Ref: C1-EX-MUT-A21-01-CN
Issue 2 Revision 6
Date: 04.02.94

ALTIMETER PRODUCTS

USER MANUAL

IFREMER BP 70 29280-PLOUZANE FRANCE
CNES 18, AVENUE EDOUARD BELIN 31055-TOULOUSE CEDEX
CLS ARGOS 18, AVENUE EDOUARD BELIN 31055-TOULOUSE CEDEX

Ref: C1-EX-MUT-A21-01-CN
Issue 2 Revision 6
Date: 04.02.94

ALTIMETER PRODUCTS

USER MANUAL

IFREMER BP 70 29280-PLOUZANE FRANCE
CNES 18, AVENUE EDOUARD BELIN 31055-TOULOUSE CEDEX
CLS ARGOS 18, AVENUE EDOUARD BELIN 31055-TOULOUSE CEDEX

LIST OF CHANGES

Issue	Date	Page	Comments
1.0	26.12.91		Creation
1.1	07.07.92		Adding of informations to get an independent document from Reference document [R1]
1.2	09.07.92		Update of version 1.1
2.0	20.08.92		New version: adding of informations
2.1	04.12.92		Update of version 2.0
2.2	15.03.93	3	Update of version 2.1
2.3	19.05.93	44	Adding a comment on the body tide correction
2.4	09.07.93		Update for OPR software version 3.0: pages 30, 32, 34, 38, 41, 43, 44, 45, 46, 47 and 49
2.5	01.10.93		Comment on body tide and geoid: pages 39, 41, and 44
2.6	04.02.94		Comment on radial orbit error interpolation : page 43

CONTENTS

REFERENCE DOCUMENTS

(R1) : CERSAT Products General Description
C1-EX-MUT-A2-07-CN - Issue 1.0 - 26/12/91

<u>Authors' address</u> :

JP. DUMONT, J. STUM
CLS/ARGOS
18 Avenue Edouard Belin
31055 TOULOUSE CEDEX

GLOSSARY

ESA	:	European Space Agency
FDP	:	Fast Delivery Product
F-PAF	:	French Processing and Archiving Facility
G-PAF	:	German Processing and Archiving Facility
MMCC	:	Mission Management and Control Center
OIP	:	Ocean Intermediate Product
OPR	:	Ocean Product
PAF	:	Processing and Archiving Facility
PCD	:	Product Confidence Data
PRI	:	Pulse Repetition Interval
TBC	:	To Be Confirmed
USO	:	Ultra-Stable Oscillator
UTC	:	Universal Time Coordinate

1 - THE MISSION AND THE INSTRUMENT

1.1 The mission

The ERS-1 altimeter is a remote sensing instrument which measures several parameters relative to the illuminated nadir area :

- the altitude of the satellite above the sea surface (distance between the centre of gravity of the satellite and the sea surface)
- the backscatter coefficient, used to compute the wind speed modulus over ocean
- the significant waveheight over ocean

The observation mission covers the world ocean. The F-PAF center processes the altimeter data over ocean, by using data recorded onboard the satellite and telemetered to the ground when ERS-1 flies over receiving stations.

Exploitation of the altimeter data should make a significant contribution to the study of topography and circulation of the oceans, of wind and sea state, as well as in the field of marine geophysics. Mesoscale variability of the ocean dynamic topography could be studied with a 35 day orbit whereas a 176 day orbit would be used rather to determine a mean sea surface and an improved geoid for geophysical applications.

1.2 The instrument

1.2.1 Measuring principles

The altimeter is an active microwave instrument (Ku band), which transmits pulses towards the nadir by means of a parabollic antenna. Pulses are reflected on the overflown surface, detected by the antenna and processed so as to provide a measurement relative to a footprint of some kilometers. Over ocean, collected waveforms are described by the Brown model which is represented in figure 1.

The following parameters are analyzed from the waveforms :

- the position of the "center" of the echo leading edge relative to the moment of transmission, which provides an estimate of the pulse's round trip time and hence of the altitude.

- the slope of the echo leading edge, which is directly related to the standard deviation of the heights distribution of the surface reflectors, and therefore to the significant waveheight.

- the power level of the echo trailing edge, which is used to estimate the backscatter coefficient of the overflown surface, depending on the surface roughness on a small scale, and hence of the wind speed.

