



## ENVISAT RA2/MWR Product Handbook



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# Abstract



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# Chapter 1

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## RA2/MWR Products User Guide

This User Guide is published to provide in-depth information to Users of ENVISAT RA2 and MWR data products format and their contents. This document provides also information on the instruments, the principle of the measurement and the main algorithm used in the processing chains.

Section 1 presents an overview of the geophysical measurement and provides information on the radar altimeter and the microwave instruments and their applications in oceanography as well as for ice sheet and sea-ice.

Section 2 describes the definition and the convention used for the data products and presents the main processing algorithms used to produce them. This section describes also the different kind of data that corresponds to different application. For each of them the format is given

Section 3 presents in detail the RA-2 and MWR instruments

Section 4 gives the most frequently asked question

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Section 5 concerns the glossary

Section 6 gives in detail the RA2 and MWR data formats products (Level 0, Level1b, Level2, FD/I/GDR, I/G/MAR, and SGDR) and the auxiliary data file.

## 1.1 How To Choose RA-2/MWR Data Products

### 1.1.1 Geophysical Measurements

The RA-2 measures the transit time and radar backscatter power of individual transmitted pulses. The transit time is proportional to the satellite's altitude above the ocean, land, or ice surface. Over ocean surfaces the measured range is accurate to better than 2.5 cm. The magnitude and shape of the returned echoes also contain information about the characteristics of the reflecting surface, from which it is possible to retrieve geophysical parameters such as (when over the ocean) significant wave height, wind speed, and sea ice edge location.

The RA-2 instrument has several new features offering a significant advance upon the performance of the RA-1 flown on ERS. The RA-2 has a second radar channel (S-band, 3.2 GHz) allowing in-situ correction of the range delay due to the ionosphere. The S-band should also benefit new applications including ice type classification and rain-cell detection. The RA-2 uses a robust Model Free Tracker and surface tracking logic which switches autonomously between 3 different resolution modes to provide greater coverage in areas of difficult terrain.

The MWR is a nadir-viewing, two channel, passive microwave radiometer operating at 23.8 and 36.5 GHz. At these two frequencies, it receives and measures microwave radiation generated and reflected by the Earth. The signals received can be related to surface temperature but, most importantly, combined together they provide an estimate of the total water content in the atmosphere, which will be used to correct for the altimeter measurements path delay. The MWR has a 20 km diameter field of view.

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## 1.1.2 Scientific Background

The main objective of the EnviSat Radar Altimetry Mission is to ensure the continuity of the altimetric observations started with the ERS-1 satellite in 1991. The science mission objectives are similar to that of ERS but the length of the altimeter record will exceed 15 years and will permit the examination of changes on interannual to decadal time scales of:

- global and regional sea level
- dynamic ocean circulation patterns
- significant waveheight and wind speed climatology
- ice sheet elevation, sea-ice thickness

Another objective is to provide for the enhancement of the ERS mission, notably in ocean and ice missions, by improving the quality of the measurements and monitoring capabilities for:

- Ocean mesoscale, significant wave height and wind speed in Near Real Time
- Marine geophysics - Polar oceans
- Ice sheet margins - sea ice
- Lakes, wetlands and river levels
- Land
- Ionosphere, water vapor

The EnviSat Mission is part of a coherent European Earth Observation Programme ensuring the long-term provision of continuous data sets, essential for addressing environmental and climatological issues. As such, the ENVISAT Altimetry Mission is a contribution to international Earth Observation programmes such as International Geosphere Biosphere Programme and World Climate Research Programme. ENVISAT also aims at the promotion of applications and commercial use of Earth Observation data, namely for Altimetry: the operational sea-state and ocean circulation forecasting.

## Oceanographic Applications

The Ocean covers 70% of the Planet and plays a key role in regulating the global climate. The ocean is the main reservoir for heat as well as a powerful vehicle to transport warm water masses poleward. It has the capacity to intake (but also reject) significant amounts of carbon dioxide, one of the greenhouse gases. It also supports a cost-effective type of

transportation of goods, is a milieu where to discover new oil fields, is a feeding ground for fish and sea-food to nourish the ever-growing human population. The Oceanographic mission objectives of EnviSat are derived from the ERS results. To resolve low frequency signals in the ocean spectrum and to further understand oceanic processes a longer time series is however needed. The Oceanographic mission objectives of EnviSat Altimetry are dynamic topography monitoring, mesoscale variability, seasonal and interannual variability, mean global and regional sea level trends, marine geophysics -especially in polar oceans even covered with sea-ice-, sea-state monitoring. The objectives are to be met with data products available either in near real time (3 hours), in quasi near real time (2-3 days) or with the highest precision off-line products (50 days).

Seasonal and interannual variability has an important impact on climate. Planetary waves propagate from months to seasons across basins to adjust the ocean in response to wind forcing. Interannual variations of the seasonal or annual cycles have a direct and sometimes dramatic impact of the global climate, well illustrated by the El Niño-Southern Oscillation (ENSO) ([Figure 1.1](#)). The data serve mainly to tune and evolve global ocean and atmosphere models, to better understand the ocean-atmosphere interaction and the underlying processes.

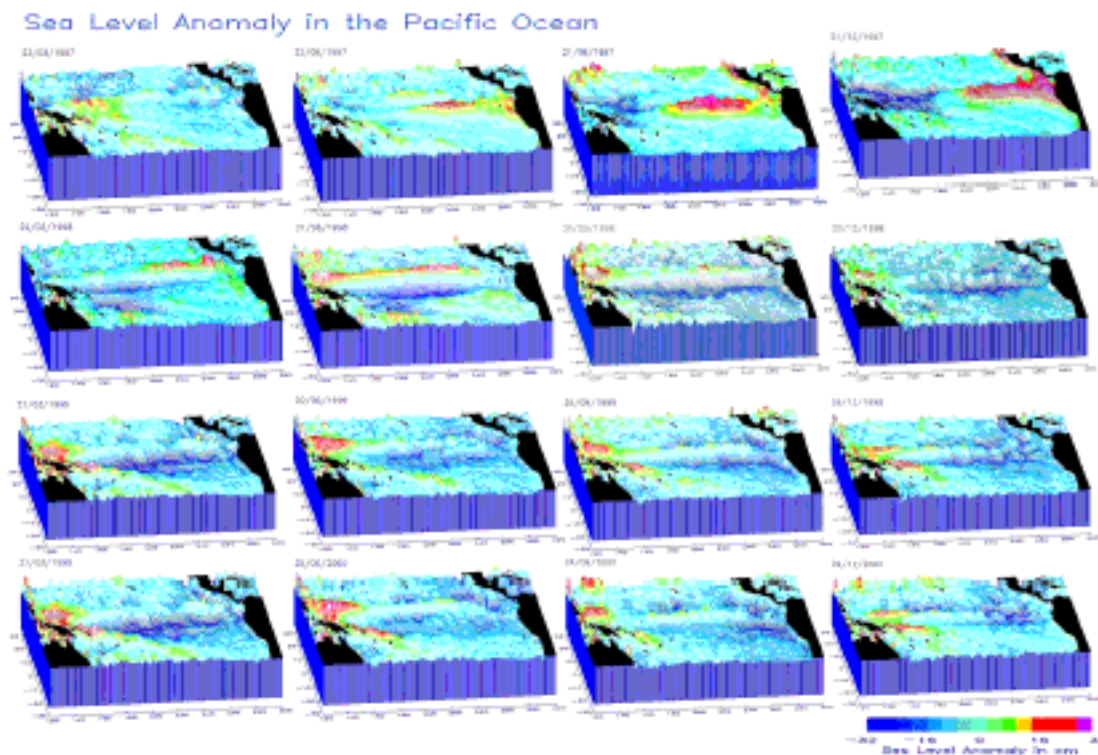


Figure 1.1 Series of Sea Level Anomaly (cm) in the Tropical Pacific. Each row is one year -'97, '98, '99, '00- with one sample of the sea level anomaly field at each season, by column: March, June, September and December. The strong El Niño Event of late '97 followed by a

La Niña event is clearly visible. A film of such 3D vignettes helps the researcher "visualize" the wave propagation involved in such events. Each weekly field can be assimilated in an ocean model. (SLA data processed by R. Scharroo, DEOS, NL, graphics processed at ESA/ESRIN.)

The ocean is vast and hosts a full spectrum of signals. One orbiting satellite alone cannot pretend to cover that spectrum. There are significant advantages in merging the data from two or more Altimetry missions sampling the Earth with different orbital patterns. A good illustration is the enrichment in space resolution of the mesoscale variability field computed with merged data from ERS and Topex-Poseidon ([Figure 1.2](#)) which are in the same orbital configuration as EnviSat and Jason will be [1].

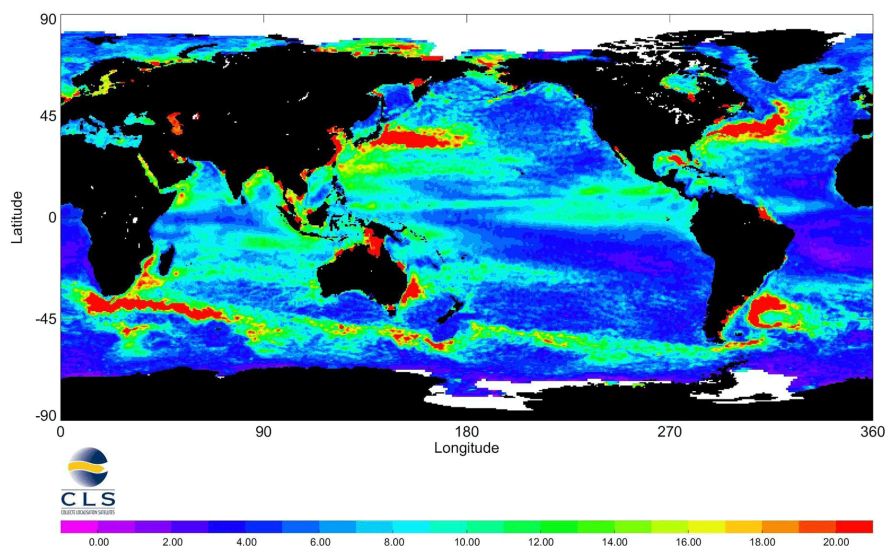


Figure 1.2 Root mean square of sea level anomaly (in cm) obtained from merged ERS and T/P data from October `92 to October `97. Note the high resolution of the map brought by the denser ground track mesh of ERS. (Courtesy of PY LeTraon, CLS.)

## Ice and Sea-Ice Applications

Polar ice sheets and sea ice play a vital role in the global climate system due to both their effectiveness in reflecting incoming solar radiation, and as a huge store of freshwater. Sea Ice acts as a barrier between the ocean and the atmosphere, cutting off exchanges of heat, moisture and momentum. Brine expulsion during seasonal sea ice formation and intense cooling of the sea surface through polynyas drive the thermohaline circulation of the oceans. This process creates the dense bottom water in the Pacific, Indian and Atlantic Oceans. It is

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responsible for the poleward transport of heat in the North Atlantic, which ensures mild winters for Western Europe.

This critical component of the climate system is not well represented in current climate models but is clearly important if accurate predictions of the consequences of global warming are to be made. Global warming is predicted to be greatest in the Arctic region. If Arctic sea-ice is lost, it could change the circulation pattern of the North Atlantic resulting in severe winters for Western Europe. Melting of the Greenland and Antarctic ice sheets would contribute to global sea level rise.

The vast, remote and inhospitable polar regions can only be effectively monitored through a global remote sensing system. Polar regions experience between 50 and 90% cloud cover and spend long periods in darkness, which limits the observations of optical and thermal infrared instrument. However, this task is particularly well served by satellite-borne active Radar instruments.

Techniques developed using the ERS Radar Altimeters have allowed the monitoring of ice sheet mass balance and the derivation of sea ice thickness through the measurement of freeboard. Continuous Altimetric measurement of the Antarctic ice sheet since 1992 has revealed for the first time a significant thinning of a West Antarctic glacier [Figure 1.3](#) . The Pine Island Glacier has retreated and thinned inland by as much as 10 metres. It is important to continue this monitoring with the ENVISAT RA-2 to establish if this retreat will accelerate the mass discharge from the West Antarctic Ice Sheet.



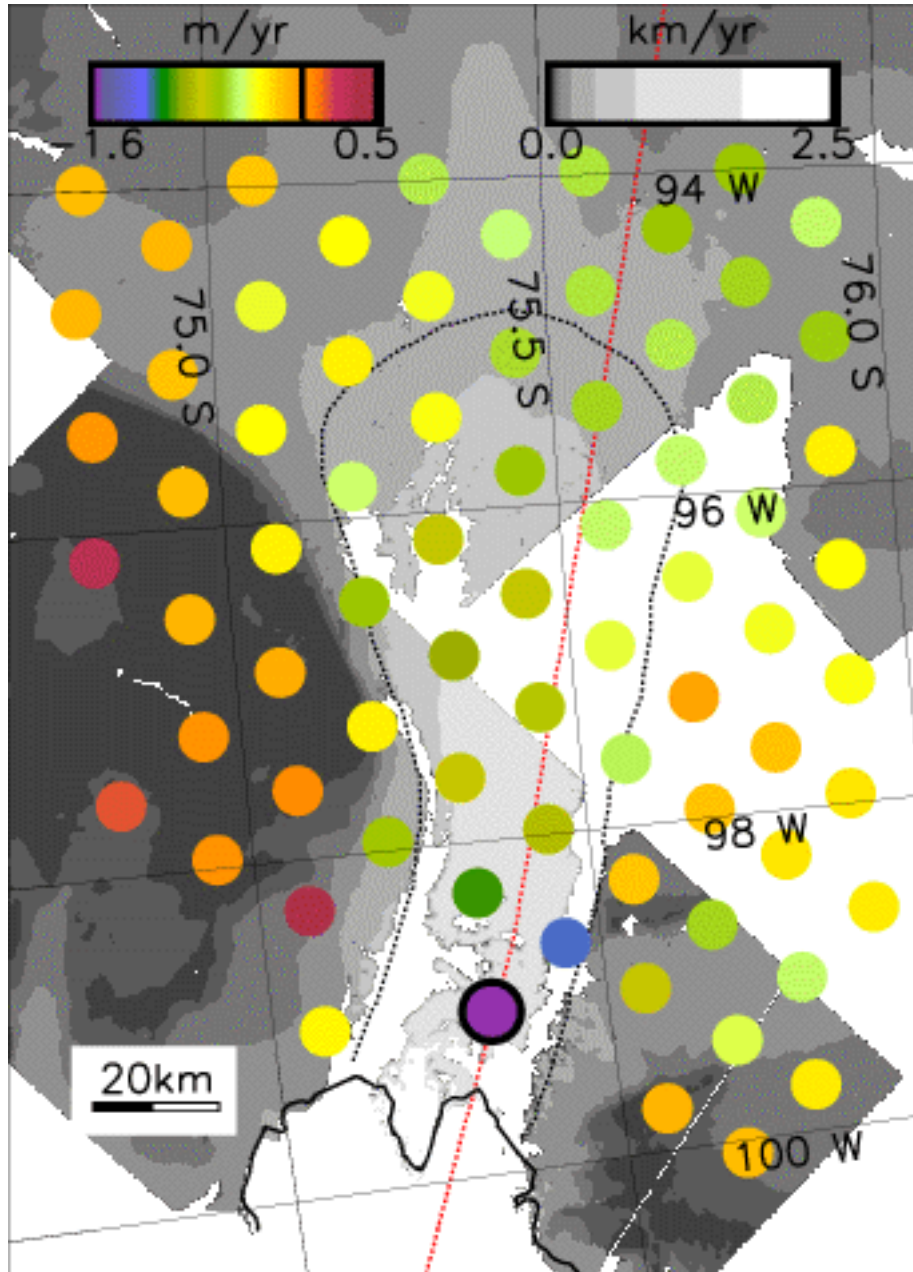


Figure 1.3 Rate of elevation change of the lower 200km of the Pine Island Glacier. The coloured dots are located at crossover points and have an area equal to the RA footprint. The grey shading is the velocity field derived from ERS SAR data. (Produced at MSSL/UCL.)

Balance velocities, i.e., depth-averaged velocity required to maintain the ice sheet in a state of balance at a given point for a given surface mass flux, have been estimated over the Antarctic grounded ice sheet using ERS altimeter data ([Figure 1.4](#)). Balance velocities depend mainly on the surface slope and are modulated by surface mass balance and ice thickness. Their study contributes to the understanding of ice sheet dynamics and their response to climatic forcing.

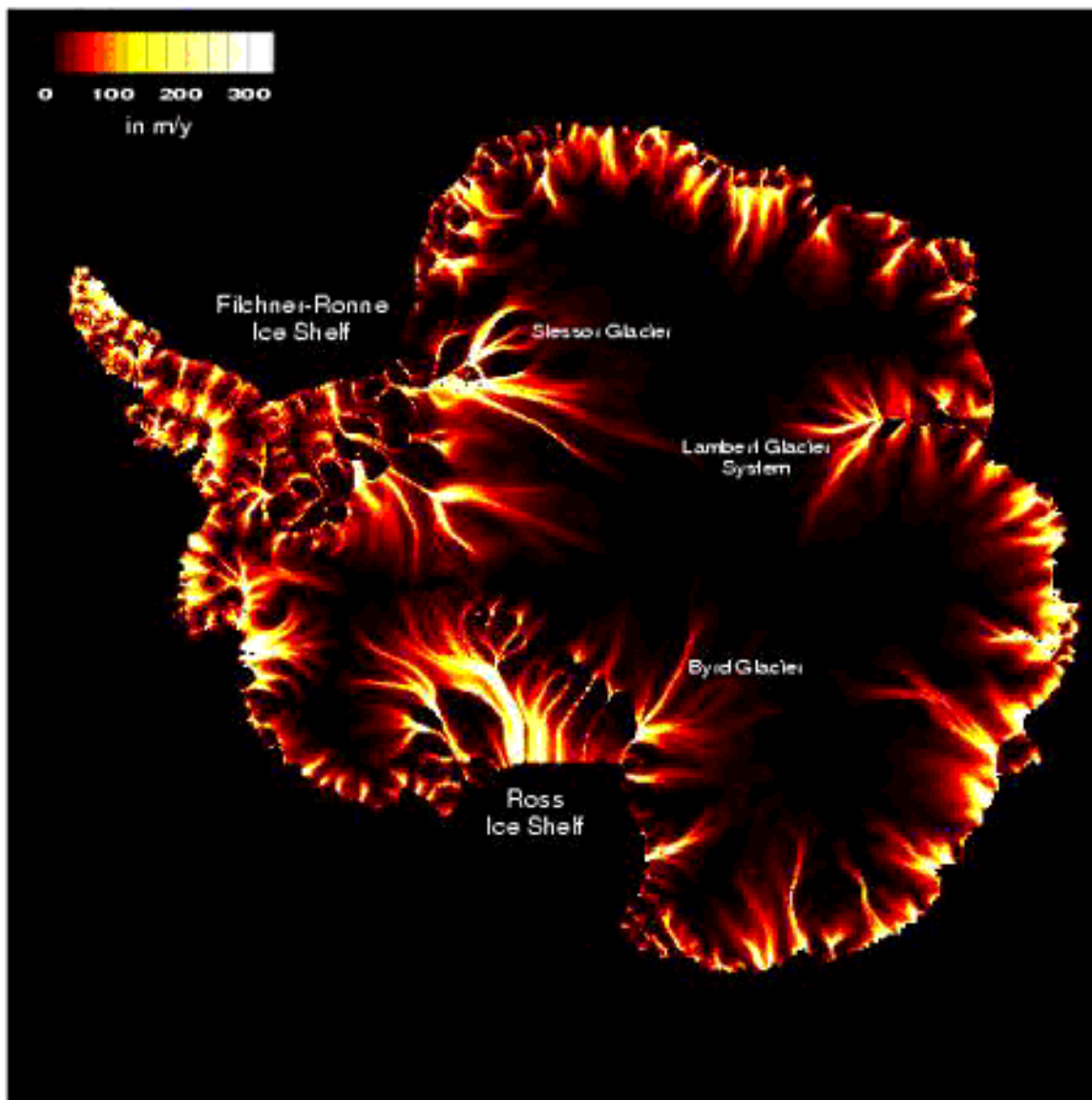


Figure 1.4 Balance velocities estimated from ERS Altimeter. (Produced by F. Remy, LEGOS)



Sea-ice thickness can be sampled using moored or submarine mounted Upward Looking Sonar (ULS). Moored ULS are only sampling a fixed location and Submarines tend to sample limited areas for only a few weeks each year. This is not sufficient to deduce full regional and seasonal variations. Freeboard measurement by satellite is the only technique which can measure sea ice thickness at the time and length scales that climate investigation demands. The technique has been developed using ERS Altimeter data, verified using the ULS measurements and implemented in the ENVISAT RA-2 ground processing. Results from ERS suggest that the recently reported thinning of Arctic sea ice may be localised ([Figure 1.5](#)). Continued monitoring by the EnviSat RA-2 is critical to establish long term trends.

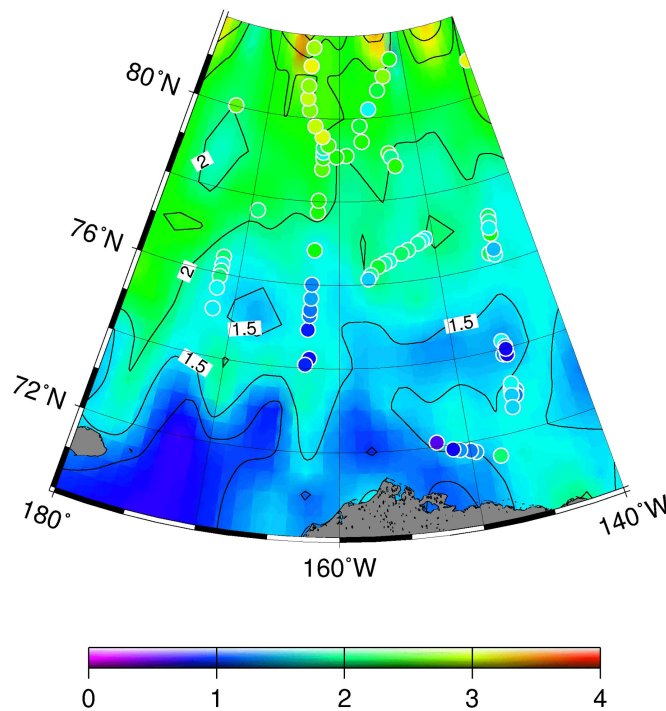


Figure 1.5 A comparison between RA derived sea ice thickness (m) and sparse measurements from Upward Looking Sonar on submarines (dots). Both sets of measurements are from October 1996. (Produced at MSSL/UCL.)

The EnviSat Altimetry mission will extend and improve the monitoring of the cryosphere in the climatically important Polar Regions.

## Land Applications

Over land the Radar Altimeter echoes have a non-predictable shape. This is why this field of applications has slowly and painstakingly matured. A remarkable result from the ERS 1 Geodetic phase is the Altimeter Corrected Elevation Model ACE [Berry et al., 2000] which replaces more than 28 % of the most precise Global Digital Elevation Model with an altimeter derived height dataset and corrects another 17 % (Figure 1.6 ). The Envisat Altimeter , even if it will not fly an orbit as dense as the ERS-1 Geodetic mission, will enhance this result in terms of accuracy and new areas never measured before, thanks to its enhanced tracking capacity.

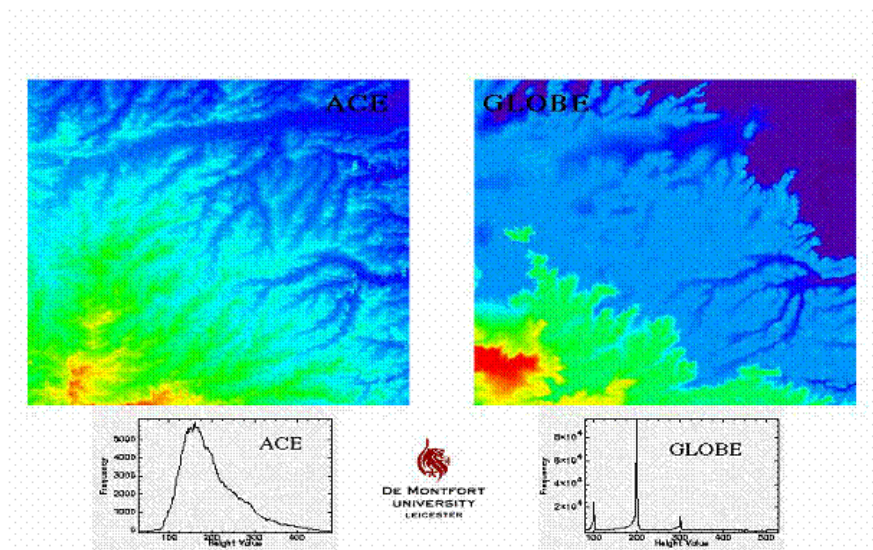


Figure 1.6 This figure compares the ERS altimeter derived map (ACE) of part of the Amazon basin together with the GLOBE map of the same area (73-68W, 11-6S). Note the 100m contours in the GLOBE histogram and the fine detail -rich histogram- in ACE.  
(Produced by P. Berry, De Montfort University, UK)

Another Land application that has been painstakingly attempted since SeaSat is river and lake levels monitoring. Radar Altimetry is a powerful tool for this application as it unifies all the worldwide river and lake level measurements, even the ones most remote or inaccessible, with a unique gauge. Being able to measure the global river levels, be it only once or twice a month would be a significant contribution to Hydrology. It has been demonstrated with ERS Altimeters that echoes from an continental water surface are clearly discernible and convertible to river or lake levels. The inclusion of an Ice mode on ERS-1 and ERS-2 has led to a huge increase in the percentage of the earth's land surfaces from which valid altimeter echoes have been obtained. This has also resulted in coverage of the majority of the world's river systems, raising the exciting possibility of a ten-year time series of river height data. The inclusion of a third tracking mode on EnviSat should further increase the land hydrology potential of Altimetry with even greater river coverage, as well as continuing the hydrology time series. To illustrate the ERS/EnviSat contribution, Figure 1.7 shows part of the Amazon

River system, with 35-day river crossings from ERS-2 superimposed on an altimeter derived rivers map.

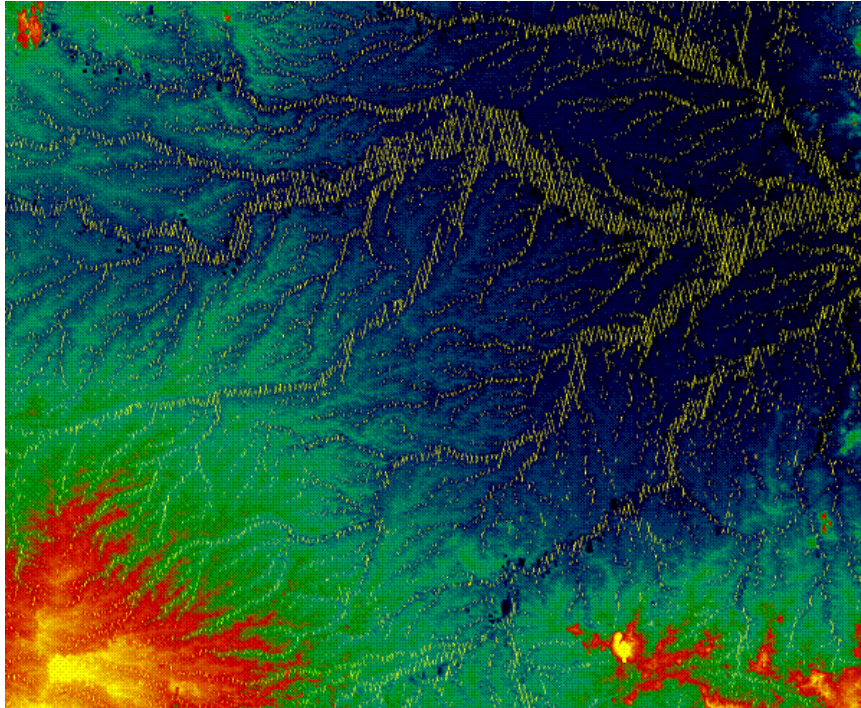


Figure 1.7 River echoes superimposed on high-resolution ERS-1 Altimeter derived topography and river network. The plot shows a 11x12 degree square of South America containing part of the Amazon basin (15-4S, 75-63W) with the ACE GDEM heights (high: yellow through red low: green to dark blue) overlaid with ERS-1 Geodetic Mission "water type" returns in sulphur yellow. Note that this part of the ACE GDEM is totally derived from Altimetry, which has provided a huge increase in spatial and vertical resolution over previous GDEM models for this region rich in river networks. (Produced by P. Berry, De Montfort University, UK)

### 1.1.3 Principles Of Measurement

The Radar Altimeter measures the transit time of a radar pulse reflected from the Earth's surface back to the instrument. If the transit time is measured with great accuracy then the range from the instrument to the surface can be determined with great accuracy. Precise orbit determination computes the altitude of the satellite above the reference ellipsoid to cm accuracy. Subtracting the measured range from the satellite altitude leave the height of the surface above the reference ellipsoid.



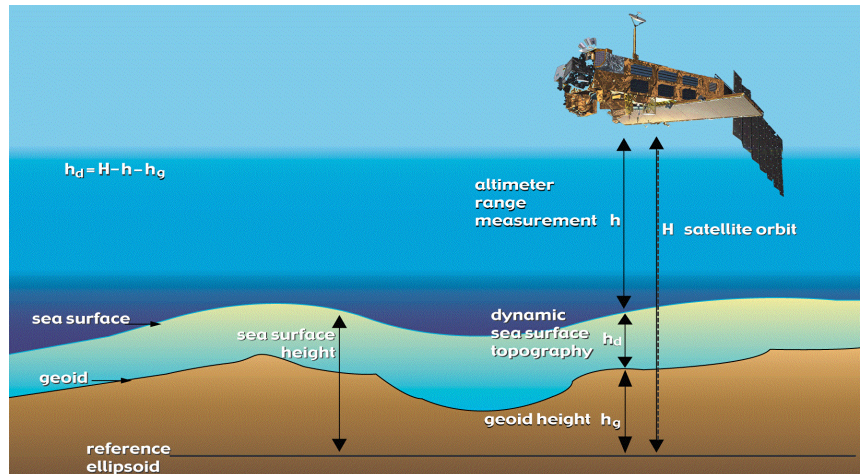


Figure 1.8 Altimeter Measurement Principle

Surface Height = Satellite Altitude - (Measured Range + Corrections)

In practice the measurement must be corrected for a number of effects to provide an accurate range. The instrument must be regularly calibrated to determine the delay times of the signal within the instrument electronics. These instrument delays vary with the heating/cooling cycle of the satellite around the orbit. Although Radar travels at the speed of light in vacuum it is delayed when travelling through the Ionosphere and Atmosphere. A range of geophysical corrections are needed to allow correction for these delays. Finally the tides at the Earth's surface must be accounted for to determine an instantaneous surface height.

Usually the corrections to be added to the measured range are as follows:

Geophysical Corrections = Inverse Barometer + Sea State Bias + Ionospheric correction + Ocean Tide + Polar Tide + Earth Tide + Wet Tropospheric correction + Dry Tropospheric correction

Note that the Instrumental Corrections are nominally already applied to the altimetric range

## 1.1.4 Geophysical Coverage

The RA-2 and MWR are Nadir-pointing instruments in continuous operation around the whole orbit. This provides global along-track sampling up to the latitude limit of 81.5 degrees N/S.

The RA telemetry provides 18 range measurements per second which corresponds to an along-track sampling interval of about 400m. Over the ocean it is common to average 20 of these measurements to give a sampling interval of 1.1 seconds or about 8km. The Altimeter is essentially a 1-dimensional instrument: the concept of a swath-width does not apply.

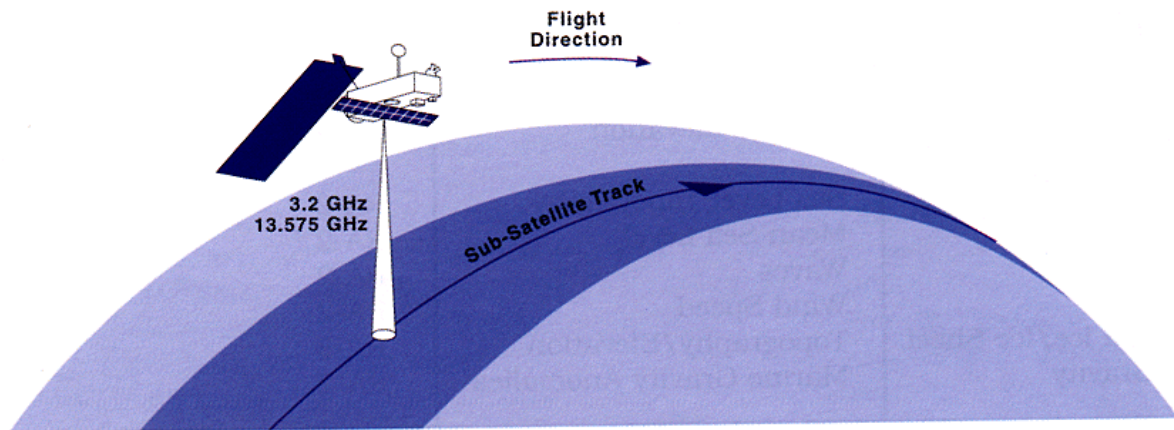


Figure 1.9 RA-2 Viewing Geometry

Across-track sampling is determined by the Orbit pattern. ENVISAT will operate with a 35 day exact repeat cycle of 501 orbits with an inclination of 98.5 degrees. This gives an across-track sampling of 80km at the equator. The across-track spacing reduces at higher latitude. This orbit pattern has sub-cycles of 3 days and 17 days, providing global coverage, with correspondingly coarser sampling, at these intervals.

An example of the coverage provided by the RA2 over the Mediterranean region is shown in [Figure 1.10](#).

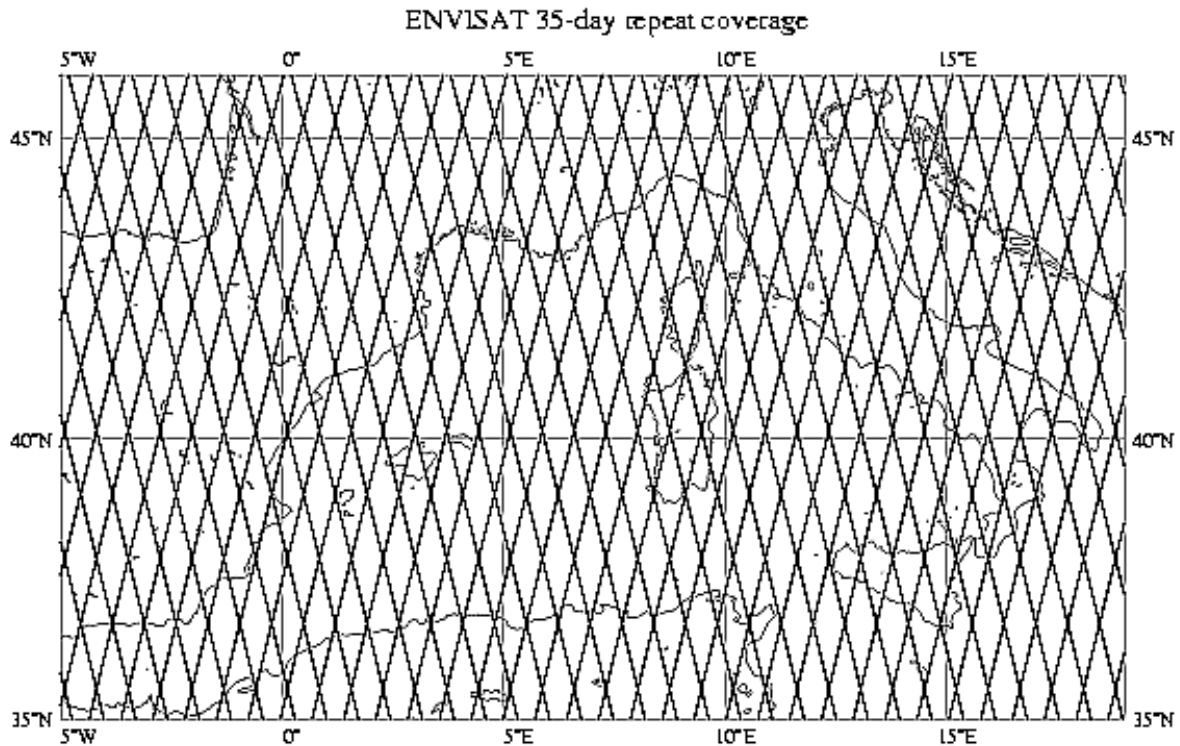


Figure 1.10 Showing the Sampling per 35 day cycle from the RA2

The MWR is also a nadir-viewing instrument which provides continuous along-track sampling. Again the concept of a swath-width is not applicable. The field of view has a 20km diameter at the Earth's surface and the measurement represents an average over this footprint. The global across-track sampling is as described for the RA above.

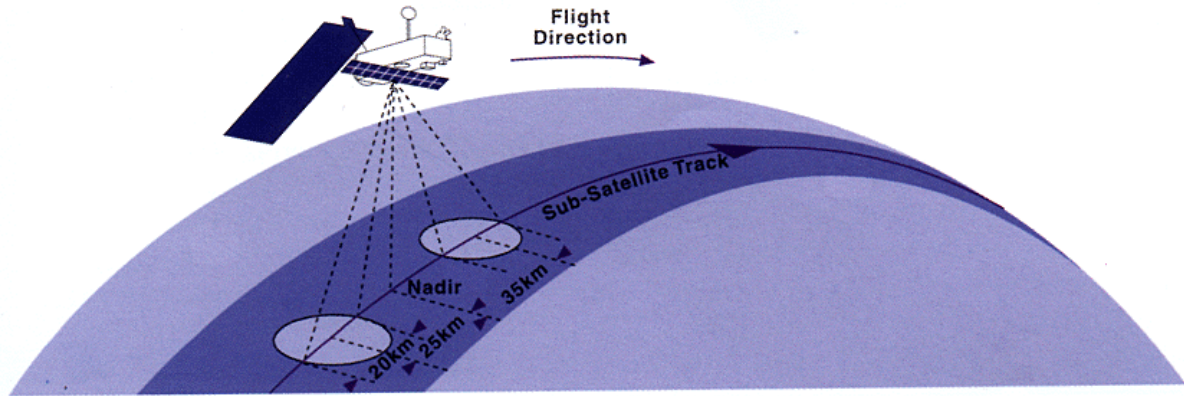


Figure 1.11 MWR Viewing Geometry

### 1.1.5 Peculiarities of RA2

The Radar Altimeter of second generation (RA-2) is an instrument for determining the two-way delay of the radar echo from the Earth's surface to a very high precision: less than a nanosecond. It also measures the power and the shape of the reflected radar pulses.

The RA-2 is derived from the ERS-1 and 2 Radar Altimeters, providing improved measurement performance and new capabilities.

The main objective of the RA-2 instrument is to collect, on global scale, radar echoes from ocean, land, ice without interruption. In the case of land regions this is a rather demanding task, since it implies design of a robust tracking algorithm for on board real time processing to avoid losing track.

This has been successfully met by the RA-2 design thanks to an innovative tracking algorithm

developed in ALS known as Model Free Tracker (MFT). This algorithm does not perform precise estimate of radar to surface range, echo power or of other echo features, but concentrates its effort in maintaining the earliest part of radar echoes within the tracking window, independently of its shape. For this purpose, the tracking algorithm can adjust the radar resolution for the operations in Ku band among three values available, in order to optimally tune the width of the tracking window to the topographic features observed.

The following features are modified / improved in the RA-2 of ENVISAT-1:

- Dual frequency instrument

RA-2 is a nadir-looking pulse limited radar functioning at the main nominal frequency of 13.575 GHz (Ku Band).

A secondary channel at a nominal frequency of 3.2 GHz (S band) is also operated to compensate the range error on altitude measurements caused by the propagation of the radar signals through the ionosphere.

- Three different resolutions

The RA-2 is provided with three different bandwidths (320 MHz, 80 MHz, and 20 MHz, corresponding to resolution of about 0.5, 2 and 8 m, respectively) so that the resolution can be adapted to different scenarios (Ocean, ice, ice sheets, sea ice, and land).

