEN_MEC_INT_03 - Bilinear interpolation",

  the input parameters of which being:

  - VAL_LL = DL(0)
  - VAL_LR = DL(1)
  - VAL_UL = DL(2)
  - VAL_UR = DL(3)
  - W_LL = Wp(0)
  - W_LR = Wp(1)
  - W_UL = Wp(2)
  - W_UR = Wp(3)
  - NIL = Def_Value

  and the output parameters of which being:

  - H_Depth
  - Nb_Pts_Valid_Bathy
  - The execution status

ACCURACY

DTM2000.1 was compiled by combining data and information from the following primary sources:

- (1) NGDC's Global Land One-kilometer Base Elevation (GLOBE), Version 1.0 (30" resolution. See web site: http://www.ngdc.noaa.gov/seg/topo. The disclaimers listed in Section 12 and throughout GLOBE's documentation (Hastings, David A., and Paula K. Dunbar, 1999. Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Documentation, Volume 1.0. Key to Geophysical Records Documentation (KGRD) 34. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A.) apply to all the data of DTM2000.1 that were extracted from GLOBE.
- (2) Smith and Sandwell's global sea floor topography derived from satellite altimetry and ship depth sounding. This data covers latitudes between +/- 72.006 degrees with 2' resolution, on a Mercator projection [JGR, 1994, 99, pp.21803-21824]. See the web site: http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html.
- (3) The global topographic database JGP95E [NASA/TP-1998-206861]. This is a 5' resolution database. It provided bathymetry for latitudes outside the +/- 72.006 degree band, water column height underneath ice shelfs, lake depths and ice thickness in various places on the Earth other than Antarctica and Greenland and surface elevations in lake Eyre in Australia. See web page: http://cddisa.gsfc.nasa.gov/926/egm96/egm96.html.
- (4) Wessel and Smith's shoreline and terrain type (ocean, land, lake, island, pond) data [JGR, 1996, 101, B4, pp.8741-8743]. A gridded version of these data was constructed originally by sampling the full resolution shoreline file of GMT every 6" in both latitude and longitude. This gridded file was then averaged to 30", 2' and 5'. See web site: http://www.soest.hawaii.edu/gmt.
- (5) The Ice Altimetry System (IAS) data of NASA GSFC, version 990811. This is a 5 km resolution surface elevation data which covers Antarctica (down to latitude -81.5 degrees) and Greenland. The IAS CD-ROM is complemented with surface elevation data from non-altimetric sources south of latitude -81.5 degrees. These

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heights are orthometric, referenced to the EGM96 geoid to degree and order 360.These data are gridded on a polar stereographic projection.

- (6) Scott Polar Research Institute (SPRI) Ice thickness data for Antarctica, compiled by Mario Giovinetto (Raytheon). These data were given on a 50 km grid on a polar stereographic projection.
- (7) Kort & Matrikelstyrelsen (KMS) ice thickness data for Greenland provided by Simon Ekholm [JGR, 1996, B10, 21, pp.961-972]. These data were provided as 5'x10' block mean values.

The compilation of DTM2000.1 was carried out following techniques similar to those described by Pavlis [1989] in the OSU Internal Report: 'The OSUJAN89 Global Topographic Database - Origin, Set-up and Characteristics'. At the time of creation of DTM2000.1, detailed lake depth data was not available for most of the Earth's lakes. Apart of large lakes and inland seas, DTM2000.1 contains no depth information at all for most lakes. Small lakes are identified geographically (through the terrain type), but only the elevation of their surface is available in DTM2000.1.

COMMENTS

None

REFERENCES

None

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ALT_MAN_INT_01 - To interpolate RA-2 data to MWR time tag

DEFINITION, ACCURACY AND SPECIFICATION

Prepared by:	J. STUM CLS	
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Approved by:	P. VINCENT CNES	