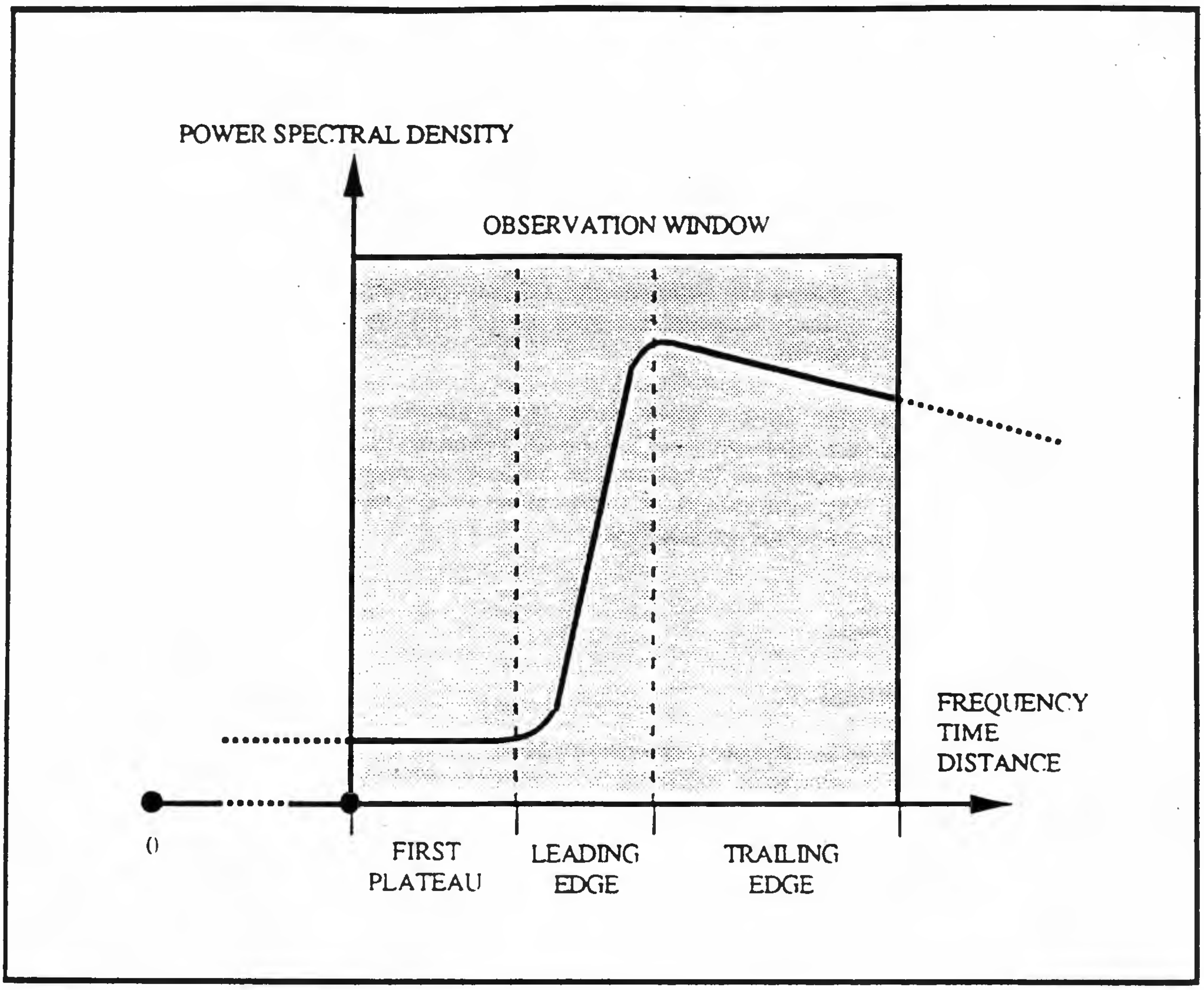

POWER SPECTRAL DENSITY
OBSERVATION WINDOW
FREQUENCY
TIME
DISTANCE
0
FIRST PLATEAU
LEADING EDGE
TRAILING EDGE

Figure 1

1.2.2 Description

A simplified diagram of the instrument is given in figure 2. The main characteristics of the altimeter are defined in table 3.

The instrument operates in acquisition mode to detect signals in the range covering the possible time delays. This mode is activated for initial detection of the signal, or following a loss of the signal. The switching to the tracking mode is automatic.

In tracking mode, the altimeter estimates the parameters and maintains the waveforms in the analysis window.

Linear frequency modulated pulses are generated by a dispersive line, amplified and transmitted by the antenna. After reflection on the overflown surface and return to the antenna, each pulse is mixed with a copy of the transmitted signal, triggered off according to the onboard estimate of the round trip time. This technique (full deramp) provides an equivalence between time, distance and frequency for the resulting signal. The signal is then filtered, attenuated by means of automatic gain control, demodulated and undergoes a fast Fourier transform. The spectra, which represent the signal power (spectral density) as a function of time (or of frequency) are averaged in packets of 50 in order to reduce the speckle noise. The resulting spectrum consists of 64 samples, each of which representing about 3.03 nanoseconds (or 45.45 cm) in ocean mode. Each spectrum (waveform) constitutes an elementary measurement (20Hz).

The system is controlled by means of two second order loops which process error signals, obtained by comparing the measured signal to the return power model. The objective is on the one hand to monitor the changes in the signal's amplitude and distance, in order to keep it in the analysis window and to prevent loss of track (tracking function) and, on the other hand to estimate the parameters.

The telemetry contains onboard estimations, as well as all the waveforms and associated informations, allowing onground estimations.

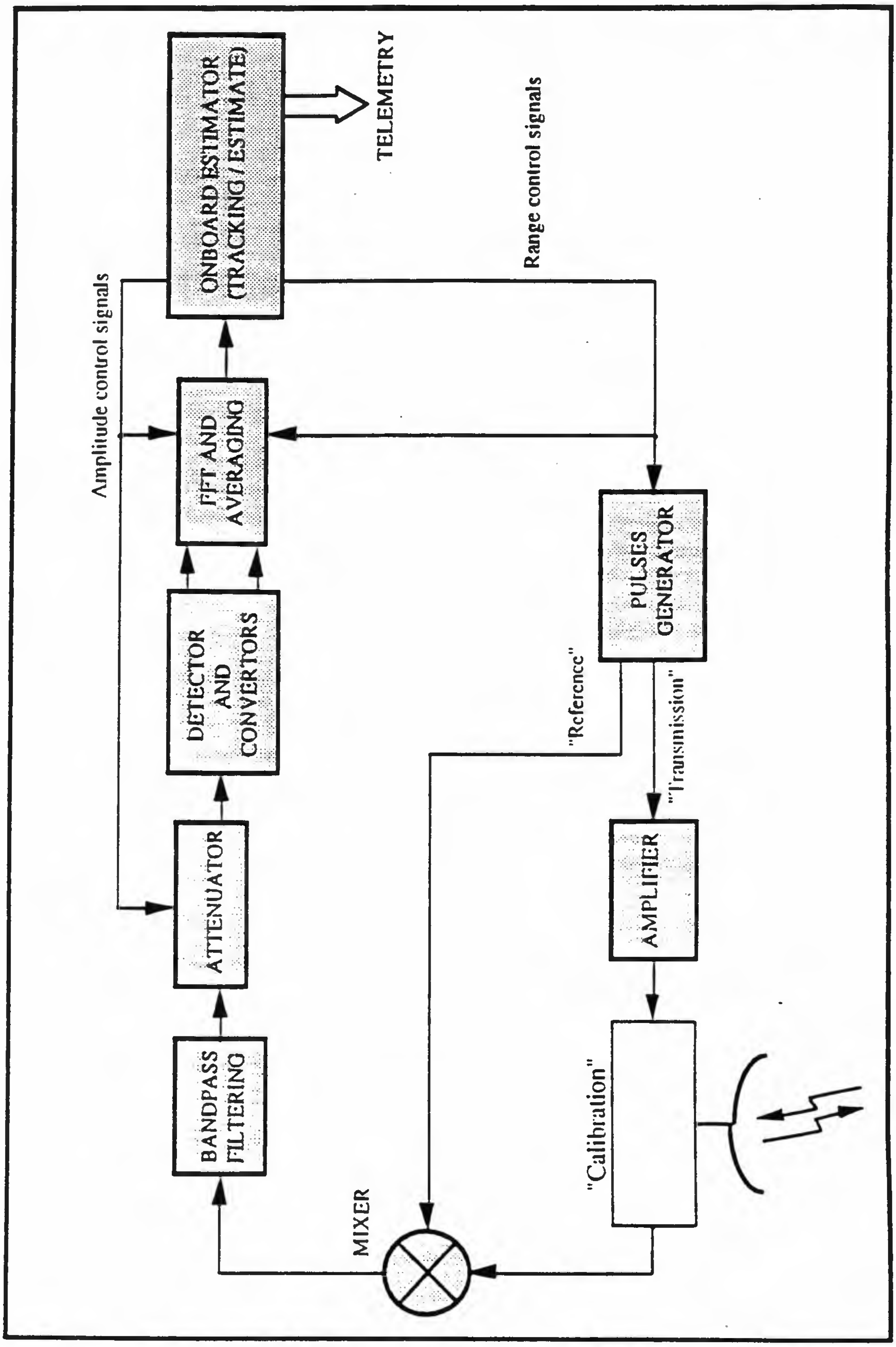
Other operating modes :

- In tracking mode, internal calibration cycles are automatically and regularly performed (every minute approximatively). Their duration is about 150 msec, and allow the measurement of the altimeter's point target response.