- Autonomous adaptative resolution

The change of the resolution is done autonomously by the instrument, through the so-called resolution selection logic, to adapt tracker performances to surface characteristics. Based on the Signal to Noise Ratio (RSN) of the on-board waveform and the waveform position (P) compared to reference values stored in the on-board memory, the MFT will decide whether the range window is using the adequate resolution, whether the resolution could be increased, or need to be decreased.

Further details on the complete functionality of the RA-2 on-board tracker and how its Resolution Selection Logic (RSL) works can be found in the Technical Note "The RA-2 On-board Tracker and its Autonomous Adaptable Resolution" PO-TN-ESA-RA-1316.

- Robust tracking

The implementation of MFT in RA-2 provides very robust tracking over difficult surfaces as well as the capability to autonomously control the resolution



- The new alpha-beta tracker

The only function of the RA-2 alpha-beta tracker is keeping the return waveform within the range window whereas the ERS tracker also had to estimate the engineering parameters. This estimation will now be done on ground instead of being done on board. Therefore the only function of the new tracker is the tracking itself and not also the estimation as it was performed in ERS. This fact extremely increases the robustness of the tracker. Another improvement on the alpha-beta tracker is the capability of compensating for the computation time lag.

- Double dynamic range and two additional samples

RA-2 provides 128 samples of the waveform compared to the 64 samples of ERS. For extremely low SWH conditions, range and SWH estimates can be further improved by including in the precision processing the usage of two extra echo samples, computed by the on board digital processor through a standard DFT algorithm and made available for each Ku band radar echo down linked to ground. The location of the two additional waveform samples is programmable from ground so that it can be optimally tuned with respect to the position of the tracking point in the FFT bank. This is a unique feature of the RA-2 together with the possibility of transmitting to ground the In-phase and Quadrature components (i.e. raw data without any processing applied on board) of the echoes from 2000 consecutive Ku radar pulses. Experimental processing of these so called "individual echoes" on ground can provide more insights on surface topography at the boundaries.

- Individual echoes mode

The RA-2 has the capability to provide limited bursts of individual, unaveraged echo sample data at the full rate for research purposes. In this concept the full-rate data are stored, for a short burst of about 1 sec, into an internal buffer memory, in parallel to the normal averaging and other functions of the instrument. The buffered data are subsequently read out at a much lower rate and appended to the normal science data. They will be available as a dedicated-data product. Users will be able to extract these data along with adjacent 18 Hz waveforms and geophysical corrections. Having easy access to the surrounding data is necessary for the research work on individual echoes.

- MWR correction

RA-2 data will contain MWR corrections in all Level 2 products and MWR brightness temperature can be found in the Level 1b and level 2 MWR measurements data sets (MDS).

A summary of the main characteristics is reported in the following table.

Table 1.1

Instrument parameter	Range	Accuracy
Altitude	764 km to 825 km	< 4.5 cm (highest res.)
Backscatter Coefficient	-10 dB to +50 dB	< 0.4 dB (bias)
		0.2 dB (residual)
Measurement Datation		100 $\mu$ s (UTC)
Wave height	0.5 m to 20 m	< 5% or 0.25 m
Operating Frequency	13.575 GHz (Ku-Band)	
	3.2 GHz (S-Band)	
Bandwidth	320 , 80 , 20 MHz and CW (Ku-Band)	
	160 MHz (S-Band)	
Pulse Repetition Frequency	1795.33 Hz (for Ku-Band)	interleaved operation
	448.83 Hz (for S-Band)	
Pulse Width	20 $\mu$ s	
IF Bandwidth	6.4 MHz	
Operation	continuously over a complete orbit	
Data Rate	100 kb/s	
Mass	110 kg	
Power	161 W	

### 1.1.6 Peculiarities of MWR

The MWR design concept derives from the experimental radiometers embarked on ERS-1 satellite. It is a two channels passive Dicke microwave radiometer, operating at 23.8 GHz and 36.5 GHz, and devoted to measure the amount of water content in the atmosphere beneath the satellite's track (Nadir pointing).

Its output products are of prime importance for products of Radar Altimeter (RA-2) Instrument, part of the Envisat-1 payload, providing correction of atmospheric propagation data. A secondary objective is the direct evaluation of brightness temperature to characterise polar ice, land surface properties.

Elements of the experimental radiometer of ERS mission have been used as input, but substantial new design has been done to improve instrument performance and its calibration accuracy, and to upgrade the design to current technology. In particular the Calibration and characterisation approach, the radio frequency design and electromagnetic compatibility aspects, the thermal and structural design, have been completely re-addressed.

The following key elements are modified/improved in the MWR of ENVISAT-1:

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- Instrument Supporting Structure

The structure subsystem is fully re-designed due to ENVISAT-1 requirements and to the new satellite configuration. The new structure provides optimum stiffness and stability performance, reduced mass, and includes also the Reflector support interface.

- Instrument Thermal Control

Instrument thermal design is completely revised and an active thermal control is included to optimise the performance reducing temperature excursions on the Radio Frequency section.

- Antenna

The reflector design is the same as for ERS, except for its supporting interfaces which are new design. Feed-horns design is optimised to improve some performance and to optimise the beam efficiency performance, which was not specified on ERS. The antenna does not need deployment like on ERS, it is already in place, thus reducing the risk of misdeployment or mispointing.

- RF Front End

From functional point of view the ERS architecture is maintained. The overall RF Front End design is reviewed from mechanical view point, for thermal control hardware implementation, for EMC design, and for reliability and product assurance aspects.

- Centralised Electronic Unit (CEU)

From functional architecture point of view a similar architecture to the ERS one is adopted. The CEU is significantly re-designed due to new system requirements either in terms of interfaces and performance.

- Ground Support Equipment

This area is really new design area, given the completely new calibration, verification and validation approach. Also the development of a set of stimuli equipment for radiometric tests and calibration has been necessary to allow the completion of these activities (waveguide cryogenic loads, blackbody targets, thermal vacuum calibration targets, etc.).

The driving performances of the Instrument are summarised in the following table:

Table 1.2

Performance	Value
Radiometric Sensitivity	0.4 K
Radiometric Stability	0.4 K
Dynamic Range	3K to 335K
Non-linearity	0.35 K
Radiometric Accuracy (after calibration)	1 K, with $T_{ant} = 300K$ < 3K with $T_{ant} = 85$ to 330K
On board settable Intercalibration period	38.4, 76.8, 153.7, 307.4 sec
Noise Figure	4.8 dB incl. Antenna
Frequency accuracy 36.5 and 23.8 GHz	< $\pm 3.0$ MHz
Antenna Radiation Efficiency	97 %
Antenna Main Beam Efficiency	95.26% worst case (23.8 GHz)
Antenna Side Lobes Level (in 3° half angle)	24 dB 31 dB
Antenna Half Power beamwidth (3 dB)	1.5 °
Instrument Mass	24 Kg
Operational Power	18 Watts

In the following figure the apparent radiometric temperature contributions are shown:

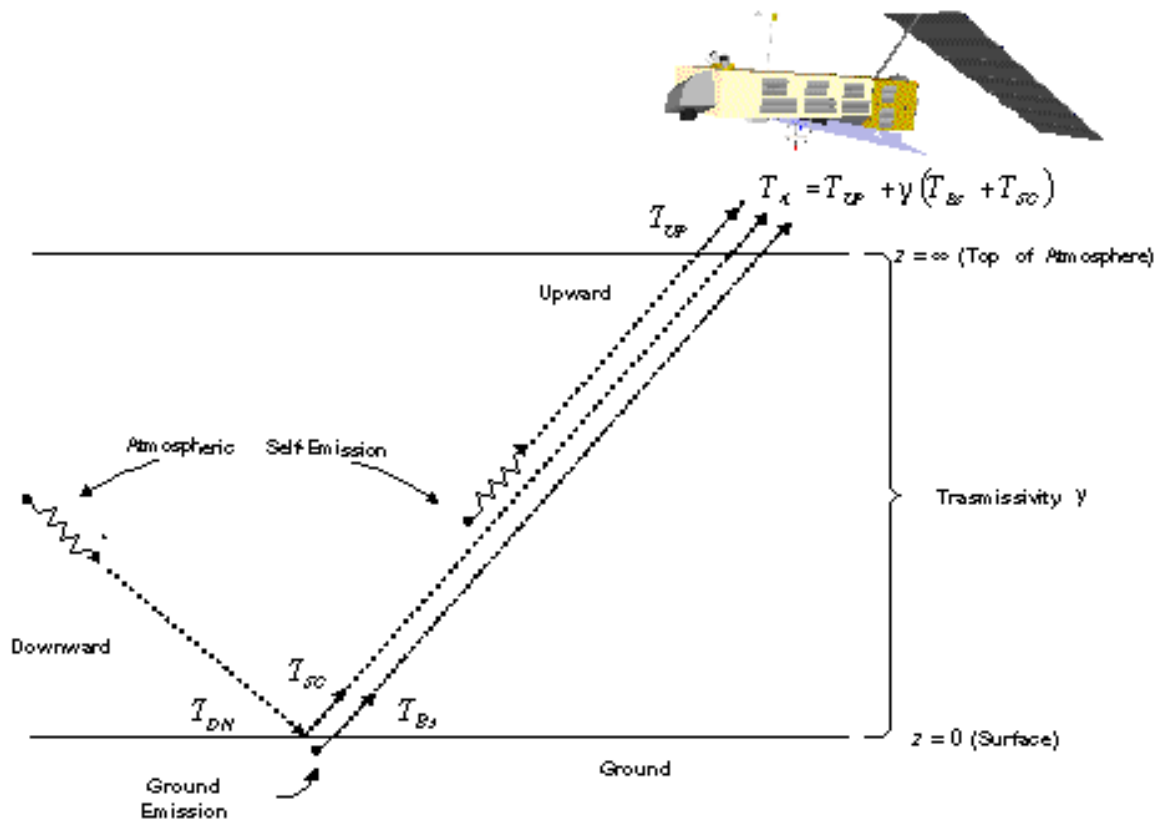


Figure 1.12 Schematic representation of the apparent radiometric temperature contributions.

## 1.1.7 Summary of Applications vs. Products

Level 1B products are routinely produced and archived but not distributed to Users. Users requiring the altimeter waveforms will find them conveniently stored in the L2 SGDR product with collocated geophysical corrections and the output of the four retracking algorithms. In other words, the SGDR product holds the full GDR product augmented by averaged and individual echo waveforms. Therefore users of ENVISAT Altimetry need not access the Level 1B products.

The table below shows the applicability of the L2 products to various user applications. This

table provides a quick reference whereas the products are described in detail in [RA2/MWR Products and Algorithms \(Chapter 2.\)](#).

Table 1.3 Applications vs Products

Applications Products \	FDGR	IGDR	GDR	FD MAR	I MAR	SGDR
Operational Sea State (wind and waves)	X			X		
Operational Ocean Forecasting	X	X		X	X	
Sea level rise			X		X	
Ocean Circulation			X			
Waveheight Climatology			X		X	
Ice Sheet Elevation and Mass Balance			X			X
Sea Ice Thickness and extent						X
Marine Geoid			X			X
Lakes and Inland Waters						X
Land Topography						X

L1b products are of interest to Algorithm developers and the RA2/MWR Cal/Val team.

## 1.2 How to use RA-2/MWR data

### 1.2.1 Software Tools

RA-2/MWR products are delivered in the standard ENVISAT data products format.

ESA-provided software tools can be used to access RA-2/MWR products.

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### 1.2.1.1 General tools

Unlike many other remote sensing instruments RA-2/MWR data are not two-dimensional images. The geophysical data records are provided in sequence along the satellite ground track. Their format is rather mission specific. There is no commercial software packages aimed at reading, displaying and analysing the RA-2/MWR products.

### 1.2.1.2 EnviView

The EnviView tool has been specially developed to read and visualize data products in the ENVISAT format. It provides the capability to display the contents of the products as simple text in HTML format, as graphs, or as images where these are appropriate. EnviView will also output products in hdf, allowing them to be read by any third party software packages supporting this format.

Further information on EnviView is provided in -<http://envisat.esa.int/services/enviview>

## 1.3 Further reading

#### Ref 1.1

J.L. Bamber, 1994, "Ice sheet altimeter processing scheme", Int. J. Remote Sensing, 15, 925-938.

#### Ref 1.2

T.V. Martin and Others, 1983, "Analysis and retracking of continental ice sheet radar altimeter waveforms", J.Geophys. Res., 88, 1608-1616.

#### Ref 1.3

P. Femenias and Others, 1993, "Analysis of satellite-altimeter height measurements above continental ice sheets", J.Glac., 39, 591-600.

## Ref 1.4

F. Remy and Others, 1990, "Intensity of satellite radar altimeter return power over continental ice: a potential measurement of katabatic wind intensity", J.Glac., 36, 133-142.

## Ref 1.5

G.S. Brown, 1977, "The average impulse response of a rough surface and its application, IEEE Trans. Antennas Propag., AP-25, 67-73.

## Ref 1.6

Defense Mapping Agency Technical Report " Department of Defense World Geodetic System 1984. Its definition and relationships with local geodetic systems". DMA-TR-8350.2

## Ref 1.7

W. Cudlip et al., 1994, "Corrections for altimeter low-level processing at the Earth Observation Data Centre", Int. J. Remote Sensing, 15, 889-914.

## Ref 1.8

S. Laxon, 1994, " Sea ice altimeter processing scheme at the EODC", Int. J.

## Ref 1.9

Remote Sensing, 15, 915-924.

## Ref 1.10

EnviSat Web site : <http://envisat.esa.int>

## Ref 1.11

Roca M., "The RA-2 On-board Tracker and its Autonomous Adaptable Resolution", ESA Technical Note, PO-TN-ESA-RA-1316, iss. 1.a, February 2002.

## Ref 1.12

Roca M., et al, "RA-2 Level 1b processor verification", Proceedings of Envisat Calibration Workshop at ESTEC, September 2002, SP-520 ESA Publication

## Ref 1.13

Milagro Perez M. P., et al, "Verification of the RA2/MWR Level 2 geophysical reference processors" Proceedings of Envisat Validation Workshop at ESRIN, December 2002, SP-531 ESA Publication



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Ref 1.14

J. Benveniste and the RA2/MWR CCVT, "RA-2/MWR Cross-Calibration and Validation: Objectives, Approach Results and Recommendations", Proceedings of Envisat Validation Workshop at ESRIN, December 2002, SP-531 ESA Publication

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## Chapter 2

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# RA2/MWR Products and Algorithms

## 2.1 Introduction

In section 2, the RA-2/MWR data products and the algorithms developed to compute the main parameters in the products are described.

Based on the experience from the ERS missions, significant improvements have been built into this new generation of altimetric products, particularly in terms of the enhanced quality of the near-real-time observations, which will be almost as accurate as the final precise product. The product-specification process has included wide consultation with users of ERS and Topex/Poseidon altimetric data. Further product refinement and state-of-the-art algorithm specification were conducted with the help of three European Expert Support Laboratories (ESLs): Alenia Aerospazio (I), Collecte Localisation Satellites (F) and Mullard Space Science Laboratory (UK).

The algorithm specifications were validated by prototyping within the ESL. Once verified, ESL prototypes became reference processors to produce test data sets designed to validate the ground-segment Instrument-data Processing Facility (IPF). Moreover, the RA-2 and MWR products and algorithms were peer-reviewed by dedicated experts and were the subject of an open review at the Envisat Altimetry Products and Algorithms Review Workshop held at ESRIN in Frascati in June 1999.

The EnviSat RA-2 and MWR Data Products will have - already available in near-real-time - global coverage, the wet tropospheric correction from the microwave radiometer and the ionospheric correction from the two frequencies, as well as many other improvements coming from the novel design of second-generation Radar Altimeter. The comprehensive near-real-time processing runs the same algorithms as for the offline products, with only the availability and quality of the auxiliary data differing.

## 2.2 Organisation of Products

The suite of RA-2/MWR data products is based on one main Geophysical Data Record (GDR) product. The Envisat general product format is exploited to add sub-structure inside the product to hold additional data such as the averaged waveforms (at 18 Hz), the individual waveforms (at 1800 Hz) and the Microwave Radiometer data set. Thus, the waveform data product (SGDR) is a superset containing the same geophysical data records as the GDR, but with waveform data sets appended. Moreover, following a user requirement survey, these products were made global, independent of the sub-satellite terrain and of the Radar Altimeter measurement resolution mode, thus avoiding artificial boundaries between geographical features like land/sea, land/ice or land/lake transitions. This design ensures that ocean, land, ice, lake or wetland data always ends up in the same (unique, global) data product.



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The Fast Delivery GDR (FDGDR) product is transmitted in less than three hours, for weather forecasting, sea-state and real-time ocean-circulation applications. An ocean-related parameter subset of the FDGDR called FDMAR (for Marine Abridged Record) is extracted to reduce the volume of on-line data transfers. FDMAR is converted into the BUFR format commonly used by Meteorological Offices. Less than three days later, the so-called Interim GDR (IGDR) for ocean-circulation monitoring and forecasting applications is delivered, replacing the original meteorological predictions with more precise analyses, and the preliminary orbit with an improved orbit solution. The final GDR and SGDR products containing the most precise instrument calibrations and orbit solutions are delivered after 30 days (not more than 50 days). The schematic in Figure 2.2.1 summarises the organisation, the inter-relationships and latency of the product generation. The terminology used to name products is based on the nomenclature traditionally used in Altimetry, with the product names stored in the first field of the specific product header.

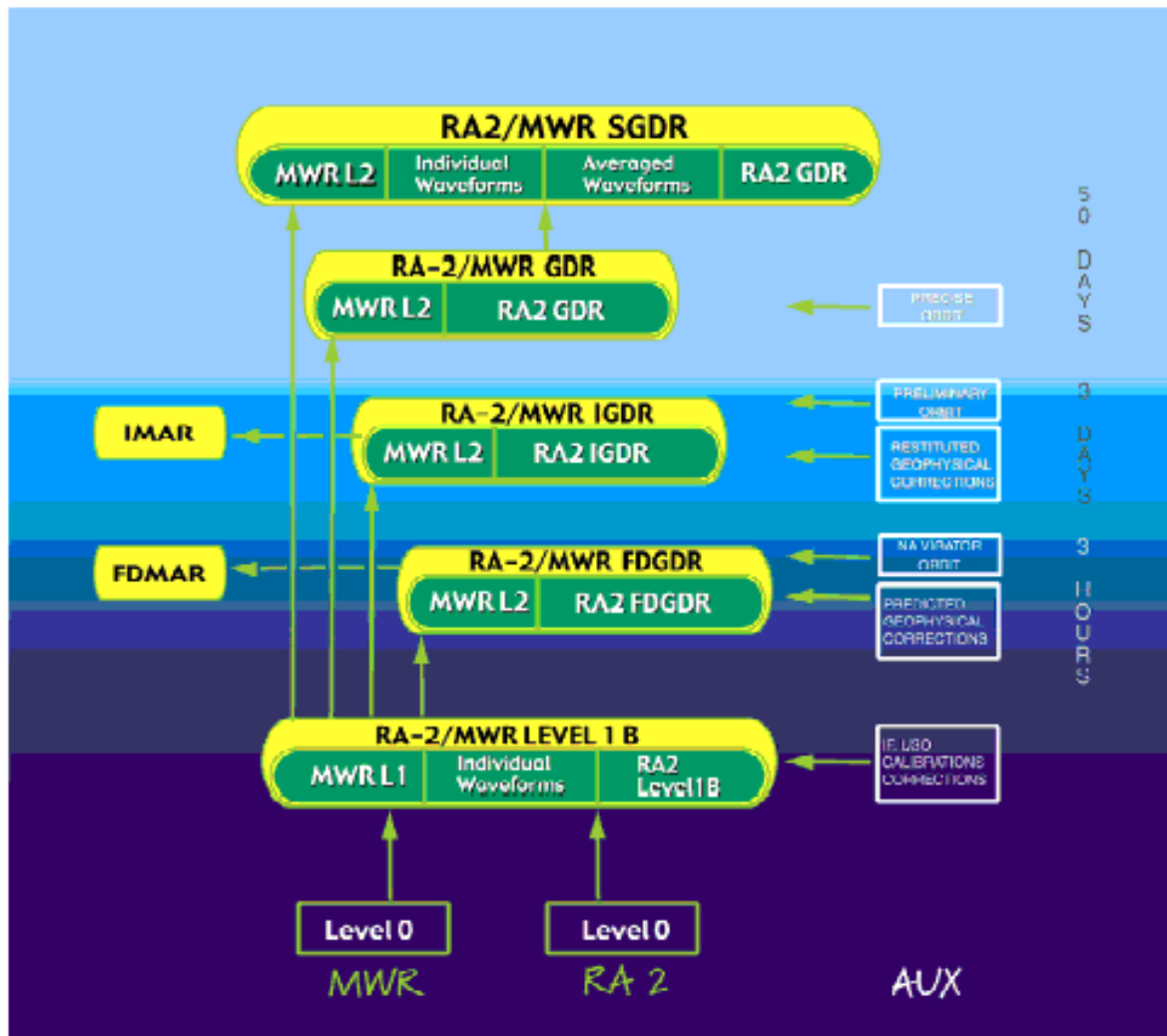


Figure 2.1 The RA-2/MWR Product Tree

The Envisat products are categorised into three distinct levels:

- Level 0 (raw): unprocessed data as it comes from the instrument.
- Level 1b (engineering): data converted to engineering units, with instrumental calibration applied (IF filtering, to correct power distortions of echo waveforms, internal range calibrations, corrections for possible drift of reference timing source, no re-tracking); the half-orbit segmented (pole-to pole) product mainly contains: datation (conversion of satellite time to UTC), geo-location, time delay, orbital altitude, sigma-zero, averaged wave-form

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samples at 18 Hz data rate, individual waveform at full pulse repetition frequency and MWR brightness temperatures.

- Level 2 (geophysical): data converted to geophysical units (with re-tracking); the product mainly contains datation, geo-location, output from re-trackers (range, wind speed, significant wave height, etc.), at 1 Hz plus some 18 Hz parameters (range, orbital altitude). All geophysical products, including the near-real time products, are re-tracked (waveform data are fully processed in the ground processor to extract the geophysical parameters). In order to retrieve the geophysical parameters over all types of surface (ocean, ice, sea-ice, etc.), four specialised re-trackers are continuously run in parallel (over all surfaces):

- Ocean re-tracker: optimised for ocean surfaces, and based on a modification of the Hayne model [Hayne, 1980]

- Ice-1 re-tracker: optimised for general continental ice sheets, it is a model-free re-tracker called the 'Offset Centre of Gravity Echo Model'; it is used for ERS and will ensure measurement continuity [Bamber, 1994]

- Ice-2 re-tracker: optimised for ocean-like echoes from continental ice-sheet interior, it is a Brown-based model re-tracking algorithm [Legrésy, 1997]

- Sea-Ice re-tracker: optimised for specular returns from sea-ice, it is a threshold re-tracking scheme for peaky waveforms [Laxon, 1994]

The usual necessary geophysical corrections are available in the Level-2 products. The ionospheric correction will come from the dual-frequency altimeter, backed-up by the measurements from DORIS and the Bent model. The wet tropospheric correction will come from the on-board microwave radiometer, backed-up by a value computed from ECMWF fields. Users requiring the Altimeter waveforms will find them conveniently stored in the Level-2 SGDR product, along with the co-located geophysical corrections and the outputs of the four re-trackers. In other words, the SGDR holds the GDR data augmented by averaged and individual waveforms. Therefore, users of Envisat Altimetry need not access the Level-1b products.

The Fast Delivery data (FDGDR) will be processed at the ESA receiving stations (PFHS Kiruna and ESRIN) and delivered in less than 3 hours. The Interim Geophysical Data Record (IGDR) and the final precision Geophysical Data Record (GDR) products will be processed offline at the French Processing and Archiving Centre in Toulouse, the so-called F-PAC, with the same algorithms as the Fast Delivery processor. The SGDR is also built at F-PAC.

## 2.3 Definitions and Conventions

The Radar Altimetry user community has developed a vocabulary of common terms which have a specific meaning. While these are (mostly) clear to experienced users the terms can be confusing to new-comers. This section explains common terms and conventions as used within this Product Handbook.

Range is the one-way distance from the satellite to the mean surface below. It is referenced to the satellite centre of gravity. It is the principal measurement of the radar altimeter. Range is estimated from the echo waveforms as part of the processing so-called retracking. This measurement is not the altitude, it is still only a measurement of distance.

Altitude is the distance of a satellite centre of mass above a reference point on the earth. The reference point will usually be on a geodetic reference frame or the centre of the Earth. The altitude is given by the orbit computation.

Height is the elevation of the mean surface observed at nadir above the reference ellipsoid. As a first approximation it is calculated from range and altitude ( $\text{height} = \text{altitude} - \text{range}$ ).

Time delay is the basic on-board instrument measurement converted to standard physical units. It is the 2-way travel time of the radar pulse from the satellite to the surface and back. It is uncalibrated. The measurement is referenced to the centre of the range window: that is bin 63 (in the range 0 - 127) for the Ku band window, and bin 31 (in the range 0 - 63) for the S band window.

AGC, automatic gain control, is the setting of the on-board receiver attenuator as transmitted in the telemetry.

Sigma0 is the backscatter estimate calculated from AGC and the power level of the radar echo. The signal path attenuation, as calculated from the in-flight Calibration records, is

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applied. To compute an accurate  $\sigma_0$  geophysical corrections such as liquid water attenuation correction must be applied.

Slope refers to the gradient of the leading edge of the radar echo, so called the leading-edge slope.

SWH is the significant waveheight calculated from the radar echo leading edge Slope.

Footprint is the area on the surface illuminated by the Radar pulse. The Altimeter boresite is pointed at Nadir and the antenna half-power beamwidth is 1.3 degrees. At a height of 800km this corresponds to a circular area 18km across. However the short duration of the radar pulse normally means that a much smaller area of illumination is seen by the instrument. This is often referred to as the Pulse Limited Footprint.

Array numbering convention: Arrays of parameters are numbered from 0 to  $n_{\text{elements}} - 1$ . For example this means high rate measurements are numbered 0 to 19, and waveform bins numbered 0 to 127 for Ku-band and 0 to 63 for S-band.

Timing: The convention for the ENVISAT mission is to use a Modified Julian Day which is referenced to Universal Time from a datum of 1st January 2000.

Instrument source packet is a group of 20 elementary measurements packaged on-board and downlinked in the telemetry. It holds the basic science data.

Elementary measurements are the 20 measurements in the source packet.

Individual echoes, or individual waveforms, are the 1800 Hz un-averaged waveforms. No other Radar Altimeter provide individual echoes until RA-2.

Pass is one half revolution around the earth. Usually from minimum (resp., maximum)



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latitude to maximum (resp., minimum) latitude, in other words, from pole to pole.

Orbit is one revolution around the earth, when referring to amount of data. Else it refers to the positioning of the satellite; orbital altitude.

Sea level is synonymous with sea surface height (SSH).

Sea surface height is synonymous to height.

Sea surface topography, or dynamic topography, is the departure of the sea surface from an equipotential surface, the marine geoid.

Instrumental Corrections are already applied to correct the retracked range.

$$\text{Range\_Instr\_Corr} = \text{Doppler\_Comp\_Update} + \text{Td\_Flight\_Cal} + \text{Td\_Ground\_Cal} + \text{Ant\_COG}$$

Using the Doppler Compensation correction, the In flight Calibration, Ground Calibration, and Centre of Gravity corrections.

Geophysical corrections are to correct the measurement for environmental effects (e.g. tropospheric, ionospheric) or remove geophysical signal of no interest (or even detrimental) to the application pursued (e.g. tides). These corrections are external to the measurement and come from other sources of data and models. As a rule the geophysical correction given in the Level 2 Products already hold the appropriate sign and are to be added to the range.

Flags are used to convey quality information or operating modes. They are usually set to zero to mean OK and 1 for not OK. The spare flag are set to zero. There may be exceptions, then a particular description of the usage of the flag is provided.

Default value: when a physically meaningful value cannot be computed a default value is provided. It is in most cases the maximum value of the field. There may be exceptions, then a

particular description of the default value is provided.

## 2.4 Products Evolution History

The Level 1B, L1B, and near real time Level 2, L2 NRT, data are produced by the IPF processing chain. While the level 2 offline data are produced with the CMA processing chain. The tables below show for each version of the processing chains, the algorithms and auxiliary data files upgrade.

### 2.4.1 L1B IPF upgrades

IPF Version	Date of issue PDHS-K&E, LRAC	L1B Algorithm upgrades	L1B ADF updates	ADF filename
V4.53	Nov. 27, 2002			
V4.54	Apr. 7, 2003	<ul style="list-style-type: none"> <li>*Wrong sign in AGC calibration estimation</li> <li>*Missing integrity check for the Data Block number read from the Level 0 Data Blocks</li> <li>*The altitude above CoG and the altitude rate have to be included in the records also in case of dummy records</li> <li>*1Hz data should be referenced to data block 9.5 not block 10</li> </ul>	Correction of the Tx-Rx gain of Ku and S band parameters (3.5 dB)	RA2_CHD_AX
V4.56	Nov. 26, 2003	<ul style="list-style-type: none"> <li>1- Extrapolation of AGC value to the Waveform center (49.5) for both Ku- and S-band.</li> <li>2 - Correction for an error found in the evaluation of S band AGC.</li> </ul>	RA2 IF Mask	RA2_IFF_AX
V4.57	PDHS-K: 29-04-2004 PDHS-E: 28-04-2004			
V4.58	Aug. 9, 2004			
V5.0.2	Oct. 24, 2005	<ul style="list-style-type: none"> <li>MWR Side Lobe correction upgrade</li> <li>USO clock period units correction</li> <li>RA-2 alignment: OBDH &amp; USO datation, IE flags correction</li> <li>Rain Flag tuning to compensate for the increase of the S band Signal</li> <li>Monthly IF estimation</li> <li>Level 1B S-Band anomaly flag</li> <li>DORIS Navigator CFI upgrade (RA-2 &amp; MWR)</li> </ul>	<ul style="list-style-type: none"> <li>- side lobe table and Configparam</li> <li>New ADF format - clock period unit</li> <li>New table in SOI file</li> <li>New format</li> </ul>	<ul style="list-style-type: none"> <li>MWR_SLT_AX</li> <li>MWR_CON_AX</li> <li>RA2_USO_AX</li> <li>RA2_CHD_AX</li> <li>RA2_CON_AX</li> <li>RA2_SOI_AX</li> <li>RA2_IFF_AX</li> <li>RA2_CON_AX</li> </ul>

Table 2.1 L1B IPF version

### 2.4.2 L2 IPF upgrades

IPF Version	Date of issue PDHS-K&E, LRAC	L2 Algorithms upgrades	L2 ADF updates	ADF filename
V4.53	Nov. 27, 2002			
V4.54	Apr. 7, 2003			
V4.56	Nov. 26, 2003	SPR26 Tuning of the Ice2 retracking New MWR NN algorithm	MSS CLS01 Rain flag Updated OCO Gretracker thresholds Ice1/Sea Ice Conf. file Sea State Bias Table file GOT002 Ocean Tide Sol1 Map file FES 2002 Ocean Tide Sol2 Map file FES 2002 Tidal Loading Coeff. Map file	RA2_MSS_AX RA2_SOI_AX RA2_IST_AX RA2_SSE_AX RA2_0T1_AX RA2_0T2_AX RA2_TLD_AX
V4.57	PDHS-K: 29-04-2004 PDHS-E: 28-04-2004	ECMWF meteorology files handling		
V4.58	Aug. 9, 2004	Addition of a Pass Number Field in FD Level 2 SPH product.		
V5.0.2	Oct. 24, 2005	Handling of the new RA2_CHD_ADF format Rain Flag tuning to compensate for the increase of the S band Signal Improving the mispointing estimation Export of the Level 1B S-band flag into the Level 2 data product Export of the Level 1B NRT orbit quality flag into the Level 2 data product Addition of a Pass Number Field in FD Level 2 SPH product Addition of peakiness in Ku and S band in FDMAR Addition of square of the SWH in Ku and S band Correction of MCD flag SPH pass number (field 8) set to 0 in SPH NRT Level 2 data products	New table in SOI file Two needed parameters in SOI file New format Addition of GOT20002 TLD New DEM AUX file (IMACESS) merge of ACE land elevation data and Smith and Sandwell ocean bathymetry	RA2_CHD_AX RA2_SOI_AX RA2_SOI_AX RA2_SOI_AX        RA2_TLG_AX AUX_DEM_AX

Table 2.2 IPF version

### 2.4.3 L2 CMA upgrades

CMA Version	Date of issue	IFF Version	Algorithm upgrades	ADF updates	ADF filename
V6.1	Aug. 4, 2003	V4.54 or V4.56	Tuning of the Ice2 retracking New MWR NN algorithm	MSS CLS01	RA2_MSS_AX
				Rain flag	RA2_SOI_AX
				Updated OCCG retracker thresholds	RA2_IGT_AX
				Ice/Sea Ice Conf. file	RA2_SSE_AX
				Sea State Bias Table file	RA2_OT1_AX
				GOT00.2 Ocean Tide Sol 1 Map file	RA2_OT2_AX
				FES 2002 Ocean Tide Sol2 Map file	RA2_TLD_AX
V7.1	Oct. 26, 2005	V5.0.2	Rain Flag tuning to compensate for the increase of the S band Sigma0	New table in SOI file	RA2_SOI_AX
			Handling of the new RA2_CHD_AX ADF format		RA2_CHD_AX
			Improvement of the mispointing estimation	Two needed parameters in SOI file	RA2_SOI_AX
			Export of the Level 1B S-band flag into the Level 2 data product	New format	RA2_SOI_AX
			Addition of square of the SWH in Ku and S band		
			Dry tropospheric correction estimated through the Meteorological Pressure corrected from a climatological value and from S1 and S2 waves.		
			MO G2-D estimation		
			GIM correction		
			Estimation of 20 Hz Latitude and longitude parameters		
			IPF L1b version inside the Level 2 product		
			Contribution of S1 and M4 for GOT00.2		
			MWR Land Ocean flag set to Default value (instead 1 which mean Land) if the estimation has not succeed		
			MWR to RA2 interpolation quality flag set to 3 if equals to default value instead of 0, which means "good"		
			Addition of sea-ice in Ku and S band in	New DEM MACCESS	ADY DEM_AX
				New Ocean tide and Tidal loading FES2004	
				Addition of GOT2000.2 TLD	RA2_TLD_AX

Table 2.3 L2 CMA version

## 2.5 Level 0 products

### 2.5.1 RA-2 Level 0 products

#### 2.5.1.1 Definition

All the information relative to the Measurement, BITE and IF Calibration modes of the instrument are packed in binary format and sent to ground in the form of Source Packets. They are generated by the instrument at a rate of one every 1.114 seconds. Approximately

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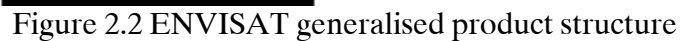
6000 Source Packets are sent each orbit.

Each Source Packet contains 75712 bits in normal operation (no individual echoes are transmitted) and 101312 bits whenever individual echoes are transmitted.

The Level 0 products, used as input for the L1b processing, will be a stream of RA-2 source packets in the same format as the instrument delivers them to the multiplexer of the ENVISAT satellite. The data will have overlaps and similar artifacts removed, although they may still contain gaps.

### 2.5.1.2 Structure

The generalised structure of ENVISAT products consists of a Main Product Header, a Specific Product Header and a certain number of Data Sets, each composed of Data Set Records, as shown in the following figure:



The RA2 Level 0 Data Set records are composed of some FEP and PF-HS annotations, and quality indicators, common to all ENVISAT instruments, and a dedicated part called

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## Instrument Source Packets.

The Source Packets consist of two major fields:

- the Packet Header, of fixed length, which provides the standardized control information like Packet Identification, Packet Sequence Control and Packet Length;
- the Packet Data Field which contains a Header and the scientific information distributed among 20 Science Data Blocks,
- a Calibration Field (always present but is effectively filled up only during the tracking phase of the measurement mode)
- an Individual Echoes Field ( present only when the transmission of individual echoes to ground is commanded by macrocommand)

The 20 Science Data Blocks will contain data relative to Acquisition or Tracking phase of the Measurement mode as well as data derived from operation in BITE and IF calibration. The internal structure of the Science Data Blocks and of the Data Field Header is function of the specific mode and phase within the mode; during tracking, for example, the samples of the averaged Ku and S waveforms are stored in the Science Data Blocks with auxiliary information gathered over 55.7 msec.

### 2.5.1.3 Packet Header

The Packet Header contains information of the ISP, and not DB dependant.

Parameters such as source sequence count (to be used for the OBDH/USO datation checks and for the PTR processing) and packet length (to be used for the packet length check) are stored in this part of the ISP.

### 2.5.1.4 Packet Data Field

The Packet Data field is composed of Data Field Header and Source Data Field.

The Data Field Header, whose format depends on the instrument operative mode, contains in Measurement mode (when at least one DB is in Tracking), parameters like the OBDH/USO datation, mode id, redundancy vector, averaged noise power, AGC attenuation for NPM, Delta Offset, etc.

The Source Data field contains the Data Blocks, with the Ku/S and extra DFT samples and all the information that is DB dependant, like coarse and fine Rx distance values, coarse and fine AGC values, chirp bandwidth, fault identification, etc.



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## 2.5.2 MWR Level 0 products

### 2.5.2.1 Definition

The Microwave Radiometer operates only in the MWR-ON mode. When in this mode, the instrument measures in two frequencies (24 GHz and 36 GHz), operating continuously in the whole orbit. The data coming from the instrument are packed in binary format and sent to ground in the form of Source Packets.

### 2.5.2.2 Structure

The Microwave Radiometer is a Low Bit Rate Instrument, and its Level 0 products, that correspond to one full orbit of data, have a standard LBR Level 0 data format:

- a Main Product Header (MPH) containing the product identification, the UTC time of data sensing, the geographical location of the product scene, the orbit parameters to generate the product, the On Board Time (OBT) to UTC conversion table, etc.
- a Secondary Product Header (SPH) containing information specific of the instrument/ data processing/ overall quality of the product, the instrument status at the time of product generation, etc., and
- a number of data set records (MDSRs) in one only MDS

The MPH is not specific of the product level, while the SPH is specific of each level.

The number of Data Sets attached in the L0 MWR products is always 1, although there are DSs referred to in the SPH, through DSDs, for the auxiliary data used to build the products.

The MWR Level 0 Data Set records are composed of some FEP and PF-HS annotations, and quality indicators, common to all ENVISAT instruments, and a dedicated part called Instrument Source Packets. The ISPs are organised with a Packet Header and a Packet Data Field.

### 2.5.2.3 Packet Header

The Packet Header contains general information about the data contained in the Source Packet, like packet identification, packet sequence control and packet length, and has fixed length (3 words).

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#### 2.5.2.4 Packet Data Field

The Packet Data Field contains the scientific data and any auxiliary data which are specific to the generating source on board the spacecraft (Instrument Mode definition, ICU on board time code, etc,) and has variable length.

The scientific data will be inserted in Science data field composed of a certain number of CEU generated Telemetry data (TM data) and contain information on calibration status, operational mode flag, source packet counter and radiometer output data.

## 2.6 RA-2/MWR Level 1b Products and Algorithms

### 2.6.1 RA-2 Level 1b algorithms

The key processing algorithms required for the generation of the L1b product starting from the RA2 Level 0 product are:

- Level 0 data decoding
- Orbit Data generation and datation correction
- Point Target Response data processing
- IF shape correction
- Window time reference extraction
- Automatic Gain Control calibration
- Level 1b data formatting

The Level 0 data decoding and PTR data processing are called once very source packet analysed. The Level 0 data decoding is also in charge of providing information from the 20 DBs of the ISP analysed to the IF shape correction, Window Time reference extraction, AGC calibration and Orbit data generation functions which operate on single DB basis.

The Output Data packaging function operates on single DB basis for the information relative to individual DBs, and on ISP basis for the information retrieved from the PTR analysis and individual echoes data.

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### 2.6.1.1 Level 0 data decoding

The Configuration file, the Characterization file, the Calibration files, the Constant and Orbit State Vector files and the Level 0 data are handled by this function. Configuration and Characterization informations are extracted from the corresponding file to setup the processor and the processing constants (i.e. configuration parameters and characterization parameters).

Each field of each Source Packet contained in the raw data stream (Level 0) is extracted and converted to engineering units according to its binary format (signed/unsigned integer or floating point C2 format) and the value and physical dimensions of the least significant bit.