Document ref:	SMM-ST-M2-EA-11005-CN	18th October, 2001	Issue: 3	Update: 3

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HERITAGE

None

FUNCTION

The RA-2 operates independently of the MWR, and although the RA-2 data rate is close to the MWR rate (about 1/sec), they are asynchronous. In order to apply altimeter-derived wind speed to the MWR level 2 processing, we must therefore first interpolate the RA-2 data to the desired MWR time. Thus, this algorithm acts as a synchronizer between the RA-2 and the MWR processing.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the RA-2 data at the MWR time will be performed for all surface types (land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - MWR time tag
- Computed data:
  - From "ALT_COM_TIM_01 - To compute the averaged time tags":
    - 1-Hz RA-2 time tags
  - From "GEN_ENV_SUR_01 - To determine the surface type"
    - Surface type (“open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, or “land”)
  - From "ALT_PHY_WIN_01 - To correct the backscatter coefficients for atmospheric attenuation and to compute the 10 meter altimeter wind speed (Witter and Chelton, 1991)” :
    - RA-2 wind speed
    - Corrected Ku-band backscatter coefficient
    - Corrected S-band backscatter coefficient

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- From "ALT_COM_BAC_03 - To edit and compress the on-ground retracked backscatter coefficients":
  - Ku-band ocean backscatter coefficient (uncorrected for atmospheric attenuation)
  - Ku-band ocean backscatter coefficient validity flag
  - S-band ocean backscatter coefficient validity flag
- From "ALT_COM_SWH_01 - To edit and compress the on-ground retracked significant waveheights":
  - Ku-band significant waveheight (SWH_Ku)
  - Ku-band ocean significant waveheight validity flag

- Dynamic auxiliary data: None
- Static auxiliary data: None

Output data

RA-2 data at MWR time tag:

- Wind speed
- Ku-band significant wave height
- Corrected Ku-band backscatter coefficient
- Corrected S-band backscatter coefficient
- Ku-band backscatter coefficient uncorrected for atmospheric attenuation
- Interpolation quality flag

Mathematical statement

The RA-2 data are computed at the MWR time tag by linear interpolation of the two nearest valid bracketing RA-2 measurements found within ±16 s of the MWR time. Valid means that only RA-2 measurements with the surface type set to "open ocean or semi-enclosed seas" or “semi-enclosed seas or lakes” are considered .

If two RA-2 measurements are not found within ±16 s of the MWR time but if only one valid RA-2 point is found within ±8 s of the MWR time, the corresponding RA-2 data are assigned to the MWR time tag. The quality of the interpolation will be "good" if the linear interpolation is successful and if there is no gap between RA-2 measurements, "interp" if interpolation is successful with a gap between the two RA-2 measurements, "extrap", if extrapolation is used, and "fail" if both interpolation and extrapolation fail.

ALGORITHM SPECIFICATION

Input data

- The following time intervals:
  - Time interval for RA-2 interpolation : Dt_Int_Max_RA2 (s)
  - Time interval for RA-2 extrapolation : Dt_Ext_Max_RA2 (s)
  - Time interval between two successive RA-2 meas. : Dt_No_Gap_RA2 (s)

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- Number of RA-2 meas. for the whole MWR sequence : N_mes (/)
- Number of RA-2 parameters to be interpolated : N_param (/)
- RA-2 time tags : RA2_Time_Tag[0:N_mes-1] (1)
- RA-2 data to be interpolated : RA2_Data [0:N_param-1][0:N_mes-1]
- RA-2 surface types (3) : RA2_Surf[0: N_mes-1]
- The Ku-band significant waveheight validity flags : Flag_Valid_SWH_Ku[0:N_mes-1]
- The Ku-band backscatter coefficient validity flags : Flag_Valid_Sigma0_Ku[0:N_mes-1]
- The S-band backscatter coefficient validity flags : Flag_Valid_Sigma0_S[0:N_mes-1]
- MWR time tag : MWR_Time_Tag_Mean

Output data

- RA-2 data interpolated to MWR time : RA2_Data_Int [0:N_param-1]
- Interpolation quality flag : Qual_Int_RA2_To_MWR
- Execution status

Processing

The processing consists, for the input MWR measurement, of:

- Selecting, in the input RA-2 data, the couple of RA-2 measurements (j) and (j + 1) which satisfy the four following conditions:
  - The two RA-2 measurements bracket the MWR measurement in time
  - The RA-2 measurements are valid in both Ku- and S-band (check the Ku-band and S-band validity flags).
  - The time span between the MWR measurement and each RA-2 measurement is minimum, and its absolute value is less than Dt_Int_Max_RA2
  - The RA-2 surface type of each RA-2 measurement is set to “open ocean or semi-enclosed seas”, or to “enclosed seas or lakes”.
- If such bracketing couple exists:
  - Computing the weights of linear interpolation, using mechanism "GEN_MEC_INT_01 - Linear weighting",

    the input parameters of which are :
    - Xmin = RA2_Time_Tag(j)
    - Xmax = RA2_Time_Tag(j+1)
    - Xstep = RA2_Time_Tag(j+1) – RA2_Time_Tag(j)
    - X = MWR_Time_Tag_Mean