- The initializing mode is similar to the tracking mode but in this case the controlled system conditions are defined by a telecommand from the ground.

Over 1 second ocean measurement, the performance specifications are :

- 10 cm (at 1 σ) for altitude (between 745 and 825 km)
- 0.7 db (rms) for backscatter coefficient
- 50 cm (rms) for waveheights smaller than 5 m, 10% otherwise.



ONBOARD ESTIMATOR
(TRACKING / ESTIMATE)
TELEMETRY
Range control signals
Amplitude control signals
FFT AND
AVERAGING
PULSES
GENERATOR
DETECTOR
AND
CONVERTORS
"Reference"
"Transmission"
ATTENUATOR
AMPLIFIER
BANDPASS
FILTERING
"Calibration"
MIXER

Figure 2

Frequency	13.8 GHz
Pulse width	20 microseconds
Bandwidth	330 MHz (ocean mode) 82.5 MHz (ice mode)
Transmitted power (peak)	50 Watts
Pulse repetition frequency	1020 Hz
Antenna diameter	1.2 m
Aperture angle	1.3 °
Width of analysis window	64 samples x 3.03 ns (ocean mode) 64 samples x 12.12 ns (ice mode)
Duration of an internal calibration cycle	approximately 150 ms.

Table 3

2 - LEVEL 1.5 PRODUCT (OIP PRODUCT)

2.1 Processing description

2.1.1 Data processed

The processing handles the following data :

- altimeter telemetry (organised in source packets consisting of 20 elementary measurements of 50 PRI in tracking mode)
- time correlation (relationship between satellite onboard time and universal time)
- original ESA (MMCC) or German PAF (G-PAF) orbit data
- engineering parameters of the instrument which vary over time

Additionally, the processing chain uses a technical parameters file and a continent file for eliminating measurements over land. This file is defined on a grid of 10' in longitude and latitude. Each point of the grid corresponds to the state of the surface for a "squared" cell with sides of approximately 55 km, got by integration of elementary cells (10'x10'). Three states are possible: ocean, land, ambigous (neither 100% land, nor 100% sea)

The processing generates the OIP products, the information for catalogue updating and for the long term monitoring file.

2.1.2 Processing

The processing is broken down into several steps :

- ***Extraction and verification of input data***

- ***Sorting and converting of measurements :***

  Elementary measurements (20hz) in sea tracking and internal calibration mode are extracted and converted (1 elementary measurement every 49 ms).

  The continent file is used to eliminate the sea tracking measurements over 100 % land-covered areas. Measurements at this stage, are labelled "sea" or "ambiguous".

- ***Estimation of altimeter parameters :***

  The processing consists of estimating from each waveform :

  - the distance position of the signal
  - the amplitude of thermal noise and useful signal
  - the significant waveheight
  - the squared mispointing angle resulting from satellite pitch and roll (attitude).

  The noise level is estimated by averaging samples from the first plateau of the waveform. The parameters for the signal's distance position, the amplitude of the useful signal and the significant waveheight are estimated by means of an iterative algorithm. This algorithm is used to make the measured waveform coincide with a return power model according to maximum likelihood estimators. Processing attempts to retrieve the attitude from an estimation of the slope of the trailing edge of the waveform.

- ***Ocean/non-ocean sorting :***

  Quality control of two parameters is used to eliminate measurements which are not of the ocean type. These two parameters are the automatic gain control, and the mean quadratic error between the measured waveform and its corresponding model (built from altimetric parameters estimation).

- ***Computing of physical quantities :***

  They are: altitude (at this stage: distance between the antenna and the sea surface, corrected from USO drift), altitude rate of change and backscatter coefficient.

- ***Computing of mean and standard deviation of physical quantities :***

  These computations are done over 0.98 s, from "ocean" elementary measurements.
  The altitude mean is computed by linear regression at the center of the average measurement, while the other means (altitude rate of change, significant waveheight, backscatter coefficient and squared attitude) are arithmetic means. The altitude standard deviation is computed with respect to the linear model, and is set to zero if the number of "ocean" elementary measurement is 1 or 2. For the other physical quantitites, the standard deviation is set to zero if only one elementary measurement is "ocean".

- ***Date-stamping and location (longitude and geographical latitude) of average measurements :***

  The onboard time T_b associated to a source packet corresponds to the transmission of the last pulse (among 1000) of the previous source packet.
  The date T_o of the first elementary measurement in the source packet, corresponding to the center of the footprint relative to this measurement, is computed as follows (where H is the satellite altitude, and c the light velocity) :

T_b ->	TU	: universal time derived from onboard time
	+ H/c	: ground impact of the last pulse of the previous source packet
	+34.PRI	: ground impact of the 34^{th} pulse of the source packet (reference pulse for altitude computation)
	-50.PRI	: shift of one elementary measurement, because the waveform associated to a measurement is derived from the 50 pulses transmitted in the previous measurement

  Thus : $T_o = TU + H/c - 16.PRI$

  The date T of the average measurement (20 elementary measurements), corresponding to the center of the footprint, is therefore :

  $$T = T_o + (19/2).50.PRI = TU + H/c + 459.PRI$$

- ***Computing of instrumental corrections and corrected physical quantities :***

  These computations are done for each average measurement. At this stage, altitude is the distance between the center of gravity of the satellite and the sea surface.

- ***Generation of products***

2.2 OIP description

The product consists of :

- the general header : 106 bytes (see annex 1 for detailed content)
- the secondary header : 61 bytes
- the data set : 80 x 124 bytes

A few preliminary remarks are necessary before reading the product :

- By average ocean measurement, we mean any average measurement (0.98 s) containing at least one elementary measurement (20Hz) declared as an "ocean" measurement in the processing.

- The correcting terms contained in the product have signed values and are **ALL** to be **ADDED**, i.e. to be added to the so-called corresponding uncorrected parameter (altitude of the satellite above the sea surface, significant waveheight, backscatter coefficient).

- The constant correcting terms for a product are provided in the secondary header, whereas the correcting terms which vary according to the average measurements are provided for each measurement in the data set.

- Location of measurements :

  The longitude reference is the Greenwich meridian. Longitude is positive and increases towards the East. The range is 0 to 359.99 degrees.

  The latitude reference is the Equator. Latitude is positive in the northern hemisphere and negative in the southern hemisphere.