Whenever possible, integrity of decoded parameters is verified by means of dedicated consistency checks and warning flags set accordingly. In some cases, when no suitable way of verifying the data integrity during the decoding phase is available, consistency checks are performed throughout the Level 1b processing on the parameters computed from the original quantities extracted from the source packet.

The main processing steps performed within these functions are the following:

- Computation of the effective IF calibration mask: to be used during the processing: this is done by using the value of the IF mask selection flag and the RF redundancy flag from the Configuration file and the IF (flight or ground) mask from the IF auxiliary file.
- computation of the effective USO calibration value: to be used during the processing: this is done by using the value of the USO selection flag from the Configuration file, the flight USO Tx/Rx clock value from the USO aux. file or the ground clock value from the Characterisation file.
- Decoding of FEP annotations in the L0 DSRs: a summary error flag is generated from this check and exported into the RA2 L1b MCD check of the ISP packet length: a flag is generated (errors encountered or not) and exported into the RA2 L1b MCD.
- OBDH datation consistency check: the difference between consecutive OBDH datations is calculated and compared with respect to a tolerance (maximum number of clocks elapsed between consecutive ISPs). If the difference exceeds this number, the OBDH flag is set and reported in the output MCD. NB: the OBDH datation is not modified in the event of OBDH\_flg=1, so as to avoid the propagation of wrongly corrected OBDH values for the whole product. It will be the end user who will discriminate, using this flag, which one was the ISP with the wrong OBDH datation
- On board binary to UTC time correlation: the ICU clock counter datation (OBDH) is converted into UTC datation for each DB, using a UTC reference time. This reference time will be leap second corrected, if relevant, before being used in this algorithm.

- Redundancy flags decoding: the values of the RFSS and HPA redundancy flags from the ISPs are checked against default values from the Configuration file. If discrepancies are found, a warning flag will be raised and exported into the output MCD
- corrected Noise Power Measurement computation: the input NPM value is corrected through a scaling factor extracted from the Configuration file
- corrected Automatic Gain Control of Noise Power Measurement computation: obtained from the AGC table for NPM in the Characterisation file, and the AGC\_NPM value from the L0 data
- DFT indexes evaluation: the DFT indexes are decoded from the L0 ISPs and used to compute the final DFT indexes that will be exported into the output product.
- USO datation consistency check: the difference between consecutive USO datations is calculated and compared with respect to a tolerance (maximum number of USO datation values between consecutive ISPs). If the difference exceeds this number, the USO flag is set and reported in the output MCD. NB the USO datation is not modified in the event of USO\_flg=1, so as to avoid the propagation of wrongly corrected USO values for the whole product. It will be the end user who will discriminate, using this flag, which one was the ISP with the wrong USO datation
- Setting of fault\_id flag: the fault identifier is read from the L0 DBs, and then the L1b output MCD fault\_id flag set to 0, if all decoded bits are 0, meaning that no errors have been detected on board, or set to 1 otherwise.
- RA2 alignment processing: this processing step is aimed at correcting for the time lag existent in the RA-2 on board processor between the echoes accumulation and echoes processing. To do this, some information from a DB (i.e. Rx\_dist\_c, Rx\_dist\_f, AGC\_c1, AGC\_c2, AGC\_f, AGC\_Dist, AGC\_Rate, HTL\_Dist, HTL\_Rate, n1\_star, n2\_star and Chirp\_ID) is used to process the waveforms of the subsequent DB. If the previous DB was not Tracking, Preset Tracking or Preset Loop Output, but the current DB was in one of these modes, the mode id of the current DB is set to align failed to indicate failure in the alignment procedure. This happened every time there is an acquisition sequence.
- Computation of the UTC time tag of the PTR measurement: this is done by using the PTR datation from the ISPs calibration field, the USO datation from the L0 ISPs and the satellite on board clock frequency from the MPH.

### 2.6.1.2 PTR Data Processing

PTR data measurements are processed in order to retrieve the relevant correction factors required to compensate for the variability of instrument errors.

New calibration data is computed from every ISP by properly processing the PTR samples in the calibration field. Only data from ISPs in mode\_id= Tracking, Preset Tracking or Preset Loop Output will be considered meaningful and shall be processed. The value of the cal\_band\_id is used to verify that the data in the calibration field is effectively filled in, and to check the band (20, 80 or 320 MHz for Ku, or 160 for S) the data is associated with.

Computed calibration data from single PTR measurements are then checked versus allowed

predefined ranges from the Configuration file. The computed calibration factors, if valid, are then used to correct the measurement data (AGC and window delay values).

When a Ku PTR is processed, the computed values are transferred to the Ku filtering units while dummy values are transferred into the S buffer, and vice versa.

Each filtering units is constituted by a couple of memory buffers in which calibration data from single PTR measurements, the relevant auxiliary information and validity flags are filled in, every time throwing away the oldest values in the buffers, once the buffers are full.

The relevant source sequence counter information extracted from the packet header, is also stored in the buffers in order to check the time lag between the first and last calibration data available.

Smoothed calibration values will be generated by averaging over the meaningful data contained in the buffers under the condition that the time difference within the last and first meaningful calibration data in the buffers does not exceed a predefined time duration. This test is required since time gaps in the Level 0 raw data stream may still be present and is performed by analysing the source sequence counter.

The main steps during the PTR processing are detailed here below:

- FFT and square modulus extraction: from the In-Phase and Quadrature samples of the instrument PTR extracted from the source packets, an FFT (zero padding technique) followed by a square modules extraction is performed.
- computation of time flight calibration factors: the position of the PTR maximum of the FFT filter bank allows to compute the flight calibration factors (for Ku and S) for the time delay measurement.
- consistency check on these factors: these factors are checked against expected ranges from the Configuration file. If they are out of the allowed ranges, the factors are properly flagged to avoid their use in the evaluation of the smoothed calibration parameters
- computation of the total PTR power: the total power of the PTR signal is computed using the In-phase/Quadrature complex samples of the PTR and calculating the sum of their squared modulus values.
- evaluation of the amplitude correction factors: they are evaluated by using the total power, the PTR reference power and AGC used in ground characterisation phase to retrieve the reference PTR power, stored in the Charcaterisation file, and the AGC used for the PTR calibration, that is derived from the coarse AGC attenuation values from the calibration field.
- consistency check on these factors: these factors are also checked against expected ranges from the Configuration file. If they are out of the allowed ranges, the factors are properly flagged to avoid their use in the evaluation of the smoothed calibration parameters.
- population of the Ku/S filtering units: the computed time and amplitude correction factors will be included in the Ku or S filtering units, along with a combined quality flag that will be set to valid, only if both, time and amplitude correction factors, are in the allowed ranges.
- averaging of the meaningful measurements contained in the memory buffers of the

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- filtering units: the meaningful measures will be averaged considering that the time lag between the first and last meaningful measurements in the buffers does not have to exceed a specified amount expressed in terms of multiples of the equivalent time duration of a source packet.
  - retrieval of the final calibration correction factors: they are obtained from this averaging process if the number of valid measures in the memory buffers exceeds a minimum value (from the Config. file), otherwise, default ground values (from the Characterisation file) will be exported into the output L1b product (i.e. L1b RA2 MDSRs and PTR MDSRs).

### 2.6.1.3 IF Shape Correction

This function implements the correction of the waveform samples for the IF filter shape distortions. This function is activated only in mode Tracking, Preset Tracking or Preset Loop Output, since only in this case the waveform samples are meaningful.

A preliminary check to verify that the whole set of Ku/S samples is not equal to zero is done before processing. Only the non-null samples set(s) will be IF mask corrected.

The correction consists mainly in correcting each Ku/S waveform sample by the corresponding sample of the effective correction mask to be used. This mask has been properly modified to account for the amount of fine shift applied to the waveforms in the on board processing. In fact, IF shape compensation is really effective only if the IF correction mask samples are rearranged to account for the same amount of shift.

The main steps in this task are the following:

- consistency check on the waveform samples: if Ku (or S) samples are all null, the Ku (or S) waveforms are not IF corrected
- evaluation of the specific correction mask in terms of fine component Rx\_dist\_f of the on board Rx delay, chirp bandwidth and chirp\_id flag
- correction of the L0 waveform samples by the calculated IF mask
- S-Band anomaly flag evaluation

### 2.6.1.4 AGC Calibration

The on-board AGC measurement is corrected by the characterization corrections extracted from the Characterization Auxiliary File to provide AGC corrected values for Ku and S data. Any gain variation in the radar Tx/Rx chain with respect to the nominal condition characterized on ground is compensated using flight calibration data derived from PTR measurements. The power scaling factor required to evaluate the sigma\_0 in the level 2 processor is additionally evaluated.

The main steps to be followed in this processing task are listed here below:

- correction of on board AGC value for instrument errors: the AGC coarse values

(AGC\_c1 and AGC\_c2) and the fine AGC\_f value are combined and used in the AGCtable from the Characterisation file to obtain a unique AGC\_sig value. This value, together with the ground amplitude calibration factors (from the Characterisation file) and PTR derived amplitude correction factor will be added to obtain the corrected AGC value

- The total amount of calibration correction on the AGC is also computed and exported into the output L1b MDSRs
- the power scaling factor needed for the sigma\_0 evaluation at level2 is finally computed using the corrected AGC value, the overall gains of the receiving chain (extracted from the Characterisation file) and the chirp bandwidth

### 2.6.1.5 Window Time Reference Extraction

This function evaluates the time tag of the processed waveforms (Ku and S) from the Rx delay coarse and fine components computed by the on-board tracker and corrects it for instrument errors and Doppler shift.

The following processing steps are performed within this task:

- computation of the on board Rx delay (separately for Ku and S) from the Rx coarse and fine components extracted from the DBs of the Source Packet. The on board measurement is further compensated for the PRI ambiguity rank, for the height rate and converted to time units using the Tx/Rx clock period
- the computed Rx\_del\_Ku/Rx\_del\_S values are tested against expected ranges (min/max values from the Configuration file), and a warning flag is raised if the computed values are out of these ranges
- the time delay measurements are corrected for instrument induced errors using both ground(from the Characterisation file) and in-flight (from PTR) calibration parameters
- the Doppler effect caused by the satellite radial velocity is compensated by adding the Doppler correction factor to the time (or window) delay

### 2.6.1.6 Orbit Data Generation and Datation Correction

This function provides the calculation of latitude/longitude coordinates for each processed data block in the source packet and the needed spacecraft orbit parameters. Data are retrieved through the EnviSat Orbit computation library that uses data from the Orbit State Vectors files. Furthermore it operates datation correction for propagation delay.

These are the main steps within this function:

- orbit function call in initialisation mode and propagation calls for every DB time. From the propagation calls, only the output satellite height is kept
- This value of Height is used to obtain the propagation delay, and then used to correct the UTC of every DB
- The updated UTC\_DB time value is used as input for a second orbit function call



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(in propagation mode), and the latitude, longitude, Height and Height rate will be retrieved and exported into the output product

### 2.6.1.7 Level 1b data formatting

The processed RA-2 data, as well as MWR shall be packetised in the L1b product format.

The MWR processed data will be exported into the L1b MWR MDSRs, while the RA2 processed data will go to the first (main), second (individual waveforms) and third (PTR) MDSRs.

The individual waveforms in the 2nd MDSRs are a copy of the individual echoes contained after the L0 ISPs, when present. The OBDH datation in every individual waveforms record is a copy of the OBDH value of the ISP that contained the individual echoes, while the record time corresponds to the first DB of the source packet containing these echoes.

In general, the information to be exported into the L1b records will come from the functions that operate on a DB or ISP basis, and will be copied in the 20 L1b records output from the same ISP (if information is not DB dependant) or updated for every output record, if the record frequency is 18 Hz.

## 2.6.2 MWR Level 1b algorithms

The key processing algorithms required for the generation of the L1b product starting from the MWR Level 0 product are:

- Level 0 data extraction and decoding
- gain processing
- temperature offset evaluation
- antenna temperature retrieval
- brightness temperature evaluation
- antenna axis registration
- Level 1b data formatting

The MWR Level1b data processing outputs calibrated antenna temperature values using as input scientific raw data, and registers the two channels measurements , as they are not pointing at the same place. Moreover using an appropriate radiative model the brightness temperature is calculated using the calibrated and geolocated antenna temperature. The input of Level 1b processing is the Level 0 scientific data (Telemetry Data provided by High

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Speed Multiplexer in Low Bit Rate) for MWR.

To calculate the brightness temperature it is necessary, first, to evaluate the temperature as seen by the main antenna, and then to separate the contribution coming from the main lobe from those coming from the secondary lobes affected by spurious contributions.

Moreover to retrieve the main antenna temperature  $T_a$  from the output receiver voltage, it is necessary to characterise the radiometer response.

The result of these MWR L1b processing steps represents the engineering foundation product enabling the derivation, during the Level 2 processing, of integrated liquid water, water vapour content and altimeter path delay values.

### 2.6.2.1 Level 0 data extraction and decoding

The Level 0 data needed for the Level 1b processing is extracted from the telemetries, coming from the on board ICU, from the source packet headers, and from the product headers.

Each field of the Source Packet representing the acquired raw data stream is extracted and converted into engineering units according to its binary format. Some consistency checks are performed to validate the extracted parameters at this level; in most cases the validity is checked by simply comparing the expected values with the current ones, within the Level 1b processing itself.

The following steps are performed:

- extraction of the source packet identifier
- extraction of Packet version number and validity check (setting of warning header flag if unexpected value)
- extraction of the Packet type to distinguish telecommand from telemetry
- extraction of the data field header presence flag (setting of header warning flag if unexpected value)
- extraction of mode identification check (setting of warning header flag if unexpected value)
- extraction of the source packet segmentation flag (setting of warning header flag if unexpected value)
- extraction of the packet length value (setting of warning header flag if unexpected value)
- extraction of the Data Field header length (setting of warning header flag if unexpected value)
- extraction of instrument mode check (setting of warning header flag if unexpected value)
- extraction of number of blocks for each source packet (setting of warning header flag if unexpected value)

- on board datation consistency check, using the source sequence count from current and previous SP (setting of Header and OBDH flag if difference between consecutive OBDH datation values is not in the allowed tolerance)
- telemetry datation and location (lat/long) for each TM and for each channel. Note that the UTC reference time to be used for this calculation will be leap second corrected (if relevant) before being used for the processing. Location of each data block can be evaluated using orbital parameters and the datation corresponding to each data block. There are two different modes of operation. The first mode corresponds to the case when no Orbit file will be present in input. In this case, the orbit propagator provided by CFI Library will be used and its initialisation will be performed using the reference state vector stored into the Level 0 MPH. The second mode corresponds to the case when at least one Orbit file will be present in input. In this case, the orbit interpolator provided by CFI Library will be used and its initialisation will be performed using FOS or DORIS auxiliary file.
- extraction of Line\_Count from first Telemetry word (consistency check with previous TM value and setting of a warning flag if the difference between consecutive Telemetries is not 1)
- extraction of calibration status field CS in the telemetries for the individuation of the data source (Main Antenna, Hot Load, Sky Horn or Offset) and of the Calibration status field CF for discrimination of first or not first measurement of the current data type.
- extraction of Channel 1 and Channel 2 counts for any of the data source types
- extraction of the telemetry coming from on board thermistors, according to the data these thermistor are relevant to (indicated by Line\_Count)
- extraction of the DHK bits and check on their values (telemetry warning flag raised if different values decoded)
- extraction of the power bus protection indication, overload and overvoltage protection, normal/redundant ICU channel indication and blanking pulse status
- setting of the Temperature table full flag if at least 32 telemetries have been acquired
- calculation of the on board temperature measurement by using a 10th grade polynomial fitting algorithm
- calculation of the two channels physical receiver temperatures (and standard deviations) and consistency checks on them (telemetry and temp flag raised if values out of allowed ranges)
- computation of the temperatures relevant to the Dicke load, Hot Load, IF sections and mixers, for both channels (telemetry and temp flag raised if values out of allowed ranges)
- CRC check and setting of CRC flag if the L0 value is different from the one calculated during the processing

### 2.6.2.2 Gain Processing and Offset Temperature Evaluation

The in-flight calibration is obtained from combination of measurements from sky horn and internal load.

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This calibration performs the evaluation of the first order approximation of the current gain, that is the gain relevant to the current intercalibration period.

This is relevant to the calibration of the radiometric response using a non linear slope between the two extreme temperatures, sky horn and hot load, (and the relevant output counts) fixed by the two calibration points. The evaluation takes into account the dependence of receiver gain to the instrument physical temperature.

Moreover, due to the system noise, there is a temperature offset related to the output counts where no input is present, introducing a temperature bias in every measure. All the parameters involved in the processing and not extracted by telemetry data are expected to be estimated and calibrated on-ground before launch, and stored in the Characterisation/Calibration auxiliary file.

The gain and offset are calculated through the following processing steps:

- selection of the Offset measures (discarding the very first one), only if 32 telemetries have already been acquired
- calculation of the constant gains for both channels, using the hot load and sky horn counts, receiver physical temperatures and coefficients extracted from the Characterisation auxiliary file
- calculation of the offset temperatures, using the gain values, hotload and offset counts, Dicke switch temperatures, sky horn radiometric temperatures, hot load temperatures and sky horn calibration switch temperatures, and some coefficients from the Characterisation auxiliary file
- calculation of the smoothed (averaged) gain and offset temperatures if the calibration number reached the moving window size

NB: if the end of file occurs before the number of calibration measures (Offset) reaches the moving window size, the file shall be rewinded. That is; the new moving window size will be set to the available calibration number, and the only set of smoothed gain and offset temperature values will be used to process the whole L0 data. While rewinding, no antenna data is lost, since the smoothed offset and gain values are used to obtain antenna temperatures from all the data, even from the measures prior to the actual calibration sequence.

In case no gain values are calculated during the processing (not enough Offset measures in the L0 product), the output brightness temperatures are directly set to default (0). This shall avoid having negative values of brightness temperatures, that when casted to unsigned values in the L1b product, give temperatures values with no physical meaning.

The user shall know in this case that the gain was never evaluated, since the moving window size in the Configuration auxiliary file will be different from the moving window size in the L1b product.

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### 2.6.2.3 Antenna Temperature Retrieval

Once the radiometric response has been characterised it is possible to perform the main antenna noise temperature calculation, by retrieving its measure by the output counts of each channel, the actual gain and the actual temperature offset, and all the radiometric parameters involved.

This is an estimate and will be affected by an uncertainty due to several causes: residual uncertainty on parameters values after pre-flight calibration or uncertainty on resistances measures and temperature conversion, not completely assessed knowledge of non linear behaviour of the receiver.

For these reasons the retrieval processing is accomplished using an expected value of algorithm accuracy theoretically evaluated, that is compliant with the instrument requirements.

### 2.6.2.4 Brightness Temperature Evaluation

The geophysical parameters are computed from the temperature seen by the antenna main lobe. To calculate it, it is necessary, first, to evaluate the temperature seen by the antenna, and then to separate the contribution coming from the main lobe from those coming from the secondary lobes.

There are three different algorithms that can be used to remove the effects of the secondary lobes. In the first, ERS-1 like, algorithm, the secondary lobes effects are tabled in a Side Lobe Table auxiliary file, as function of the latitude of the satellite.

In the second, ERS-2 like, algorithm, instead, the side lobes contributions are obtained using the reflector physical temperatures, the transmission coefficients of the reflectors and the global side lobes contributions for each channel.

The third algorithm is proposed by CLS that used one full year of ERS2 brightness temperatures to evaluate the contribution of the land emissivity (directly and after reflection by the platform) inside the measurement cell.

### 2.6.2.5 Antenna axis registration

In order to obtain geophysical data, it is necessary to combine the observations of Channel 1 (23.8 GHz) and Channel 2 (36.5 GHz) and of the altimeter, when available over the same spot. As the two radiometric channel are not looking at the same spot because of their

different off-nadir angles (1.72 and 1.83 respectively) , a registration is necessary.

This is done in the following way:

The brightness temperatures, already evaluated, are co-located using a certain number of samples to be skipped between the two files (Channel 1 and Channel 2) containing all the information (e.g. brightness temperatures, location, datation, record counter, samples since last calibration period, quality flags, OBDH flag, valid data flag) of the two channels.

Then, since the 36 GHz channel looks forward in EnviSat, for every sounding of Channel 2, starting from the first valid data, the corresponding sounding in Channel 1 is searched in the record that is shifted a number of samples.

This number of samples to be skipped between the two files has been obtained during the Level 0 data extraction and decoding when the datation and location of the Telemetries were calculated.

At this point, all the co-located averaged data (brightness temperatures and standard deviations) are calculated for both channels and output into the same MWR L1b record.

Information like datation, location, source packet identifier and packet telemetry counter are exported into the output product corresponding to the 4th measure of the 8 elementary measurements that were used for the averaging process. In the case of datation and location, only the information pertaining to the forward channel is copied into the L1b output record.

## 2.6.2.6 Level 1b Data Formatting

The processed data are stored in a specific layout including some necessary information for the following processing. The output layout shall include file headers, with data relevant information like the functional mode during which the acquisition has been performed, the longitude/latitude co-ordinates and the UTC time, etc., followed by a series of records regarding the output brightness temperature specified by the actual functional mode. As the output layout is the same for Level 1b and Level 2 default values (set to 0) will be written in Level 2 data fields.

## 2.6.3 RA-2/MWR Level 1b product

### 2.6.3.1 Definition

The RA-2/MWR level 1b product contains the geolocated engineering calibrated data. When creating the L1b product, the raw Level 0 data is converted into engineering units and the relevant instruments calibration and characterisation data is applied.

Although two different products (RA2\_ME\_\_0P and MWR\_NL\_\_0P) are needed as input, only one merged RA-2/MWR product is created at Level 1b, containing the meaningful results from both the RA2 and the MWR Level 1b processing activities.

### 2.6.3.2 Structure

The RA-2/MWR Level 1b product is composed of an MPH and SPH (common to both instruments) and 4 Measurement Data Sets (RA2, individual echoes waveforms, RA-2 Point Target Response and MWR).

The layout of the MPH is common to all EnviSat instruments and contains information such as the first/last record time in the product, UTC/SBT time reference table, Orbit State Vector information, SPH size and total product size.

The SPH and the Data Sets are instead specific of each product and of each processing level.

The SPH contains information concerning the whole product, while the Measurement Data Sets contain information specific of every record.

Each MDS record includes a time record, a quality indicator flag and a record counter inside the product.

The RA2 and MWR MDSRs contain the latitude and longitude value of every record, quality fields (MCD) and the science data.

### 2.6.3.3 RA-2/MWR Level 1b SPH

The unique RA-2/MWR L1b SPH contains information coming from both the RA2 and MWR Level 1b processing steps.

The start/stop latitude and longitude values for RA2 and MWR records are contained in the SPH, along with the first and last record times for both instruments.

Quality flags indicating if the percentage of records with header or processing errors (for RA2) or header, telemetry and processing errors (for MWR) is less than a threshold (extracted from the auxiliary configuration files) are included.

Information like percentage of records in the different RA2 operational modes, and



percentage of the RA2 records in the different Ku bandwidths appears in the L1b SPH as well.

#### 2.6.3.4 Level 1b RA2 MDS

This RA2 Level 1b Data Set shall reflect the structure and contents of the input RA2 Level 0 Source Packets, with values converted into engineering units and all RA2 calibration and characterisation data applied.

One output record is generated for each Data Block of the Level 0 Source Packets. In other words, one output record represents one elementary measurement corresponding to about 55.7 milliseconds of data take.

Some information in these output records come from the Source Packet Header, and so, it will be repeated for the 20 records corresponding to the same ISP.

Instead, some other values are Data Block dependant, meaning that different values will be output for every L1b record of the same ISP.

The Ku/S IF mask corrected waveform samples, including the 2 DFT extra samples are included in the RA2 L1b records, along with the main output results from the AGC processing (corrected Ku abdn and S band AGC, scaling factors for sigma\_0 evaluation for both bands, etc.), PTR processign (time delay and sigma\_0 flight calibration factors for both bands), window delay for Ku and S, calibrated Noise Power Measurement, Doppler correction for Ku and S, Delta\_Offset, etc.

Most of the fields in these records are meaningful only if mode\_id at DB level is Tracking, Preset Tracking or Preset Loop Output. Otherwise, default values (0) are used to fill those fields in.

Nevertheless, fields like UTC time, latitude, longitude, DB number, record counter, etc., are always correctly filled in independantly of the mode of the instrument.

#### 2.6.3.5 Level 1b RA2 individual echoes waveforms MDS

This MDS contains the unaveraged individual echoes appended to the Level 0 RA2 ISPs.

This MDS will only be present in the L1b product if there are RA2 Level 0 ISPs with individual echoes present.

These records include always a time (that corresponds to the time of the first DB of the first



ISP containing individual echoes), an OBDH datation (that coincides with the OBDH value from the first ISP containing individual echoes, and that does not change for all the individual echoes waveforms records in the same sequence), a record counter, a source sequence counter (extracted from the header of the first ISP in the sequence of individual echoes) and the individual echoes themselves.

The individual echoes field contains the In-Phase and Quadrature samples, corresponding each to an 8 bit two's complement value from the Level 0 field.

### 2.6.3.6 Level 1b PTR MDS

This MDS consists of data output from the PTR processing operations in the Level 1b processing algorithms. The rate of these records is one every 1.114 seconds (same rate as the Level 0 RA2 ISPs, since the PTR data is included in the calibration field at the end of the ISPs).

These records include a time value, an OBDH datation word (copy of the value in the L0 ISP), a record counter, the 128 normalised PTR processed samples, the time delay and sigma\_0 flight calibration factors, and some other flags.

The flight calibration factors are repeated in the main RA2 L1b MDSRs as well.

### 2.6.3.7 Level 1b MWR MDS

Each record in this MDS represents data coming from 8 scans of the radiometer, i.e. 1.2 seconds of data, so that it is available at a rate similar to RA2 (1.114 seconds).

No further averaging is performed when processing from L1b to L2, thus, the same record format is used for both processing levels.

In each record, datation and geolocation are included, together with some flags (MCD) to describe the validity of each output. Some instrument flags are also inserted in each record to give some information on instrument status at the acquisition time.

The fields that are filled in at Level 2, are set to 0 when outputting the L1b product.

## 2.7 RA-2/MWR Level 2 Products And Algorithms

## 2.7.1 RA-2 Level 2 Algorithms

The level 2 processing algorithms are used to generate the three main level 2 products, namely the FDGDR (Near Real Time product, available within 3 hours), the IGDR (Off-Line product, available within 3 to 5 days) and the GDR (Off-Line product, available within 3 to 4 weeks). The relationship between these products is described in [section 2.2](#).

A general flowchart of the FDGDR, IGDR and GDR level 2 processings is given in figure. Each function (i.e. algorithm) is represented by a box, and a table indicates to which type of level 2 processing(s) it belongs (grey if the algorithm is performed, white if is not performed). For example, the algorithm "To Compute the Doris ionospheric Correction" is performed during the IGDR and GDR processings but is not performed during the FDGDR processing. Moreover, the rhythm of activation of the algorithms (RA-2 elementary measurements, RA-2 averaged measurements or MWR averaged measurements) is indicated. The first 12 algorithms process the elementary measurements at a rate of 18Hz while the remaining 23 algorithms process the average measurements at a rate of 1Hz.

Table 2.4 General flowchart of the FDGDR, IGDR and GDR level 2 processings

RHYTHM OF ACTIVATION	PROCESSING CHAIN			ALGORITHMS
	FDGDR	IGDR	GDR	
RA-2 - 20 Hz				TO COMPUTE THE AVERGAED TIME TAGS
				To compute THE AVERAGED altitude, orbital altitude rate and location
				To compute THE altitude, orbital altitude rate and location FROM ORBIT FILES
				To compute the Doppler correctionS
				To perform the sea-ice retracking
				To perform the ice-1 retracking
				To perform the ice-2 retracking
				To perform the ocean retracking
				TO COMPUTE THE PHYSICAL PARAMETERS
				To correct the RA-2 range for Doppler effects
				To compute the Doppler slope correction (ICE SURFACES)
				TO EDIT AND COMPRESS THE OCEAN ESTIMATES

RA-2 - 1 Hz				To determine the surface type
				To interpolate MWR data to RA-2 time tags
				To compute the BACKSCATTER COEFFICIENT atmospheric attenuations
				To compute the 10 meter RA-2 wind speed
				To compute the MWR geophysical parameters at RA-2 time tag
				To compute the 10 meter MODEL wind vector
				To compute the sea state biases
				To compute the dual-frequency ionospheric corrections
				To compute the doris ionospheric corrections
				To compute the Bent model ionospheric corrections
				To compute the MODEL wet and dry tropospheric corrections
				To compute the inverted barometer effect
				TO COMPUTE THE MEAN SEA SURFACE PRESSURE OVER THE OCEAN
				To compute the NON EQUILIBRIUM FROM THE ORTHOTIDE ALGORITHM
				To compute the NON EQUILIBRIUM FROM THE HARMONIC COMPONENTS ALGORITHM
				To compute the solid earth and the long period equilibrium ocean tide heights
				TO COMPUTE THE HEIGHT OF THE TIDAL LOADING
				To compute the pole tide height
				To compute the mean sea surface height
				To compute the geoid height
				To compute the ocean depth / land elevation
MWR - 1 Hz				To interpolate RA-2 data to MWR time tag
				To compute the MWR geophysical parameters at MWR time tag

### 2.7.1.1 Ocean retracking algorithm

The ocean retracking algorithm is the result of a comparative study of the various standard ocean retracking algorithms [Ref. \[2.1\]](#), 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 mathematical solution of these four retracking are very close to each other, but the

approach used in the ESTEC algorithm is more general and complete. So the retracking implemented to process the ENVISAT RA-2 data is based on ESTEC algorithm improved with some particularities of the others retracking algorithm.

The ocean retracking algorithm is performed on the Ku and on the S waveforms. The only difference in the retracking of Ku and S waveforms is the processed data (waveform, processing and instrumental parameters), while the processing is the same.

The ocean retracking algorithm objective is to make the measured waveform coincide with a return power model, according to weighted Least Square estimators using the Levenberg-Marquardt's method [Ref. \[2.2\]](#). The expression of the model versus time (t) is derived from Hayne's model [Ref. \[2.3\]](#).

Accounting for a skewness coefficient ( $\lambda_s$  = processing parameter), and assuming a gaussian point target response (Hamming weighting performed on-board the RA-2 altimeter), it is given by :

$$V_m(t) = a_s \frac{P_r}{2} \exp(-v) \left[ 1 + \alpha f(u) \right] \cdot \frac{\lambda_s}{6} \left( \frac{\sigma_s}{\sigma_c} \right)^3 \left[ 1 + \alpha f(u) \right] \frac{1}{\sigma_c} - \frac{\sqrt{2}}{\sqrt{\pi}} \left[ u^3 + 3 \sqrt{2} \sigma_s \sigma_c u + 3 \sigma_s^2 \sigma_c^2 - 1 \right] \exp(-u^2) \Bigg] + P_n \quad \text{eq 2.1}$$

with :

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \quad \text{eq 2.2}$$

$$\gamma = \frac{1}{2L\pi(2)} \cdot \sin^* \theta_s \quad \text{eq 2.3}$$

,

$$\alpha = \frac{4c}{\gamma h \left( 1 + \frac{h}{R_e} \right)} \quad \text{eq 2.4}$$

$\theta_0$  = antenna beamwidth,  $c$  = light velocity,  $h$  = satellite height,  $R_e$  = earth radius

$$\sigma_{\text{p}}^{\text{p}} = \sigma_{\text{p}}^{\text{p}} + \sigma_{\text{p}}^{\text{p}} \quad \text{eq 2.5}$$

,  $\sigma_{\text{p}}$  = PTR width ,

$$\text{SWH} = \frac{c}{2} 4 \sigma_{\text{p}} \quad \text{eq 2.6}$$

$$a_{\xi} = \exp \left( \frac{-4 \sin^2 \xi}{\gamma} \right) \quad \text{eq 2.7}$$

,

$$b_{\xi} = \cos(2\xi) - \frac{\sin^2(2\xi)}{\gamma} \quad \text{eq 2.8}$$

,

$$c_{\xi} = b_{\xi} \alpha \quad \text{eq 2.9}$$

,  $\xi$  = mispointing

$$u = \frac{t - \tau - c_{\xi} \sigma_c^2}{\sqrt{2} \sigma_c} \quad \text{eq 2.10}$$

,

$$v = c_{\xi} \left( t - \tau - \frac{c_{\xi} \sigma_c^2}{2} \right) \quad \text{eq 2.11}$$

and where the parameters to be estimated are :

$\tau$  : the epoch

$\sigma$  : the information relative to the significant waveheight (SWH)

$P_u$  : the amplitude which is related to the backscatter coefficient ( $\sigma_0$ )

$P_n$  : the thermal noise level (to be removed from the waveform samples)

The square of the mispointing is estimated using the "ice 2" retracker, see [Ice2 retracking algorithm 2.7.1.2.](#)

Computation of physical parameters

- 

Altimeter range:

The 20Hz tracker altimeter range corrected for the COG motion and decorrelated for the Doppler effects (Range in metres) is computed as follows, using in particular the distance antenna-COG (Ant\_COG) selected for the averaged measurement which contain the processed elementary measurement:

$$Range = \frac{Light\_Velocity}{2} * Tracker\_Range - Doppler\_Comp + Ant\_COG \quad eq\ 2.12$$

Where for each RA-2 nominal tracking data, the Ku-band and the S-band tracker ranges are computed (in seconds) from the input window delays and from offsets computed, by:

$$Tracker\_Range\_S = \frac{Window\_Delay\_S}{10^{12}} + (Offset\_S * FFT\_Step\_S) \quad eq\ 2.13$$

$$Tracker\_Range\_Ku = \frac{Window\_Delay\_Ku}{10^{12}} + (Offset\_Ku * FFT\_Step\_Ku) \quad eq\ 2.14$$

where

$$FFT\_Step = \frac{10^3}{Pulse\_Length * |Chirp\_Sl|} \quad eq\ 2.15$$

$$Offset\_Ku = \frac{Delta\_Offset}{256} * \left| \frac{Chirp\_Sl\_Ku}{Chirp\_Sl\_Ku3} \right| \quad eq\ 2.16$$

$$Offset\_S = \frac{Delta\_Offset}{256} * \left| \frac{Chirp\_S1\_S}{Chirp\_S1\_Ku3} \right| \quad eq\ 2.17$$

(where Chirp\_Sl be the selected chirp slope)

The 20Hz ocean altimeter range corrected for the COG motion and the Doppler effects (Range\_Ocean in metres) is computed by:

$$Range\_Ocean = Range + Doppler\_Comp\_Update + \frac{Light\_Vel}{2} * Epoch \quad eq\ 2.18$$

Where the updated Ku-band and S-band Doppler compensations (Doppler\_Comp\_Update\_Ku, Doppler\_Comp\_Update\_S) are computed from the altitude rate (Sat\_Alt\_Rate(i) in m/s), by:

$$Doppler\_Comp\_Update = - \frac{Light\_Vel * 10^{-3}}{Wavelength * Chirp\_Sl} * Sat\_Alt\_Rate \quad eq\ 2.19$$

Where:

- Wavelength (10-6 m) is the radar wavelength (RA-2 instrumental characterisation data), to be selected according to the processed band (Ku or S) and the operating RF subsystem (flag RV\_RFSS\_Def)
- Chirp\_Sl (kHz/10-6 s) is the chirp slope (RA-2 instrumental characterisation data: effective value (signed)), to be selected according to the processed band (Ku or S), the emitted bandwidth in Ku band (flag Chirp\_Id) and the operating RF subsystem (flag RV\_RFSS\_Def).
- 

Backscatter coefficient:

The 20Hz ocean backscatter coefficient (Sigma0\_Ocean in dB) is computed by:

If

$$Fu > 0 \quad eq\ 2.20$$

then:

$$\sigma_{0\_Ocean} = \sigma_{0\_Scale} + 10 * \log_{10}(P_u) \quad \text{eq 2.21}$$

Where  $\sigma_{0\_scale}$  is the scaling factor for  $\sigma_0$  evaluation (dB).

•  
Significant waveheight:

the significant waveheight ( $SWH\_Ocean$  in metres) is computed from the 1Hz  $\sigma_{0C}$  by:

If

$$\sigma_{0C\_Ocean}^2 \leq PTR\_Width^2 \quad \text{eq 2.22}$$

then

$$SWH\_Ocean = 0 \quad \text{eq 2.23}$$

Else:

$$SWH\_Ocean = 2 * \text{Light\_Velocity} * \sqrt{\sigma_{0C\_Ocean}^2 - PTR\_Width^2} \quad \text{eq 2.24}$$

Where  $PTR\_Width$  is the Point Target Response width fixed to  $0.53 * FFT\_Step$

## Applicability

- The ocean retracking algorithm is performed for FDGDR, IGDR and GDR product.
- The ocean retracking algorithm is performed continuously whatever the surface type is. Nevertheless, it is optimized for ocean surfaces.

## Accuracy

TBD

## References

Ref 2.1



"RA-2 retracking comparisons over ocean surface by CLS", CLS.OC/NT/95.028, Issue 3.1

#### Ref 2.2

Numerical Recipes : The Art of Scientific Computing in C (Edition 2). William H. Press, Brian P. Flannery, Saul A. Teukolsky, William T. Vetterling

#### Ref 2.3

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

### 2.7.1.2 Ice2 retracking algorithm

The ice2 retracking algorithm is performed on the Ku and on the S waveforms. The only difference in the retracking of Ku and S waveforms is the processed data (waveform, processing and instrumental parameters), while the processing is the same

The ice2 retracking algorithm is an adaptation to the ENVISAT RA-2 background, of the algorithm designed by LEGOS to process ERS data over continental ice sheets [Ref. \[2.4\]](#).

The aim of the ice2 retracking algorithm is to make the measured waveform coincide with a return power model, according to Least Square estimators. The expression of the model versus time (t), is derived from Brown's model [Ref. \[2.5\]](#)

$$V_m(t) = \frac{P_u}{2} \cdot \left[ 1 + \operatorname{erf} \left( \frac{t - \tau}{\sigma_L} \right) \right] \cdot \exp \left[ \frac{t - \tau}{\sigma_L} \right] + P_n \quad \text{eq 2.25}$$

(with :

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

eq 2.26

where the parameters to be estimated are :

$\tau$  : the epoch

$\sigma_L$  : the width of the leading edge

$P_u$  : the amplitude which is related to the backscatter coefficient ( $\sigma_0$ )

$s_T$  : the slope of the logarithm of the waveform at the trailing edge

$P_n$  : the thermal noise level (to be removed from the waveform samples)

Other parameters are also estimated:

The mean amplitude or "mean power" ( $P_t$ ) of the waveform which 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. This parameter is related to the ice 2 leading edge backscatter coefficient.

The slope of the first part of the logarithm of the trailing edge ( $s_{T1}$ ) and the slope of the second part of the logarithm of the trailing edge ( $s_{T2}$ ). The slope is estimated by linear regression of the logarithm of the normalised 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.

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

$$\text{Square\_Off\_Nadir} = \frac{1}{2} \times \frac{1 + \frac{S_{Tlm}}{\text{Alpha}}}{1 + \frac{2}{\text{Gamma}}} \quad \text{eq 2.27}$$

where Gamma is computed from the antenna beam and where Alpha is computed from the altitude, the earth radius, the light velocity and Gamma

Computation of the physical parameters

- Altimeter range :

The ice2 altimeter range corrected for the COG motion and the Doppler effects (Range\_Ice2 in metres) is computed by:

$$\text{Range\_Ice2} = \text{Range} + \text{Doppler\_Comp\_Update} + \frac{\text{Light\_Vel}}{2} * \text{Epoch\_Ice2} \quad \text{eq 2.28}$$

Where the tracker altimeter range, Range, is already described in the Ocean retracking algorithm paragraph.

- Backscatter coefficients :

The ice2 leading edge backscatter coefficient (Sigma0\_Le\_Ice2 in dB) related to the amplitude of the waveform fitted at the leading edge by using the Erf function is computed by:

If

$$Pu > 0 \quad \text{eq 2.29}$$

then:

$$\text{Sigma0\_Le\_Ice2} = \text{Sigma0\_Scale} + 10 * \log_{10}(Pu) \quad \text{eq 2.30}$$

The ice2 backscatter coefficient (Sigma0\_Ice2 in dB) related to the integrated signal over the waveform is computed by:

If

$$P_t > 0$$

eq 2.31

then:

$$\sigma_{Ice2} = \sigma_{Scale} + 10 * \log_{10}(P_t)$$

eq 2.32

## Applicability

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

## Accuracy

TBD.