(1) Seconds elapsed since Time_Ref

(3) Set to “open ocean or semi-enclosed seas”, “enclosed seas or lakes”, “continental ice”, or “land”

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and the output parameters of which are :

* Index_1 (unused)
* Index_2 (unused)
* W1 = w1
* W2 = w2
* The execution status

– For i = 0 to N_param-1:

Computing by linear interpolation in time the RA-2 data at MWR time, RA2_Data_Int(i), using mechanism "GEN_MEC_INT_02 - Linear interpolation",

the input parameters of which are :

* X1 = RA2_Data(i,j)
* X2 = RA2_Data(i,j+1)
* W1 = w1
* W2 = w2

and the output parameter of which is :

* RA2_Data_Int(i)
* The execution status

- If no such bracketing couple of RA-2 measurements exists:
  - If valid RA-2 measurements with surface type set to “open ocean or semi-enclosed seas”, or to “enclosed seas or lakes” are available either before, or after the MWR measurement, but within ± Dt_Ext_Max_RA2 of the MWR time, then the interpolated RA-2 data are simply the RA-2 data of the closest RA-2 measurement (let Index_RA2 be the index of this closest RA-2 measurement)
  - If no valid RA-2 measurement is available neither before, nor after the MWR measurement within ± Dt_Ext_Max_RA2 of the MWR time, then the interpolated RA-2 data are not computed
- Assigning the RA-2 to MWR interpolation quality flag, Qual_Int_RA2_To_MWR, to:
  - "good" if interpolation was successful with no gap between the two RA-2 measurements (Time_Tag_RA2(j+1) - Time_Tag_RA2(j) ≤ Dt_No_Gap_RA2)
  - "interp" if interpolation was successful with a gap between the two RA-2 measurements
  - "extrap" if extrapolation was used
  - "fail" if interpolation and extrapolation failed

ACCURACY

Experience with TOPEX data has shown that, in order to avoid out-of-bounds interpolation values, linear interpolation is preferred to cubic interpolation.

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COMMENTS

None

REFERENCES

None

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RAD_PHY_GEN_03 - To compute the MWR geophysical parameters at MWR time tag

DEFINITION, ACCURACY AND SPECIFICATION

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Approved by:	P. VINCENT CNES	

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HERITAGE

ERS-1, ERS-2

FUNCTION

To compute at MWR time tag, the wet tropospheric correction due to water vapor in the troposphere, and the water vapor and cloud liquid water contents, from the MWR brightness temperatures and using the altimeter Ku-band backscatter coefficient interpolated at MWR time tag as a correction term.

APPLICABILITY

- Procedures:

	IGDR	GDR
ENVISAT	Yes	Yes
JASON-1	/	/

- Surface type:

  The computation of the MWR level 2 parameters for the radiometer will be performed for all surface types (land and ocean), although it is relevant to ocean surfaces only.

ALGORITHM DEFINITION

Input data

- Product data:
  - MWR brightness temperatures
- Computed data:
  - From "ALT_MAN_INT_01 - To interpolate RA-2 data to MWR time tag":
    - Interpolated RA-2 Ku-band backscatter coefficient (uncorrected for atmospheric attenuation)
- Dynamic auxiliary data: None
- Static auxiliary data:
  - Processing parameters

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Output data

- MWR wet tropospheric correction: Wet_H_Rad
- Water vapor content: Vap_cont
- Cloud liquid water content: Cloud_Liq

Mathematical statement

The MWR wet tropospheric correction Wet_H_Rad, water vapor content Vap_Cont and cloud liquid water content Cloud_Liq are given by:

$$Wet_H_Rad = a_0 + a_1.Log_e(280 - TB23) + a_2.Log_e(280 - TB36) + a_3.\frac{1}{Sigma0_Ku} \quad (1)$$

$$Cloud_Liq = b_0 + b_1.Log_e(280 - TB23) + b_2.Log_e(280 - TB36) + b_3.\frac{1}{Sigma0_Ku} \quad (2)$$

$$Vap_Cont = c_0 + c_1.Log_e(280 - TB23) + c_2.Log_e(280 - TB36) + c_3.\frac{1}{Sigma0_Ku} \quad (3)$$

where TB23 and TB36 are the 23.8 GHz and 36.5 GHz brightness temperatures (in K), Sigma0_Ku is the altimeter Ku-band backscatter coefficient uncorrected for atmospheric attenuation, interpolated at MWR time tag (in dB), and where a_i, b_i and c_i are retrieval coefficients.