2.2.1 Secondary header

Field number	Number of bytes	Type	Position (bytes)	Description	Units
1	1	I1	1	Number of measurements present in the product	
2	4	SI4	2	Latitude of subsatellite point for the first valid measurement	1.E-6 deg.
3	4	I4	6	Longitude of subsatellite point for the first valid measurement	1.E-6 deg.
4	4	SI4	10	Latitude of subsatellite point for the last valid measurement	1.E-6 deg.
5	4	I4	14	Longitude of subsatellite point for the last valid measurement	1.E-6 deg.
6	1	I1	18	Number of invalid measurements	
7	1	I1	19	Number of "ocean" measurements	
8	2	I2	20	Distance center of gravity-antenna	1.E-3 m
				Corrections of external calibrations :	
9	2	SI2	22	- Altitude	1.E-3 m
10	2	SI2	24	- Waveheight	1.E-2 m
11	2	SI2	26	- Backscatter coefficient	1.E-2 dB
12	4	I4	28	Average altitude	1.E-3 m
13	4	I4	32	Standard deviation of altitudes	1.E-3 m
14	4	I4	36	Maximum altitude	1.E-3 m
15	4	I4	40	Minimum altitude	1.E-3 m
16	2	I2	44	Average waveheight	1.E-2 m
17	2	I2	46	Standard deviation of waveheights	1.E-2 m
18	2	I2	48	Maximum waveheight	1.E-2 m
19	2	I2	50	Minimum waveheight	1.E-2 m
20	2	SI2	52	Average backscatter coefficient	1.E-2 dB
21	2	I2	54	Standard deviation of backscatter coeff.	1.E-2 dB
22	2	SI2	56	Maximum backscatter coefficient	1.E-2 dB
23	2	SI2	58	MInimum backscatter coefficient	1.E-2 dB

Field number	Number of bytes	Type	Position (bytes)	Description
24	2	B	60	**Product Confidence Data** (1 bit per indicator) : Bit 0 : Blank product Bit 1 : Discontinuity with previous product Type data used (current or by default) : Bit 2 : Spare Bit 3 : USO Bit 4 : Position of center of gravity Bit 5 : Correction of closed loop internal calibration Bit 6 : Engineering parameters Bit 7 : Orbit data (MMCC or G-PAF) Bit 8 : Location quality (nominal or downgraded) Existence of out of range measurements : Bit 9 : Altitude Bit 10 : Waveheight Bit 11 : Backscatter coefficient Bit 12 : Application indicator for mispointing corrections Bit 13 : Correction of open loop internal calibration for altitude (presence,absence) Bit 14 : Correction of open loop internal calibration for backscatter coefficient (presence, absence) Bit 15 : Spare

Description of fields :

1 : Number M of average measurements, valid or invalid, in the product (nominally M=80).
The product have a constant length, corresponding to 80 measurements.
If M<80, the 80-M last measurements of the product consist of null fields (all the corresponding fields are set to zero).

6 : Number of average measurements not containing any basic ocean measurement.

9, 10, 11 : These corrections are :

for the altitude: **+192 mm** (instrumental bias initialy derived from the Venice calibration campaign) up to version 2.4, and **0 mm** from version 2.5 (according to an ESA request).

0 cm for the waveheight

-280.E-2 dB for the backscatter coefficient (this bias was identified from comparisons between OIP and FDP measurements).

12, 16, 20 : Arithmetic average of corrected quantities in the product, computed from average "ocean" measurements (Conversion into dB for field 20).

13, 17, 21 : Standard deviation of corrected quantities in the product, computed from average "ocean" measurements (conversion into dB for field 21)
Standard deviation is set to zero if the number of "ocean" measurement is 1.

24 : The coding of bits is defined in annex 2.

2.2.2. Data set for each measurement

Field number	Number of bytes	Type	Position (bytes)	Description	Units
1	1	I1	1	Product measurement no.	
2	4	B	2	**Measurement confidence data :** - Bit 0 : Measurement valid or invalid Bits 1-3 : Cause of invalidation (5 states) - Quality (nominal or downgraded) of : Bit 4 : Estimated altitude Bit 5 : Auxiliary telemetry parameters for altitude Bit 6 : Correction of open loop internal calibration for altitude Bit 7 : Estimated waveheight Bit 8 : Estimated backscatter coefficient Bit 9 : Auxiliary telemetry parameters for backscatter coefficient Bit 10 : Correction of open loop internal calibration for backscatter coefficient Bit 11 : Auxiliary telemetry parameters for thermal noise Bit 12 : Estimated mispointing Bit 13 : Estimated vertical speed - Type of open loop internal calibration (Brown model or Point Target Response) used for : Bit 14 : Altitude Bit 15 : Backscatter coefficient - Bit 16 : Type of tracking (nominal : 0 or initial : 1) - Bit 17-31: Spare	
3 - 4	8	2I4	6	Time (code T3, see annex 2)	s, µs
5 6	4 4	SI4 I4	14 18	Latitude of subsatellite point Longitude of subsatellite point	1.E-6 deg. 1.E-6 deg.

Field number	Number of bytes	Type	Position (bytes)	Description	Units
7	1	I1	22	Number of averaged elementary measurements (20hz)	
8	4	I4	23	Uncorrected altitude averaged on 0,98 s	1.E-3 m
9	2	I2	27	Standard deviation on altitude	1.E-3 m
				10 semi-elementary altitudes (deviations w.r.t. average altitude)	
10	2	SI2	29	- Altitude 1	1.E-3 m
11	2	SI2	31	- Altitude 2	1.E-3 m
...	...	...	...	...	...
19	2	SI2	47	- Altitude 10	1.E-3 m
				10 times related to semi-elementary altitudes (deviations w.r.t. average time)	
20	2	SI2	49	- t_1	0.1 ms
21	2	SI2	51	- t_2	0.1 ms
...	...	...	...	...	...
29	2	SI2	67	- t_{10}	0.1 ms
30	4	I4	69	Altitude corrected for instrumental effects	1.E-3 m
				<u>Corrections on altitude</u> :	
31	2	SI2	73	- Estimate bias	1.E-3 m
32	2	SI2	75	- Mispointing error	1.E-3 m
33	2	SI2	77	- Doppler	1.E-3 m
34	2	SI2	79	- Open loop internal calibration	1.E-3 m
35	4	SI4	81	- Closed loop internal calibration	1.E-3 m
36	2	I2	85	Uncorrected waveheight averaged on 0.98 s	1.E-2 m
37	2	I2	87	Standard deviation on waveheight	1.E-2 m
38	2	I2	89	Waveheight corrected for instrumental effects	1.E-2 m
				<u>Corrections on waveheight</u> :	
39	2	SI2	91	- Estimate bias	1.E-2 m
40	2	SI2	93	- Mispointing error	1.E-2 m