## References

Ref 2.4

B. Legresy : "Etude du retracking des formes d'ondes altimétriques au dessus des calottes polaires". CNES report CT/ED/TU/UD/96.188, CNES contract 856/2/95/CNES/0060, 1995.

Ref 2.5

G.S. Brown : "The Average Impulse Response of a Rough Surface and its Applications". IEEE Trans. on Antennas and Propagation, Vol. AP-25, Jan. 1977

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### 2.7.1.3 Level 2 Ice Algorithms : General

A sub-set of the level 2 processing is concerned with improving the accuracy of measurements over non-ocean surfaces.

The ICE1 Retracking algorithm is a range estimation technique suitable for echoes returned from non-ocean surfaces. The Sea Ice Retracking algorithm is the optimal method to apply to echoes from areas of sea ice.

### 2.7.1.4 Level 2 Ice Algorithms : Retracking

**Physical Justification :** Over topographic surfaces, a radar altimeter on-board tracking system is unable to maintain the echo waveform at the nominal tracking position in the filter bank, due to rapid range variation. This results in an error in the telemetered range known as tracker offset. Retracking is a term used to describe a group of non-linear ground processing estimation techniques which attempt to determine the tracker offset from the telemetered echoes, and thereby estimate the range to the point of closest approach on the surface. Peaky echoes from sea ice cause range tracking jitter, which also results in tracker offsets.

The Ku and S band echo waveform pairs are examined for quality prior to elevation retrieval. The waveform pair is parameterised and the parameters are compared with thresholds. Flags are set up to indicate data quality in the output. This step is referred to as pre-processing.

There are two independent retracking algorithms. The first is the Offset Centre-of-Gravity (OCOG) retracker, intended for data from topographic surfaces. The waveform pair is parameterised using the OCOG scheme. From the parameterisation, a tracker offset is calculated. Also an estimate of the backscatter is made from the power in the filter bank.

The second retracker is a threshold retracker intended for use with data from sea ice. From the parameterisation, a tracker offset is calculated. Again, an estimate of the backscatter is made from the power in the filter bank. Although the given algorithm is general, only the Ku-band calculations are done for sea ice.

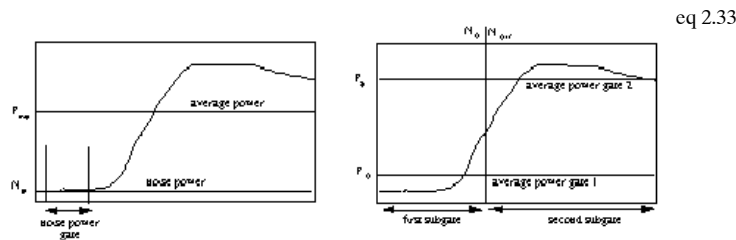
Note that for the RA2 instrument the tracker offset is always measured from the centre of the range window as this point corresponds to the telemetered time delay as given in fields 20 and 21 of the L1b product. The nominal tracking position ( $T_p$ ) is however variable and derived from field 43 in the L1b product.

### 2.7.1.4.1 Pre-processing

Description: Preprocessing attempts to determine if the received echo has a shape sufficiently recognisable that an elevation may be determined from it. If the instrument is not tracking, the outputs are defaulted, and the "Waveform OK" flags are set to bad. Several tests are performed for the echo at each frequency:

i) the noise power in the waveforms is determined. This is done by averaging the power in a set of range filters in the early part the waveforms. With echo waveforms from non-ocean surfaces, these power values may be contaminated by the surface return, and so thresholding is used in the next step to reject waveforms so contaminated, and for other reasons.

ii) the absolute average power of the echo is determined. If this power is smaller than a multiple of the noise power, the echo is regarded as not valid.



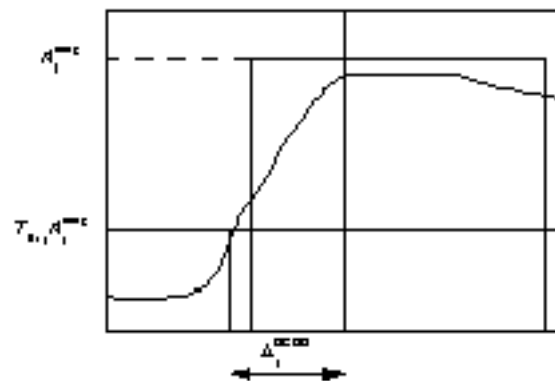
### 2.7.1.4.2 OCOG Retracking

Description: In this algorithm, the Offset Centre of Gravity waveform parameterisation is applied to the waveform pair. From this parameterisation, a tracking offset and backscatter estimate are determined. Tests are made on the extent of the tracking offset, and extreme values are flagged as retracking failures.

The OCOG waveform amplitude is determined from the waveform samples thus:

$$A_j^{ocog} = \sqrt{\frac{\sum_{i=N_{start}}^{N_{end}} \Phi_j^4(i)}{\sum_{i=N_{start}}^{N_{end}} \Phi_j^2(i)}} \quad \text{eq 2.34}$$

and the tracking offset is determined by finding the point on the waveform (by interpolation) where the waveform amplitude exceeds a threshold determined from the OCOG amplitude. A tracking offset is determined for both Ku and S band. The range must also be corrected for the Centre Of Gravity (COG) offset, which is the vertical distance from the satellite centre of mass to the RA antenna, as this correction factor is not available in the L2 product.



eq 2.35

## The OCOG Retracking Algorithm

The retracker offset and COG offset are added to the telemetered range for output thus:

$$l_j^{ocog} = c t / 2 + \Delta_j^{ocog} + d^{cog} \quad (\text{metres}) \quad \text{eq 2.36}$$

The offset itself can be recovered by subtracting the telemetered range and the COG correction. If the offset is outside a predetermined range, the retracking is deemed to have failed, and the corresponding bit in the ice1 retracking quality flag (L2 fields 134 & 135) is set to true (1).

The backscatter ( $\sigma_0$ ) is estimated using the instrument link budget, which is precalculated in the level 1b parameter  $K_{cal}$  (Fields 25 and 26), as follows:

$$\sigma_0^{deg} = K_{cal} + 10 \log_{10} A_j^{deg} \quad (dB) \quad \text{eq 2.37}$$

Accuracy: The waveform samples are quantised in FFT power units. It is very difficult to predict the extrema of the actual range of values that will be present in the filter bank. However the filters are unsigned short integers. This means that potentially at least, the accumulated squares and fourth powers can get extremely large,  $128 \times 2^{31}$  &  $128 \times 2^{64}$  respectively for Ku band. Hence care must be taken to prevent wraparound, and the calculation is best split up to avoid significance loss even in double precision (a brutal approach is to use quadruple precision). The tracker offset precision must be preserved to its theoretical maximum (i.e. consistent with the on board tracking precision) of 1/256 of a filter.

#### 2.7.1.4.3 Sea-Ice Retracking

Description: In this algorithm, waveform parameterisation based on peak threshold retracking is applied to the Ku-band waveform only. From this parameterisation, a tracking offset and backscatter estimate are determined. Tests are made on the extent of the tracking offset, and extreme values are flagged as retracking failures.

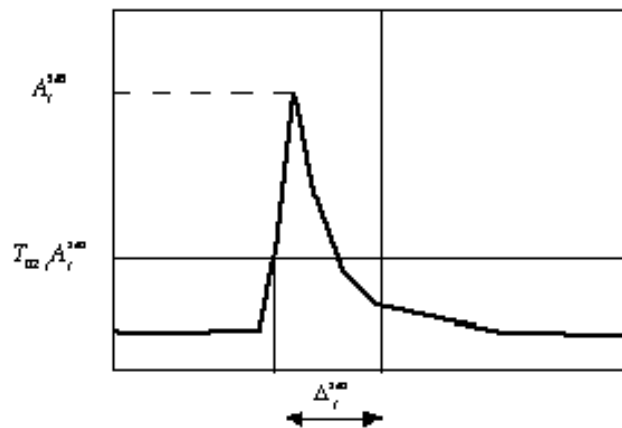
The sea-ice waveform amplitude is determined by finding the maximum value of the waveform samples thus:

$$A_{Ku}^{sm} = \max(\Phi_{Ku}(i)) \quad \text{eq 2.38}$$



and the tracking offset is determined by finding the point on the waveform (by interpolation) where the waveform amplitude exceeds a threshold determined from the above sea-ice amplitude. A tracking offset is determined for Ku band only. The Centre Of Gravity offset correction must be included in the range measurement as the correction is not available separately in the L2 product

eq 2.39



## The Sea-ice Retracking Algorithm

The retracker offset and COG offset are added to the telemetered range for output thus:

$$l_{Ku}^{Seake} = ct/2 + \Delta_{Ku}^{Seake} + d^{cog} \text{ (metres)} \quad \text{eq 2.40}$$

The offset itself can be recovered by subtracting the telemetered range. If the offset is outside a predetermined range, the retracking is deemed to have failed, and the corresponding bit in the Sea-ice retracking quality flag (L2 field 138) is set to true (1).

The backscatter is estimated using the instrument link budget, precomputed in the Level 1b

parameter  $K_{rainKu}$  (Field 25), as follows:

$$\sigma_{SeaKuKu}^0 = K_{rainKu} + 10 \log_{10} A_{Ku}^{ocog} \quad (dB) \quad \text{eq 2.41}$$

Accuracy: The waveform samples are quantised in FFT power units. It is very difficult to predict the extrema of the actual range of values that will be present in the filter bank. However the filter values are sourced as unsigned short integers. The tracker offset precision must be preserved to its theoretical maximum (i.e. consistent with the on board tracking precision) of 1/256 of a filter.

### 2.7.1.5 Level 2 Ice Algorithms : Slope Correction

Physical Justification: The Altimeter antenna boresite is pointed at Nadir and the antenna has a field of view of about 1.3 degrees (half power). The first part of the reflected echo will come from that part of the surface within the field of view, that is closest to the satellite. Over flat surfaces the closest point on the surface is at Nadir but over sloping terrain that will not be the case. When the echo waveform is retracked the resulting range measurement is a slant-range to a point offset from Nadir. To use this measurement it must be corrected for the slant and re-located to the point of first return offset from Nadir.

The correction is performed by using models of the surface slope which enable prediction of the direction of the point of first return for any given satellite location. Initially 2 models are applied: one for Greenland and one for Antarctica.

The algorithm is complex and performed in several steps:

- A co-ordinate transformation to a hemispherical Cartesian frame 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. The transformation maps any function defined in the conventional altimetric (geodetic ellipsoidal) co-ordinate system onto a plane. This is accomplished via a pair of transformations which implement the Lambert equal-area map projection, familiar from cartography.

- A check is performed to determine if a slope model is present for the point of interest. If a model is found, it is used to determine from which direction (in the local co-ordinate frame) the returned echo power came. If no slope model is found, the nadir direction is used.
- The slope-corrected elevation above the ellipsoid is determined from the OCOG retracked range and the echo direction by evaluating some simple expressions. Note that normally one would not compute an elevation at Level 2, owing to the need to correct the range for propagation delays etc. However in this case, the range error due to the atmosphere etc does not disturb the elevation position (or rather the disturbances are insignificant), and the elevation may be corrected a posteriori. Users must be careful to apply the range (elevation) correction in the correct sense however (e.g. if a correction is to be added to the range measurement it is subtracted from an elevation measurement).

### 2.7.1.5.1 Co-ordinate Conversion

Description: This algorithm determines the location of the spacecraft in a hemispherical Cartesian co-ordinate frame. The first step is a straight-forward calculation of the meridional radius of curvature of the ellipsoid using the standard expression:

eq 2.42

$$\rho_{\theta} = \frac{a_e(1 - e^2)}{(1 - e^2 \sin^2 \theta_0)^{3/2}} \text{ (metres)}$$

This quantity is then used in the equations for the Lambert equal-area projection:

eq 2.43

$$X = 2\rho_{\theta} \cos \lambda_0 \sin((\pi/2 - |\theta_0|)/2) \text{ (metres)}$$

$$Y = 2\rho_{\theta} \sin \lambda_0 \sin((\pi/2 - |\theta_0|)/2) \text{ (metres)}$$

eq 2.44

Note that this projection cannot distinguish the hemisphere of the earth under consideration. Therefore a 'hemisphere flag' is used in the slope model files, so that files from the wrong hemisphere cannot be accessed.

## Accuracy

Some quantities in these expressions are numerically small (e.g. eccentricity), and some are large (e.g. semi-major axis). The latitude is derived from the level 1b quantity which is quantised to microdegrees. It is converted to double precision radians before use. The calculation is all done in double precision arithmetic to preserve accuracy which is better than 1 centimetre on the above quantities.

### 2.7.1.5.2 Echo Direction

Description: This algorithm determines the direction from which the power in the leading edge of the echo came, by reference to a surface slopes model.

We determine the echo direction  $(\varphi, \theta)$  in a local Cartesian co-ordinate frame (x,y) with its origin at the sub-satellite point on the ellipsoid. This frame is the tangent plane to the ellipsoid, and provides a local approximation to the ellipsoid at the point in question.

We calculate the meridional radius of curvature of the ellipsoid, and the radius of the corresponding parallel circle at the geodetic latitude in question:

$$\rho_{\theta} = \frac{a_e(1 - e^2)}{(1 - e^2 \sin^2 \theta)^{3/2}} \quad (\text{metres}) \quad \text{eq 2.45}$$

$$\rho_{\lambda} = \frac{a_e \cos \theta}{\sqrt{1 - e^2 \sin^2 \theta}} \quad (\text{metres}) \quad \text{eq 2.46}$$

First, the spacecraft position (in global hemispherical Cartesian co-ordinates - see [Co-ordinate Conversion 2.7.1.5.1.](#) ) is used to determine whether the overflown surface has an associated slope model. If not, the nadir direction is assumed, and the elevation and azimuth representing the direction are both set to zero.

If a slope model is present, the processing proceeds. The slope model is interpolated to get the X and Y components of slope as follows:

$$s_x(X,Y) = f(p,q,n,m,s_x[]) \quad \text{eq 2.47}$$

$$s_y(X,Y) = f(p,q,n,m,s_y[]) \quad \text{eq 2.48}$$

Where f is an interpolation formula (six-point bivariate interpolator - which is exact if second order derivatives are zero or negligible) , with:

$$n = \text{Inf}\left(\frac{X - X_0[i]}{\Delta_m[i]}\right) \quad \text{eq 2.49}$$

;

$$m = \text{Inf}\left(\frac{Y - Y_0[i]}{\Delta_m[i]}\right) \quad \text{eq 2.50}$$

where

$$\Delta_m[i] \quad \text{eq 2.51}$$

is the resolution of the ith slope model, and

$$X_0[i] \quad \text{eq 2.52}$$

and

$$Y_0[i] \quad \text{eq 2.53}$$

are the co-ordinates of a slope value within the model. The parameter p,q are given by:

$$p = (X - X_0[i] - n\Delta_m[i]) / \Delta_m[i] \quad \text{eq 2.54}$$

$$q = (Y - Y_0[i] - m\Delta_m[i]) / \Delta_m[i] \quad \text{eq 2.55}$$

The next stage involves the computation of a set of partial derivatives of X and Y with respect to latitude, and also longitude, so that the quantities calculated in the global hemispherical Cartesian frame (X,Y ) may be related to the local Cartesian frame (x,y ).

$$\frac{\partial X}{\partial \theta}, \frac{\partial Y}{\partial \theta}, \frac{\partial X}{\partial \lambda}, \frac{\partial Y}{\partial \lambda} \quad \text{eq 2.56}$$

The interpolated slope values (in X,Y ) and the set of partial derivatives are then used to compute the range derivatives in local co-ordinates (x,y ):

$$\left. \frac{\partial l}{\partial x} \right|_{y=0} \equiv s_x = \frac{1}{(\rho_{\theta_0} + h)} \left[ s_x(X,Y) \frac{\partial X}{\partial \theta} + s_y(X,Y) \frac{\partial Y}{\partial \theta} \right] \quad \text{eq 2.57}$$

eq 2.58

$$\left. \frac{\partial l}{\partial y} \right|_{x=0} \equiv s_y = \frac{1}{(\rho_{\lambda_0} + h \cos \theta_0)} \left[ s_x(X,Y) \frac{\partial X}{\partial \lambda} + s_y(X,Y) \frac{\partial Y}{\partial \lambda} \right]$$

The last step of the algorithm involves the calculation of the echo direction angles in local co-ordinates, thus:

$$\varphi = \text{atan}(s_y / s_x) \equiv \text{atan}\left(\frac{\partial l}{\partial y} / \frac{\partial l}{\partial x}\right) \bigg|_{\substack{x=0 \\ y=0}} \quad (\text{radians}) \quad \text{eq 2.59}$$

$$\eta = \text{asin}\sqrt{s_x^2 + s_y^2} \equiv \text{asin}\sqrt{\left(\frac{\partial l}{\partial x}\right)^2 + \left(\frac{\partial l}{\partial y}\right)^2} \bigg|_{\substack{x=0 \\ y=0}} \quad (\text{radians}) \quad \text{eq 2.60}$$

## Accuracy

The ellipsoid geometry calculations mix large numbers such as the semi-major/minor axes (a, b ) with small numbers such as eccentricity (e ), and calculations are subject to loss of accuracy. Double precision arithmetic is used throughout to give accuracy to better than 1 mm.

Slopes of 1 in 10,000 lead to slope corrections at the ~ 5 millimetre level, and so the slopes in the models are safely represented as single-precision, 32-bit floating-point numbers, which translates to approximately 8 decimal significant figures. Slopes of greater than a few degrees will not be tracked at high precision (if at all) by the RA-2 , and so precision in areas of high surface slope is less important.

### 2.7.1.5.3 Elevation Calculation

Description: In this stage, the OCOG (Ku-band) retracked range (see [OCOG Retracking 2.7.1.1](#) ) and the echo direction are used to calculate the slope-corrected elevation in the geodetic (i.e. altimetric) ellipsoidal reference frame. We must transform the local co-ordinates of the echo direction using the geometry of the ellipsoid. We calculate the radius of curvature of the local ellipse in the direction of the echo azimuth using:

$$\rho = \frac{\rho_{\theta_0} \rho_{\lambda_0}}{\rho_{\theta_0} \cos \theta_0 \sin^2 \varphi + \rho_{\lambda_0} \cos^2 \varphi} \quad \text{eq 2.61}$$

We then evaluate 3 expressions to determine the slope-corrected latitude, longitude and elevation of the echoing point, in global geodetic ellipsoidal co-ordinates, i.e. the altimeter reference frame:

$$z_e = h - l_1^{\text{ocog}} \cos \eta + \frac{(l_1^{\text{ocog}} \sin \eta)^2}{2\rho} \quad (\text{metres}) \quad \text{eq 2.62}$$

$$\theta_c = \theta_0 + \frac{l_1^{\text{ocog}} \sin \eta \cos \varphi}{\rho_{\theta_0}} \quad (\text{radians}) \quad \text{eq 2.63}$$

$$\lambda_c = \lambda_0 + \frac{l_1^{\text{ocog}} \sin \eta \sin \varphi}{\rho_{\lambda_0}} \quad (\text{radians}) \quad \text{eq 2.64}$$

## Accuracy

It is unusual to calculate an elevation at Level 2, as this is normally left up to the user, as he or she will correct the range with a mixture of atmospheric and geophysical corrections appropriate to an application, before determining the elevation. However the transformation equations in this algorithm are linear to a good approximation with respect to constant offsets applied to range. Within the range of correction values likely to be encountered, the position is unaffected to better than microdegree accuracy, and the range corrections (applied in the correct sense!) can be applied to elevation a posteriori, with error less than 1 mm.



### 2.7.1.6 Level 2 Ice Algorithms : Delta Doppler Correction

**Physical Justification:** It is well known that there is a contribution to range arising from the Doppler effect due to the vertical component of spacecraft orbital velocity. However, over sloping surfaces, there is an additional contribution to range due to the Doppler effect, that arises because the echo direction (line of sight from the scattering facet) is no longer to the nadir of the spacecraft in general. This has the effect of adding in a component of the spacecraft forward orbital velocity in addition to the more generally appreciated vertical component. The 'conventional' vertical-component Doppler correction may be determined using a scalar calculation by differencing the supplied vertical orbit altitude. However for the generalised Doppler, one must perform a full vector calculation using the spacecraft velocity and position, and the echo direction. The position and velocity vectors are determined from the available orbit information supplied in the Level 1b product.

We subtract the vertical-component Doppler correction from our general Doppler correction to arrive at a delta-Doppler correction due to slope.

**Description:** This algorithm determines the additional Doppler correction to range, due to the effects of sloping surfaces. This is known as the delta-Doppler range correction.

Non-tracking data are not a problem, as the orbit information is always included, but as no elevation data are available the delta-Doppler correction is set to zero.

Firstly the spacecraft velocity vector is found from two successive 18 Hz data blocks. Hence the algorithm is initialised at the start of processing, and before every data gap.

At several points in the processing vectors in the spacecraft frame, i.e. in geodetic ellipsoidal co-ordinates, are converted to Cartesian co-ordinates, in order to manipulate vector components:

$$(r, \theta, \lambda) \rightarrow (X, Y, Z) \quad \text{eq 2.65}$$

We first determine the spacecraft velocity vector by differentiation of the spacecraft position vector. This requires two position determinations at altimetric sounding  $N$  and  $N+1$  (ie the current record and the next record). From the orbit parameters we obtain altitude, latitude and longitude, and transform these to Cartesian co-ordinates:

$$(h_N, \theta_N, \lambda_N) \rightarrow (X_N, Y_N, Z_N) \quad \text{eq 2.66}$$

$$(h_{N+1}, \theta_{N+1}, \lambda_{N+1}) \rightarrow (X_{N+1}, Y_{N+1}, Z_{N+1}) \quad \text{eq 2.67}$$

We then determine the velocity by differentiation, e.g. for the X component we have:

$$V_x = \frac{(X_{N+1} - X_N)}{\text{time\_interval}} \quad \text{m/s} \quad \text{eq 2.68}$$

Next we determine the Cartesian components of the position vector of the echoing point, determined in the slope correction algorithm:

$$(z_e, \theta_e, \lambda_e) \rightarrow (X_e, Y_e, Z_e) \quad \text{eq 2.69}$$

We determine the line of sight vector from the echoing point to the altimeter, using vector arithmetic with the spacecraft position vector, and the position vector of the echoing point. For e.g. the X component we have:

$$l_x = X_N - X_e \quad \text{eq 2.70}$$

The driving parameter for the Doppler range effect is the velocity component of the satellite in the line of sight of the observer. This is obtained by forming a scalar product of the spacecraft velocity vector with the unit line-of-sight vector thus:

$$V_s = V_N \cdot \hat{l}, \quad \hat{l} = \frac{1}{\sqrt{l_x^2 + l_y^2 + l_z^2}} \quad \text{eq 2.71}$$

$$V_s = V_x \hat{l}_x + V_y \hat{l}_y + V_z \hat{l}_z \quad \text{eq 2.72}$$

The Doppler range correction (Ku and S band) for the altimeter may now be found in the normal way from:

$$D_j^{Dop} = \frac{f_{cj} V_s}{S_{cj}} \quad (\text{metres}) \quad \text{eq 2.73}$$

where

$$f_{cj} = \frac{c}{\lambda_{cj}} \quad (\text{Hz}) \quad \text{eq 2.74}$$

In order to convert this to a delta-Doppler range correction, the conventional flat-surface range correction from the Level 1b product is required. (

$$R_j^{flat} \quad \text{eq 2.75}$$

comes from the L1b data in the NRT processing but is the value recomputed at Level 2 in the off-line processing.)

$$\delta_j^{Doppler} = D_j^{slope} - D_j^{flat} \quad (\text{metres}) \quad \text{eq 2.76}$$

## Accuracy

The magnitude of the Doppler range correction over flat surfaces is discussed by Cudlip et al [S7]. We do not expect the altitude rate ever to be greater than 100ms<sup>-1</sup>. At 13.58 GHz, the Doppler range correction will not be greater than approximately ±8.4 cm for a 320 MHz chirp, .34 m for a 80 MHz chirp, and 1.36 m for a 20 MHz chirp. At S-band at 3.2 GHz, the correction will not be greater than 4 cm.

However over sloping terrain there is an additional contribution, as discussed above, due to the change in line-of-sight to the spacecraft from the echoing point. From the geometry of the situation, this additional contribution could be very large, but in practice, the antenna gain function reduces the returned power effectively to zero at large displacements from nadir. The footprint radius at Ku-band is approximately 10 km, and at S-band this increases to approximately 60 km.

Thus at Ku-band, the maximum possible additional contribution (as output as delta Doppler at Level 2) is approximately: a) 320 MHz, ±10 cm, b) 80 MHz, ±40 cm, and c) 20 MHz, ±1.6 m. At S-band (3.2 GHz) at 160 MHz it is no greater than ±18 cm. The correction is thus of the same order of magnitude as the altitude rate correction, but note that the sign may be opposite, and may in fact cancel the altitude rate contribution. Hence the maximum total Doppler range correction will be approximately ±20cm, ±80cm, or ±3.2m, corresponding to 320, 80 and 20 Mhz chirps respectively.

The accuracy of the correction is dominated by the accuracy of the slope model, which is variable. The orbit accuracy is a factor, but is negligible compared to that of the slope model.

Ref 2.6

RA-2 Ice Algorithms: Retracker Trade-Off Study, MSSSL, UCL-TN-0002 v 1a, 17/04/96

Ref 2.7

RA-2 Ice Algorithms: Algorithm Model Description v 1, 13/6/96

### 2.7.1.7 Doppler correction

The vertical (radial) velocity of the satellite causes a frequency Doppler shift which affects the time delay measurement, thus the range. For each elementary measurement, the Doppler correction  $\delta h$  (in m), to be added on the altimeter range, is computed for Ku and S bands, from the altitude rate, by :

$$\delta h_{\text{Doppler}} = - \frac{\text{Light\_Vel} \cdot 10^{-3}}{\text{Wavelength} \cdot \text{Chirp\_Sl}} \cdot \text{Sat\_Alt\_Rate} \quad \text{eq 2.77}$$

where:

Sat\_Alt\_Rate (m/s) is the satellite altitude rate computed in the orbit interpolation module for each elementary measurement.

Wavelength (10<sup>-6</sup> m) is the radar wavelength (provided by the RA-2 instrumental characterisation file), to be selected according to the processed band (Ku or S) and the operating RF subsystem (flag RV\_RFSS\_Def)

Chirp\_Sl (kHz/10<sup>-6</sup> s) is the chirp slope (provided by the RA-2 instrumental characterisation file: effective value (positive for Ku-Band and negative for S-Band), to be selected according to the processed band (Ku or S), the emitted bandwidth in Ku band (flag Chirp\_Id) and the operating RF subsystem (flag RV\_RFSS\_Def).

Light\_Vel (m/s) is the light velocity (provided by the constant file)

and Sat\_Alt\_Rate(i) is the elementary value of the altitude rate obtained from the orbit CFI interpolator routine (if a restituted OSV is available for the Level 2 processing).

If no restituted OSV file is available, the Doppler correction is not calculated at Level 2 but just copied from the Level 1b RA2 MDSRs.

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### 2.7.1.8 ECMWF model derived wet and dry tropospheric corrections, u and v components of the wind vector, and surface pressure

The input ECMWF meteorological fields used to calculate these parameters are different for the near real time products (FDGDR and FDMAR) and for the off line products (IGDR, IMAR, GDR and SGDR).

For the near real time, the meteorological fields used are the following: U and V components of the 10 meter wind vector, surface pressure, relative humidity profile, geopotential profile and temperature profile. These six parameters are provided on a regular 1 X 1 degree grid. From the relative humidity, geopotential and temperature profiles, the wet tropospheric correction field is computed, and from the surface pressure the dry tropospheric correction is computed.

For the off line, the meteorological fields used are the following: U and V components of the 10 meter wind vector, dry tropospheric correction, wet tropospheric correction, surface pressure. These five parameters are provided on the so-called gaussian grid (quasi regular in latitude, nonregular in longitude). This grid is the internal grid of the ECMWF model used for the model run. The wet and dry tropospheric corrections are computed by the French met office from the ECMWF humidity and temperature profiles.

The SWT 2004 recommendation was to use the new tide model FES2004, which already includes the S1 and S2 waves. Then, in case of offline processing, the dry tropospheric correction is now derived from the surface pressure filtered and corrected from the S1 and S2 waves.

In both cases, the wet and dry tropospheric corrections, the two components U and V of the 10 meter model wind vector, the 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. 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, whatever their altitude is.

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## Applicability

- These parameters are computed for FDGDR, IGDR and GDR product. For FDGDR, predicted meteorological fields are used whereas for the IGDR and GDR the analysed fields are used.
- These parameters are computed for all surface types (over land and ocean).

## Accuracy

Generally speaking, analysed fields are more accurate than predicted fields. The error introduced by space and time interpolation under the satellite track is small compared with the intrinsic accuracy of the meteorological fields.

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 accuracy of the dry tropospheric correction primarily depends on the accuracy of the surface pressure. 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. For land surfaces, additional error is induced by inaccurate knowledge of the altitude of the grid points and of the altimeter measurements.

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.

## Reference

Ref 2.8

Saastamoinen, J., 1972: Atmospheric correction for the troposphere and stratosphere in radio ranging of satellites, Geophys. Monogr., 15, American Geophysical Union, Washington D.C.

### 2.7.1.9 Inverted barometer correction algorithm

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

$$H\_Baro = -b \ [Psurf- Pbar] \quad \text{eq 2.78}$$

Psurf is the surface atmospheric pressure at the location and time of the altimeter measurement, and Pbar is the mean atmospheric pressure over the global ocean at the location and time of the altimeter measurement. Psurf is computed by bilinear interpolation in space and linear interpolation in time from the surface pressure field before and after the altimeter measurement. Pbar is computed by linear interpolation in time from the mean atmospheric pressure before and after the altimeter measurement.

#### Important notice:

Prior to Psurf and Pbar computation at the time and location of the altimeter measurement, the surface pressure fields are filtered for S1 and S2 (diurnal and semi-diurnal) atmospheric tides. Two main reasons have governed this choice:

- S1 and S2 signals are poorly retrieved in 6-hourly pressure fields (S2 is sampled at its exact Nyquist frequency).
- Radiational and gravitational tides are undistinguishable when computing an ocean tide model. For instance, previous ocean tide models (GOT99, FES2002) already included the full S2 tide effect.

Thus the following strategy has been decided, as proposed by Ponte and Ray (2002):

- Let the full S1 and S2 signals (both radiational and gravitational effects) in the ocean tide models
- Remove the radiational part from the surface pressure fields (otherwise, it would be applied twice).

#### S1 and S2 filtering:

A climatology (ancillary data files) of S1 and S2 has been built from a long series of surface pressure fields. It is then simply subtracted from the input pressure fields to obtain an output



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pressure field without S1 and S2 effects.

## Applicability

- The inverted barometer effect is computed for FDGDR, IGDR and GDR product
- The computation of the inverted barometer effect is performed continuously for all surface types (over land and ocean), although it is relevant to ocean surfaces only

## Accuracy

Extensive modeling work by Ponte et al. [Ref. \[2.9\]](#) 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,  $P_{bar}$ . As stated by Dorandeu and Le Traon [Ref. \[2.10\]](#), 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.

## References

### Ref 2.9

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

### Ref 2.10

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.

### Ref 2.11

Ponte, R.M. and Ray, R.D., "Atmospheric pressure corrections in geodesy and oceanography: A strategy for handling air tides", *Geophys. Res. Letters*, 29 (24), 2002.

## Ref 2.12

Boone C., " Etudes SALP pour GDR 2i me generation Jason. Partie 1 : Signaux diurne et semi-diurne de pression ", CLS-DOS-NT-03.909, CLS, Ramonville Saint-Agne, 2003.

## Ref 2.13

Dorandeu J., "Impact of S1 and S2 atmospheric signals on T/P and Jason SSH variability", minutes of SWT meeting at Arles, Nov.18-21, 2003.

## Ref 2.14

Dorandeu J., "EnviSat data quality: Envisat GDR evolutions, Third QWG meeting, Marsh 2004.

### 2.7.1.10 Combined atmospheric correction from MOG2D and IB

High frequency atmospheric signals are badly retrieved by altimeters, due to poor time sampling. High frequency signals are thus aliased by altimeter measurements and translate into apparently lower frequency signals undistinguishable from other ocean signals of interest. Therefore, it is important to remove these effects.

As a first approximation, the so-called Inverse Barometer correction is conventionally used to correct altimeter data. This simple correction assumes a static ocean response to atmospheric pressure forcing. Neither dynamical effects at high frequency nor wind effects are taken into account in this correction.

In order to take account of dynamical effects and wind forcing, a new correction is computed from the MOG2D (Carrere and Lyard, 2003) barotropic model forced by pressure and wind. Only the high frequency part of these model outputs are retained and combined to the low frequency inverse barometer. This new correction provides a great improvement in terms of ocean variability reduction (Carrere doctoral thesis, 2003)

The difference between this new correction and the Inverse Barometer is computed and set in the GDR product. The users are advised to add this difference to the Inverse Barometer.

## Applicability

- The difference between the new correction and the Inverse Barometer is computed for GDR product
- The computation of the difference between the new correction and the Inverse Barometer is performed continuously for all surface types (over land, ice and ocean). Nevertheless, it is applicable only for ocean surfaces.

## Reference

#### Ref 2.15

Carrère L. and Lyard F., "Modelling the barotropic response of the global ocean to atmospheric wind and pressure forcing - comparisons with observations", GRL, 30(6), pp1275, 2003.

#### Ref 2.16

Carrère L., "Etude et modélisation de la réponse haute fréquence de l'océan global aux forçage météorologiques", Doctoral Thesis, 24 Nov. 2003.

### 2.7.1.11 MWR wet tropospheric correction

The MWR wet tropospheric correction,  $Dh\_RA2$ , is obtained with a neural algorithm. A global and representative database has been built using ECMWF analyses from surface and atmospheric parameters, and simulations of the brightness temperatures and backscattering coefficient in Ku band. Then the architecture of the network (one layer of 8 hidden neurons) and the weights of each neuron are determined to produce the most accurate estimation of the wet tropospheric correction (in mm) from brightness temperatures ( $TB23\_Int$  and  $TB36\_Int$ ) and  $s0\_Ku$ .

Where  $TB23\_Int$  and  $TB36\_Int$  are the 23.8 GHz and 36.5 GHz brightness temperatures (in K) interpolated to RA-2 time tag,  $s0\_Ku$  is the ocean backscatter coefficient for Ku-band (dB).

## Applicability

- The MWR wet tropospheric correction is computed for FDGDR, IGDR and GDR product
- The computation of the MWR wet tropospheric correction is performed continuously for all surface types (over land, ice and ocean). Nevertheless, it is applicable only for ocean surfaces.

## Accuracy

As this algorithm has been formulated over a representative database [RD], a minorant of the error is the rms difference obtained when applying directly the algorithm over the database, i.e. 0.5 cm.

Comparisons between retrievals obtained with the Envisat algorithm applied to ERS2 measurements and radiosounding measurements, indicate an rms difference of 1.5 cm. As this error contains the error on radiosounding measurements, it gives an upper bound of the error for the wet tropospheric correction.

## Reference

Ref 2.17

S. LABROUE and E. OBLIGIS, "Neural network retrieval algorithm for the Envisat/MWR", report CLS/DOS/NT/03.848 of ESA contract 13681/99/NL/GD, January 2003.

### 2.7.1.12 Sea state bias

Sea state bias is the difference between the apparent sea level as "seen" by an altimeter and the actual mean sea level.

The sea state biases for Ku band and S band are computed, in mm, by bilinear interpolation from a table given as function of Ku-band significant wave height and the RA-2 wind speed, (SWH\_Ku and W).

The look up table in Ku band has been derived from ten cycles of ENVISAT data (cycle 17 to 26), using residuals relative to a mean sea surface as proposed by Vandemark et al. [Ref. \[2.18\]](#) and applying the non parametric estimation technique as developed by Gaspar et al. [Ref. \[2.19\]](#), [Ref. \[2.20\]](#). All the details on the data set and the method used for the estimation can be found in the study report [Ref. \[2.21\]](#).

## Applicability

- The sea state bias is computed for FDGDR, IGDR and GDR product
- The computation of the sea state bias is performed continuously for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

## Accuracy

The underlying physics of the sea state bias is not completely understood. Nevertheless, the non parametric estimate is more suitable than a parametric model, since the non parametric SSB reduces the crossover variance with a gain of about 1 cm<sup>2</sup>, compared to a BM3 model fitted on ENVISAT data.

## References

Ref 2.18

Vandemark, D., N. Tran, B. Beckley, B. Chapron and P. Gaspar, Direct estimation of sea state impacts on radar altimeter sea level measurements. Geophysical Research Letters, 29, n 24, 2148, 2002

Ref 2.19

Gaspar, P. and J.P. Florens, Estimation of the sea state bias in radar altimeter measurements of sea level: Results from a new non parametric method. J. Geophys. Res., 103, 15803-15814, 1998

### Ref 2.20

Gaspar, P., S. Labroue, F. Ogor, G. Lafitte, L. Marchal and M. Rafanel, Improving non parametric estimates of the sea state bias in radar altimeter measurements of sea level. JAOT, 19, 1690-1707, 2002.

### Ref 2.21

Labroue S., RA2 Ocean and MWR measurement long term monitoring. Final report for WP3, Task2 SSB estimation for RA2 altimeter, CLS\_DOS-NT-04-284

## 2.7.1.13 RA-2 ionospheric correction

The Ku band and S band sea state bias corrections are first added to the Ku band and S band altimeter ranges to correct them, because sea state bias may be different for the two frequencies. Let RKu and RS be the corresponding corrected values.

The ionospheric corrections Iono\_alt\_Ku and Iono\_alt\_S (in mm) are given for the two frequencies by the following equations :

$$\begin{aligned} \text{Iono\_Alt\_Ku} &= \delta f_{\text{Ku}} \cdot (R_{\text{Ku}} - R_{\text{S}}) \\ \text{Iono\_Alt\_S} &= \delta f_{\text{S}} \cdot (R_{\text{Ku}} - R_{\text{S}}) \end{aligned} \quad \text{eq 2.79}$$

(1)

with:

$$\delta f_{\text{Ku}} = \frac{f_{\text{S}}^3}{f_{\text{Ku}}^3 - f_{\text{S}}^3} \approx 0.0588 \quad \text{eq 2.80}$$

$$\delta f_{\text{S}} = \frac{f_{\text{Ku}}^3}{f_{\text{Ku}}^3 - f_{\text{S}}^3} \approx 10588 \quad \text{eq 2.81}$$

where  $f_{Ku}$  and  $f_S$  are the emitted frequencies (in Hz)

The RA-2 total electron content expressed in 10<sup>-1</sup> TEC units (1 TEC unit = 10<sup>16</sup> e-/m<sup>2</sup>).is given by :

$$TEC_{RA2} = -Iono\_Alt\_Ku * (f_{Ku})^2 / 40250 \quad \text{eq 2.82}$$

## Applicability

- The dual frequency ionospheric correction and the total electron content are computed for FDGDR, IGDR and GDR products.
- The computation of the dual frequency ionospheric correction and the total electron content are performed, continuously for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

## Accuracy

From equation (1) of the mathematical statement, one can derive the standard deviation of Ku band and auxiliary band ionospheric corrections  $\sigma(Iono\_Alt\_Ku)$  and  $\sigma(Iono\_Alt\_Aux)$ :

$$\sigma(Iono\_Alt\_Ku) = \delta f_{Ku} \sqrt{\sigma^2(R_{Ku}) + \sigma^2(R_S)} \quad \text{eq 2.83}$$

$$\sigma(Iono\_Alt\_S) = \delta f_S \sqrt{\sigma^2(R_{Ku}) + \sigma^2(R_S)} \quad \text{eq 2.84}$$

where  $\sigma(RKu)$  and  $\sigma(RS)$  are respectively the 1-Hz range standard deviation for Ku band and auxiliary band.

The table below gives the values of  $\sigma(Iono\_Alt\_Ku)$  and  $\sigma(Iono\_Alt\_S)$ , assuming probable values for Ku band and S band 1-Hz range standard deviations  $\sigma(RKu)$  and  $\sigma(RS)$  as function of waveheight SWH.