EMBEDEMBEDEMBED**ALGORITHM SPECIFICATION**

Input data

- MWR 23.8 GHz brightness temperature : MWR_TB23 (K)
- MWR 36.5 GHz brightness temperature : MWR_TB36 (K)
- RA-2 to MWR interpolation quality flag : RA2_To_MWR_Qual_Interp
- Interpolated Ku-band backscatter coefficient : Sigma0_Ku_Int (dB)
- Retrieval coefficients for water vapor : Coef_c0 (kg/m^2)
  Coef_c1 ((kg/m^2)/K)
  Coef_c2 ((kg/m^2)/K)
  Coef_c3 ($kg/m^2.(dB^2)$)

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- Retrieval coefficients for liquid water : Coef_b0 (kg/m^2)
  Coef_b1 ((kg/m^2)/K)
  Coef_b2 ((kg/m^2)/K)
  Coef_b3 ($kg/m^2.(dB^2)$)
- Retrieval coefficients for wet tropospheric correction : Coef_a0(m)
  Coef_a1(m/K)
  Coef_a2(m/K)
  Coef_a3($m.dB^2$)
- The Sigma0_Ku value corresponding to the windspeed climatological value : Sigma0_Ku_Clim (dB)
- Processing mode : Proc_Mode (/)

Output data

- MWR wet tropospheric correction : Wet_H_Rad (m)
- Water vapor content : Vap_cont (kg/m^2)
- Cloud liquid water content : Cloud_Liq (kg/m^2)
- Execution status

Processing

- If the processing mode is set to "RA-2", or if one of the input brightness temperatures is > 279.9, then the processing is not performed.
- Else, the processing consists of computing the MWR wet tropospheric correction Wet_Hrad, the MWR water vapor content Vap_Cont, the MWR liquid water content Cloud_Liq, from the input brightness temperatures MWR_TB23 and MWR_TB36, and from the input interpolated RA-2 Ku-band backscatter coefficient, Sigma0_Ku_Int:
  - If RA2_To_MWR_Qual_Interp is set to "fail", then:
    - Sigma0_Ku_In = Sigma0_Ku_Clim (1)

    Else:
    - Sigma0_Ku_In = Sigma0_Ku_Int (2)
  - Wet_Hrad = Coeff_a_0 + Coeff_a_1 ∗ Log_e(280 – MWR_TB23) + Coeff_a_2 ∗ Log_e(280 – MWR_TB36)

$$+ \text{Coeff_a}_3 * \frac{1}{(\text{Sigma0_Ku_In})^2} \quad (3)$$

  - If Wet_Hrad ≥ - 0.08 m, then (correction in case of dry atmosphere) :
    - Wet_Hrad = 1.25∗Wet_Hrad + 0.02 (4)

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– $Vap_Cont = Coeff_c_0 + Coeff_c_1 * Log_e(280 - MWR_TB23) + Coeff_c_2 * Log_e(280 - MWR_TB36)$

$$+ Coeff_c_3 * \frac{1}{(Sigma0_Ku_In)^2} \quad (5)$$

– $Cloud_Liq = Coeff_b_0 + Coeff_b_1 * Log_e(280 - MWR_TB23) + Coeff_b_2 * Log_e(280 - MWR_TB36)$

$$+ Coeff_b_3 * \frac{1}{(Sigma0_Ku_In)^2} \quad (6)$$

ACCURACY

The MWR wet tropospheric correction accuracy is about 1 to 2 cm, and the water vapor content accuracy is about 0.3 g/cm^2. The cloud liquid water accuracy has never been assessed, due to the lack of comparison data.

COMMENTS

None

REFERENCES

- In flight calibration/validation of the Envisat MWR. Estelle Obligis, Report of WP3000 of ESA contract N° 13681/99/NL/GD, CLS/DOS/NT/01.378, 30 March 2001.