Field number	Number of bytes	Type	Position (bytes)	Description	Units
41	2	SI2	95	Uncorrected backscatter coefficient averaged on 0.98 s	1.E-2 dB
42	2	I2	97	Standard deviation on backscatter coefficient	1.E-2 dB
43	2	SI2	99	Backscatter coefficient corrected for instrumental effects	1.E-2 dB
				<u>Corrections on backscatter coefficient</u> :	
44	2	SI2	101	- Estimate bias	1.E-2 dB
45	2	SI2	103	- Mispointing error	1.E-2 dB
46	2	SI2	105	- Open loop internal calibration	1.E-2 dB
47	2	SI2	107	Signal to noise ratio	1.E-2 dB
48	2	I2	109	Standard deviation on squared mispointing	1.E-6 $deg.^2$
49	2	I2	111	Corrected instrument mispointing	1.E-3 deg.
50	4	SI4	113	Estimate bias on the squared mispointing	1.E-6 $deg.^2$
51	2	SI2	117	Spare	
52	2	SI2	119	Spare	
53	2	SI2	121	Vertical speed averaged on 0.98 s	1.E-2 m/s
54	2	I2	123	Standard deviation on vertical speed	1.E-2 m/s

Description of fields :

2 : Quality descriptor of average measurement

Bit 0 : 0 : ocean measurement (valid)
1 : no basic ocean measurement (invalid)

Bits 1-3 : Cause of invalidation of average measurement
001 : measurement in acquisition mode
010 : measurement not in acquisition mode but over land
011 : measurement not in acquistion mode, not over land, but analysed as not over the ocean
100 : other operating mode
101 : telemetry lacking

Nominal or downgraded quality of quantities :
(0 : nominal, 1 : downgraded)
Bit 4 : Estimated altitude
Bit7 : Estimated significant waveheight
Bit 8 : Estimated backscatter coefficient
Bit 12 : Estimated mispointing
Bit 13 : Estimated vertical speed

Nominal or downgraded quality of parameters :
(0 : nominal, 1 : downgraded)
Bit 5 : Auxiliary telemetry parameters for altitude
Bit 9 : Auxiliary telemetry parameters for backscatter coefficient
Bit 11 : Auxiliary telemetry parameters for thermal noise level

Nominal or downgraded quality of parameters :
(0 : nominal, 1 : downgraded)
Bit 6 : Correction of internal calibration on altitude
Bit 10 : Correction of internal calibration on backscatter coefficient

Type of internal calibration used :
(0 : Brown model, 1 : Point Target Response)
Bit 14 : For the altitude
Bit 15 : For the backscatter coefficient

Bit 16 : Type of tracking (0 : Nominal mode, 1 : Initialization mode)

3,4 : Universal date corresponding to the centre of the ground position of the average measurement

5,6 : Geographical latitude and longitude of this point.

7 : Number of elementary measurements (20hz) declared to be "ocean", used for computation of average quantities and standard deviations.

8 : Uncorrected average altitude (distance between the antenna aperture plane and the level of the sea surface, taking into account the USO drift). This measurement is obtained by linear regression at the center of the average measurement, using altitudes computed for the basic "ocean" measurements.

9 : Standard deviation of the uncorrected average measurement of altitude, calculated in relation to the linear model (cf. field 8)

10 to 19 : 10 semi-elementary altitudes are computed by averaging two successive elementary measurements (20hz). Fields 10 to 19 contain the difference between the semi-elementary altitudes and the average altitude.

20 to 29 : the 10 differences between the dates of the semi-elementary measurements (20hz) and the date of the average measurement.

3 0 : Average altitude corrected for the following effects :

- Estimate bias: instrumental correction by look-up table (field 31)
- Effect of a mispointing error (field 32)
- Doppler effect (field 33)
- Distance from the satellite's antenna to its center of gravity (field 8, secondary header)
- Closed loop (field 35) and open loop (field 34) internal calibration
- External calibration (field 9, secondary header)

31 to 35 : Instrument corrections on altitude.

3 6 : Uncorrected average significant waveheight, equal to 4 times the standard deviation of the heights distribution of reflectors on the sea surface (assumed to be Gaussian). Negative values, when they exist, are set to zero.

3 7 : Standard deviation of the average measurement of the waveheight.

3 8 : Average waveheight corrected for instrumental effects (negative values, when they exist, are set to zero) :

- Estimate bias: instrumental correction by look-up table (field 39)
- Effect of a mispointing error (field 40)
- Correction of external calibration (field 10, secondary header)

39, 40 : Instrument corrections on the waveheight.

4 1 : Uncorrected average backscatter coefficient (the default value of -32700.E-2 dB is set, when the conversion in dB is impossible to do).

4 2 : Standard deviation on the average measurement of the backscatter coefficient.

4 3 : Average backscatter coefficient corrected for instrumental effects (the default value of -32700.E-2 dB is set, when the uncorrected value or the open loop internal calibration value is a default value) :

- Estimate bias: instrumental correction by look-up table (field 44)
- Effect of a mispointing error (field 45)
- Open loop internal calibration (field 46)
- External calibration (field 11, secondary header)

44 to 46 : Instrument corrections on the backscatter coefficient.

4 7 : Average signal to noise ratio (the default value of +32700.E-2 dB is set, when its computation is impossible to do).

4 8 : Standard deviation on the average measurement of the squared mispointing.

4 9 : Mispointing resulting from pitch and roll of the instrument, corrected for instrumental effects. The squared mispointing, estimated by using the waveforms of the basic ocean measurements is averaged (sliding arithmetic average) and corrected for estimate bias (instrumental correction by look-up table). The resulting mispointing is obtained by extracting the square root of this value if it is positive. Otherwise it is considered to be zero.

5 0 : Correction of estimate bias on mispointing.

51, 52 : Spare

5 3 : Average altitude rate of change.

5 4 : Standard deviation on the estimate of the average altitude rate of change.

2.3 Advices for using OIP

2.3.1 Measurements present / valid / invalid

The number M of measurements present in a product (field 1 of the secondary header) indicates the number of real physical measurements recorded in the product, and should be identified at the time of the product data extraction.
A value M<80 means that the 80-M last measurements of the product are null measurements (all the corresponding fields are set to zero).

These M measurements (the M first measurements of the product), may be valid or invalid. Fileds 6 and 7 of the secondary header give respectiveley the number of invalid and valid measurements in the product.

The only informations supplied for an invalid measurement, are its number, its measurement confidence data, its time and its location (fields 1, 2, 3-4, 5 and 6 of the measurement), while the other fields are set to zero. The cause of invalidation (among 5 possible causes) may be identified thanks to the measurement confidence data (bits 1 to 3 of field 2).