Table 2.5

SWH (m)	$\sigma(RKu)$ (cm)	$\sigma(RS)$ (cm)	$\sigma(Iono\_Alt\_Ku)$ (cm)	$\sigma(Iono\_Alt\_S)$ (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 dual frequency TOPEX altimeter, the ionospheric correction for the Ku band is given by equation (8) in Imel's paper [Ref. \[2.22\]](#):

$$\Delta r_{ion} = \delta f_{Ku} [(R_c - b_c) - (R_{Ku} - b_{Ku})] \quad \text{eq 2.85}$$

, with

$$\delta f_{Ku} = \frac{f_c^2}{f_{Ku}^2 - f_c^2} \approx 0.179 \quad \text{eq 2.86}$$

for TOPEX

In the above equation,  $\Delta r_{ion}$  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.

## Reference

Ref 2.22

Imel, D., Evaluation of the TOPEX/POSEIDON dual-frequency ionosphere correction, J. Geophys. Res., 99, 24,895-24,906, 1994

### 2.7.1.14 DORIS ionospheric correction

The ionospheric corrections are obtained (in mm) by using the TEC (Total Electron Content, in e-/m<sup>2</sup>), from DORIS maps, which is interpolated, bilinearly in latitude and longitude, and linearly in time at the altimeter measurement. It is then used in the two following equations to derive the ionospheric corrections (in mm) :

$$\begin{aligned} \text{Iono\_Dor\_Ku} &= -40250. \frac{\text{TEC}_{\text{Doris}}}{f_{\text{Ku}}^2} \\ \text{Iono\_Dor\_S} &= -40250. \frac{\text{TEC}_{\text{Doris}}}{f_{\text{S}}^2} \end{aligned} \quad \text{eq 2.87}$$

where  $f_{\text{Ku}}$  and  $f_{\text{S}}$  are the emitted frequencies (in Hz). This algorithm is relevant only for GDR and IGDR products.

## Applicability

- The Doris ionospheric correction is computed for IGDR and GDR product.
- The computation of the Doris ionospheric correction is performed continuously for



all surface types (over land and ocean).

## 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 .

## Reference

Ref 2.23

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/ESA contract number 11583/95/NL/CN

### 2.7.1.15 BENT model ionospheric correction

The ionospheric corrections are obtained (in mm) by using the first order expansion of the refraction index:

$$\begin{aligned} \text{Iono\_Mod\_Ku} &= -40250. \frac{\text{TEC}_{\text{model}}}{f_{\text{Ku}}^2} \\ \text{Iono\_Mod\_S} &= -40250. \frac{\text{TEC}_{\text{model}}}{f_{\text{S}}^2} \end{aligned}$$

eq 2.88

where  $f_{Ku}$  and  $f_S$  are the emitted frequencies (in Hz), 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 2.7.1.15](#).

### 2.7.1.16 GIM Ionospheric correction

The GIM ionospheric correction is based on Total Electron Content (TEC) grids which are operationally produced by JPL in delayed time (5 days) as well as in near real time (10 hours). The TEC is an integrated content (basically from 0km to >1400km). So an altitude correction factor is used to take account the EnviSat altitude. IRI95 was recommended by Iijima and al, 99 [Ref. \[2.24\]](#). Studies drawn at CLS [Ref. \[2.25\]](#) had demonstrated that GIM correction is an efficient alternative to the dual-frequency ionospheric correction.

## Applicability

- The GIM correction is computed for IGDR and GDR product
- The computation of GIM correction is performed continuously for all surface types (over land, ice and ocean). Nevertheless, it is applicable only for ocean surfaces.

## Reference

### Ref 2.24

Automated daily process for global ionospheric total electron content maps and satellite ocean altimeter ionospheric calibration based on Global Positioning System data B.A Iijima et al Journal of Atmospheric and Solar-Terrestrial Physics 61 (1999) 1205-1218

### Ref 2.25

Jason GIM Ionosphere Correction Study Report, CLS.DOS-NT-04-194

Comparison IRI2001 / IRI95 in altitude correction for GIM based ionospheric corrections on EnviSat CLS.DOS-NT-04-193

### 2.7.1.17 Atmospheric attenuation correction

The Ku and S-band backscatter coefficient two-way MWR atmospheric attenuation ( $Att_{\sigma_{Ku}}$  and  $Att_{\sigma_S}$  in dB) are computed with neural algorithms as a function of  $TB23\_Int$ ,  $TB36\_Int$  and  $\sigma_{Ku}$ .

where  $TB23\_Int$  and  $TB36\_Int$  are the 23.8 GHz and 36.5 GHz brightness temperatures (in K) interpolated to RA-2 time tag,  $\sigma_{Ku}$  is the ocean backscatter coefficient for Ku-band (dB).

---

## Applicability

- The MWR atmospheric attenuation correction is computed for FDGDR, IGDR and GDR product
- The computation of the atmospheric attenuation correction is performed continuously for all surface types (over land, ice and ocean). Nevertheless, it is applicable only for ocean surfaces.

## Accuracy

As this algorithm has been formulated over a representative database [RD], a minorant of the error is the rms difference obtained when applying directly the algorithm over the database:  $2 \cdot 10^{-3}$  dB for the atmospheric attenuation of the S band backscattering coefficient and  $8 \cdot 10^{-3}$  dB for the Ku band backscattering coefficient.

As there are no measurements performed, no upper bound of the errors can be given.

## Reference

Ref 2.26

S. LABROUE and E. OBLIGIS, "Neural network retrieval algorithm for the Envisat/MWR", report CLS/DOS/NT/03.848 of ESA contract n° 13681/99/NL/GD, January 2003.

### 2.7.1.18 Ku-band rain attenuation

The rain attenuation (dB) is calculated using the ocean backscatter coefficient for Ku-band,  $\sigma^0_{\text{Ku}}$  (dB) [Ref. \[2.27\]](#) by :

$$\text{Rain\_Att} = \text{Exp\_Sigma0\_Ku} - \sigma^0_{\text{Ku}} \quad \text{eq 2.89}$$

Where the expected Ku-band backscatter coefficient,  $\text{Exp\_Sigma0\_Ku}$ , is determined by linear interpolation in the input table, as function of the S-band backscatter coefficient.

## Applicability

- The Ku-band rain attenuation is computed for FDGDR, IGDR and GDR product

- The computation of the Ku-band rain attenuation is performed continuously for all surface types (over land and ocean)

## Accuracy

None

## Reference

Ref 2.27

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.

### 2.7.1.19 Squared Off nadir angle of the satellite computed from platform data

The squared off-nadir angle (Off\_Nadir in radians) is derived from the interpolated pitch and roll mispointing angles by :

$$\text{Off\_Nadir} = \left(\frac{\pi}{180}\right)^2 * \left[ \left( \frac{\text{Pitch\_Angle\_Int}}{10^6} \right)^2 + \left( \frac{\text{Roll\_Angle\_Int}}{10^6} \right)^2 \right] \quad \text{eq 2.90}$$

## Applicability

- The platform-derived squared off-nadir angle is computed for FDGDR, IGDR and GDR products.

- The computation of the platform-derived squared off-nadir angle is performed continuously for all surface types.

## Accuracy

At present, an interpolation mechanism is implemented as follows:

The absolute value of the difference between the input averaged L1b time to be processed and the State Vector time is calculated. If two records from the Envisat wide attitude file are found such that they embrace the time difference, the pitch and roll angles from the two records are extracted and used to obtain the interpolated pitch and roll angles.

## Reference

None

### 2.7.1.20 Mean sea surface height

The mean sea surface used is from CLS (Collecte Localisation Satellite), CLS01 [Ref. \[2.28\]](#).

The mean sea surface has been estimated on a 1/30 (2 minutes) of a degree grid using a local inverse method, which also provides an estimation and an associated error field.

The height of the MSS is computed at altimeter measurement by spline interpolation in latitude and longitude of the gridded values at the altimeter measurement, using the mechanism so-called "Spline interpolation of grid values".

The mean sea surface has been computed using a 7-year TOPEX/POSEIDON mean profile, a 5-year ERS-1/2 mean profile, a 2-Year GEOSAT mean profile and the 2 168-day non repeat cycle data of the ERS-1 geodetic phase. All these data have been pre-processed in order to be

1. more homogeneous, and referenced to the 7-year T/P mean profile
2. less contaminated by the ocean topography variable signal (the mean ocean topography signal contained in the surface is thus corresponding to the mean sea level during the period 1993-1999).

This mean sea surface contains:

- Over ocean, the mean geoid plus the mean ocean dynamic topography (1993-1999)

- Over land, the EGS96 mean geoid
- In coastal areas (between ocean and land)... A smooth extrapolation/relaxation of the ocean values (geoid+mean dynamic topography) toward the EGM96 geoid

More information can be obtained at: <http://www.cls.fr/mss/>

## Applicability

- The computation of the mean sea surface is performed for FDGDR, IGDR and GDR products.
- The computation of the mean sea surface is performed continuously for all surface types.

## Accuracy

To validate these MSS, the CLS01 and GSFC00.1 MSS were interpolated along the groundtracks of the T/P (7 years), ERS (5 years), and GEOSAT (2 years) mean profiles. The statistics show a systematic height difference between the two surfaces, characterised by mean difference of the order of 2.5-3 cm rms.

## Reference

Ref 2.28

Hernandez, F. and P. Schaeffer, 2000: Altimetric Mean Sea Surfaces and Gravity Anomaly maps inter-comparisons, AVI-NT-011-5242-CLS, 48 pp. CLS Ramonville St Agne.

Ref 2.29

Hernandez and P. Schaeffer, The CLS01 Mean Sea Surface: A validation with the GSFC00.1 surface., December 2001, CLS, Ramonville St Agne.

### 2.7.1.21 Geoid height

The geoid model used is the EGM96 model [Ref. \[2.30\]](#). The height of the geoid is computed at altimeter measurement by spline interpolation in latitude and longitude of the gridded values at the altimeter measurement, using the mechanism so-called "Spline interpolation of grid values".

## Applicability

- The geoid height is computed for FDGDR, IGDR and GDR products.
- The computation of the geoid height is performed continuously for all surface types.

---

## Accuracy

The geoid model used is the EGM96 model (Lemoine et al., 1998)

## Reference

Ref 2.30

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

### 2.7.1.22 Ocean depth/land elevation

The new Global Digital Elevation Model, MACESS, has been developed in ESRIN by merging the ACE land elevation data and the Smith and Sandwell ocean bathymetry data. This new DEM is available at 5min arc resolution for the NRT data and at 2min arc resolution for the offline data.

The ocean depth / land elevation is obtained by bilinear interpolation in space.

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.

## Applicability

- The ocean depth/land elevation is computed for FDGDR, IGDR and GDR products.
- The computation of the ocean depth/land elevation is performed continuously for all surface types.

## Accuracy

TBD

## Reference

Ref 2.31

Defrenne D. and Benveniste J., "A global land elevation and ocean bathymetry model from radar altimetry", QWG meeting minutes, Marsh 2004

### 2.7.1.23 Total geocentric ocean tide height (solution 1)

The ocean tide solution 1 is based on the GOT00.2 model.

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

$$h_i = F_i \cdot [A_i(\varphi, \lambda) \cos(\psi_i) + B_i(\varphi, \lambda) \sin(\psi_i)] \quad \text{eq 2.91}$$

( $i=1,N$ )

with:

$$\psi_i = \sigma_i \cdot t + X_i + U_i \quad \text{eq 2.92}$$

$F_i$  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)

$\sigma_i$  is the tidal frequency

$t$ ,  $\varphi$  and  $\lambda$  are respectively the altimeter time tag, latitude and longitude

$A_i(\varphi, \lambda)$  and  $B_i(\varphi, \lambda)$  are harmonic coefficients bilinearly interpolated at the altimeter location ( $\varphi, \lambda$ ) from the input harmonic coefficients map given by the GOT00.2b model by Ray [Ref. \[2.32\]](#) Harmonic coefficients A and B are tidal amplitude x cos(phase) and tidal amplitude x sin(phase) respectively.

The total geocentric ocean tide is the sum of the ocean tide, the tidal loading height and the long period tide equilibrium.



## Applicability

- The total geocentric ocean tide height is computed for FDGDR, IGDR and GDR products
- The computation of the total geocentric ocean tide height is performed continuously for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

## Accuracy

The ocean tide model GOT00.2b, is essentially an update of the one (GOT99.2) described in details in Ray [RD.1]. GOT00.2, is the latest solution in a series beginning with the work described in: E J O Schrama and R Ray, Journal of Geophysical Research, v.99, p 24799, 1994.

GOT00.2b used 286 10-day cycles of Topex and Poseidon data, supplemented in shallow seas and in polar seas (latitudes above 66deg) by 81 35-day cycles of ERS-1 and ERS-2 data., The solution consists of independent near-global estimates of 8 constituents (Q1,O1,P1,K1,N2,M2,S2 and K2).

## Reference

Ref 2.32

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.

Ref 2.33

Discussion, Recommendations and Conclusion, CCVT meeting, 25-27 Mar 2003, ESRIN

### 2.7.1.24 Total geocentric ocean tide height (solution 2)

The ocean tide solution 2 is based on the FES model.

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

$$h_i = F_i \cdot [A_i(\phi, \lambda) \cdot \cos(\psi_i) + B_i(\phi, \lambda) \cdot \sin(\psi_i)] \quad \text{eq 2.93}$$

( $i=1,N$ )

with:

$$\eta_i = \sigma_i \cdot t + X_i + U_i$$

eq 2.94

$F_i$  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)

$\sigma_i$  is the tidal frequency

$t$ ,  $\varphi$  and  $\lambda$  are respectively the altimeter time tag, latitude and longitude

$A_i(\varphi, \lambda)$  and  $B_i(\varphi, \lambda)$  are harmonic coefficients bilinearly interpolated at the location  $(\varphi, \lambda)$  from the input harmonic coefficients map given by the FES model. Harmonic coefficients A and B are tidal amplitude x cos(phase) and tidal amplitude x sin(phase) respectively.

The total geocentric ocean tide is the sum of the ocean tide, the tidal loading height and the long period tide equilibrium.

FES2002 model is computed for FDGDR, and FES2004 is computed for I/GDR.

## Applicability

- The total geocentric ocean tide height FES2002 is computed for FDGDR
- The total geocentric ocean tide height FES2004 is computed for IGDR and GDR products
- The computation of the total geocentric ocean tide height is performed continuously for all surface types (over land and ocean), although it is relevant to ocean surfaces only.

## Accuracy

FES2002 version of the Grenoble FES hydrodynamical model is used [RD.1] in NRT. FES2002 is a fully revised version of the older FES99 version. The finite element mesh used in the computation was fully rebuilt. Topex/Poseidon, ERS-2, deep ocean tide gauges and coastal tide gauges data were analyzed so as to be assimilated in the solution. To compute the tidal signal from FES2002, 27 tidal constituents are used. Among these 27 tidal constituents, 9 principal ones are given in input amplitudes and phases maps (M2, S2, N2, K2, K1, O1, 2N2, Q1 and P1). The 18 remaining ones are computed by admittance from the principal constituents 1 to 9, using admittance coefficients.

FES2004 version, used for the Offline, is generated at LEGOS. It is the last update of the FES2002 solution. The altimeter data reprocessing consists in a new atmospheric forcing

response correction (mog2D-G) applied to the data before the harmonic analysis.

This new model includes two extra waves, S1 and M4, adding to the 9 waves of FES2002 model. The validation of the FES2004 solutions shows an overall improvement in FES2004 vs GOT00 compared to FES2002 vs GOT00, especially in the mid and high latitude. [Ref. \[2.35\]](#)

## References

Ref 2.34

Lefevre, F., Modélisation de la mer océanique à l'échelle globale par la méthode des éléments finis avec assimilation de données altimétriques, SALP-RP-MA-E2-21060-CLS, pp. 87, CLS, Ramonville Saint-Agne, 2002.

Ref 2.35

Letellier T, Lyard F. and Lefevre F. The new global tidal solution: FES2004, Proceeding of the Ocean Surface Topography Science Team Meeting, St. Petersburg, Florida, 4-6 November 2004

### 2.7.1.25 Solid earth tide height and long period tide height

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

$$V = \sum_{n=2}^{\infty} \sum_s V_n(s) \quad \text{eq 2.95}$$

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

$$\begin{aligned} V_n(s) &= c_n(s).W_n^m.\cos[\omega(s).t + \phi(s) + m.\lambda] \leftarrow \text{for } (m+n) = \text{even} \\ V_n(s) &= c_n(s).W_n^m.\sin[\omega(s).t + \phi(s) + m.\lambda] \leftarrow \text{for } (m+n) = \text{odd} \end{aligned} \quad \text{eq 2.96}$$

where the phase  $\omega(s).t + \phi(s)$  of constituent  $s$  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  $\omega_i t + \phi_i$  :

eq 2.97

$$\omega(s).t + \phi(s) = \sum_{i=1}^6 k_i(s) [\omega_i.t + \phi_i]$$

where  $\lambda$  is the altimeter longitude, and where

eq 2.98

$$W_m^n$$

is the associated Legendre polynomial (spherical harmonic) of degree  $n$  and order  $m$  (

eq 2.99

$$W_m^n(\sin \theta)$$

, with  $\theta$  altimeter latitude).

The Cartwright's 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 [Ref. \[2.36\]](#), and Cartwright and Edden [Ref. \[2.37\]](#)). This allows for the potential to be computed.

The solid Earth tide height and the height of the long period equilibrium 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  $H_{\text{solid}}$  is thus :

eq 2.100

$$H_{\text{Solid}} = H_2 \cdot \frac{V_2}{g} + H_3 \cdot \frac{V_3}{g}$$

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 long period equilibrium tide  $H_{\text{Equi}}$  is thus :

$$H_{\text{Equi}} = (1 - H_1 + K_1) \frac{V_{20}}{g} + (1 - H_3 + K_3) \frac{V_{30}}{g} \quad \text{eq 2.101}$$

with :  $K_2 = 0.302$

$K_3 = 0.093$

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

## Applicability

- The solid earth tide height and the equilibrium long period ocean tide height are computed for FDGDR, IGDR and GDR products
- The computation of the solid earth tide height and of the equilibrium long period ocean tide height are performed continuously 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.

## 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.

## References

Ref 2.36

Cartwright, D.E., and R.J. Tayler : New computations of the tide-generating potential, Geophys.J.R.Astr.Soc, v23, 45-74, 1971

Ref 2.37

Cartwright, D.E., and A.C. Edden : Corrected tables of tidal harmonics, Geophys.J.R.Astr.Soc, v33, 253-264, 1973

### 2.7.1.26 Tidal loading height according to ocean tide solution 1

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

$$h_i = F_i [C_i(\varphi, \mu) \cos(\psi_i) + D_i(\varphi, \mu) \sin(\psi_i)] \quad \text{eq 2.102}$$

$C_i(\varphi, \mu)$  and  $D_i(\varphi, \mu)$  are harmonic coefficients bilinearly interpolated at the altimeter location  $(\varphi, \mu)$  from the input harmonic coefficients map. This map has been computed from Cartwright and Ray method [Ref. \[2.38\]](#). This method is based on spherical harmonic approach.

## Applicability

- The tidal loading height is computed for FDGDR, IGDR and GDR products
- The computation of the tidal loading height is performed continuously for all surface types (over land and ocean).

## Accuracy

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 [Ref. \[2.38\]](#) for the Cartwright and Ray tide model used a high-degree spherical harmonic method.

## References

Ref 2.38

Cartwright and Ray and Sanchez, Oceanic tide maps and spherical harmonic coefficients from Geosat altimetry, NASA tech memo. 104544 GSFC, Greenbelt, 74 pages, 1991.

### 2.7.1.27 Tidal loading height according to ocean tide solution 2

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

$$h_i = E_i \cdot [C_i(\varphi, \mu) \cos(\psi_i) + D_i(\varphi, \mu) \sin(\psi_i)] \quad \text{eq 2.103}$$

( $i=1, N$ )

$C_i(\varphi, \mu)$  and  $D_i(\varphi, \mu)$  are harmonic coefficients bilinearly interpolated at the altimeter location ( $\varphi, \mu$ ) from the input harmonic coefficients map. This map has been computed from Francis and Mazzega's method [Ref. \[2.39\]](#): 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 FES2002 model.

## Applicability

- The tidal loading height is computed for FDGDR, IGDR and GDR products
- The computation of the tidal loading height is performed continuously for all surface types (over land and ocean).

## Accuracy

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 [Ref. \[2.40\]](#) 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).

## References

Ref 2.39

Francis, O., and P. Mazzega, Global charts of ocean tide loading effects, J. Geophys. Res., Vol. 95, 11,411-11,424, 1990.

Ref 2.40

Ray, R.D., and B.V. Sanchez, Radial deformation of the Earth by oceanic tidal loading, NASA Tech. Memo, 100743, July, 1989.

### 2.7.1.28 Geocentric pole tide height

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 [Ref. \[2.41\]](#), by :

$$H\_Pole = A \cdot \sin(2\varphi) \left[ (x - x\_avg) \cdot \cos(\lambda) - (y - y\_avg) \cdot \sin(\lambda) \right] \quad \text{eq 2.104}$$

where  $H\_Pole$  is expressed in mm, and where  $\lambda$  and  $\varphi$  are respectively the longitude and latitude of the measurement.  $x$  and  $y$ , in arc second, are the nearest previous pole location data relative to the altimeter time and  $x\_avg$  and  $y\_avg$  are the averaged pole co-ordinates (in



arc second).

$$A = -69.435 \cdot 10^{-3}$$

eq 2.105

is the scaled amplitude factor in m:

$$A = \frac{\Omega^2 R^3}{2g} \cdot \frac{1}{180 \times 3600} \cdot (1 + K_2)$$

eq 2.106

where  $\Omega$  is the nominal earth rotation angular velocity in radian/s,  $R$  is the earth radius in m,  $g$  is gravity in m/s<sup>2</sup>,

$$\frac{1}{180 \times 3600}$$

eq 2.107

is a conversion factor from arc second to radian, and  $K_2$  is the Love number ( $K_2 = 0.302$ ).

$x$  and  $y$  are obtained from IERS, and an update of the auxiliary file containing those coordinates is updated every 4-5 days.

## Applicability

- The pole tide height is computed for FDGDR, IGDR and GDR products
- The computation of the pole tide height is performed continuously for all surface types (over land and ocean).

## Accuracy

IGDR processing uses predicted pole locations, whereas GDR processing 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.

## Reference

Ref 2.41

Wahr, J. : J. Geophys. Res., Vol. 90, pp. 9363-9368, 1985.

### 2.7.1.29 MWR water vapour content

Vap\_Cont is the MWR water vapour content in g.cm<sup>-2</sup>. It is computed with neural algorithm (see [2.7.1.10](#) ) from the MWR 23.8GHz and 36.5 GHz brightness temperatures (TB23 and TB36), interpolated to altimeter time, if the MWR land flag interpolated to altimeter time is set to " ocean ", and from  $\sigma_0$ \_Ku.

where TB23\_Int and TB36\_Int are the 23.8 GHz and 36.5 GHz brightness temperatures (in K) interpolated to RA-2 time tag,  $\sigma_0$ \_Ku is the ocean backscatter coefficient for Ku-band (dB).

## Applicability

- The MWR water vapour content is computed for FDGDR, IGDR and GDR products
- The computation of the MWR water vapour content is performed continuously for all surface types (over land, ice and ocean). Nevertheless, it is applicable only for ocean surfaces.

## Accuracy

As this algorithm has been formulated over a representative database [Ref. \[2.42\]](#), a minorant of the error is the rms difference obtained when applying directly the algorithms over the database, i.e. 0.1 g/cm<sup>2</sup> for the integrated water vapour content.

As there are no measurements performed, no upper bound of the error can be given.

## Reference

Ref 2.42

S. LABROUE and E. OBLIGIS, "Neural network retrieval algorithm for the Envisat/MWR", report CLS/DOS/NT/03.848 of ESA contract n 13681/99/NL/GD, January 2003.

### 2.7.1.30 MWR liquid water content

Cloud\_Liquid is the MWR cloud liquid water contents in kg.m<sup>-2</sup>. It is computed from the MWR 23.8 GHz and 36.5 GHz brightness temperatures (TB23 and TB36) interpolated to RA2-time, if the MWR land flag interpolated to altimeter time is set to " ocean ", and from  $\sigma_0$ \_Ku.

Where TB23\_Int and TB36\_Int are the 23.8 GHz and 36.5 GHz brightness temperatures (in K) interpolated to RA-2 time tag,  $\sigma_0$ \_Ku is the ocean backscatter coefficient for Ku-band (dB).

## Applicability

- The MWR liquid water content is computed for FDGDR, IGDR and GDR products
- The computation of the MWR liquid water content is performed continuously for all surface types (over land, ice and ocean). Nevertheless, it is applicable only for ocean surfaces.

## Accuracy

As this algorithm has been formulated over a representative database [Ref. \[2.43\]](#), a minorant of the error is the rms difference obtained when applying directly the algorithms over the database, i.e. 0.1 g/cm<sup>2</sup> for the integrated water vapour content.

As there are no measurements performed, no upper bound of the error can be given.

## Reference

Ref 2.43

S. LABROUE and E. OBLIGIS, "Neural network retrieval algorithm for the Envisat/MWR", report CLS/DOS/NT/03.848 of ESA contract n° 13681/99/NL/GD, January 2003.

### 2.7.1.31 RA-2 wind speed algorithm

First, the atmospheric attenuation is added to the backscatter coefficient to correct it. Then wind speed is computed (in m/s), using a linear interpolation in the input wind table, according to the modified Witter and Chelton algorithm [Ref. \[2.44\]](#).

## Applicability

- The RA-2 wind speed is computed for FDGDR, IGDR and GDR products
- The computation of the RA-2 wind speed is performed continuously for all surface

types (over land and ocean).

## Accuracy

The derived wind speed is considered to be accurate to the 2 m/s level.

## Reference

Ref 2.44

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

### 2.7.1.32 Averaged Ku chirp band

In Ku band, the possible change of the emitted bandwidth within a source packet is taken into account. Only one bandwidth will be accounted for in the averaging process:

$$\text{Mean\_Chirp\_Id} = \text{Min}\{\text{Chirp\_Id}\} \quad \text{eq 2.108}$$

where Chirp\_Id is the Ku chirp band identifier (0: 320 MHz, 1: 80: MHz, 2: 20 MHz)

### 2.7.2 RA2/MWR Level 2 Products

The Level 2 products are the science products that are user-oriented. The Level2 product family is composed of three types specifically design for different applications. It basically consists of three main products: GDR (Geophysical Data Record), SGDR (Sensor GDR) and MAR (Marine Abridged Records). In the following paragraphs the definition of the products is first given. It is followed by the description of the structure.

### 2.7.2.1 Definition

The GDR Products are:

- FDGDR product : The RA-2 / MWR level 2 Fast Delivery GDR (or FDGDR) products are generated by the Near Real Time processing from level 1b unconsolidated products, using predicted auxiliary data. "Unconsolidated" means parameters which do not account for the final instrumental calibration data.
- IGDR product : The RA-2 / MWR level 2 Interim GDR (or IGDR) products are generated by the Off-Line processing, within a few days (3 to 5), from level 1b unconsolidated products, using restituted auxiliary data (meteorological fields, pole location, DORIS ionospheric data) and a DORIS preliminary orbit.
- GDR product : The RA-2 / MWR level 2 GDR products are generated by the Off-Line processing, within a few weeks (3 to 4), from level 1b consolidated products, 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.

The SGDR Products are :

- SGDR product : The SGDR is essentially the same product as the GDR, with waveforms added to the product. The SGDR is generated from the consolidated Level 1B (waveforms corrected for long term instrument variations) and from the GDR (same geophysical corrections).

The MAR Products are :

- A MAR product contains an ocean oriented (only ocean retracker) subset of the FD/I/GDR. It is made available for near real time or quasi near real time meteorological and oceanographic applications. The subsets are called, respectively, FDMAR and IMAR.

The FDGDR and FDMAR products correspond to a segment of the orbit, corresponding to the data downlinked over a receiving station, while the IGDR, GDR, SGDR and IMAR products span half an orbit, i.e. a pass from pole to pole.

Note that the FDMAR products are also made available in BUFR format through the PDS for the METEO offices.

The product tree is given in the following figure.

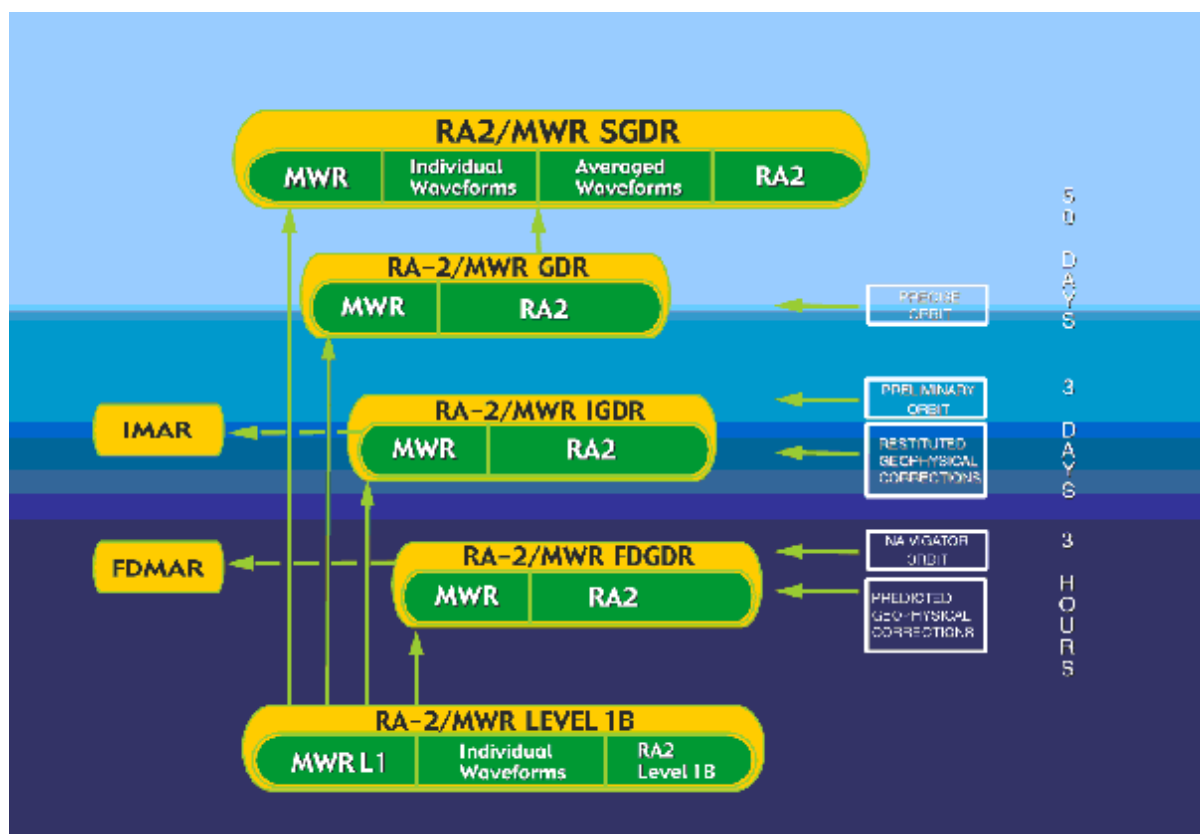


Figure 2.3 RA-2/MWR products tree

### 2.7.2.2 Structure

All these products follow the PDS structure which consists of a MPH, a SPH and one or several MDS. Below is given the structure for each of the products listed above.

---

For the FDGDR, IGDR, GDR products the structure is the following :

- MPH/SPH/RA2 MDS/MWR MDS

For the SGDR product the structure is the following :

- MPH/SPH/RA2 MDS/MWR MDS/Average Waveforms MDS/Individual Waveforms MDS

For the FDMAR and IMAR product the structure is the following :

- MPH/SPH/RA2 MDS

### 2.7.2.3 Level 2 RA2/MWR SPH

The SPH is an ASCII header and has the same format for every product. The fields of the SPH are of the following types:

- RA-2 Time Information
- RA-2 Positioning Information
- RA-2 Quality Information
- RA2 Subsystem Identification
- RA-2 Processing Information
- MWR Time Information
- MWR Positioning Information
- MWR Quality Information
- DSDs for included Data Sets
- DSDs for referenced files

### 2.7.2.4 Level 2 RA2 MDS in FDGDR, IGDR and GDR

The RA-2 MDS is composed of several MDSRs (1 MDSR every 1.114s). The records in the MDS contain 1 Hz and 18 Hz data. Within a MDSR the fields are of the following types :

- Time Information
- Geolocation Information
- Quality Information
- Orbit Information
- Range Information
- Range Corrections Information
- Significant Wave Height Information
- Backscatter Information
- Backscatter Corrections Information
- Off-nadir Angle Information
- Geophysical Information

- 
- MWR Information
  - Flags and Other Quality Information

### 2.7.2.5 Level 2 RA2 MDS in FDMAR and IMAR

The RA-2 MDS for FDMAR and IMAR products is a subset of the GDR product which contains only the 1 Hz data and results of the ocean retracker. The type of information found is the same as the RA-2 MDS in the GDR products.

### 2.7.2.6 Level 2 MWR MDS

The format of the MWR MDS is identical to that described in [Level 1b MWR MDS 2.6.3.7.](#)

### 2.7.2.7 Level 2 Averaged Waveforms MDS

The RA-2 Average Waveform MDS is composed of several MDSRs. The records in the MDS contain 18 Hz data. Within a MDSR the fields are of the following types :

- Time Information
- Quality Information
- Waveform Information
- Power Information

### 2.7.2.8 Level 2 Individual Waveforms MDS

The format of the Individual Waveform MDS is identical to that described in [Level 1b RA2 individual echoes waveforms MDS 2.6.3.5.](#)

## 2.8 Specific Topics Related To The Radar Altimeter

### 2.8.1 Data Packeting



The RA2 telemetry consists of Source Packets generated at intervals of 1.11 seconds. Each source packet contains 20 Ku band echoes and 20 measurements of range (plus 20 corresponding S band echoes and measurements). The data at 1.11 seconds is often referred to as "low-rate data" and the higher frequency measurements referred to as "high-rate data".

In L1b products records are produced at the high-rate (18Hz) and some fields only change every 20 records.

At L2 the data records are at the low-rate (1.11 secs). This interval is appropriate for representing most of the geophysical corrections and provides a measurement interval suitable for many oceanographic applications. High-rate measurements are represented by fields which are arrays of 20 values.

## 2.8.2 Time Handling And Leap Seconds

Time Handling is described in : "Time and Orbit State Vector handling within the PDS processing chain." Guidelines PO-TN-ESA-GS-00554 Iss. 1.3

### 2.8.2.1 Leap Second Description

There are three fields, leap\_utc, leap\_sign and leap\_err that relate to the leap second usage. They are contained in the MPH (fields 31, 32 and 33).

Before analysing in detail each of these fields a description of the leap second origin can be useful at this point.

There are several time references used in the EnviSat context:

- TAI: a very stable atomic time scale found only in DORIS products, and not used in PDS processing.
- UT1: time of the Earth clock, which performs one revolution in about 24h. It's used as time reference for all orbit state vectors and it's necessary for pointing at celestial targets.
- UTC : time scale used as reference for all products datations. This time is an approximation of UT1, but for pointing at terrestrial targets from the satellite, it provides enough accuracy, due to the short distance between the satellite and the Earth.

### 2.8.2.2 Leap second correction

The occurrence of a leap second may introduce a discontinuity in the UTC time line used during the processing, and has to be corrected.

This discontinuity is introduced when one of the following conditions is fulfilled:

$$\text{state\_vector\_time} < \text{leap\_utc} < \text{utc\_sbt\_time} \quad (1)$$

or

$$\text{utc\_sbt\_time} < \text{leap\_utc} < \text{state\_vector\_time} \quad (2)$$

where `state_vector_time` is the UTC time of the Orbit State Vector (field 17 in the MPH) and `utc_sbt_time`, or UTC reference time, is the utc time corresponding to the satellite binary time (field 27 in the MPH). The Orbit State Vector time corresponds to the time of the Ascending Node crossing if the OSV information is generated from a predicted file. The OSV time is equal or just after the sensing start time of the product being processed, if the OSV is generated from a restituted file.

The important point here is that there is no warranty that the `state_vector_time` and the `utc_sbt_time` will coincide. Hence, conditions (1) or (2) are likely to be satisfied.

The key point to remember is that all information provided by the PF\_HS related to the UTC time that occurs after the `leap_utc` has been corrected for the leap second. That's why there will exist a discontinuity between the UTC reference time (`utc_sbt_time`) and the OSV time (`orbit_state_vector`) in case eqs. (1) or (2) are fulfilled, since one of the times will be already corrected for the leap second while the other not.

The L1b processing must remove this discontinuity in the UTC time line by adjusting the UTC reference time before using it for the processing.

The correction to be performed in case (1) is fulfilled is:

$$\text{utc\_sbt\_time} = \text{utc\_sbt\_time} + \text{leap\_sign}$$

while in case of (2) is:

$$\text{utc\_sbt\_time} = \text{utc\_sbt\_time} - \text{leap\_sign}$$

The leap second correction will ensure that the results obtained using the corrected `utc_sbt_time` are time continuous with respect to the OSV time.

The corrected `utc_sbt_time` is not to be written to the output MPH. The correction is only

---

done internally to the L1b processing.

Note that the leap information (i.e. `leap_utc`, `leap_sign` and `state_vector_time`) necessary to perform the leap correction is extracted:

- for the IPF: from the product model
- for the ESLs reference prototypes: from the input product MPH (Level 0), or from the OSV file MPH, if a restituted orbit file is available.

Thus, the coherency between the data used by both IPF and ESLs processors is warranted, since the PF\_HS will always include the best available OSV information in the product model.

### 2.8.2.3 Evolution of L1b time stamps during a leap second occurrence

As stated before, the leap second will be introduced (`leap_utc`), if necessary, at midnight of the last day of December or June.

Let's call 'true UTC time', the time that follows the leap second jump, and 'product UTC time' the one used to tag the processed records. We will see below that the 'product UTC time' will differ from the 'true UTC time'.

If a leap second occurs, the 'true UTC time' line will have a jump of one second at `leap_utc`. That is; a second will be added, if `leap_sign` = +1 (i.e. time will pass from 23:59:59 to 23:59:60, then to 00:00:00 and then to 00:00:01), or subtracted, if `leap_sign` = -1 (i.e. time will pass directly from 23:59:59 to 00:00:01).

Instead, this jump will NOT be reflected in the evolution of the 'product UTC time' line. This is because in the product, the time is always continuous with respect to the OSV time, thanks to the leap second correction. [Figure 2.4](#) and [Figure 2.5](#) show the evolution of the 'true UTC time' with respect to the 'product UTC time' in case of a positive and negative leap second.

Hence, if there is a leap second in the middle of a L0 product, this will be ignored by the 'product UTC time'. In other words, the 'product UTC time' will always be continuous, regardless of the leap second occurrence.

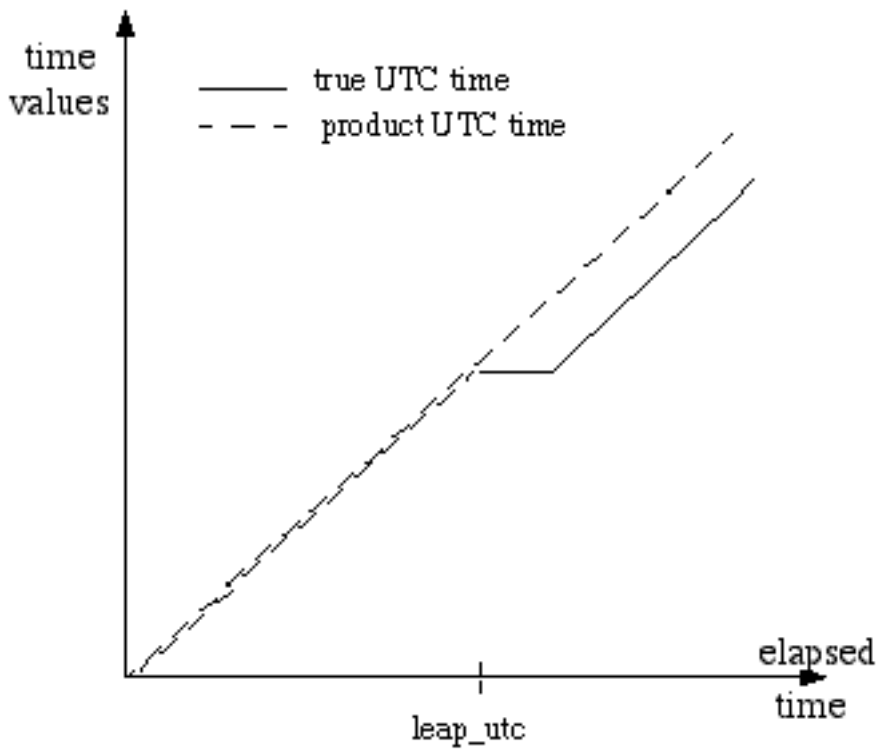


Figure 2.4 evolution of the true and product UTC times, as a function of the elapsed time, if positive leap second

Once the time stamps of the processed records have been calculated, the CFI routines (po\_ppforb/po\_interpol) will be called for the geolocation.