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APPENDIX 1

Management of the instrumental corrections in the JASON-1 altimeter processing

- **Tracker ranges (20 Hz and 1 Hz, Ku and C bands)**

  These parameters are corrected for:

  – the USO frequency drift (1 Hz)

  – the internal path correction (1 Hz), accounting in particular for the difference of travel between the transmission and the reference lines within the altimeter (internal calibration correction)

  – the distance antenna - COG (1 Hz)

  These corrections are applied in the level 1b processing. The corrected tracker ranges are not updated in the level 2 procedures (IGDR, GDR). The tracker range estimates do not account for the correction of the Doppler effects.

  [Only for CMA specifiers and developers, do not forget that:

  For ENVISAT:

  – Level 1b products consist of 20-Hz records. The 20-Hz tracker range level 1b estimates are corrected for the Doppler effects, using the orbital altitude rate computed from the orbit data available for the level 1b processing. These 20-Hz corrections are removed in the IGDR processing, leading in the level 2 products to 20-Hz tracker range estimates without correction for the Doppler effects.

  – Be aware also that the distance antenna - COG is added to the level 1b input tracker ranges in the IGDR processing.]

- **Tracker range rates (1 Hz)**

  These parameters are corrected for:

  – the modeled instrumental correction (1 Hz)

  This correction is applied in the level 1b processing. It is computed from a table built from a simulator of the altimeter and of the on-board retracking algorithm. The corrected tracker range rate is updated in the level 2 procedures (IGDR, GDR) to account for the refined estimates of the significant waveheight and of the signal to noise ration (inputs of the correction table).

- **On-board/ground retracked altimeter ranges (20 Hz and 1 Hz, Ku and C bands)**

  These parameters are corrected for:

  – the USO frequency drift (1 Hz)

  – the internal path correction (1 Hz)

  – the distance antenna - COG (1 Hz)

  – the Doppler correction (1 Hz)

  – the mispointing correction (1 Hz): Level 1b only

  – the modeled instrumental correction (1 Hz)

  – the system bias (1 Hz)

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The retracked altimeter ranges result from the combination of:

- the tracker ranges, corrected in the level 1b processing for the USO frequency drift, the internal path correction and the distance antenna - COG
- the position of the waveform in the analysis window (epoch) provided by the retracking algorithm (on-board retracking for level 1b parameters, on-ground retracking for level 2 parameters).

Doppler correction

In the level 1b processing, the 1-Hz Doppler corrections are computed from the orbital altitude rate provided in the level 1.0 input product. These corrections are recomputed and the corrected altimeter range are updated in the IGDR and possibly in the GDR procedures (see 3.1.4), accounting for preliminary and precise orbit data.

[In the ENVISAT processing, Doppler corrections are computed and applied to 20-Hz measurements (i.e. before the 1-Hz compression process) because the emitted bandwidth for Ku band (320 MHz, 80 MHz or 20 Hz) may change within a 1-Hz measurement.]

Mispointing correction

In the level 1b processing, the mispointing corrections are computed from models depending on the significant waveheight and the square of the off-nadir angle (interpolated platform data or possibly waveforms-derived data).

These corrections are not relevant to IGDR and GDR parameters (for JASON-1 and for ENVISAT), because in the IGDR procedures, mispointing is accounted for through the on-ground retracking algorithm.

Modeled instrumental correction

In the level 1b processing, the modeled instrumental corrections are computed from tables which are built from a simulator of the altimeter and from the on-board retracking algorithm. These tables represent a global modeling of the instrumental errors due to the imperfections of the altimeter components (errors of the on-board software, errors due to the low-pass filtering before FFT, errors due to the leakage spikes, errors due to the on-board FFT, errors due to the PTR). They account in particular for all the instrumental features provided by the POSEIDON-2 internal calibration (PTR and LPF). Input parameters for these tables are the signal to noise ratio derived in the level 1b processing from the on-board estimates, and the on-board estimate of the significant waveheight (corrected for the mispointing effects).

These corrections are recomputed and the altimeter ranges are updated in the IGDR processing, using different tables accounting for the on-ground retracking algorithm and ignoring the low-pass filter effects (as the level 1b waveforms are already corrected for them). Input parameters for these tables are the signal to noise ratio estimated in the IGDR processing from the averaged on-ground estimates of the waveforms amplitude and thermal noise level, and the averaged on-ground estimate of the significant waveheight.

[Regarding ENVISAT, this type of corrections is performed in the level 1b processing only.]