A product is "blank" when all the measurements are invalid. Blank products may be identified from bit 0 of the product confidence data (field 24 of the secondary header).

2.3.2 Quality of measurements

Quality informations about a measurement are stored in the product confidence data and the measurement confidence data.

The number N of averaged elementary measurements (field 7), is the number of elementary measurements considered as "ocean" measurements by the processing, and taken into account in the computations relative to the average measurement.
It seems to be a good indicator of the global quality of the measurement.
N=20 is the maximal value, and points out a good quality. The value N=17 frequently occurs, and corresponds to the measurements containing an open loop internal calibration sequence (3 elementary measurements). This value also generally points out a good global quality of the measurement.
The averaged value of N is greater than 19 (estimation derived from a 3 days cycle analysis).

2.3.3 Mispointing (attitude)

The estimate of the mispointing resulting in pitch and roll from waveforms (field 49) is not valid. Indeed, this estimate takes into account some instrumental errors which cannot be accurately corrected (anti-aliasing filter effect on waveforms ...), and presents a too high level of noise.
So, corrections of the effect of a mispointing error on the waveforms are not applied to the estimated physical quantities (altitude, significant waveheight and backscatter coefficient). The corresponding fields (fields 32, 40 and 45) are set to zero, and bit 12 of the product confidence data is set to 1.

2.3.4 Quality of waveforms , consequences

Onboard software constraints involve a systematically null level of thermal noise on the waveforms (first plateau, see figure 1). The main consequences are :

- the signal to noise ratio (field 47) can't be estimated and is set to its default value
- the "estimate bias" (fields 31, 39 and 44), which are instrumental corrections (effect of the anti-aliasing filter ...) stored in look-up tables depending on waveheight and signal to noise ratio, may be slightly erroneous.
- the impact on the waveform's parameters estimation (altitude, waveheight, backscatter coefficient) is not evaluated, but could be not negligible. Indeed a part of the information contained in the leading edge of the waveforms is lost.

2.3.5 Altitude and corrections

- The correction of Doppler effect on the altitude measurement (field 33) is computed with the bad sign from version 1.5 to version 2.8 (included). The corrected altitude (field 30) of corresponding products is therefore incorrect, and have to be modified by removing twice the computed correction (field 33).
- The open loop internal calibration correction on the altitude (field 34) may be absent for some products (see bit 13 of PCD). Such an absence shows an overestimate of the corrected altitude (field 30) of about 3.6 meters (rough mean value of the correction). About 0.025% of valid measurements among the first 35 days repeat cycle measurements are concerned by this problem.

2.3.6 Waveheight and corrections

- The instrumental correction on the waveheight (field 39) is not valid. It is suppressed (set to zero) from version 2.9 of the software.

2.3.7 Backscatter coefficient and corrections

- The open loop internal calibration correction on the backscatter coefficient (field 46) may be absent for some products (see bit 14 of PCD). The impact of such an absence on the quality of the corrected backscatter coefficient (field 43) is very small, because this correction has a mean value about zero, and a small peak to peak variation. About 0.058% of valid measurements among the first 35 days repeat cycle measurements are concerned by this problem.
- The distribution of the backscatter coefficient values is incorrect, because of instrumental imperfections, which can not be taken into acount at the present time (errors are not clearly identified or caracterised). The consequence is the presence of peaks on the histogramm of backscatter coefficient measurements, corresponding to ranges of preferential values. These peaks are distant of about 0.8 to 0.9 dB.

2.4 References

BROWN G.S., 1977 : The average impulse response of a rough surface and its applications, IEEE transactions on Antennas and Propagation, Vol. AP-25, n°1.

3 - LEVEL 2 PRODUCT (OPR)

3.1 Processing description

The processing develops OPR products for the altimeter and for the microwave radiometer using OIP products relative to both instruments. The output OPR products can be superimposed for location and dating on the input OIP products. However, the altimeter products are not synchronized with the radiometer products. An altimeter product nominally contains 80 measurements spaced at intervals of about 0.98 s. A radiometer product nominally contains 64 measurements spaced at intervals of about 1.2 s. During processing the interaction between the two instruments is as follows : the liquid water content of the clouds calculated using the radiometer OIP product is used to calculate a sigma naught and a wind value corrected for cloud attenuation. The altimetric wind is then used to improve the estimate of the radiometer OPR product parameters. For any simultaneous processing of the two instruments, the radiometer measurements are resampled over time using the altimeter dating (i.e. 0.98 s instead of 1.2 s).

In addition the processing uses orbit data produced by the German PAF to calculate the radial height of the orbit above the ellipsoid, as well as the meteorological fields provided every six hours by the French Meteorological Office for calculating tropospheric corrections. Monthly sunspot numbers predicted by the CCIR are the input for the ionospheric correction algorithm.

3.2 OPR description

The OPR consists of :

- the main header : 106 bytes (see annex 1 for detailed content)
- the secondary header : 39 bytes
- the data set : 80 x 111 bytes

3.2.1. Secondary header

Field number	Number of bytes	Type	Position (bytes)	Description	Units
1	1	I1	1	Number of measurements present in the product	
2	4	SI4	2	Latitude of subsatellite point for the first valid measurement	1.E-6 deg.
3	4	I4	6	Longitude of subsatellite point for the first valid measurement	1.E-6 deg.
4	4	SI4	10	Latitude of subsatellite point for the last valid measurement	1.E-6 deg.
5	4	I4	14	Longitude of subsatellite point for the last valid measurement	1.E-6 deg.
6	1	I1	18	Number of invalid measurements	
7	1	I1	19	Number of simultaneous altimeter and radiometer measurements	
8	2	I2	20	Mean value of wind speed	1.E-2 m/s
9	2	I2	22	Standard deviation of the mean wind speed value	1.E-2 m/s
10	2	I2	24	Maximum value of wind speed	1.E-2 m/s
11	2	I2	26	Minimum value of wind speed	1.E-2 m/s
12	2	I2	28	Mean value of significant waveheight	1.E-2 m
13	2	I2	30	Standard deviation of the mean significant waveheight	1.E-2 m
14	2	I2	32	Maximum value of significant waveheight	1.E-2 m
15	2	I2	34	Minimum value of significant waveheight	1.E-2 m

Field number	Number of bytes	Type	Position (bytes)	Description
16	4	B	36	**Product Confidence Data** (1 bit per indicator) : Bit 0 : Blank product Bit 1 : Discontinuity with previous product Type data used (current or by default) : Bit 2 : Spare Bit 3 : USO Bit 4 : Position of center of gravity Bit 5 : Correction of closed loop internal calibration Bit 6 : Engineering parameters Bit 7 : Orbit data (MMCC or G-PAF) Bit 8 : Location quality (nominal or downgraded) Existence of out of range measurements : Bit 9 : Altitude Bit 10 : Waveheight Bit 11 : Backscatter coefficient Bit 12 : Application indicator for mispointing corrections Bit 13 : Correction of open loop internal calibration for altitude (presence, absence) Bit 14 : Correction of open loop internal calibration for backscatter coeffcient (presence, absence) Bit 15 : Spare Bit 16 : Presence or absence of simultaneous radiometer data Bit 17 : Type of orbit used for calculating the height of satellite above ellipsoid Bit 18 : Manoeuvre Bit 19 to 31: Spare

Description of fields :

Field 1 :

The nominal value is 80.