These routines produce time continuous results with respect to the time of the OSV time given as input for the `po_ppforb` initialization (i.e. the one contained in the product MPH) or to the OSV time obtained as output from the `po_interpol` initialization.

It means that the CFIs will NOT introduce any leap second correction. This is important, in particular, for the `po_interpol`, since the restituted orbit files used as input are always corrected for leap second (i.e. use 'true UTC time').

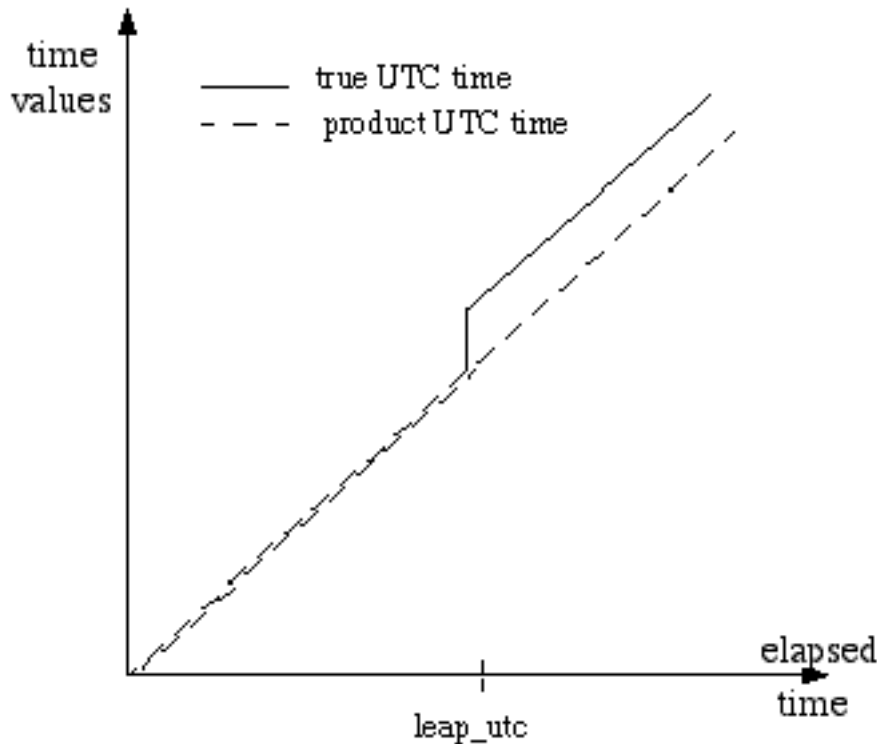


Figure 2.5 evolution of the true and product UTC times, as a function of the elapsed time, if negative leap second

If the user wants to derive the true UTC times corresponding to the time stamps of a product (L1b or L2), the leap\_err flag in the MPH has to be used. This flag, as it will be explained later on, indicates if the leap second correction has been performed or not during the processing.

#### 2.8.2.4 Leap\_sign

The leap\_sign value indicates whether the leap second corresponds to an addition of one second (leap\_sign = +1) or a subtraction of one second (leap\_sign = -1).

The leap\_sign, along with the leap\_utc, are provided originally by the Bureau des Longitudes. These values are then retrieved by ESOC and put into the Variable Header of the FOS orbit files. These files are finally incorporated into the PDS and the two leap fields copied into the orbit files MPH.

The way the leap\_sign is set, by the PF\_HS, is such that, in case of leap second occurrence, it

is set to +1 or -1 in the products corresponding to the three days around the leap second (i.e. the day before the leap second jump, the day of the leap second jump, and the day after).

The leap\_sign value appearing in the input L0 MPH for the ESL reference processors, or in the partially filled L1b MPH (i.e. product model) for the IPF is just copied into the higher output products (i.e. L1b and L2 for the ESL reference processors and L2 for the IPF).

That is; the leap\_sign value from the MPH shall not be modified during the processing.

### 2.8.2.5 Leap\_err

The leap second error flag, set to 1 if a leap second has occurred during the processing, and to 0 if not, is to be determined by the ESL reference processors/IPF according to the following algorithm:

if ((state\_vector\_time <= leap\_utc <= end time of the data set to be processed ) or

(start time of the data set to be processed <= leap\_utc <= state\_vector\_time ))

then leap\_err = 1

otherwise

leap\_err = 0

The start/end time of the data set to be processed will coincide with the sensing\_start/sensing\_stop parameters from the input Level 0 MPH (fields 10 and 11).

### 2.8.3 Datation

To derive the surface height the RA measures, very precisely, the range to the surface. It is also necessary to locate the time and position on the surface where the measurement was taken. This is called the Datation. As the RA is a high-precision instrument the Datation must also be know to a high precision.

A single RA-2 measurement is actually an average of 100 pulses reflected from the surface and we define Datation as:-

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The exact time when the averaged waveform is reflected from the surface, and hence, when the middle of the 100 averaged waveform is at the surface.

It is important to remember that a Range measurement and its Datation must be consistent. This consistency is ensured in the RA-2 data products due to processing at Level 1. The computation takes into account all the important factors including:-

- Location of the mid point of the averaged waveform
- Time when the value of the datation is actually generated by the hardware
- The rate of change of the time delay (Window Delay) during a measurement
- Propagation time delay from satellite to surface
- Time when the value of the range is taken from the on-board hardware

Full details of the Datation computation are documented in an ESA Tec-note PO-TN-ESA-GS-00588

## 2.8.4 Measurement Reference

The final measurement required in altimetry is the surface height. The altimeter, however, measures the range, which is the distance between the altimeter, mounted on the satellite, and the surface the satellite is flying over. In order to derive the surface height, the satellite altitude with respect to the ellipsoid is required. By subtracting the range measured by the altimeter from the satellite altitude we obtain the surface height with respect to the ellipsoid (see [Figure 1.8](#) in [Principles Of Measurement 1.1.3.](#) ).

Satellite Altitude defined for the ENVISAT orbits is referenced to the satellite Centre of Mass (CoM). Whereas the range measurement of the RA2 is referenced to the phase centre of the antenna. To obtain a precise surface height we must know the vertical offset of the phase centre from the CoM.

The RA2 instrument measurement is actually made at some point (the FEE circulator) inside the instrument electronics. However, by applying on-ground characterisation measurements and the in-flight calibration corrections in the level 1b processing, the measurement in the data products is referenced to the antenna phase centre.

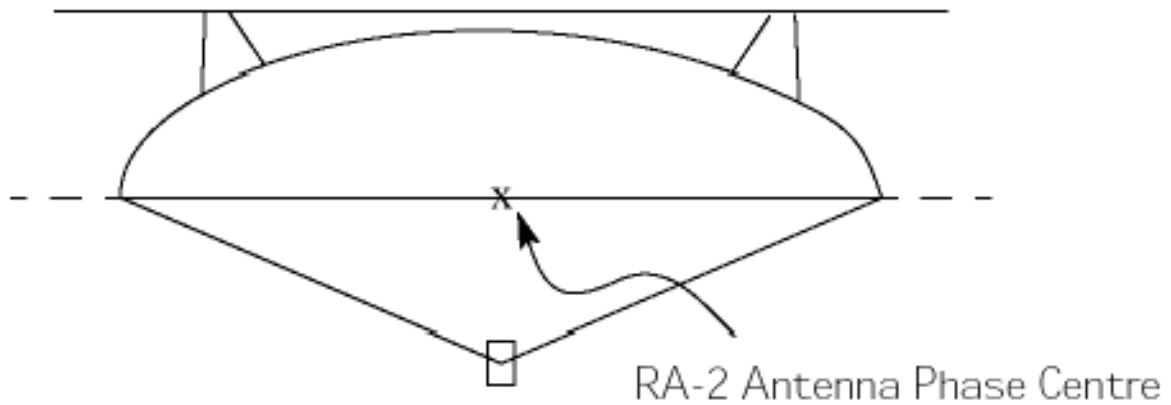


Figure 2.6 Reference point for Altimeter range measurement

The satellite orbit is calculated using DORIS data and information from ground laser stations which track the on-board Laser Retro Reflector (LRR). To relate the orbit to the CoM we require precise knowledge of the DORIS antenna position and the LRR position.



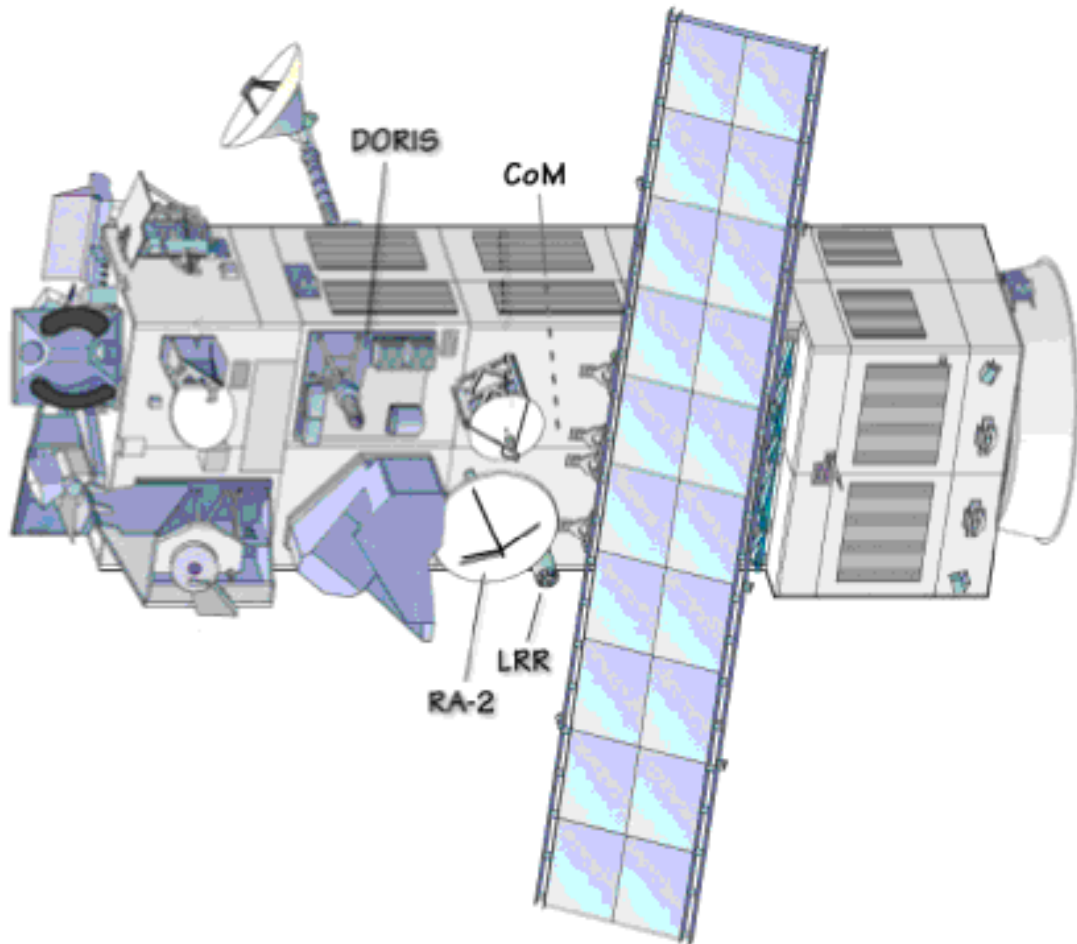


Figure 2.7 Positions of the RA2, LRR and DORIS instrument on EnviSat

The positions of all these elements, in the satellite reference frame, were determined in tests performed at ESTEC and Kourou. For RA2, LRR and DORIS the accuracy of the measurement was better than  $\pm 1$  mm in each of the x, y, z, axes. These positions are taken as fixed for the mission duration.

The CoM position at the start of mission was determined to an accuracy of 3.65mm rms. The position of the CoM changes with time due to consumption of on-board fuel and a new offset is calculated after manoeuvres.

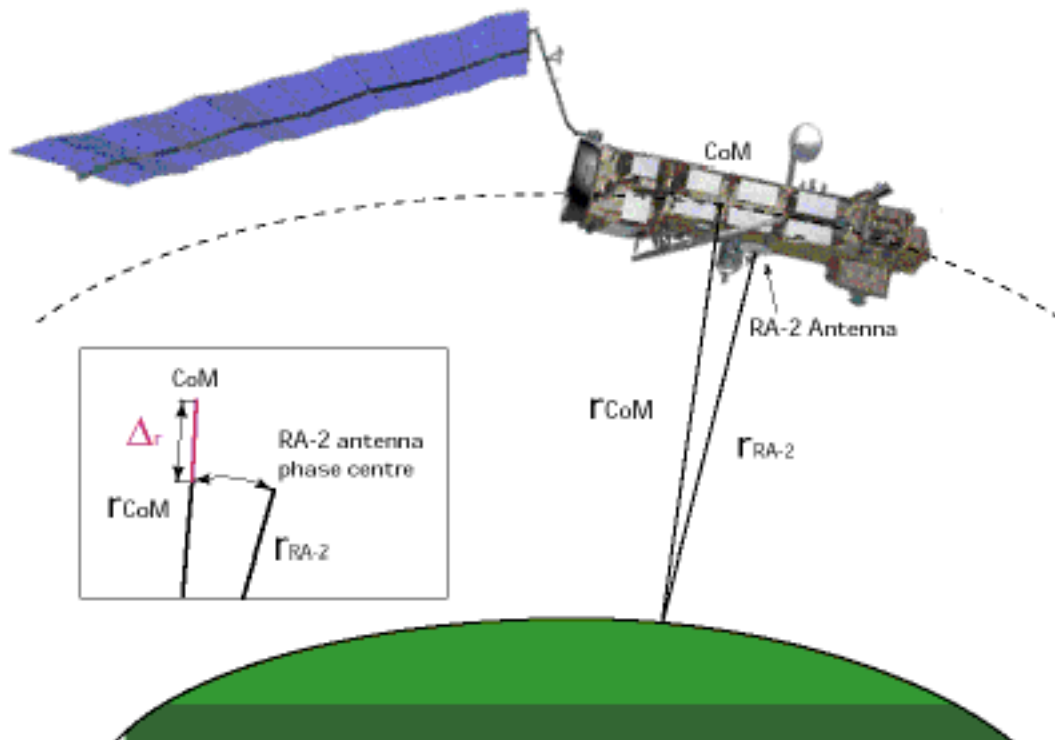


Figure 2.8 Showing the range offset between the CoM and the RA2 antenna

The relative offset of the antenna phase centre from the CoM is stored in the auxiliary file RA2\_PLA\_AUX which is updated whenever the CoM changes due to manoeuvres.

This correction is included in the range measurements of the Level 2 data products.

Full details of the Measurement reference Points are documented in an ESA Tec-note PO-TN-ESA-RA-1319.

## 2.8.5 Orbit interpolation

This section is intended to provide a description of the EnviSat orbit CFI functions (PPF\_ORBIT libraries) in the NRT RA2/MWR processing chain.

The only orbit routines to be used within the processing are the orbit propagator (po\_ppforb)

and the orbit interpolator (`po_interpol`), that allow the calculation of the orbit and the satellite ground track related parameters (i.e. latitude, longitude, altitude and altitude rate).

In the Level 2 OFL chain, different interpolation routines are used, with input DORIS preliminary orbit files (for the production of IGDR/IMAR products) and DORIS precise orbit files (for the production of GDR/SGDR products).

### 2.8.5.1 `po_ppforb`

This routine is currently used for the NRT (IPF) processing since no restituted orbit file is available within 3 hours after data take.

In this case, only one state vector from a predicted orbit state vector file is used for the calculation of the orbital parameters for all records in the input product, by propagating the state vector.

A proper sequence of orbit propagator calls consists of one initialisation call and a number of propagation calls (one per record).

The predicted orbit files are:

- DORIS Navigator Level 0 file (product id= `DOR_NAV_0P`)
- Predicted orbit file from FOS (product id= `AUX_FPO_AX`)

Until now, only the predicted FOS file has been used for the propagation of the OSV in the RA2/MWR NRT processing.

The use of a predicted OSV file, instead of a restituted one, seriously impacts the quality of the NRT orbital parameters, where errors of several meters in the orbital altitude can be observed.

This is why an interpolation strategy is being implemented for the NRT processing, by using the DORIS Level 0 Navigator files.

This strategy implies an update of the orbit routines, so they can accept a new orbit file for the interpolation, and an upgrade in the NRT official processor.

When this scheme will be implemented, the NRT orbital errors will be reduced to some centimeters.

The info on the orbit file used for the selection of the OSV to be propagated, appears in the product header: field 25 in MPH (vector source).

### 2.8.5.2 `po_interpol`

This routine, based on the interpolation of state vectors from restituted OSV files, is not currently used in the NRT RA2/MWR processing, due to the specific time constraints (i.e. the restituted orbit files are not available within  $\sim 3$  hours after data take to be used for the NRT processing).

The restituted orbit files are the following:

- DORIS precise orbit file (product id=DOR\_VOR\_AX)
- DORIS preliminary orbit file (product id=DOR\_POR\_AX)
- FOS restituted orbit file (product id=AUX\_FRO\_AX)

In order to avoid the huge inaccuracies in the NRT orbital parameters (see previous paragraph) a new strategy will become operative soon, based on the use, in NRT, of the full-rate DORIS Navigator file for the orbit state vectors interpolation.

A proper sequence of orbit interpolator calls consists of one initialisation call and a number of interpolation calls (one per record), as in the case of the propagator routine.

The info on the specific orbit file used for the interpolation appears in the L2 product SPH.

## 2.9 RA-2/MWR Auxiliary files

### 2.9.1 Summary of Auxiliary Data Sets

The auxiliary, or external, data sets, used to process the L0 and L1b data, can be divided into static and dynamic data.

The static data (e.g. RA2\_CON\_AX, or RA2 Configuration file, for L1b, or RA2\_SOI\_AX, or ocean/ice2 system file, for Level 2) is not updated very frequently.

During Commissioning Phase most of them were modified (e.g. tuning of thresholds, modification of scaling factors, ...), following the L1b and L2 algorithms verification groups activities.

The dynamic data (e.g. RA2\_USO\_AX, or USO frequency file, for L1b or RA2\_POL\_AX, or polar motion file, for Level 2) are always updated (typically every 2 or 3 days for the Polar motion file, and whenever an USO drift is detected, for the USO file).

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The external set of files used for the processing is present in the Data Set Descriptors structure of the output SPH.

## 2.9.2 Level 1b processing

The auxiliary files to be used solely for the RA2/MWR L1b processing are the following:

### RA2\_CON\_AX (RA2 Configuration file)

This file contains all thresholds and scaling factors to be used during the RA2 Level 1b processing. Some fields needed to fill in some quality information in the L1b SPH are also included in this file (i.e. thresholds to set the RA2 L1b processing and headers quality flags).

Some of the fields within this file were updated during Commissioning Phase as part of the L1b algorithms verification group activities. No future updates are foreseen.

### RA2\_IFF\_AX (RA2 flight IF mask data)

This file contains the correction mask to be applied to the waveforms samples for the instrument IF filter shape. The IF mask may be derived on-ground or in-flight. Also, the on-ground data may differ for chain A (RA2\_IFA\_AX) or chain B (RA2\_IFB\_AX), but keeping always an identical format.

The IF flight data has been updated several times since Envisat launch.

The update is done by switching the instrument into IF Calibration mode, when 128 thermal noise samples are collected by the instrument, instead of the 128 Ku waveform samples. These samples are used on ground to estimate the IF filter shape.

The instrument is switched into this calibration mode regularly once per day, when flying over the Himalayas.

When enough IF CAL data are accumulated, and depending on the IF mask variability as function of the temperature along the orbit, a new IF Mask is created. This is done by a dedicated IECF function.

Although there is a way to select the proper IF calibration mask inside the L1b processing, (by using the altimeter measurement date, the altimeter RF subsystem chain in use and the quality flag associated to the measurement), the flight data has and will be always used for the processing.

An ESA study had shown that monthly update of the IF Mask is required. This is applied

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starting from cycle 42 with IPF version 5.02.

## RA2\_USO\_AX (RA2 USO file)

This file contains the accurate estimate of the USO frequency (Tx/Rx clock period) and is updated by means of an IECF dedicated function.

Although there is a way to select the proper USO Tx/Rx clock period inside the L1b processing, (by using the altimeter measurement date, the altimeter RF subsystem chain in use and the quality flag associated to the measurement), the flight data will be used for the processing.

An update of the USO clock period format has taken place to improve the accuracy of the L1b/L2 range measurements.

## MWR\_SLT\_AX (MWR Side Lobes Temperature file)

This file contains the side lobes contribution to the MWR brightness temperatures. There are three different algorithms that can be used to remove the effects of the secondary lobes. In the first, ERS-1 like, algorithm, the secondary lobes effects are tabled in a Side Lobe Table auxiliary file, as function of the latitude of the satellite. In the second, ERS-2 like, algorithm, instead, the side lobes contributions are obtained using the reflector physical temperatures, the transmission coefficients of the reflectors and the global side lobes contributions for each channel. The third algorithm is proposed by CLS that used one full year of ERS2 brightness temperatures to evaluate the contribution of the land emissivity (directly and after reflection by the platform) inside the measurement cell.

Two methods are available for the calculation of the side lobe contributions: ERS-1 like strategy (using a side lobe contribution table in terms of the latitude), or ERS-2 like strategy (using transmission coefficients of the reflectors for both channels, and global side lobe contributions, including cosmic background, sun and satellite contributions). Currently, the ERS-2 like method is being used for the processing of the real data.

New algorithms for the calculation of the side lobe temperature (implying a change in the aux. file format) are envisaged for a near future.

## MWR\_CHD\_AX (MWR Characterisation file)

This file includes all the radio frequency front-end relevant parameters such as switching assembly insertion losses, hot load mismatching, cold (sky horn) chain characterisation, IF gain characteristics in terms of linearity, variation in temperature, noise figures, stability and sensitivity measurements, etc. In particular, the data in the 4 Data Sets in this file contains: thermistor polynomial coefficients to be used to evaluate the temperature of the 32 on-board thermistors by their telemetry (1st DS), expected maximum and minimum limits in temperature of the most significant thermistors, for 24 GHz and 36 GHz channels (2nd DS),

linear and quadratic coefficients of the receiver gain response as a function of on-board temperature, for 24 GHz and 36 GHz channels (3rd DS) and characterisation parameters of 24 GHz and 36 GHz channels for five different reference temperatures (0 °C, 10 °C, 20 °C, 30 °C, 40 °C) and for the two modes of operation (nominal and redundant).

Data from this file was updated during Commissioning Phase in the frame of the MWR cal/val group activities. No further updates are foreseen.

## MWR\_CON\_AX (MWR Configuration file)

This file contains data used to configure the MWR processor (e.g. moving window size for the calculation of the Gain and offset temperatures, or pointing configuration for the forward and backward channels).

Data from this file was updated during Commissioning Phase in the frame of the MWR cal/val group activities. No further updates are foreseen.

### 2.9.3 Level 2 processing

The auxiliary files to be used solely for the RA2/MWR L2 processing are the following:

## RA2\_IOC\_AX (Model ionospheric coefficients file)

This file contains the values of the polynomial coefficients to be used in the computation of the ionospheric correction from the Bent model in the FDGDR processing. There are two sets of coefficients in every record: the first set of coefficients is related to the critical frequency and the second set to the ratio of maximum usable frequency to the critical frequency. This file has to be updated typically once a year, since these coefficients cover one year (one record per month). This file, used only for NRT processing, has not been updated yet.

In the off line processing, the ionospheric correction is computed using daily TEC maps coming from a different (non-PDS formatted) auxiliary file, that can be distributed only by the AVISO catalogue entity.

## RA2\_MSS\_AX (Mean Sea Surface)

This file contains the values of the mean sea surface heights.

The MSS model used for the calculation of the sea heights has been updated since launch. Currently the CLS01 model is used.

The values are recorded on a regular grid with 2 minutes resolution in longitude and latitude.

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This file is used in the FDGDR, IGDR and GDR processing.

## RA2\_SOL\_AX (Solar activity data file)

The data in this file, containing the 12 month running average of the sunspot numbers (solar activity indexes), is used to compute the Bent model ionospheric correction in NRT. The solar activity indexes needed for the OFL DORIS iono correction are extracted from a different external file (daily DORIS TEC maps).

Predicted solar activity data is used for NRT while measured data is used for the off line processing. The data in this file is updated approx. once per month by a dedicated IECF function.

## RA2\_POL\_AX (Pole location position data file)

The data contained in this file is related to the position of the pole, needed to calculate the geocentric pole tide height. The predicted pole data is used for NRT processing, while the analysed data is used for off line. The polar motion data in this file is updated twice per week by a dedicated IECF function.

## RA2\_PLA\_AX (Platform data file)

This file contains the center of mass correction (i.e. distance between antenna phase center and the center of gravity of the satellite) that is applied during the (NRT and off line) level 2 processing to the retracked altimeter range. The CoM - antenna phase center distance is obtained only from the projection on the z-axis, since the x-axis component is negligible. The file is updated every time there is a consumption of satellite fuel due to a manoeuvre. In NRT this is done automatically by a dedicated IECF function.

In OFL, the CoM-antenna data, coming also from the FOS file, is stored in a different aux. file.

## RA2\_SOI\_AX (Ocean/Ice 2 configuration system file)

This file contains the processing parameters (constants, thresholds, tables) for the ocean/ice2 processing. These parameters are used for NRT and off line processing. The file has been updated during Commissioning Phase in the frame of the Level 2 algorithms verification group activities.

## RA2\_ICT\_AX (Ice1/ sea ice Configuration system file)

This file contains the processing parameters (constants, thresholds, tables) for the ice 1/sea



ice processing. These parameters are used for off line processing. The file has been updated during Commissioning Phase in the frame of the Level 2 algorithms verification group activities

## RA2\_SSB\_AX (Sea State Bias table file)

This file contains the values of the sea state bias corrections for the Ku and S bands, to be used for NRT and off line processing. It is a double input table depending on significant waveheight and windspeed. The SWH coverage is from 0 to 12 m, with a resolution of 0.25 m, while the coverage for windspeed is from 0 to 25 m/s with a resolution of 0.25 m/s.

This file has been updated with a new one that is based on the analysis of ten cycles (cycle 25 to 35), using residuals relative to a mean sea surface and applying the non parametric estimation technique

## RA2\_DIP\_AX (Modified Dip Map file)

This file contains the values of the modified magnetic dip used in the computation of the ionospheric correction from the Bent model in the NRT processing. The values are recorded on a regular grid with 2 degrees resolution in longitude and latitude.

## RA2\_SET\_AX (Cartwright Amplitudes file)

This file contains the values of Cartwright amplitudes of the tidal constituents harmonic coefficients and amplitudes which are used for the computation of the solid earth tide height in the NRT and off line processing. Each record contains six harmonic coefficients and the amplitude for each potential term of the second and third order.

No update of this file has been done during Commissioning Phase.

## RA2\_OT1\_AX (Coefficient map for the ocean tide calculation - solution 1)

This file contains the values of the harmonic coefficients for the height of the principal tide waves of the GOT00.2 model. They are used for the computation of the non-equilibrium ocean tide height in the NRT and off line processing. The values are recorded on a regular grid with 0.5 deg resolution in longitude and latitude. Eight values of the A1 harmonic coefficients and eight values of the A2 harmonic coefficients are recorded at each grid point.

## RA2\_OT2\_AX (Coefficient map for the ocean tide calculation - solution 2)

This file contains the values of the harmonic coefficients for the height of the principal tide waves of FES2002 model for NRT and FES2004 for Offline processing. They are used for the

computation of the non-equilibrium ocean tide height. The values are recorded on a regular grid with 0.25 deg resolution for NRT, and 0.125 deg for OFL, in latitude and longitude. Eight values of the A1 harmonic coefficients and eight values of the A2 harmonic coefficients are recorded at each grid point.

## RA2\_TLG\_AX (Coefficients map for the tidal loading calculation - solution 1)

This file contains the values of the harmonic coefficients for the height principal tide waves of the GOT00.2 model. They are used for the computation of the height of the tidal loading effect in the NRT and off line processing. The values are recorded on a regular grid with 0.5 deg resolution in latitude and longitude. Eight values of the B1 harmonic coefficients and eight values of the B2 harmonic coefficients are recorded at each grid point.

## RA2\_TLD\_AX (Coefficients map for the tidal loading calculation - solution 2)

This file contains the values of the harmonic coefficients for the height principal tide waves computed from the Francis and Mazzega's method, using the solution 2 ocean tide model as input. They are used for the computation of the height of the tidal loading effect in the NRT and off line processing. The values are recorded on a regular grid with 0.25 deg resolution in latitude and longitude. Eight values of the B1 harmonic coefficients and eight values of the B2 harmonic coefficients are recorded at each grid point.

## RA2\_GEO\_AX (Geoid height map)

This file contains the values of the geoid heights, EGM96, during NRT and off line processing. The values are recorded on a regular grid with 0.25 deg resolution in latitude and longitude.

## AUX\_DEM\_AX (Ocean depth/land elevation map)

This ENVISAT wide file contains the values of the ocean depth or land elevation, MACCESS model to be used for the NRT processing. The values are recorded on a regular grid with a 5 minutes resolution in longitude and latitude for NRT and with a 2 minutes resolution in longitude and latitude for off line processing.

## RA2\_SL1\_AX (RA-2 slope model for Greenland data file)

This file contains the Greenland slope data to be used in the ice1/sea ice processing in off line processing. The horizontal sampling resolution for this model is 2.5 Km. Each record contains the x and y range slope components.

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## RA2\_SL2\_AX (RA-2 slope model for Antarctica data file)

This file contains the Antarctica slope data to be used in the ice1/sea ice processing in off line processing. The horizontal sampling resolution for this model is 5 Km. Each record contains the x and y range slope components.

## MWR\_LSF\_AX (Land/Sea mask map)

This file contains the values of the land/sea flag to be used for the RA2/MWR level 2 NRT and off line processing. The values are recorded on a regular grid with 2 minutes resolution in latitude and longitude. Each value is recorded at each grid point with the following meaning: 0 (oceans or semi-enclosed seas), 1 (enclosed seas or lakes), 2 (continental ice) or 3 (land).

## RA2\_MET\_AX (Altitude of meteorological grid points)

This file contains the altitude of meteorological grid points to be used during the NRT processing. This file contains only one record corresponding to the 360X181 grid points of the meteorological grid found in the predicted meteorological data.

## AUX\_ECF\_AX and AUX\_ECA\_AX (ECMWF forecast and analysis meteorological data files)

The predicted ECMWF data provided by ECMWF are relative to the prediction of the wet and dry tropospheric corrections, and the 10 m wind vectors. They are used in the NRT processing to compute the wet and dry tropospheric range corrections and the sea state bias correction to be applied on the altimeter measurement. The ECMWF parameters used during the processing are the relative humidity, geopotential, temperature, mean sea level pressure, and U and V components of the 10 m wind vector. The first three parameters are profiles (relative to 21 altitude levels of the meteorological model) while the three latter ones are surface parameters. All of them are provided on a global regular grid, with 1 deg resolution in longitude and latitude.

The meteo data coming from Meteo-France, that uses as input the analysis ECMWF products, is used for the off line processing.

### 2.9.4 Common Auxiliary Data Sets

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The auxiliary files used for both Level 1b and Level 2 processing are the following:

## RA2\_CST\_AX (RA2/MWR Constants file)

This file contains constant values (e.g. semi minor/major axis of the ellipsoid, speed of light) that are extracted from the L1b and L2 processing functions such that they are used with the same resolution and accuracy during both levels of processing.

## RA2\_CHD\_AX (RA2 Characterisation file)

This file contains data that describes the basic characteristics of the instrument (e.g. AGC tables chirp slopes) and default calibration factors to be used during the L1b processing in case the nominal processing does not retrieve valid results. Some parameters in this file are also used during the L2 retracking processing (e.g. chirp slopes, factor for PTR width computation).

## DOR\_POR\_AX, DOR\_VOR\_AX and AUX\_FRO\_AX (restituted Orbit State vector files)

These files are used to obtain the orbital parameters (lat, long, height and height rate) by using orbit computation routines.

In order to improve the accuracy of the orbital parameters in NRT, a new Orbit file: the DORIS Full rate NRT Navigator file (DOR\_NAV\_0P) is foreseen to be used for the NRT processing, by using an interpolation routine.

## 2.10 Latency, Throughput And Data Volume.

### 2.10.1 Product Latency

The Fast Delivery GDR (FDGDR) product is transmitted in less than three hours. An ocean-related parameter subset of the FDGDR called FDMAR (for Marine Abridged Record, the ocean-related parameter subset of the FDGDR extracted to reduce the volume of on-line data transfers) is converted into the BUFR format commonly used by Meteorological Offices and transmitted in less than three hours.

The interim GDR, IGDR, (for ocean-circulation monitoring and forecasting applications is delivered in less than three days.

The final GDR and SGDR products (containing the most precise instrument calibrations and orbit solutions) are delivered after 30 days (not more than 50 days).

A description of the relationship between products is given in [Organization of Products 2.2.](#)

## 2.10.2 Product size

Table 2.6 Product size

Level 0 RA-2 and MWR	75 Mb per orbit and 2.5 MB per orbit
Level 1b	34 to 43 MB (when burst mode data is included) per pass (pole to pole)
Level 2:	
FDGDR, IGDR, GDR	7 MB per pass (pole to pole)
FDMAR, IMAR	2MB per pass (pole to pole)
SDGR	31 to 40 MB (when burst mode data is included) per pass (pole to pole)

## 2.11 Characterisation And Calibration

Any instrument, after it has been built, is submitted to test in the industry laboratory in order to characterise it and calibrate it. This set of tests is normally called "Characterisation and Parameter Optimisation", and they are devoted to:

- verify that the operating characteristics of the instrument (e.g. Tx peak power, Rx gain, etc.) are within the specified limits
- measure the real values of some of the instrument characteristics, that are later used in the ground processing (e.g. Level 1b) through the Characterisation file
- ameliorate the tuning of the instrument parameters by finely varying, when necessary, parameters of the dispatch area or look-up tables

Later, in-flight, the majority of these tests when possible shall be repeated, to ensure that this characterisation is maintained after the launch. In particular for the third point described above, the test shall be repeated in-flight using real data to improve the results found on-ground with test or simulated data. For this in-flight optimisation see Section 3.2.2 (RA-2 In flight Performance verification).

Instrument characterisation and calibration are described in [RA-2 and MWR Instruments \(Chapter 3.\)](#) for both RA-2 and MWR.

## 2.12 Data Handling Cookbook

### 2.12.1 Hints And Algorithms For Product Use

The evaluation of the quality of the EnviSat Altimetry geophysical data products and the cross calibration on ERS-2 and other flying altimeters (e.g. TOPEX, Jason, GFO,...) has been performed during the Commissioning Phase within a team of scientists drawn up from the pre-launch announcement of opportunity: the RA-2/ MWR Cross-Calibration and Validation Team (CCVT).

The product validation approach has been to verify, with real data, the consistency of the product package (document, media, format and actual data set), to quantify the inherent validity and accuracy of the range, altitude, wave height, wind speed measurements. etc. and geophysical corrections.

Here follow the main results of the work performed by the CCVT in terms of altimetric parameters performance, errors, proposals for future algorithmic improvements, etc.

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SWH:

RA-2 measures low wave heights much better than ERS, due to the presence of two additional digital filters located on the waveform leading edge to improve the slope estimation. The zero-clipping has been reduced (although not completely eliminated) in EnviSat, wrt ERS-2, due to a better SWH retrieval algorithm.

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EnviSat SWH compares well with ERS-2, buoys and models: EnviSat SWH are 21 cm (or 3%) higher than ERS-2, there is a 10 cm bias with buoys, a 16 cm bias with WAM SWH model and 21 cm rms/WAM.

- 

Sigma0/wind speed:

RA2 wind speed rms is only 1.4 m/s, compared to ECMWF fields.

Ku-band sigma0 was artificially aligned with ERS-2 to satisfy modified Witter and Chelton wind model.

The estimated value of the sigma0 bias, coming from the absolute calibration activities, is around 0.95 dB (RA-2 higher), pretty much in line with the results of the RA2 passive calibration (0.91 dB). The passive calibration activities have provided also with a (preliminary) value of the interfrequency bias, set currently to 1.05 dB.

This value will be further tuned with larger sets of data.

The actual values of Ku sigma0 coming from the absolute calibration will be applied to the data only when a new wind model will be developed.

- 

Range:

The range noise, estimated on short segments over low waveheight areas of the ocean, is 1.8 cm and 5.2 cm (at 1 Hz) for Ku-band and S-band, respectively.

From the cross-calibration with ERS-2, a bias of around -40 cm was found (but this value could be still sensitive to preliminary sea state bias model).

An improved noise spectrum, with a higher frequency signal (than in ERS) is present: 14 Km, and less when 20 Hz data is used.

Using the output of the ocean retracker and the geophysical corrections in the product, the sea surface height rms at cross-overs was estimated by CLS, Newcastle Univ. and MSSSL, at respectively, 8.22, 7.0 and 8.5 cm, with a further reduction to 6.25 cm when an orbit error correction was applied by CLS.

- 

Time-tag bias:

The pseudo time-tag was estimated minimising cross-overs over ocean. No significant slope was detected in the sea surface height as a function of the altitude rate, therefore confirming that there is no significant time tag error.

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Mispointing:

The square estimated mispointing is less than 0.01 deg<sup>2</sup>. The mispointing value in the L2 products (around 0.026 deg<sup>2</sup>) is erroneous.

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The algorithm in the operational processors is being investigated.

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Geophysical corrections:

The dual frequency ionospheric correction was evaluated against JPL GIM model (depending on the SSB which is not yet final on the limited data set available) with good agreement between both. The DORIS model, instead, showed an unrealistically limited dynamic range compared to the GIM and dual-freq corrections.

The DORIS iono has been in the meantime improved.

All other geophysical corrections have been validated.

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MWR calibration and validation:

The Level 2 wet tropo correction is in very good agreement with the ERS-2 MWR one (relative bias < 5 mm) and with the radio-soundings.

MWR 36 GHz channel may require anyway some stabilisation due to aging and thermal cycling of the components. The current drift from the beginning of the mission is of 0.25 counts/K.

A new MWR side lobes correction, to be implemented in a near future in the operational L1b processor, will improve the MWR corrections in the affected areas (coastal zones).

A new neural network algorithm has been recently implemented for the computation of the MWR corrections.

Continuous monitoring of the 36 GHz channel gain drift and local oscillator behaviour is recommended, to assess possible stabilisation.

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Orbit error:

Orbit heights from CNES, NCL, DUT and ESOC agree to within 2-3 cm rms. Radial orbit error on the GDRs is estimated < 4 cm rms.

The orbit propagated into the NRT FDGDR/FDMAR products does not yet use the DORIS Navigator, so it is very poor: 20 to 30 m error in the radial component with jumps of several meters between orbit state vectors.

The orbit upgrade is currently under investigation and will be implemented in a near future.



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## Chapter 3

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# RA-2 and MWR Instruments

### 3.1 RA-2 Instrument Description

RA-2 is a nadir-looking pulse-limited radar altimeter based on the heritage of ERS-1 RA functioning at the main nominal frequency of 13.575 GHz (Ku Band), which has been selected as a good compromise between the affordable antenna dimension that provides the necessary gain and the relatively low attenuation which experience the signals propagating through the troposphere.