System bias

The system bias added to the altimeter range estimates in the level 1b processing is aimed at providing data sets consistent with data sets issued from a reference mission (e.g. TOPEX). This system bias is susceptible of being updated in the IGDR processing, to account for differences between both procedures.

- **Net instrumental correction on the altimeter range (1 Hz, Ku and C bands)**

  In the IGDR and GDR products, the net instrumental correction on the altimeter range will be the sum of the following corrections:

  - the USO frequency drift (1 Hz)
  - the internal path correction, including the internal calibration correction (1 Hz)
  - the distance antenna - COG (1 Hz)

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- the Doppler correction (1 Hz)
- the modeled instrumental correction (1 Hz)
- the system bias (1 Hz)

The mispointing correction is not accounted for as it is irrelevant for level 2 parameters.

- **On-board/ground significant waveheight (1 Hz, Ku and C bands)**

  These parameters are corrected for:

  - the mispointing correction (1 Hz): Level 1b only
  - the modeled instrumental correction (1 Hz)
  - the system bias (1 Hz)

  The level 1b significant waveheight is the Ku-band estimate derived from the on-board retracking. In the IGDR and GDR products, the significant waveheight estimates are issued from the on-ground retracking in both bands (Ku and C).

  For the same reasons as for the retracked altimeter ranges:

  - the mispointing corrections computed in the level 1b processing are not relevant to level 2 parameters
  - the modeled instrumental corrections computed in the level 1b processing are recomputed and the corrected significant waveheights are updated in the IGDR processing
  - the system biases computed in the level 1b processing are susceptible of being updated in the IGDR processing

- **Net instrumental correction on the significant waveheight (1 Hz, Ku and C bands)**

  In the IGDR and GDR products, the net instrumental correction on the significant waveheight will be the sum of the following corrections:

  - the modeled instrumental correction (1 Hz)
  - the system bias (1 Hz)

  The mispointing correction is not accounted for as it is irrelevant for level 2 parameters.

- **AGC (20 Hz and 1 Hz, Ku and C bands)**

  These parameters are corrected for:

  - the AGC errors (20 Hz), i.e. the difference between the transmitted value and the value applied on-board

  The corrected AGCs are computed in the level 1b processing. They are not updated in the level 2 procedures (IGDR, GDR).

- **Scaling factors for Sigma0 evaluation (20 Hz, Ku and C bands)**

  These parameters, which represent the backscatter coefficients corresponding to a retracked amplitude equal to 1, are corrected for:

  - the AGC errors (20 Hz)
  - the internal calibration (1 Hz)

  The corrected scaling factors for Sigma0 evaluation are computed in the level 1b processing. They are not updated in the level 2 procedures (IGDR, GDR).

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- **On-board/ground retracked backscatter coefficient (1 Hz, Ku and C bands)**

  These parameters are corrected for:

  – the AGC errors (20 Hz)

  – the internal calibration (1 Hz)

  – the mispointing correction (1 Hz): Level 1b only

  – the modeled instrumental correction (1 Hz)

  – the system bias (1 Hz)

  In the level 1b processing, the (raw) retracked backscatter coefficients are computed from on-board estimates (AGC combined with the on-board retracked amplitude of the waveforms), corrected for the AGC errors. The internal calibration corrections are accounted for in the level 1b processing.

  In the level 2 processing, the (raw) retracked backscatter coefficients result from the combination of:

  – the scaling factors for Sigma0 evaluation, corrected in the level 1b processing for the AGC errors and the internal calibration

  – the amplitude of the waveform in the analysis window provided by the on-ground retracking algorithm

  For the same reasons as for the retracked altimeter ranges:

  – the mispointing corrections computed in the level 1b processing are not relevant to level 2 parameters

  – the modeled instrumental corrections computed in the level 1b processing are recomputed and the corrected backscatter coefficients are updated in the IGDR processing

  – the system biases computed in the level 1b processing are susceptible of being updated in the IGDR processing

- **Net instrumental correction on the backscatter coefficients (1 Hz, Ku and C bands)**

  In the IGDR and GDR products, the net instrumental correction on the backscatter coefficients will be the sum of the following corrections:

  – the AGC errors (1 Hz)

  – the internal calibration (1 Hz)

  – the modeled instrumental correction (1 Hz)

  – the system bias (1 Hz)

  The mispointing correction is not accounted for as it is irrelevant for level 2 parameters.

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