Field 7 :

A simultaneous altimeter and radiometer measurement is an altimeter measurement for which there is a radiometer measurement within an interval of ± 0.6 s centered on the date of the altimeter measurement. The nominal number of simultaneous measurements is 80 over the ocean if both the instruments are functionning correctly.

Field 16 :

The OPR product confidence data is a 32 bit field made up as follows :

(Bit 0 : high order bit, bit 7 : low order bit in first byte,
bits 8 & 15 : bits 0 and 7 of second byte, etc.)

Bits 0 to 15 : Bits 0 to 15 of the OIP product confidence data (the coding of bits is defined in annex 2)

Bit 16 : 0 if there is at least one simultaneous altimeter and radiometer measurement in the product

Otherwise 1.

Bit 17 : Indicates the type of orbit used for computing the height of the orbit above the ellipsoid :

0 : preliminary orbit
1 : precise orbit

Bit 18 : Indicates the presence of an orbit manoeuvre for the product :

0 : nominal orbit
1 : orbit affected by a manoeuvre

3.2.2 Data set for each measurement

Field number	Number of bytes	Type	Position (bytes)	Description	Units
1	1	I1	1	Product measurement no	
2	2	B	2	**Measurement confidence data :** Bit 0: Measurement valid or invalid Bit 1-3: Cause of invalidation (5 states) Quality (good or bad) of the 4 estimated data at OIP level : Bit 4: Altitude Bit 5: Backscatter coefficient Bit 6: Significant waveheight Bit 7: Mispointing Bit 8: Backscatter coefficient out of range for wind calculation Presence or absence of: Bit 9: Tide corrections Bit 10: Simultaneous radiometer data Bit 11: Rain or ice in the radiometer footprint Bit 12: Brightness temperature 23.8 GHz channel, out of range Bit 13: Brightness temperature 36.5 GHz channel, out of range Bit 14: Presence or absence of model wet tropospheric correction Bit 15: Presence or absence of mean sea surface height	

Field number	Number of bytes	Type	Position (bytes)	Description	Units
3 - 4	8	2I4	4	Time (code T3, see annex A2)	s, µs
5	4	SI4	12	Latitude of subsatellite point	1.E-6 deg.
6	4	I4	16	Longitude of subsatellite point	1.E-6 deg.
7	1	I1	20	Number of averaged measurements	
8	4	I4	21	Altitude corrected for instrumental instrumental effects	1.E-3 m
9	2	I2	25	Standard deviation on altitude	1.E-3 m
				10 semi-elementary altitudes (deviations w.r.t. the average altitude)	
10	2	SI2	27	- Altitude 1	1.E-3 m
11	2	SI2	29	- Altitude 2	1.E-3 m
...	...	...	...	...	...
19	2	SI2	45	- Altitude 10	1.E-3 m
				10 times related to semi-elementary altitudes (deviations w.r.t. average time)	
20	2	SI2	47	- t_1	0.1 ms
21	2	SI2	49	- t_2	0.1 ms
...	...	...	...	...	...
29	2	SI2	65	- t_{10}	0.1 ms
				<u>Corrections on altitude</u> :	
30	2	SI2	67	- Dry tropospheric correction	1.E-3 m
31	2	SI2	69	- Wet tropospheric correction (1)	1.E-3 m
32	2	SI2	71	- Wet tropospheric correction (2)	1.E-3 m
33	2	SI2	73	- Ionospheric correction	1.E-3 m
34	2	SI2	75	- Electromagnetic bias correction	1.E-3 m
35	1	I1	77	Pressure field error	hPa

(1) Correction by the meteorological fields

(2) Correction by the microwave radiometer measurement

Field number	Number of bytes	Type	Position (bytes)	Description	Units
36	2	SI2	78	Ocean tide	1.E-3 m
37	2	SI2	80	Tidal loading	1.E-3 m
38	2	SI2	82	Body tide	1.E-3 m
39	4	SI4	84	Geoid height	1.E-3 m
40	4	I4	88	Orbit height of satellite	1.E-3 m
41	2	I2	92	Significant waveheight	1.E-2 m
42	2	I2	94	Standard deviation on significant waveheight	1.E-2 m
43	2	I2	96	Sigma naught (backscatter coefficient)	1.E-2 dB
44	2	I2	98	Standard deviation on sigma naught	1.E-2 dB
45	2	I2	100	Wind speed	1.E-2 m/s
46	2	I2	102	* Sigma naught corrected for cloud liquid water path attenaution	1.E-2 dB
47	2	I2	104	* wind speed corrected for cloud liquid water path attenuation	1.E-2 m/s
48	2	SI2	106	Orbit error	1.E-2 m
49	4	SI4	108	Mean sea surface height	1.E-3m.

* Only provided in the case of simultaneous altimeter and microwave sounder operation : these measurements are detected by a bit contained in the measurement confidence data.

Description of fields:

Field 2 :

The measurement confidence data (MCD) of the OPR product is a 16 bit field made up as follows :

(Bit 0 : high order bit, bit 7 : low order bit in first byte, bits 8 and 15 : Bits 0 and 7 of second byte)

Bit 0 : 0 : ocean measurement (valid)
1 : non ocean measurement (invalid)
(copy of bit 0 of OIP MCD)

Bits 1-3 : Cause of invalidation of average measurement
001 : measurement in acquisition mode
010 : measurement not in acquisition mode but over land
011 : measurement not in acquistion mode, not over land, but analysed as not over the ocean
100 : other operating mode
101 : telemetry lacking
(copy of bits 1-3 of OIP MCD)

Bit 4 : quality of altitude estimate (copy of bit 4 of OIP MCD)
0 : nominal
1 : downgraded

Bit 5 : quality of backscatter coefficient estimate (copy of bit 8 of OIP MCD)
0 : nominal
1 : downgraded

Bit 6 : quality of significant waveheight estimate (copy of bit 7 of OIP MCD)
0 : nominal
1 : downgraded

Bit 7 : quality of mispointing estimate (copy of bit 12 of OIP MCD)
0 : nominal
1 : downgraded

Bit 8 : 1 if the backscatter coefficient σo is outside of the limits of the table relating σo to the wind

otherwise 0

Bit 9 : 1 if there is no ocean tide calculation for this point (e.g. in the Mediterranean or in certain narrow sea inlets)

otherwise 0

Bit 10 : 1 if there is no simultaneous radiometer measurement for the altimeter measurement under consideration

otherwise 0

Bit 11 : 1 if there is a risk that the simultaneous radiometer measurement has been contaminated by rain or ice

otherwise 0

Bit 12 : 1 if the brightness temperature of the 23.8 GHz channel for the simultaneous radiometer measurement is outside of the input limits of the table linking the brightness temperatures to the altimetric correction.