A secondary channel at a nominal frequency of 3.2 GHz (S band) is also operated to estimate the errors on range measurements caused by the propagation of the radar signals through the ionosphere.

At the main operative frequency RA-2 shall autonomously detect, acquire, lock-on and track the earliest part of the radar echoes from ocean, ice and land surfaces without any interruption, irrespective of sudden changes in surface characteristics and elevation; after successful acquisition RA-2 shall autonomously start the tracking. Operations shall be accomplished by automatically changing the range resolution, the width, the position and the overall gain of the radar tracking window. The tracking shall always be performed with the highest resolution that allows the earliest part of the radar echoes to be maintained within the radar tracking window, in order to continuously measure on board their power levels and time positioning with respect to transmitted pulse power and time. Over ocean the resolution shall always be the highest available on-board. Furthermore RA-2 shall detect whenever the earliest part of the radar echo is no longer within the tracking window and autonomously recover from this condition.

The estimates of the time delay, radar cross section ( $\sigma_0$ ) and the standard deviation ( $\sigma_s$ ) of the height distribution of the scatters on the Earth's surface are performed on ground by fitting to the samples of radar echoes, for both the Ku and S band, the model of the shape of the radar echoes from ocean (G. S. Brown). From these parameters, the satellite altitude, the wind speed magnitude, and the wave height of the oceans can be respectively retrieved. The estimations of these parameters can be averaged over a period of approximately 1 second to reduce random fluctuations.

The RA-2 transmits with constant repetition rates radar pulses of 20  $\mu\text{sec}$  length; namely one Ku pulse is transmitted every 557  $\mu\text{sec}$ , and one S pulse is transmitted every 4 Ku consecutive pulses which corresponds to a pulse repetition interval of 2228  $\mu\text{sec}$ .

At Ku band pulses may be unmodulated (CW pulse) or linear frequency modulated with bandwidths selected among the three (320 - 80 - 20 MHz) available to adapt the range resolution to the observed scenario. In particular use of CW pulse is foreseen during the acquisition phase of the measurement mode which is required to initialize the tracking measurement phase. On the contrary, at S band a unique linear frequency modulated pulse 160 MHz bandwidth is used.

RA-2 is composed by the following sub-systems: Antenna, Ku-Band Front End Electronics (KFEE), S-Band Front End Electronics (SFEE), Ku-Band Transmitter (KTx), S-Band Transmitter (STx), Microwave Subsystem (MR), Frequency Generation and Conversions Unit (FGCU), Chirp generator (CG), Signal Processor Subassembly (SPSA), Low Voltage Power Supply (LVPS) and the Instrument Control Unit (ICU). A block diagram of the radar is shown in fig. 3-1. All the Subsystems with the exception of the Antenna are redounded to improve instrument reliability.

Each Front End connects the related transmitter and receiver input with the Antenna. Its main purpose is to isolate during transmission the high sensitive receiver and prevent it from being damaged by the high peak power level of the transmitted waveform which is however also injected in the receiver through a well controlled coupling path inside the FEE to calibrate the radar. On reception, when the transmitter is off, the FEE routes to the receiver the weak radar echoes impinging on the antenna through a very low loss path. In the MR each received radar echo is mixed with a delayed replica of the transmitted chirps (deramping operation) and down-converted to an Intermediate Frequency (IF) where signals can be more easily amplified and then split into their in-phase and quadrature components (I & Q) and filtered to 6.4 MHz. An Automatic Gain Control (AGC) adjusts the whole value of the receiver amplification to maintain the I and Q components at a constant and suitable level for the sampling.

FGCU provides all the frequencies which are necessary to the instrument. It contains the Ultra Stable Oscillator (USO) which is the frequency reference of the instrument.

CG generates the CW pulses and linear frequency modulated pulses through Surface Acoustic Wave (SAW) devices.

SPSA converts to digital samples the I & Q components of the signal and calculates the signal spectrum by an FFT on 128 points. After square modules extraction the results are accumulated over 55.7 msec to reduce signal fluctuations, leading to average Ku and S waveforms. In particular, 100 return echoes from the primary channel (Ku Band) and 25 from the secondary channel (S Band) will be accumulated during the specified time interval, being the Pulse Repetition Interval for the primary channel equal to 557 sec and for the S channel equal to 2228 sec (one S pulse in transmitted every four Ku pulses).

Pulse compression of LFM pulses is accomplished through the well established concept of deramping. The returning signal, actually composed of many chirps each reflected from a different facet of the surface observed, is then mixed with a delayed replica of the transmitted signal.

The Deramping Mixer generates signals which are the difference frequency between its two inputs. As the two inputs have the same rate of change of frequency, the output frequencies are constant tones. Being the input signals linear, mapping between the time offset of each individual chirp respect to the reference chirp into a frequency offset is then being generated.

As a result of the deramping process, targets with different range will give tones at different frequencies that can be resolved by a filter bank of adequate frequency resolution (comparable to the reciprocal of the radar pulse length) which is efficiently implemented through a simple FFT processing after analogue to digital conversion. Deramping allows to reduce the analogue signal bandwidth when receiving LFM pulses from scatters over a small range swath size like the one observed by an altimeter, strongly reducing the speed requirements of A/D converters. Furthermore, the deramping approach allows to strongly

reduce instrument performance sensitivity to amplitude and phase distortions of RF subsystems up to the DRM stage. Just the amplitude distortions of filters and amplifiers down the DRM shall be taken into account and properly monitored through specific in-flight internal calibration procedure for their off-line correction on the altimeter echoes samples on ground.

The RA-2 instrument can be operated in different modes which belong to the following major classes:

Support modes

Operation modes

Support modes are used during instrument initialization procedures, and failure recovery procedures.

The Operation modes include the Measurement mode, the RF and Digital BITE (Built In Test Equipment) and the IF Calibration mode.

All the relevant information collected in any of the operation modes are transferred to ground in a standard layout denoted as Source Packet which contains 1.114 seconds of data (corresponding to 2000 Ku PRIs) organised in sets of 20 data blocks; each data block includes data collected over a period of 100 Ku PRIs.

RF and Digital BITE allow testing of the RF chains and of the digital sections respectively. Due to their specific verification oriented purpose, their use in orbit is not planned unless problems are encountered in the operations with the nominal chain.

The IF Calibration mode is instead specifically designed for periodic in-flight absolute calibration of amplitude distortions within the receiver noise bandwidth of the receiving sections after the deramping mixers (common to Ku and S chains). The instrument is operated to collect thermal noise samples and perform spectral analysis by FFT algorithm to retrieve the spectral shape of the noise within the bandwidth of interest. Noise spectra, averaged over sets of 100, are down linked on ground to calculate the IF filter correction

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mask.

- Measurement Mode

The Measurement mode is the principal operation mode of the altimeter, the main objective being the continuous tracking of the return echo time delay and the return signal power. During tracking additional functions are sequentially performed under control of a scheduler.

- Acquisition

Acquisition measurements will be performed at the beginning of the Measurement mode since no a priori knowledge of the satellite height over the surface is available. Furthermore an Acquisition phase is required whenever a loss of tracking is detected by the on board tracker of the RA-2 in order to properly reinitialize the Tracking.

Acquisition consists of an NPE (Noise Power Estimation), a Detection Phase and an AGC Setting Phase. Each of these phases shall in principle be skipped if requested from ground but default values shall be used in place. Even the whole Acquisition phase shall be skipped and the Tracking phase of the Measurement mode shall start with default preloaded values. This particular situation is known as "Preset Tracking"

The NPE phase is required to measure the instrument thermal noise level. It is accomplished by averaging over the Ku band noise samples collected in five time windows of 426.66 msec duration each and sampled at a frequency of 6.4 MHz. This results in 2731 noise samples for each of the 5 PRIs considered. During this phase the AGC is maintained constant at a default value AGCNPE contained in the Dispatch Area of the SPSA unit.

NPE can be repeated for two times in case of failure (i.e. comparison between the computed value and an allowed expected predefined range fails). After a second attempt a default value for the noise power level, extracted from the Dispatch Area, is used.

Completion of the NPE phase is followed by a FIRST DETECTION phase: 232 Ku band echoes, one every two Ku PRIs, resulting from the transmission of 20 \_sec unmodulated radar pulses, are averaged together and compared with the previously computed noise power level to estimate the echo leading edge position within the pulse repetition interval. During this phase the AGC is maintained at a constant reference level AGC Det1 defined in the Dispatch Area.

The computed leading edge position is compared wrt an allowed predefined range (typically the expected orbit variation). If the value is out of range, the detection is repeated from the beginning with a new AGC Det2 value.

If the SECOND DETECTION phase test also fails, the Acquisition phase will restart from the beginning otherwise the AGC SETTING phase is executed.

During this phase the mean power level of the averaged echo is computed to properly set the AGC for the incoming Tracking phase. The mean power level is evaluated from the 100 signal samples around the estimated leading edge position. The computed AGC is then compared wrt an expected allowed range. In case of failure, a default value, defined in the Dispatch Area of the SPSA, shall be used in place.

The duration of the Acquisition phase is mainly driven by the result of the Detection phase. To give an idea the following 5 elementary cases are reported:

Table 3.1

Case	Acquisition Case	Duration
1	- first NPE successfully completed - first Detection successfully completed	600 Ku PRIs (6 Data Blocks)
2	- first NPE failed - second NPE successfully completed - first Detection successfully completed	700 Ku PRIs (7 Data Blocks)
3	- first NPE successfully completed - first Detection failed - second Detection successfully completed	1200 Ku PRIs (12 Data Blocks)
4	- first NPE failed - second NPE successfully completed - first Detection failed - second Detection successfully completed	1200 Ku PRIs (12 Data Blocks)
5	- first NPE successfully completed - first Detection failed - second Detection failed -----> AQUISITION Restarted - first NPE successfully completed - first Detection successfully completed	1800 Ku PRIs (18 Data Blocks)

- Tracking

The instrument is continuously transmitting in both bands linear frequency modulated pulses. Only received Ku band waveforms are fully processed on-board; S band waveforms are, instead, simply collected and sent to ground in the science data telemetry.

For each Ku band echo 128 In-Phase/Quadrature samples are gathered using 8 bit A/D converters with 6.4 MHz sampling frequency.

Samples are then Hamming weighted and corrected for the fine Rx-delay information:

$$X_{WH}(n) = X(n) \cdot W_H(n) \cdot e^{j \cdot \frac{2 \cdot \pi}{N_{fft}} \cdot \Delta_{shift}} \quad \text{eq 3.1}$$

where:

$n = 0..NF-1$  ( $NF = 128$ )

$W_H(n)$  is the Hamming weighting law

$X(n)$  is the n-th I/Q sample

$XW(n)$  is the n-th corrected I/Q sample

$\Delta_{shift}$  is the fine shift component of the Rx delay information

The Rx delay information computed by the on-board processor to give the position of the tracking window within the Ku PRI, is quantized according to the Tx/Rx clock period, derived from the Ultra Stable Oscillator frequency, i.e. 12.5 nsec; any fine adjustment within 12.5 nsec is accomplished in principle by right rotating the waveform spectrum in the FFT filter bank through the complex exponential term of equation [\(click here\)](#) -1 instead of moving the receiving window.  $\Delta_{shift}$  thus represents the fine adjustment required once expressed in units of FFT filters.

The corrected 128 I/Q samples are then Fast Fourier Transformed:

$$X_F(K) = \sum_{n=0}^{N_{sc}-1} X_{I/Q}(n) \cdot e^{j \cdot \frac{2 \cdot \pi}{N_{sc}} \cdot K \cdot n} \quad \text{eq 3.2}$$

$K = 0, \dots, N_F - 1$

The square modules of each transformed sample is extracted and an amplitude fine correction term is applied as a multiplicative factor:

$$P(K) = |X_F(K)|^2 \cdot A_{fA} \quad \text{eq 3.3}$$

The fine amplitude correction term accounts for that part of the on-board attenuation, AGC, which cannot be applied through the RF attenuators since these devices are controlled with a resolution of 1 dB.

The computed waveform is finally accumulated over 100 Ku PRIs.

Two additional waveform samples shall also be computed by the on-board processor by performing a DFT algorithm on the corrected I/Q signal samples. A square modules extraction and an accumulation over 100 Ku PRIs is performed even in this case. The two



DFT samples are computed in the middle of any two adjacent FFT filters; the indexes for the two selected DFT samples are specified in the Dispatch Area in the form of memory addresses for the selection of the sine/cosine table required in the evaluation of the DFT formula.

Except for the DFT samples computation, the above steps apply even for the S band echo samples processing; accumulation is in this case accomplished over 25 echoes and only the 64 central waveform samples of the average echo will then be passed into the source packet and transferred to ground.

The 128 samples of the Ku average waveform will instead be used to update the tracking window position and the AGC. To properly perform this operation a parallel task called Noise Power Measurement (NPM) is periodically (every 32 seconds) performed and consists in estimating the instrument mean noise power level by collecting noise samples for 10 µsec soon after the transmission of the Tx pulses within the Ku PRI. The computed noise power level, once it is multiplied by a proper scaling factor, is used to hard limit the Ku average waveform samples:

[See](#)

$$T(i) = 1 \quad \text{eq 3.4}$$

if

$$P_{av}(i) \geq T_s \quad \text{eq 3.5}$$

$$T(i) = 0 \quad \text{eq 3.6}$$

if

$$P_{av}(i) < T_s \quad \text{eq 3.7}$$

where  $T_s$  is the threshold computed from the noise power level estimate. The width  $W$  and the centre of gravity  $B$  of the binary vector  $T(i)$  are then evaluated:

$$W = \sum_{-N_{\text{fft}}/2}^{N_{\text{fft}}/2 - 1} T(i) \quad \text{eq 3.8}$$

$$B = \frac{\sum_{-N_{\text{fft}}/2}^{N_{\text{fft}}/2 - 1} i \cdot T(i)}{W} \quad \text{eq 3.9}$$

The echo leading edge position wrt a reference FFT filter shifted of  $\Delta_{\text{offset}}$  filters on the left side of the centre of the FFT filter bank is then computed as:

$$P = B - W/2 - \Delta_{\text{offset}} \quad \text{eq 3.10}$$

The leading edge positioning error is then converted in to time units through the chirp bandwidth currently in use:

$$\varepsilon_P = P \cdot \frac{1}{B_c} \quad \text{eq 3.11}$$

and also used as a key information by the Resolution Selection and Loss of Lock Detection logic to allow automatic switching among the three resolutions available at Ku band as well

as to go back to the Acquisition phase whenever the tracking condition is considered lost.

See further details on the on-board tracker and the Resolution Selection Logic in "The On-board tracker and its autonomous adaptable resolution" technical note (PO-TN-ESA-RA-1316).

Similarly for the AGC correction, the waveform amplitude is estimated first:

$$A = \frac{\sum_{i=-N_{\text{win}}/2}^{N_{\text{win}}/2-1} P_{av(i)}^2}{\sum_{i=-N_{\text{win}}/2}^{N_{\text{win}}/2-1} P_{av(i)}} \quad \text{eq 3.12}$$

The error wrt a reference power value Pref, defined in the Dispatch Area of the SPSA unit, is then evaluated:

$$\varepsilon_{AGC} = 10 \cdot \log_{10}(A) + P_{ref} \quad \text{eq 3.13}$$

Both errors  $\varepsilon_p$  and  $\varepsilon_{AGC}$  are fed in input to a-b filters whose purpose is to update estimates of the tracking window position and of the AGC. The general structure of the  $\alpha$ - $\beta$  filter is the following:

$$x_c(n) = x_p(n) + \alpha \cdot \tilde{x}(n) \quad \text{eq 3.14}$$

$$x_w(n) = x_w(n-1) + \beta \cdot e(n) \quad \text{eq 3.15}$$

$$x_p(n+1) = x_c(n) + x_p(n) \quad \text{eq 3.16}$$

The values  $x_p$  (predicted rate) and  $x_c$  (predicted value) are updated every 100 Ku PRIs since the error terms are available only after a Ku average waveform has been collected. Since the tracking window position and the AGC values are required every Ku PRI a linear interpolation technique starting from  $x_p$  and  $x_c$  will be used to generate values at the required rate. These values will be split in coarse and fine correction terms as already briefly indicated.

During Tracking the instrument is also performing internal calibration measurements without interruption of tracking by coupling the output signal in the receiver through the calibration path of the Front End. One Point Target Response (PTR) measurement is performed every source packet (1.114 seconds) interleaving between the Ku and the S band. In particular, one S PTR measurement is performed every 4 source packets, leaving the other 3 source packets available for the PTR measurement at Ku band. In this case, since more than one chirp bandwidth is managed by the on board processor, only the chirp bandwidth currently in use at the time of the calibration task execution is then effectively calibrated. The In-phase and Quadrature samples of the PTR measurement will be used on ground to retrieve the flight calibration data needed for instrument errors correction.

On request by macrocommand individual echoes can be included in the scientific data stream and sent to ground: single Ku channel return echoes after A/D conversion are sent to ground

without performing FFT, square modules extraction and accumulation. The only constraint is that no more than 1.114 seconds (2000 PRIs) of individual echoes shall be acquired and transmitted.

A special operating function within the tracking phase is also available on request by macrocommand. It is the "Preset Loop Output" and consists in opening the two on-board tracking loops (one or both) for a predefined duration.

- RF and Digital BITE

BITE mode is initiated by macrocommand and it is suitable for both hardware and software check. It is divided into RF and Digital BITE for verification of the Tx/Rx chain and digital processing, respectively. RF BITE is executed from the Measurement mode by performing and open loop calibration using the same technique as for open loop calibration during tracking. RF BITE is executed cyclically until a mode change request is received. Three test phases are identified within the RF BITE:

the first phase lasts 2400 Ku PRIs (24 Data Blocks: 1 full source packet- except for first data block, always spare - and 4 data blocks of the successive one);

the second one lasts 600 Ku PRIs (6 Data Blocks);

the third one lasts 1000 Ku PRIs (10 Data Blocks).

In the first phase averaged waveform data are collected 6 times for each of the 3 Ku chirp + S chirp bandwidths using every time a different AGC value.

In the second phase an A/D conversion process is executed over a time window of 30  $\mu$ seconds leading to the collection of 192 I/Q samples. A square modules extraction and an averaging over 100 Ku PRIs will then take place and samples transferred in the source packet in place of the 128 Ku and 64 S waveform samples of a data block. This type of measurement is executed 6 times using the following resolutions: CW - 320 MHz - 80 MHz - 20 MHz - 160 MHz (S band) and 1 dummy.

In the third phase, 128 I/Q samples are acquired, then a square modules extraction and an averaging process over 100 Ku PRIs takes place.

The total duration is of 8 data blocks. The source packet is completed with one spare data block. In the first five the 320 MHz chirp bandwidth is used, in the second five the 160 MHz chirp bandwidth is used in place. The 128 averaged waveform samples are finally transferred in the data blocks of the source packet in place of the 128 Ku waveform samples during tracking.

Digital BITE is instead based on an open loop tracking technique (Preset Loop Output) as the one already foreseen during the Tracking phase, using preloaded I/Q signal test samples. Digital BITE is executed cyclically with a minimum duration of one source packet, i.e. 20 data blocks are filled in with Digital BITE data.

- IF Calibration Mode

Switching from Measurement mode to the IF Calibration mode is required to monitor changes in the IF filter mask caused by significant variation of the mean operating temperature of the instrument.

In IF Calibration mode the instrument collects thermal noise samples and performs Fast Fourier Transform over sets of 128 noise samples.

Average noise spectra resulting from the averaging of 100 consecutive FFT outputs after square modules extraction are transferred in the data blocks of the source packet in place of the 128 Ku waveform samples. They will be used on ground to estimate the IF filter shape. The IF Calibration mode is commanded from ground via a macrocommand.

## 3.2 RA-2 Instrument Characteristics and Performance

### 3.2.1 Pre-flight Characteristics and expected performance

A simplified RA-2 block diagram is sketched in the following figure: to reduce impacts on instrument complexity, the same hardware is used (on a time-shared basis) as much as possible for both the Ku and S band channels. All the subsystems with the exception of the antenna are redounded according to ENVISAT project system level requirements. The key system parameters of the instrument are listed in Table 3.2-1.

RA-2 is composed by the following sub-systems: Antenna, Ku-Band Front End Electronics (KFEE), S-Band Front End Electronics (SFEE), Ku-Band Transmitter (KTx), S-Band Transmitter (STx), Microwave Subsystem (MR), Frequency Generation and Conversions Unit (FGCU), Chirp generator (CG), Signal Processor Subassembly (SPSA), Low Voltage Power Supply (LVPS) and the Instrument Control Unit (ICU).

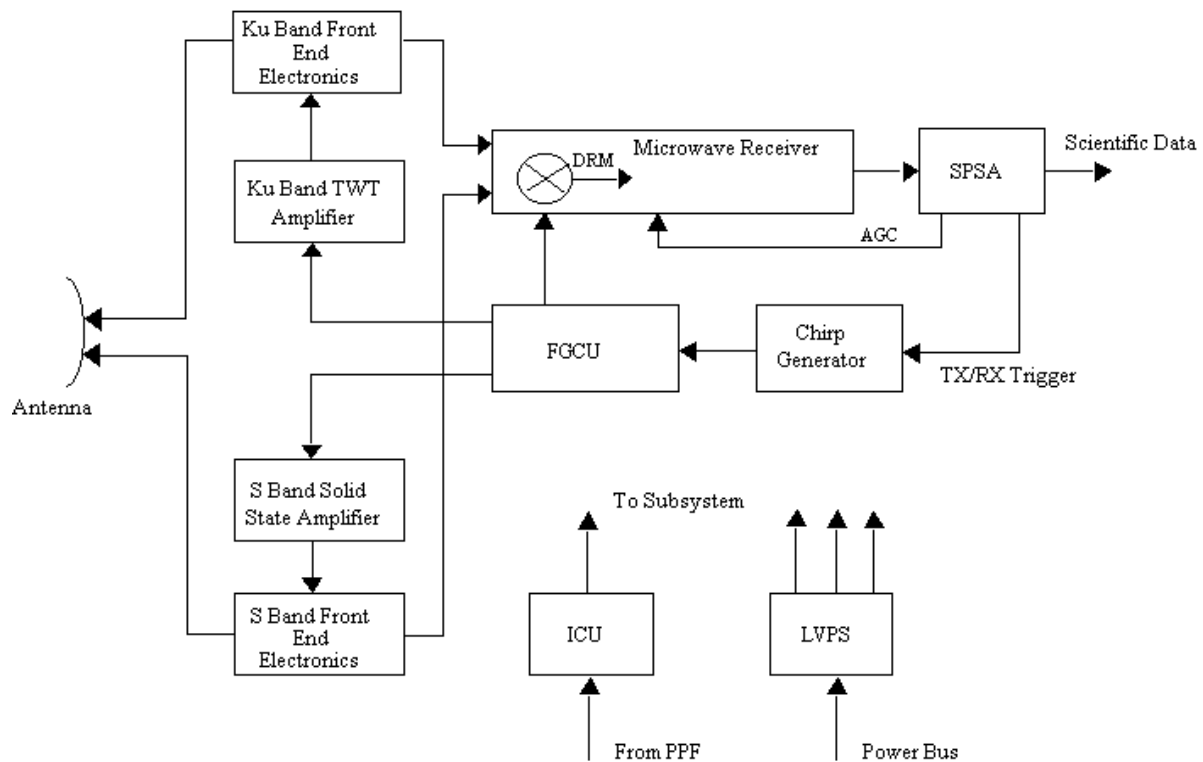


Figure 3.1 RA-2 Functional Block Diagram

Table 3.2 RA-2 key system parameters

Orbit Range	764 - 825 Km
Operative Frequency	13.575 GHz (Ku) 3.2 GHz (S)
Pulse Length	20 $\mu$ s

Ku Tx pulse Bandwidth	320 - 80 - 20 MHz - CW
S Tx pulse Bandwidth	160 MHz
Tx Peak Power	60 W (Ku) 60 W (S)
Pulse Repetition Interval	557 ms (Ku) 2228 ms (S)
Antenna Gain	41.6 dBi (Ku) 29.2 dBi (S)
Antenna -3 dB Beamwidth	1.35 deg (Ku) 5.5 deg (S)
IF centre frequencies	1223 MHz / 75 MHz
RF Losses	1.8 dB (Ku) 1.7 dB (S)
Receiver Maximum Gain	107 dB
AGC dynamic range	60 dB programmable in 1 dB step
Receiver Noise Bandwidth	6.4 MHz
Receiver Noise Figure	3.0 dB (Ku) 2.5 dB (S)
USO frequency & stability	10 MHz (10-9 over 24 Hours)
FFT Processor	128 points
A/D conversion (no. bits)	8 + 8
Data Rate	100 Kbit/s

### 3.2.1.1 Chirp Generator

The Chirp Generator (CG) unit provides the chirp signals at 450 MHz centre frequency employed for the generation of the transmission signal and for the LO signal used in the deramping process, for both Ku and S band chains. The three chirp bandwidths that can be synthesised are 160 MHz, 40 MHz and 10 MHz. The CG uses SAW RAC (Surface Acoustic Wave - Reflective Array Compressor) technology. To achieve the 35% bandwidth needed for the 160 MHz LFM signal, a LiNbO<sub>3</sub> substrate has been used; this design provides a very tight control of the amplitude and phase ripples required to keep sidelobes of the compressed signal down to -30 dB.

### 3.2.1.2 Frequency Generation and Conversion Unit

The Frequency Generation and Conversion Unit (FGCU) has two major tasks: to provide all the reference frequencies required by the instrument and to up-convert the chirp signal from the CG. All frequencies are synthesised from a reference 10 MHz Ultra Stable Oscillator (USO) and from a stable local oscillator 101.937 MHz frequency. The Ku band up-converter chain includes a frequency doubler and provides 320 MHz, 80 MHz and 20 MHz chirp signals at 13.575 GHz centre frequency to the Ku band transmitter and to the Microwave Receiver, where, after a further translation to 14.798 GHz, is used in the LO branch of the DRM. A single tone pulse for the Tx and a CW LO can also be provided for the acquisition phase. The S band up-converter operates only with the 160 MHz chirp which is translated to a centre frequency of 3.2 GHz; a second chain derives the 4.423 GHz for the LO branch of



the S band DRM in the receiver.

### 3.2.1.3 Transmitter

The Ku band signal is amplified by the Ku band transmitter, which uses a TWT amplifier to provide 60 W peak power at 3.6 % duty cycle, the amplified signal is sent to the antenna through the Ku band Front End, a high isolation switch that uses switched circulators to perform the Tx/Rx duplexing function.

As far as the S band RF chain, it is similar to the Ku chain but uses a solid state transmitter and a PIN diode duplexer switch in the transmission section.

The S band solid state technology amplifier uses class C bipolar transistor in the final and driver stages and provides 60 W peak power at 1 % duty cycle.

### 3.2.1.4 Antenna

The antenna is an onset 1.2 meters diameter parabola using a coaxial Ku/S band feed, developed by ALS.

### 3.2.1.5 Microwave Receiver

The signal received from the antenna is supplied, through the Ku FEE, to the Microwave Receiver (MR), which after low noise amplification, performs the deramping function. The 14.798 GHz LO is generated in the MR from the same 13.575 GHz used in the transmission chain through the 1.223 MHz frequency which, together with the 75 MHz, are used as the reference frequencies to down convert the received signals. The MR performs also the AGC and band-limiting functions providing as output the in-phase and quadrature components of the received signals. Also, separate low noise amplifier and deramping mixer are used in the MR: all the electronics following the deramping function is instead common to the Ku and S band chains.

For the S FEE is concerned, need for a compact design but allowing at the same time good insertion loss and isolation figures, have led to develop an innovative design approach, using PIN diode switches in shunt configuration on a Squared Coax transmission line.

### 3.2.1.6 Digital Processing Subassembly Unit

In-Phase and Quadrature samples of the received signals as provided by the MR are digitally converted in 8+8 bit format by the Signal Processing Subassembly Unit. The 128 I/Q samples thus obtained (a 6.4 MHz clock is used in the A/D conversion process over a time window of 20  $\mu$ s) are further processed to allow real time on board tracking of the radar echoes by exploitation of the Ku band data. Additional processing tasks are actually performed by the SPSA during the tracking operations like instrument Point Target Response samples collection, Receiver Noise Power Measurement, computation of two additional Ku band waveform samples in user's selected positions, collection of individual echoes on request from ground. A more detailed description is hereafter available. The SPSA, core of the altimeter instrument has been developed by ALS.

The FFT processing board required to implement the digital filter bank for the radar pulse compression through the full deramping technique is based on the TMC2310 DSP device (by TRW-USA), which performs 128 points complex FFT using a block floating point arithmetic in 16 bit format. Echoes accumulation over multiple radar sweeps (100 for Ku and 25 for S band) is performed using a 24 bit internal adder while averaged waveforms are returned in 16 bit unsigned integer format.

The tracker processing board is instead based on the general purpose microprocessor MA61750.

Most of the tracker processing functions are implemented in 32 bit floating point arithmetic, but for the range measurement related processing tasks which are implemented in 48 bit extended floating point format to guarantee for the best precision of the data. Approximately 70 parameters are used to optimise operations in the Measurement mode. All parameters are modifiable from ground using specific macrocommands. More generally the entire SPSA SW is patchable from ground via the ICU.

The whole instrument timing is generated by the SPSA and relies on the 80 MHz reference signal synthesised by the FGCU starting from the 10 MHz USO frequency. Tracking is accomplished by shifting within the PRI the position of the LO chirp pulse in steps of 12.5 nsec. Fine adjustments of the tracker window position within the 12.5 nsec are obtained by shift rotating the echo samples through complex multiply by a phase varying reference function before FFT execution. Shifts as fine as 1/256 of the 12.5 nsec clock period are made possible by the implemented technique.

### 3.2.1.7 Low Voltage Power Supply and Instrument Control Unit

The last two units in the block diagram are the Low Voltage Power Supply (LVPS) which provides regulated voltages lines to the other units and the Instrument Control Unit (ICU).

The ICU is in charge of controlling and monitoring the instrument health and operations and interfaces with the platform. The ICU architecture is still based on the MA61750 general purpose microprocessor and similarly to SPSA, ICU SW is fully patchable from ground.

### 3.2.2 In-flight Performance verification

Results can be found on the web site of the ENVISAT Symposium, helded in Salzburg - Austria from 6 to 10 September 2004 : <http://earth.esa.int/workshops>

## 3.3 MWR Instrument Description

The Instrument is a dual channel radiometer, operating at 23.8 GHz and 36.5 GHz, based on the Dicke radiometer principle.

The nadir pointing antenna receives radiation in two microwave frequency bands, in linear (vertical) polarisation.

These frequencies are separately routed into the RF front-end, where the two signals are filtered from external interferences, separately down converted and Low Noise amplified.

IF amplification, filtering quadratic detection and continuous interleaved samplings performed by the CEU, which also provides the function of analogue to digital conversion of the scientific data-sample, by means of a Voltage to Frequency converter.

Digitised measurement data are transferred to the common ICU subsystem for transmission to the ground station via OBDH and LBR interfaces to the PPF.

A 2 point calibration scheme is adopted, with Hot and Cold reference calibration points, so that periodically the measurements of the Earth scene radiation are interrupted to allow the measurement of an on-board calibration load and of the deep cold space.

The deep Cold Space measurement shall be accomplished via the Sky-horn feed so that to provide a Cold-Reference signal, while the on-board calibration reference load, kept by the

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thermal control at the instrument physical temperature, provides a Hot Reference signal.

The calibration data-base and post-processing, will allow the calibration of the measured Earth scene data and the optimisation of the instrument accuracy performance.

The Instrument electrical interfaces, for Power, Command and Control will be accomplished via the common ICU of the MWR/Doris instrument composite, which has the tasks to:

translate Higher Level OBDH macrocommands into serial commands for MWR;

acquire MWR serial telemetry and science data packets;

translate them as Higher Level OBDH telemetry reports or as LBR Measurement Data Interface packets;

provide the Instrument with unregulated Primary Power Busses;

provide the instrument with Blanking and control signals;

include a Redundancy Switching Unit, RSU, to control the instrument interface redundancy.

Some interfaces of MWR are directly connected to the PPF, like Operational and Survival Power Buses, Blanking Pulses, Thermistors, but shall be routed in any case via the common ICU.

When integrated on Envisat-1 PPF, the MWR can only be operated as an Instrument Composite by the common ICU, together with the Doris instrument.

## 3.4 MWR Instrument Characteristics and Performance

### 3.4.1 Pre-flight Characteristics and expected performance

#### 3.4.1.1 Radiometric Receiving System

Key performances which have to be considered as the receiver design driving elements are

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the Noise Equivalent Temperature, the input impedance matching (VSWR), the frequency response, gain linearity, gain stability over temperature and ageing, Analog to Digital Converter quantisation noise.

Further design driving requirements are imposed to receivers as flight space hardware, in particular for minimum power consumption, mass, dimensions, wide temperature ranges under vacuum conditions, high reliability, exposure to radiation, electro-magnetic and radio frequency compatibility with the instrument and the spacecraft environment, mechanical vibrations and shocks, use of proven and already qualified (or at least qualifiable) technologies for space applications.

In the following major emphasis will be put on the trade-offs and design choices driven by radiometric performance, with some basic considerations regarding the construction, environment and technological aspects, as far as performance are concerned.

MWR receivers are based on the "Dicke Radiometer" concept, thus providing the improved short term gain stability but degraded ( $1/2$  according to theory) radiometric sensitivity performance when compared to Total power radiometer concept.

The detected output voltage is linear with respect to the input mean noise power collected from the antenna, i.e. the detector diode is operated within the quadratic region of its characteristics.

The receiver architectures used is the superheterodyne.

The superheterodyne offers the inherent advantage of flexibility, as by proper selection of the Local Oscillator (LO) frequency, the band defining filtering, as well as most of the needed amplification, can be allocated in a convenient Intermediate Frequency (IF) band, where adequate components and technologies can be selected to satisfy the requirements.

The key elements to be considered in the trade-offs are the filtering, amplification, and the stability aspects.

The filtering of a radiometric chain is a key element. Supposing an ideal quadratic detector characteristics, the digitalised output voltage can be expressed, in a simplified form, as:

$$V_{od} = k (T_{rec} + T_A) B_n G \quad \text{eq 3.17}$$

where  $k$  is the Boltzmann constant,  $T_{rec}$  is the receiver noise temperature,  $T_A$  is the antenna noise temperature,  $G$  is the receiver end to end transfer function (expressed as output voltage to input Antenna noise power, Volts/Watts),  $B_n$  is the noise equivalent bandwidth.

This means that all the energy collected in  $B_n$  will be detected as brightness temperature coming from the Earth scene being observed, and therefore the  $B_n$  shall be as much as possible closed to the allocated bandwidth for the radiometric measurement of that channel (the filter shape shall be as much as possible rectangular).

MWR requirements impose a pre-detector rejection of at least 40 dB in a band which is 1.7 times the RF band (pass band 200 MHz, 40 dB stop-band 340 MHz), which means that the energy collected outside the 1.7 band is 1/10000 with respect to the in-band energy.

Also the  $B_n$  variations over temperature and life will be seen as gain variations, and therefore the selected filter shall be very stable.

The best suited filters are of the Elliptical and Chebyshev type, where excellent out of band attenuation characteristics are achievable at frequencies of 1.7 times the pass band frequency, with acceptable pass band ripple and order number (acceptable filter complexity).

In case a direct detection topology would have been chosen for each of the MWR channels, fractional bandwidths in the range 0.84 % (at 23.8 GHz) to 0.55 % (at 36.5 GHz) would result.

In these conditions to achieve the required rejection a rather complex cavity filter would have

been developed, with significant size and losses. An additional constraint is represented by the required center frequency stability over temperature and life, which leads to the development of an extremely stable Invar filter or similar.

Selecting the current superheterodyne concept, the IF frequency is selected in order to achieve a comfortable fractional bandwidth, where a lumped elements filter can be used with excellent performance and higher level of miniaturisation.

Frequency stability is higher for the superheterodyne concept, due to the lower frequency (as it is a percentage of the centre frequency) and by proper selection of the Local Oscillator performance.

MWR receiver is a superheterodyne Double Side Band (DSB) with low pass filtering function at low frequency range (DC to 340 MHz).

The DSB concept also improves the receiver Noise Figure, at the expense of considering a wider RF bandwidth with respect to the IF one.

The required pre-detection band-width is about 200 MHz, and therefore by extending the RF band to 400 MHz and by choosing a LO frequency equal to the centre frequency (23.8 GHz and 36.5 GHz respectively), a base band of 0 · 200 MHz results at the mixer output: the energy in this 200 MHz base band includes the energy of the full 400 MHz RF band, which means a noise power 3 dB higher (as the "negative" frequency side-band folds-up to the positive one).

Consequently, from the radiometric point of view, the mixer insertion losses, and hence the receiver Noise Figure, is improved by a 3 dB factor. This characteristic of the DSB architecture makes it very attractive when compared to a Single Side Band (SSB) one or to a direct detection one.

The disadvantage is, of course, the double RF bandwidth to be considered, which will degrade the mixer input VSWR, the Noise Figure and the in band ripple.

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A more detailed description of each receiver component (Antenna, RF Front-End, IF module, and Analog module) follows in the following paragraphs [See Antenna 3.4.1.2.](#) to See Intermediate Frequency (IF) and Video.

Two directional couplers have been implemented at the input of the Measurement Antenna paths, in order to allow injection of RF signals in the receiver channels for RFC and functional tests.

These couplers are embedded in the Measurement feed-horns, as described in the following section See Measurement Feed-Horns.

From a functional and development philosophy view point, the following subsystems have been identified.

### 3.4.1.2 Antenna

Antenna subsystem includes a reflector, the measurement feed-horns (one for each frequency channel), and the Sky-Horn.

The measurement antenna retains the concept of a single 60 cm chord offset parabolic antenna with a the reflector in aluminium structure.

The feed-horns are configured so as to optimize the antenna pattern as well as to provide high beam efficiency performance. The tight HPBW allows high spatial resolution on Earth surface.

The measurement feed-horns and the Sky-Horn have been breadboarded and test measurements have exhibited performances in accordance with specifications.

A summary of the main characteristics is reported in the following paragraphs.



### 3.4.1.2.1 Measurement Feed-Horns

The measurement feed-horns are two, namely FH-24 for 23.8 GHz channel and FH-37 for the 36.5 GHz one.

These feeds have an internal geometry constituted of stepped circular sections, which, near the feed throat, guarantee with their diameter and length an adequate return loss behaviour of the feed, and simultaneously the excitation of only one fundamental mode TE<sub>11</sub>.

The other stepped circular sections near the feed aperture excite higher order modes, mainly the TM<sub>11</sub> mode.

The internal feed geometry near the aperture provides a symmetric primary pattern with an adequate combination in phase and amplitude of the two TE<sub>11</sub> and TM<sub>11</sub> modes.

Each feed is connected to a circular to rectangular waveguide transition to extract the vertical polarisation. The two feeds are placed in adequate positions near the parabola focus to satisfy (and not exceed) at secondary pattern level the required antenna boresight depointing of  $\pm 3^\circ$  and ellipticity of 0.4°.

The last section of the rectangular waveguide allocates a directional coupler, to allow, with the feed integrated on the instrument, the injection of RF signals within radiometric receivers for RFC and functional tests at instrument level.

### 3.4.1.2.2 Measurement Antenna

The measurement Antenna optic is the same as per ERS-1 and ERS-2 design.

The reflector is an offset paraboloid with the following geometry:

Projected diameter: 600 mm

Focal Length: 350 mm

Clearance: 50 mm

Offset angle: 46.965°

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Half illumination angle:  $38.793^\circ$

The feed-horn positions with respect to the parabola focus have been chosen to optimise the beam pointing and ellipticity requirements for the secondary patterns.

### 3.4.1.2.3 Sky-Horn Antenna

The Sky-Horn is a feed able to receive simultaneously the Cold Sky radiation in the two frequency band of interest for MWR.

The ratio between the two frequencies is 1.534, and, to achieve good radiative performances in such wide band, a corrugated feed design has been necessary.

The frequency ratio of 1.534 imposes a careful design and optimisation to provide a corrugated feed which simultaneously presents resonances in the two bands.

ALS have taken into account the necessity to have a compact feed design with a narrow pattern.

For these reasons a scalar horn has been selected, with a  $20^\circ$  flare angle and an aperture diameter of about 80 mm.

Considering the narrow Sky-Horn pattern the Cold Sky radiation is received with the minimum interference from potential spurious hot sources.

An orthomode Tee transducer (OMT) has been implemented to separate the two frequency bands and extract the Cold Sky reference signal for each of the MWR receiver channels.

### 3.4.1.3 Radio Frequency Front End

The RF Front - End Assembly (RFFE) is composed by two receivers, one for 23.8 GHz and the other for 36.5 GHz channels. Each channel contains the following subassemblies:

Switching and Load Subassembly (SA)

Mixer-Amplifier Subassembly (MA)

Local Oscillator Subassembly (LO)

All these unit is mounted on a common baseplate and is interconnected by a dedicated harness.

On the RFFE is implemented an heating system (HS) to maintain the temperature in a reduced range, in order to improve the stability of the Dicke and Hot reference loads, and to optimise the Isolation characteristics of the ferrite circulators used in the Switching Assembly.

The RFFE is integrated to the CEU in terms of DC power lines, switch control lines, IF coaxial lines and thermistors monitor lines.

The latter are connected to thermistors which are used to measure the reference temperatures inside the RFFE which is necessary for the instrument MWR calibration algorithm.

The RFFE is also interfaced to the feeds (Main Horn and Sky Horn) of the Antenna unit.

A cold redundancy is foreseen per each Local Oscillator assembly.

The operating LO is selected activating at CEU level the proper power supply line.

A functional block diagram of the RFFE is given in figure below.

Extensive trade-off was performed to select the best solution for the RF input filter included in the Switching assembly. The solution adopted is the most performing in terms of low

insertion losses, with the objective of improve Instrument sensitivity, with slightly degraded out of band rejection characteristics.

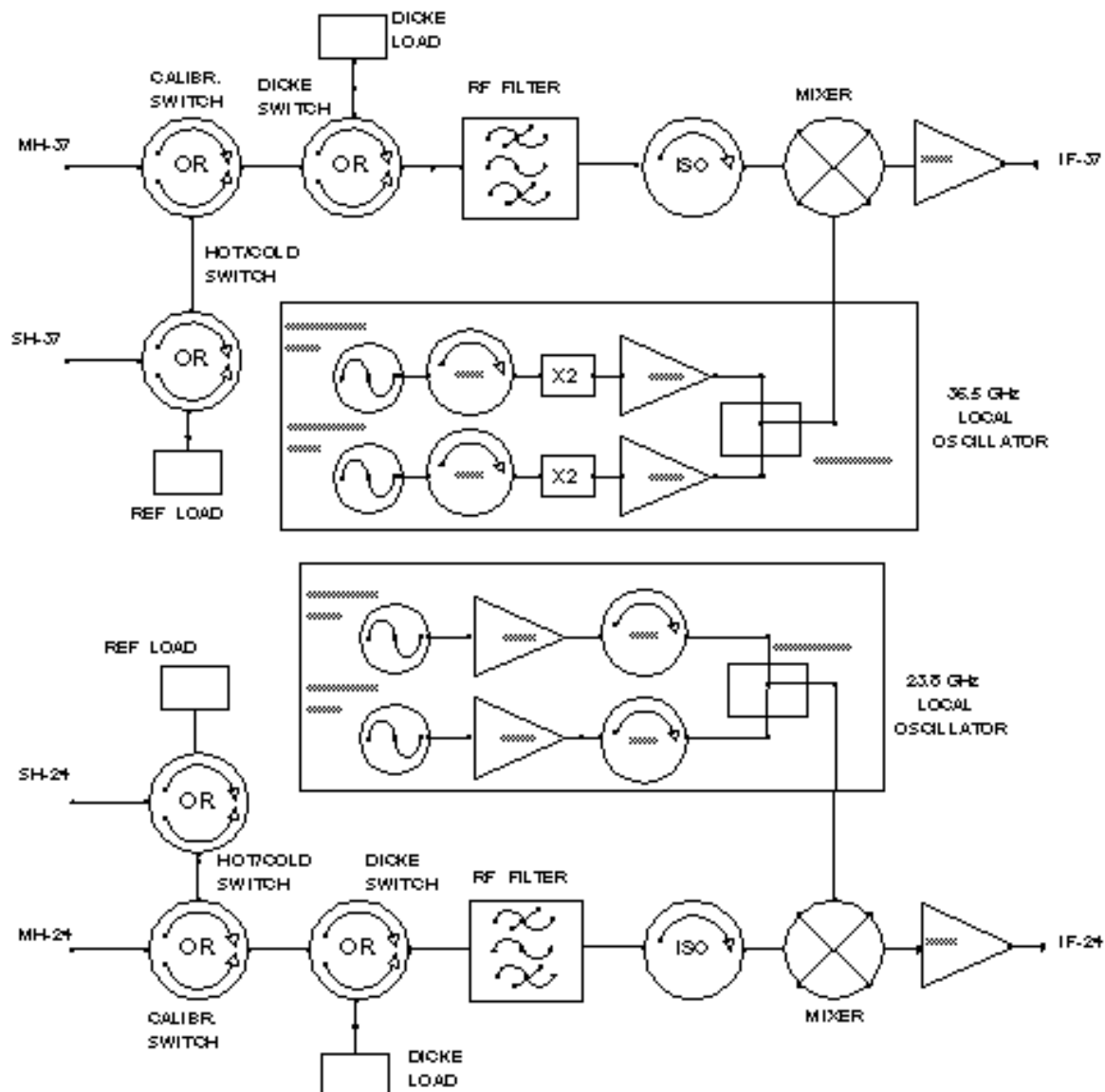


Figure 3.2 RFFE Functional Block Diagram

### 3.4.1.4 Intermediate Frequency (IF) and Video

The combination of Intermediate Frequency Module and the Analog Board is used to process the downconverted radiometric signals. Two identical units are required, one for channel 1 (23.8 GHz) and the other one for channel 2 (36.5 GHz).

IF Module (historically named Amplifilter) and Analog Module are allocated within the Centralised Electronic Unit (CEU) assembly.

### 3.4.1.5 Instrument Operational Mode

The MWR is a standalone instrument: it operates as an instrument composite by the common ICU together with DORIS.

The only operating mode of the instrument is the MWR-ON mode. When MWR is in the MWR-ON mode it shall measure in two frequency band, operating continuously in the whole orbit, the thermally emitted microwave radiation coming from the antenna look direction.

During the MWR-ON several calibration status are actionable by the telecommands: they establish the intercalibration periods (functional modes) i.e. how many main antenna measurements can be performed before performing again hot load and sky horn calibration. The possible intercalibration periods (calibration status) are reported in the following table.

Table 3.3

CALIBRATION PERIOD	OPERATION
Every 38.4 sec	Nominal
Every 76.8 sec	Nominal
Every 153.6 sec	Nominal
Every 307.2 sec	Nominal

### 3.4.1.6 Instrument Data Characteristics and Data Rate

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The MWR is a LBR Instrument ( Data Rate is <10 Mbit/sec ).

The overall MWR system breaks down into two propagation paths from the observed scene (one for each measurement channel) to the instrument, the source segment (MWR instrument and platform interface) an up/down link to the ground segment and the ground segment itself.

The ground segment includes some co-processing of data with the Radar Altimeter (RA-2) instrument data.

The Data rate of MWR scientific data is 0.427 Kbps (64 bit every 0.150 sec)

As in Nominal conditions it will operate continuously, the 100 minutes orbit total amount of data is 2.56 Mbits only for scientific data.

Considering the expected ICU packaging and the data rate of the MWR dedicated channel the global data rate is 1332 bytes every 24 sec sent to ICU to High Speed Multiplexer, i.e. 0.375 Mbytes for the whole orbit taking into account the whole data (headers, packet controls, etc.).

### 3.4.1.7 Instrument Improvements

The following key elements are modified/improved in the MWR of ENVISAT-1:

- Instrument Supporting Structure

The structure subsystem is fully re-designed due to ENVISAT-1 requirements and to the new configuration (different launch loads, different position, non deployable antenna, etc.). The structure is developed in CFRP (Carbon Fibre Reinforced Plastic) to provide optimum stiffness and stability performance, while reducing mass, and include also the Reflector support interface, thus being a key element for the Antenna and instrument performance optimisation (pointing, beam efficiency, etc.).

- Instrument Thermal Control

Thermal design is significantly different due to the class A definition of the instrument, which is now mounted externally to the PEB and completely de-coupled from PPF structure (radiative coupling to cold space only). Instrument thermal design is completely revised and an active thermal control is included to optimise the performance reducing temperature excursions on the RF section.

- Antenna

The reflector design is the same as for ERS, except for its supporting interfaces which are new design. Feed-horns design is optimised to improve some performance (return loss, side lobes level, sky horn OMT isolation, etc.) and to optimise the beam efficiency performance, which was not specified on ERS. Pointing and thermal distortions are re-considered given the new structure approach.

- RF Front End

From functional point of view the ERS architecture is maintained. The overall RF Front End design is reviewed from mechanical view point, for thermal control hardware implementation, for EMC design, and for reliability and product assurance aspects. Technological improvements/upgrade are extensively implemented for the:

Switching and Loads Sub-assembly new design to reduce insertion losses, improve isolation and return losses, improve Dicke and Reference Loads characteristics and thermal stability.

Local Oscillators to implement higher reliability, higher efficiency and higher frequency stability Dielectric Resonator Oscillator technology, which is qualified in the frame of this programme. The unit is completely re-designed (fundamental 23.8 GHz Oscillator, active doubler for 36.5 GHz oscillator, single supply operation).

Mixer amplifier to improve Noise figure and stability performance and to implement state of the out beam lead schottky diodes waveguide mixer and Low Noise hybrid amplifier.

- Centralised Electronic Unit (CEU)

From functional architecture point of view a similar architecture to the ERS one is adopted. The CEU is significantly re-designed due to new system requirements either in terms of interfaces and performance, in particular:

Technological upgrade, new components/functions are implemented.

The RF Front End evolution requires significant improvement of the power supply performance, with excellent stability at End Of Life and very low noise.

The CEU power supply is a completely new design, also from architecture point of view, given the new requirements.

Higher accuracy for instrument temperature measurement, required by the instrument radiometric performance optimisation and calibration.

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Receiver performance improvement, e.g. linearity, temperature stability, short term gain stability, video section, IF section, etc.

Failure propagation avoidance requirements for implementation of switches/heaters redundancy protections implementation.

New functions requiring additional commands and telemetry data.

Reliability figure required (N/A or ERS).

EMC requirements (N/A or ERS).

Mechanical/Thermal design modifications, to meet the ENVISAT-1 launch loads and the new instrument thermal control concept (category A).

- Ground Support Equipment

This area is really new design area, given the completely new calibration, verification and validation approach. Therefore new EGSE and MGSE developments are necessary to meet these objectives. Also the development of a set of stimuli equipment for radiometric tests and calibration is necessary to allow the completion of these activities (waveguide cryogenic loads, blackbody targets, thermal vacuum calibration targets, etc.).

### 3.4.2 In-flight performance verification

Results can be found on the web site of the ENVISAT Symposium, helded in Salzburg - Austria from 6 to 10 September 2004 : <http://earth.esa.int/workshops>



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# Chapter 4

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## Frequently Asked Questions

This chapter questions

- Question 4.1      [Which are the innovative characteristics of the Envisat Radar instrument?](#)
- Question 4.2      [Why is it that RA-2 does not lose track whatever is the surface type underneath?](#)
- Question 4.3      [Why are there three different Ku resolutions on RA-2?](#)
- Question 4.4      [Is the resolution change done manually or automatically?](#)
- Question 4.5      [Which is the advantage of having a dual frequency instrument?](#)
- Question 4.6      [Why two extra DFT samples have been included on RA-2?](#)
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- Question 4.8      [Which are the quality flags to be used for editing RA2 and MWR data?](#)
- Question 4.9      [What's the use of the RA-2 peakiness?](#)
- Question 4.10      [What's the RA2 reference point for the derivation of the range?](#)
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- Question 4.13      [How has the MWR performance been optimised on EnviSat?](#)
- Question 4.14      [How is calibration on MWR performed?](#)
- Question 4.15      [How is the time window delay calculated?](#)
- Question 4.16      [How is the sigma0 scaling factor calculated?](#)

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Question 4.17	<a href="#">How is the datation calculated?</a>
Question 4.18	<a href="#">How is MWR data from one channel aligned to the data from the second channel?</a>
Question 4.19	<a href="#">What is Retracking ?</a>
Question 4.20	<a href="#">What does the Slope Correction do ?</a>
Question 4.21	<a href="#">What Is the Delta Doppler Correction ?</a>

## 4.1 RA-2 Instrument

**Question 4.1 : Which are the innovative characteristics of the Envisat Radar instrument?**

The radar altimeter on board EnviSat is a nadir looking pulse limited radar altimeter functioning at the main nominal frequency of 13.575 GHz (Ku band), at which the instrument automatically detects, acquires and tracks the earliest part of the radar echoes from any surface without interruption. A secondary channel at a nominal frequency of 3.2 GHz (S band) is also operated to estimate the ionospheric range delay.

The new features of the RA-2, compared to previous altimeters are mainly:

- the robustness of the on-board tracker, not particularised for ocean waveforms but with an alternative algorithm that generates a height error signal which is linear over the entire width of the range window, independently of the pulse shape
- the capability of the instrument to autonomously adapt its resolution to be able to follow any type of surface

**Question 4.2 : Why is it that RA-2 does not lose track whatever is the surface type underneath?**

An innovative tracking algorithm, known as Model Free Tracker (MFT), has been designed on RA-2 such that the estimate of radar to surface range, echo power or other echo features is not so accurate, while the instrument concentrates its effort maintaining the earliest part of radar echoes within the tracking window, independently of its shape.

In particular, the MFT will decide whether the range window is using the adequate resolution, whether the resolution could be increased, or decreased, based on the Signal to Noise ratio (SNR) of the on-board waveform position compared to reference values stored

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in the on-board memory.

When the radar echo is about to move out of the tracking window, due for example to a sudden change in the surface elevation, the window is broadened to recapture the echo. This allows uninterrupted radar operation over all type of surfaces and its boundaries, and will avoid a dedicated mode change, commanded from ground. Ocean, ice sheets and land surface topography are measured to the highest possible accuracy, and new terrains are tracked

### Question 4.3 : Why are there three different Ku resolutions on RA-2?

The RA-2 is provided with three different bandwidths:

- 320 MHz, with resolution of 47 cm and tracking window width of 61 m
- 80 MHz, with resolution of 190 cm and tracking window width of 243 m
- 20 MHz, with resolution of 750 cm and tracking window width of 960 m

so that the resolution can be adapted to different scenarios (ocean, ice, ice-sheet, sea ice and land).

### Question 4.4 : Is the resolution change done manually or automatically?

The change of the resolution is done autonomously by the instrument, through the so called resolution selection logic, to optimally tune the width of the tracking window to the topographic features observed.

That is; if the instrument is, say, on the maximum resolution (320 MHz bandwidth) and the surface type changes, the resolution will autonomously change (from 320 MHz to 80 MHz) in order to keep always the echo within the tracking window, avoiding, as it happened on ERS-2 RA, to lose track.

If at 80 MHz it's still difficult to maintain the echo within the window, the resolution shall be again changed from 80 to 20 MHz.

Only under critical conditions, over abrupted terrains, when the 20 MHz window width is not enough to hold the echo, the track is lost. This lasts about 0.6 s (12 Data Blocks) and is called Acquisition sequence, needed in order to properly reinitialise the tracking. During this period, a Noise power estimation phase, a detection phase and an AGC setting phase occur.

The tracking will restart after that, with the instrument at 20 MHz. Then, according to the SNR of the on-board waveform position, as explained in the previous paragraph, the instrument will decide if the resolution can be changed, first to 80 MHz and then to 320 MHz.

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#### Question 4.5 : Which is the advantage of having a dual frequency instrument?

RA-2 is a nadir looking pulse limited radar functioning at the main nominal frequency of 13.575 GHz (Ku band).

A secondary channel at nominal frequency of 3.2 GHz (S band) is also operated to compensate the range error on altitude measurements caused by the propagation of the radar signals through the ionosphere.

Furthermore, a dual frequency instrument is used in the retrieval of the rain algorithm and is used for scientific research using the difference of backscattering coefficients for the two bands.

#### Question 4.6 : Why two extra DFT samples have been included on RA-2?

RA-2 provides 128 samples and 2 DFT Ku samples of the waveform compared to the 64 samples of ERS. For extremely low SWH conditions, range and SWH estimates can be further improved by including in the precision processing, the use of two extra echo samples, computed by the on board digital processor through a standard DFT algorithm and made available for each Ku band radar echo down linked to ground. The location of the two additional waveform samples is programmable from ground so that it can be optimally tuned with respect to the position of the tracking point in the FFT bank. This is a unique feature of the RA-2.

#### Question 4.7 : Why are individual echoes provided by RA-2?

RA-2 is able to transmit to ground In Phase and Quadrature components (i.e. raw data without any processing applied on board) of the echoes from 2000 consecutive Ku radar pulses. In this concept, the full-rate data are stored, for a short burst, in an internal buffer memory, in parallel to the normal averaging and other functions of the instrument. The buffered data are subsequently read out at a such lower rate and appended to the normal science data (RA2 Level 0 ISPs). Experimental processing of these individual echoes on ground can provide more insights on surface topography at the boundaries.

These individual echoes are available as a dedicated Data Set in the L1b products and in the Level 2 SGDR products.

#### Question 4.8 : Which are the quality flags to be used for editing RA2 and MWR data?

By looking at every single flag in the L2 RA2 MCD (field 8 in all L2 products) the following information and useful advices for the users can be derived:

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a) Packet length error flag (bit 0 in L2 RA2 MCD)

**DEFINITION:** This flag is set to 1 (bad) when the source packet length inside the packet does not coincide with the length in the FEP annotations (i.e. error during transmission of data from the satellite).

**ADVICE:** If this flag is set to 1, the source packet is not processed at L1b (the corresponding L2 record will be set to default). Therefore, only source packets with this flag set to 0 should be used for any processing.

b) OBDH validity flag (bit 1 in L2 RA2 MCD)

**DEFINITION:** This flag is set to 1 (bad) if the source packet counter difference of consecutive packets is different from 1 (data gap), or if the OBDH datation difference of consecutive packets (with counter difference = 1) is different from the expected value (584056) +/- a tolerance (i.e. instrument timing error).

**ADVICE:** If it happens only once, the data can be used for further processing. If the flag is set very often for consecutive packets, there could be an error in the instrument (i.e. corrupted OBDH values or data associated to a wrong datation by the on-board s/w). In this case the data should be discarded.

c) USO validity flag (bit 2 in L2 RA2 MCD)

**DEFINITION:** This flag is set to 1 (bad) if the difference in the source packet counter of consecutive packets is different from 1 (data gap), or if the USO datation difference of consecutive packets (with counter difference = 1) is different from the expected value (111400) +/- a tolerance (i.e. instrument timing error).

**ADVICE:** If it happens only once, the data can be used for further processing. If the flag is set very often, there could be an error in the instrument (i.e. corrupted USO values or data associated to a wrong USO datation). In this case the data should be discarded.

d) Fault identifier (bit 3 in L2 RA2 MCD)

**DEFINITION:** This flag is set to 1 if at least one of the 20 elementary measurements has the on-board width of the discriminator set to 0, the CoG discriminator out of range, the leading edge position out of range, the sum of the samples of the on board averaged waveform out of range, the AGC predicted rate out of range, the AGC corrected value out of range, the AGC X0 out of range, the time delay predicted rate out of range, the time delay corrected value out of range, the time delay X0 out of range, the SNR out of range, N' out of range or the waveform samples not available.

**ADVICE:** Most of the above errors situations are not likely to appear anymore since the corresponding on-board parameters were tuned during Comm. Phase to avoid them to happen. In the case of the first one, W set to 0 (i.e. very noisy waveform), the instrument automatically reacts by reducing the resolution.

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Therefore, the data with this flag set to 1 can be used for further processing.

e) AGC Fault identifier (bit 4 in L2 RA2 MCD)

**DEFINITION:** This flag is set to 1 if any of the 20 elementary AGC\_Ku input values is out of bounds.

**ADVICE:** The min/max thresholds currently used to perform this check are wide enough to include all possible values of the L1b Ku AGC values. Therefore, no flagged records are expected.

Anyway, this flag can be eventually considered as editing criterion in case something wrong happened during the L1b processing.

f) Rx delay identifier (bit 5 in L2 RA2 MCD)

**DEFINITION:** This flag is set to 1 if any of the 20 elementary Ku on-board Rx delay input values is out of bounds.

**ADVICE:** The min/max thresholds currently used to perform this check are wide enough to include all possible values of the L1b Ku Rx delay values.

Therefore, no flagged records are expected.

g) Waveform samples fault identifier (bit 6 in L2 RA2 MCD)

**DEFINITION:** This flag is set to 1 as soon as any of the 20 input elementary measurements has all Ku/S samples set to 0.

**ADVICE:** 1 second of data should not be thrown away only because of this flag. The 18 Hz retracking quality flags (fields 132 to 138 in FD/I/GDRs) indicate specifically which elementary measurement had all Ku/S samples set to 0 (corresponding bit set to 1).

h) MWR validity (bits 8-10 in L2 RA2 MCD)

**DEFINITION:** Bit 10 is set to 1 if a MWR data gap is present (failed check on consecutive MWR source packets OBDH datations). Bit 9 is set if there is something wrong with MWR thermal control (e.g. instrument temperatures out of bounds). Bit 8 is set if the blanking pulse is present.

**ADVICE:** Bit 10 just indicates if there was a gap between consecutive MWR SPs, not that the data inside the SPs is wrong. Bit 9 is a warning on the thermal control of the instrument that could imply a lower quality of the output Tbs (no need of throwing away the data in this case either). Bit 8 is always set to 0 by macrocommand.

i) Brightness temperatures range check (bits 11-12 in RA2 L2 MCD)

**DEFINITION:** These bits are set to 1 if the brightness temperatures values are out of bounds.

**ADVICE:** If these flags are set to 1, the corresponding Tbs should not be used for the processing.

j) Ku/S ocean/ice2/ice1 retracking and Ku sea-ice retracking quality flags (bits 16 to 22 in RA2 L2 MCD)

**DEFINITION:** These flags are set to 1 if the retracking failed for at least one of the 20 elementary measurements. That is; if input waveform samples are set to 0, input data not in Tracking, Preset Tracking or Preset Loop Output modes, too low average power wrt noise power, or leading edge position out of bounds.

**ADVICE:** There is no need of throwing away the whole source packet only for this flag. The 18 Hz retracking quality flags (fields 132 to 138 in FD/I/GDRs) indicate specifically which elementary measurement was wrong (corresponding bit set to 1).

k) Absence of processing errors (arithmetic faults) (bit 24 in RA2 L2 MCD)

**DEFINITION:** This flag is set to 1 if mathematical exceptions (e.g. division by 0, log of a negative number, ...) were encountered while processing any of the 20 elementary measurements.

**ADVICE:** There is no need of throwing away the whole source packet only for this flag. The 18 Hz retracking quality flags (fields 132 to 138 in FD/I/GDRs) indicate specifically which elementary measurement was wrong (corresponding bit set to 1).

l) Meteo data state (bits 25-26 in RA2 L2 MCD)

**DEFINITION:** These bits indicate if two valid Meteo files, two degraded Meteo files (i.e. too large time difference between the RA2 record and the Meteo time), only one or none, were used for the processing. The 2 bits flag is set to 0, 1, 2 or 3, respectively.

**ADVICE:** This flag should not be used for the editing. The user has only to know that in case this flag is set to 1 or 2, the quality of the meteo corrections will be lower than in case flag is 0. If the flag is set to 3, all meteo corrections will be set to default values.

m) Orbit status flag (bits 28-31 in RA2 L2 MCD)

**DEFINITION:** In NRT this flag can be set to 0 (if a fatal error happened while calling the orbit routines), to 1 (orbit routines output ok for all 20 elementary measurements) or 2 (some non-fatal error occurred for at least one of the elementary measurements).

Currently these 4 bits are set to 0 in OFL products.

**ADVICE:** If the flag value is 2, the routines output is still valid and the data can be used for



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further processing. If the flag value is 0 the processing gets blocked and no more data is processed.

#### Question 4.9 : What's the use of the RA-2 peakiness?

The computation of the peakiness is part of the preprocessing Level 2 'ice' algorithms, aimed at determining if the received echo has a shape sufficiently recognisable so that an elevation may be determined from it.

The peakiness algorithm consists essentially in calculating the ratio of the maximum filter (bin) value to the mean filter value of the filters to the 'right' of the tracking point.

This processing is performed on 128 bins for Ku band, since the Ku waveforms are composed of 128 samples, and on 64 bins for S band.

Note that even for cases when the echo is regarded as non valid (i.e. if the echo waveform is contaminated by the surface return or if the leading edge does not lie within the range window) the peakiness is always calculated since this is an independent waveform quality assessment parameter.

Furthermore, the peakiness has proved to be very efficient at removing most of sea-ice data (around 95% of it, depending on the season), and in a lesser extent rain. In fact, ocean data could be retained if peakiness values are in the range 1.5-1.8.

#### Question 4.10 : What's the RA2 reference point for the derivation of the range?

The way in which the altimeter derives the range is by measuring the time since a radar pulse is transmitted and then received, after having bounced on the surface. The counting of the time starts when the pulse is transmitted by the Tx, and stops when the received pulse is mixed with a second pulse from Rx in the on-board deramp mixer.

However, the altimeter range is assumed to be referred to the antenna phase center. Therefore, the physical delays inside the altimeter hardware have to be measured and compensated for. These values have been characterised during testing on ground and are stored in an external auxiliary file.

They are applied to the Level 1b window time delay to obtain the final altimeter range measurement (at L2) with respect to the antenna phase center.

Moreover, since the satellite height is referred to the Centre of Mass (CoM), and the altimeter range to the antenna phase center, a new correction term has to be accounted for in order to obtain a coherent surface height (satellite height - altimeter range) with respect to the ellipsoid.

This is done by adding the distance between the CoM and the antenna phase centre, before



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calculating the final Level 2 altimeter range.

#### Question 4.11 : What is the set of criteria that can be used to exclude "non-ocean" data?

Most users are interested in editing non-ocean data. The following is a listing of the main fields/flags ESA makes available in the L2 products for this scope:

- RA2 land/sea flag: values of this flag set to 0 or 1 indicate open oceans and semi enclosed seas, or enclosed seas and lakes, respectively. Values set to 2 or 3 indicate continental ice and land, respectively. This is the first criterion to consider when editing non ocean data.
- MCD flags: see paragraph "Which are the quality flags to be used for editing RA2 and MWR data in this section"
- SWH: In principle, all values of SWH (apart from the default one, stored in the output product in case the number of valid elementary SWH values is less than a minimum value, set currently to 6, or in case the number of valid elementary SWH values with a scatter about the mean smaller than an upper bound is less than a threshold, set currently to 6) could be used for further analysis. It's up to the user to set more stringent limits for the accepted SWH values, according to the applications.
- standard deviation of SWH: all values, apart from 0 and the default one, could be used for further processing. Infact, it has been seen by some users that high values of the standard deviation could be due in most cases to radar returns affected by sea ice, but not always. Therefore discarding records with standard deviation greater than a fixed value, might not be appropriate.
- number of valid points used for the computation of SWH: This value (in the range 1 to 19) may be used in different ways for keeping valid records (e.g  $N_{val} > 15$ ), according to users needs.
- sigma0: In principle, all values of sigma0 (apart from the default one, stored in the output product in case the number of valid elementary sigma0 values is less than a minimul value, set currently to 6, or in case the number of valid elementary sigma0 values with a scatter about the mean smaller than an upper bound is less than a threshold, set currently to 6) could be used for further analysis. Actually, it has been seen by several users that negative values of sigma0 are almost always located at high latitudes, therefore, negative sigma0 values could be discarded for ocean applications.
- standard deviation of sigma0: all values, apart from the default one could be used for further processing. However, for general analysis of wind speed, it has been recommended by several users that records with standard deviation greater than 0.3 be flagged as dubious, since the affected records do not seem to be only at high latitudes.
- number of valid points used for the computation of sigma0: As in the case of SWH, the number of valid points may be used differently by the users according to the applications.
- wind speed: In principle, all values (apart from the default one) could be used for further analysis. Yet, note that due to some limitations of the current wind

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- algorithm, there is an accumulation of wind speeds at 20.15 m/s (from input sigma0 values less than 7 dB) and close to 1m/s (from all data with sigma0 > 15 dB). The wind algorithm is to be upgraded in a near future to cope with these problems.
- range: In principle, all values of range (apart from the default one, stored in the output product in case the number of valid elementary range values is less than a minimum value, set currently to 6, or in case the number of valid elementary range values with a scatter about the mean smaller than an upper bound is less than a threshold, set currently to 6) could be used for further analysis.
  - standard deviation of range: all values, apart from the default one could be used for further processing. It's up to the user to set an upper limit according to the needs (e.g. some users have seen that most of the high range standard deviation values were at high latitudes, recommending a preliminary test on this parameter such that records with standard deviation greater than 0.2 or 0.7, for Ku and S bands respectively, or records with negative or zero value, could be discarded).
  - number of valid points used for the computation of the range: As in the case of SWH, the number of valid points may be used differently by the users according to the applications.
  - peakiness: this parameter has proved to be quite effective in removing sea-ice data (and in a lesser extent rain), apart from seasonal variations. Up to 95% of sea-ice data may be edited if keeping peakiness values in the range 1.5-1.8

## 4.2 MWR Instrument

### Question 4.12 : What's the design of the EnviSat MWR?

The Envisat MWR, derived from the ERS radiometer but with improved performances and calibration accuracy, is a dual channel passive microwave Dicke radiometer operating at two frequencies: 23.8 GHz and 36.5 GHz. By receiving and analysing the Earth's generated and reflected radiation at these two frequencies, the instrument is able to measure the amount of water content in the atmosphere within a 20 Km diameter.

### Question 4.13 : How has the MWR performance been optimised on EnviSat?

Instrument thermal design has been completely revised on EnviSat and an active thermal control has been included to optimise the performance reducing temperature excursions on the Radio Frequency section. Moreover, feed horn design has been optimised to improve some performance and to optimise the beam efficiency performance, which was not specified on ERS.

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#### Question 4.14 : How is calibration on MWR performed?

A two point calibration scheme is adopted, with Hot and Cold reference calibration points, so that periodically, the measurements of the Earth scene radiation are interrupted to allow the measurement of an on board calibration load and of the deep cold space.

The deep cold space measurement shall be accomplished via the Sky horn feed in order to provide a cold reference signal, while on board calibration reference load, kept by the thermal control at the instrument physical temperature, provides a hot reference signal.

### 4.3 Main RA-2 Level 1b algorithms

#### Question 4.15 : How is the time window delay calculated?

The window delay (in time) is the first measurement of the range performed during the Level 1b RA2 processing. It is referred to the antenna phase centre, and therefore, the delays of the Tx and Rx paths, characterised during testing on ground, are taken into account.

In fact, during the L1b processing, the on board Rx distance (obtained by combining Rx coarse and fine components, and compensating for the PRI ambiguity rank and for the on board tracking filter rate of change) is corrected for instrument induced errors using both ground (Tx and Rx paths) and flight PTR calibration parameters. Finally, the retrieved on board time delay measurements are corrected for the Doppler effect, before making it available in the L1b products.

These measurements are used at Level 2 to calculate the final retracked range.

#### Question 4.16 : How is the sigma0 scaling factor calculated?

The power scaling factor for sigma0 evaluation is obtained at Level 1b from the radar equation, taking into account the following components:

- on board AGC, from the AGC coarse and fine values, corrected for instrument errors using both ground (Tx and Rx paths) and flight PTR calibration parameters,
- antenna gain and overall gain of the receiving chain
- correction of illuminated area for Earth curvature

The scaling factor thus obtained, is used at Level 2 to compute, from the amplitude of the retracked waveform, the backscattering coefficient of the echo.

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### Question 4.17 : How is the datation calculated?

The UTC datation is the exact time when the on-board averaged waveform is reflected from the surface, and hence, when the middle of the 100 pulses averaged waveform is at the surface.

It's of vital importance to have a precise and coherent measure of the time, since the altimeter range is derived from the measurement of the time between the transmission of the pulse and its reception.

The datation is derived through correlation of the RA-2 ICU clock counter OBDH datation with the satellite on-board reference binary time which is in turn correlated to a UTC reference time.

The following components are also taken into account in the final L1b expression of the records datation:

- the location of the mid point of the averaged waveform,
- estimated time for the first received echo of the current data block, since the signal that is actually triggering the request for the datation is the pulse transmitted just before the first returned echo contained in the current data block
- the propagation time delay

## 4.4 Main MWR Level 1b algorithms

### Question 4.18 : How is MWR data from one channel aligned to the data from the second channel?

In order to obtain coherent geophysical data, it is necessary to combine the observations of the two channels, pointing to different locations of the surface due to their different off-nadir angles, when available over the same spot.

This is done during the Level 1b processing in the so-called alignment processing algorithms.

On EnviSat, the second channel (at frequency 36.5 GHz) is looking forward, and therefore, certain (later in time) measurement of Channel 1, is searched such that both channels measurements are referring to the same point on ground.

This is done by considering the time difference of each channel sounding from nadir, considering the actual velocity and altitude of the satellite at each point.

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## 4.5 Main RA-2 Level 2 Algorithms (Non-Ocean)

### Question 4.19 : What is Retracking ?

Over topographic surfaces, a radar altimeter on-board tracking system is unable to maintain the echo waveform at the nominal tracking position in the filter bank, due to rapid range variation. This results in an error in the telemetered range known as tracker offset. Retracking is a term used to describe a group of non-linear ground processing estimation techniques which attempt to determine the tracker offset from the telemetered echoes, and thereby estimate the range to the point of closest approach on the surface. Peakiness of echoes from sea ice cause range tracking jitter, which also results in tracker offsets.

### Question 4.20 : What does the Slope Correction do ?

The Altimeter antenna boresite is pointed at Nadir and the antenna has a field of view of about 1.3 degrees (half power). The first part of the reflected echo will come from that part of the surface within the field of view, that is closest to the satellite. Over flat surfaces the closest point on the surface is at Nadir but over sloping terrain that will not be the case. When the echo waveform is retracked the resulting range measurement is a slant-range to a point offset from Nadir. To use this measurement it must be corrected for the slant and re-located to the point of first return offset from Nadir.

The correction is performed by using models of the surface slope which enable prediction of the direction of the point of first return for any given satellite location. Initially 2 models are applied: one for Greenland and one for Antarctica.

### Question 4.21 : What Is the Delta Doppler Correction ?

The Altimeter uses transmits a chirped pulse which sweeps a range of radar frequencies. Processing converts from the frequency to the time domain. Any motion of the satellite along the line-of-sight with the reflecting surface produces a Doppler shift in the pulse frequency. If uncorrected this translated to an error in the time delay. Over a flat surface this effect can be corrected by considering the vertical component of the satellite velocity. However over sloping surfaces the reflection does not come from the Nadir. An additional computation is required to find the component of the satellites velocity which is along the line of sight to the reflecting surface.

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# Chapter 5

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## Glossary

### 5.1 Acronyms And Abbreviations

ADS Auxiliary or Annotation Data Set

AGC Automatic Gain Control

ALS Alenia Spazio, Rome

BITE Built In Test Equipment

CAL MWR Calibration Switch

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CEU MWR Central Electronic Unit

CFRP Carbon Fibre Reinforced Plastic

CG Chirp Generator

CH1 MWR 23.8 GHz Channel

CH2 MWR 36.5 GHz Channel

CoM Centre of Mass

CW Continuous Wave

DB Data Block

DFT Discrete Fourier Transform

DPM Detailed Processing Model

DRM Deramping Mixer

DS MWR Dicke Switch

DSD Data Set Descriptor

DSR Data Set Record

EGSE Electrical Ground Support Equipment

EMC Electro-Magnetic Compatibility

EQ Equipment

EQ PWR Equipment Power Bus

EQ SOL Equipment Switch-Off Line

ERS European Remote Sensing Satellite (hence ERS1, ERS2 )

ESA European Space Agency

ESL Expert Support Laboratories

ESRIN European Space Research Institute

ESTEC European Space TECnical Centre

FEE Front End Electronics

FEP Font End Processor

FFT Fast Fourier Transform

FGCU Frequency Generation and Conversion Unit

FTN Force To Nominal Command

GDR Geophysical Data Record

GUI Graphical User Interface

HL MWR Hot Load

HSM High Speed Multiplexer

HTR Heater

HTR PWR Heater Power Bus

ICU Instrument Control Unit

ID Identification/Identifier

IF Intermediate Frequency

I/F Interface

IODD Input/Output Definitions Document

ISO Isolator

ISP Instrument Source Packet

LBR Low Bit Rate scientific data interface

LEGOS Laboratoire d'Etude en Geophysique et Oceanographie Spatiale

LFM Linear Frequency Modulated

LIP Level 2 Ice Processor (reference processor)

LO Local Oscillator



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LO24 MWR 23.8 GHz Local Oscillator Unit

LO37 MWR 36.5 GHz Local Oscillator Unit

LOP Level 2 Ocean Processor (reference processor)

LRR Laser Retro Reflector

LSB Least Significant Bit

MA Mixer Amplifier

MA24 MWR 23.8 GHz Mixer Amplifier Unit

MA37 MWR 36.5 GHz Mixer Amplifier Unit

MCD Measurement Confidence Data (flag)

MDSR Main Data Set Record

MFT Model Free Tracker

MGSE Mechanical Ground Support Equipment

MH Measurement Horn

MH24 MWR 23.8 GHz Measurement Horn

MH37 MWR 36.5 GHz Measurement Horn

MIX Mixer

MLI Multi-Layer Insulation (Thermal Blankets)

MPH Main Product Header

MSB Most Significant Bit

MSSL Mullard Space Science Laboratory (University College London)

MUX Multiplexer

MWR Microwave Radiometer

N/A Not Applicable

NPM Noise Power Measurement

NRT Near Real Time (data processing)

OBDH OnBoard Data Handling

OCOG Offset Centre of Gravity (retracker algorithm)

OMT Orthomode Transducer

OPR Ocean PProduct

PCD Product Confidence Data (flag)

PEB Payload Equipment Bay

PDHS Payload Data Handling Station

PFHS Processing Facility and Handling System

PPF Polar PlatForm

PTR Point Target Response

PWR Power

RA-2 Radar Altimeter for ENVISAT

RF Radio Frequency

RFFE MWR RF Front End assembly

Rx Receiver

SA MWR Switching and Load Unit

SDR Sensor Data Record

SH Sky Horn, MWR Cold Calibration source feed-horn

SH24 MWR 23.8 GHz Sky-Horn

SH37 MWR 36.5 GHz Sky-Horn

SNR Signal To Noise Ratio

SPH Specific Product Header

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SPSA Signal Processing Subassembly Unit

SW Switch

SWH Significant Wave Height

TC Telecommand

TDS Test Data Set Document

TM Telemetry

UCL University College London

W Watts

WG Waveguide

wrt with respect/reference to

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## Chapter 6

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# RA2/MWR Data Formats Products

A detailed description of the RA2-MWR data products is given in the following documents:

- Envisat-1 Products Specifications - Volume 5 Product structures, for the description of the Main Product Header (MPH), as well as information regarding the generic structure of the Specific Product Header (SPH) and Data Set Descriptors (DSD).
- Envisat-1 Products Specifications - Volume 14 RA2-MWR Products Specifications, for the description of the Specific Product Header (SPH), Measurement Data Sets (MDS), and Annotation Data Sets (ADS) of all the RA2-MWR products (levels 0, 1 and 2).

These documents are also available via FTP at:

- [ftp://earth.esa.int/pub/ESA\\_DOC/ENVISAT](ftp://earth.esa.int/pub/ESA_DOC/ENVISAT)

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# Chapter 7

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## Credits

The RA-2 and the MWR instruments were developed by Alenia Aerospazio (I).

The LRR was developed by Aerospatiale (F).

The DORIS system, supporting the RA-2/MWR Mission, was developed by CNES (F)

The RA-2/MWR Expert Support Laboratories (ESL) have contributed to the definitions, the specifications and the developments of the products, processing algorithms and reference processors and have participated in the authoring of the RA-2/MWR Product Handbook, this document. The ESL is composed of:

- Alenia Aerospazio (I)
- Mullard Space Science Laboratory, UCL (UK)
- Collectes Localisation Satellites (F)

Recent modifications of this document are being handled at CLS under supervision of ESA.



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