0 : otherwise

Bit 13 : Same as bit 12 for the 36.5 GHz channel

Bit 14 : When the 4 model nearby grid points are on land, the wet tropospheric correction is not calculated and this bit is set to 1.

Bit15 : When the 4 mean sea surface nearby grid points are on land, the mean sea surface height is not calculated and this bit is set to 1.

<u>Fields 3 and 4</u> :

UTC Time corresponding to the centre of the ground position of the average measurement, in code T3 (see annex A2).

<u>Fields 5 and 6</u> :

Geographic latitude and longitude of this point.

<u>Field 7 :</u>

Number of elementary measurements (20 Hz) declared to be "ocean", used for computation of average quantities and standart deviations

<u>Field 8 :</u>

Average altitude corrected for all instrumental errors, including the distance from the antenna to the satellite's centre of mass, and the external calibration correction (see OIP Secondary Header description). The average altitude is obtained by linear regression at the centre of the average measurement, using 20 Hz altitudes computed for the basic "ocean" measurements.

<u>Field 9 :</u>

Standart deviation of the average altitude given by the linear regression.

<u>Fields 10 to 19 :</u>

10 semi-elementary altitudes are computed by averaging two successive elementary measurements (20hz). Fields 10 to 19 contain the difference between the semi-elementary altitudes and the average altitude.

Fields 20 to 29 :

The 10 differences between the dates of the semi-elementary measurements (20hz) and the date of the average measurement.

Field 30 :

The correction of the dry troposphere h_{30} is calculated with the following equation (Saastamoinen, 1972):

$$h_{30} = -2.277 \times Ps\ (1 + 0.0026 \cos 2\phi)$$

with h_{30} in mm

P_s	:	surface atmospheric pressure in hPa
ϕ	:	latitude of measurement point in degrees

The atmospheric pressure is calculated on the satellite track by bilinear interpolation in space and linear interpolation in time, of the surface pressure field provided every 6 hours by the French Meteorological Office in the form of a grid of 1.5° in latitude and 2° in longitude.

Field 31 :

The correction of the wet troposphere 1, h31, is given by the following expression :

$$h_{31} = -17616 \times \int_{0}^{P_s} \frac{q}{T}\, dP$$

with :

h31 in mm

P	:	pressure in hPa
Ps	:	surface pressure in hPa
q	:	specific humidity in kg/kg
T	:	temperature in K

h31 is calculated and provided by the French Meteorological Office every 6 hours in the form of a grid of 1.5° in latitude and 2° in longitude, using analysed temperature and humidity fields for the different vertical levels of the forecasting model. The correction of the wet troposphere 1 is then calculated under the satellite's track by bilinear interpolation in space, and linear interpolation in time, of the grid point values.

Field 32 :

The correction of the wet troposphere 2, h32, is calculated using the microwave radiometer brightness temperatures and the altimeter's wind speed by means of the following algorithm :

$$h_{32} = a + b \text{ Log } (280 - T23) + c \text{ Log } (280 - T36) + d\ (U - 7)$$

with :

T23 : temperature of 23.8 GHz channel brightness in K
T36 : temperature of 36.5 GHz channel brightness in K
U : altimeter wind speed in ms^{-1}
h_{32} in cm

a, b, c and d have been calculated by regression on a statistically representative set of atmospheric and surface situations together with the corresponding simulated brightness temperatures.

Up to version 2.5 :	From version 2.6 :
a = + 187.06	a = + 208.51
b = - 61.26	b = - 72.78
c = + 25.02	c = + 32.26
d = - 0.272	d = - 0.152

h32 is not provided in the case of the absence of the simultaneous radiometer measurement (cf bit 10 of MCD).
h32 is to be considered with caution if there is a risk of the radiometer measurement being contaminated by rain or ice (cf. bit 11 of MCD).

Field 33 :

The ionospheric correction h33 is calculated with the following expression :

$$h_{33} = -40250 \times \frac{TEC}{f^2}$$

with :

h33 in mm
TEC : Total Electron Content in electrons/m^2
f : altimeter frequency in Hz (: 13.8 GHz).

TEC is calculated with Bent's model (Llewellyn and Bent, 1973). The model input consists of predictions for the 12 months running average of the monthly sunspot number R12 published by the CCIR. The predicted values of R12 are used to calculate the monthly median values of the critical frequency of the F2 layer, FoF2 according to Jones and Gallet (1962) with coefficients showing a parabolic dependency in R12. Bent's model calculates the vertical profile of the electronic concentration, which is integrated up to the satellite's altitude (≈ 790 km). The TEC obtained is a monthly median for a given time of the day.

Field 34 :

The electromagnetic bias correction h34 is calculated with the following expression :

$$h_{34} = -\frac{1000\,\lambda}{8} \times H_{1/3}$$

with :

h_{34} : in mm

$H_{1/3}$: significant waveheight in m

λ : skewness coefficient, calculated according to Barrick and Lipa (1985) :

$$\lambda = 0.25 \times (H_{1/3})^{-0.28}$$

Field 35 :

The resulting value gives the pressure field error in HPa. This is a confidence criteria for the analysed pressure field expressing both the performance of the processing scheme and the quality of the observations network used for the analysis. The pressure analysis error is calculated under the satellite's path by bilinear interpolation in space, and linear interpolation in time, by using the analysis error field calculated and provided by the French Meteorological Office every 6 hours in the form of a grid of 1.5° in latitude and 2° in longitude.

Field 36 :

The ocean tide h36 is calculated by addition of the 13 tide heights relative to the 13 following tide waves, in this order :

M2, S2, N2, K2, K1, O1, P1, Q1, L2, T2, 2N2, ν2, and μ2

$$h36 = \sum_{i=1}^{13} f_i \left[a_i \cos(\sigma_i t + \chi_i + u_i) + b_i \sin(\sigma_i t + \chi_i + u_i) \right]$$

with :
h36 in mm

σ_i : frequency of the wave i (constant for each wave)
χ_i : astronomical argument for the wave i (calculated once per day for each wave)
f_i : amplitude nodal correction
u_i : phase nodal correction
t : time of the measurement, in seconds per day.
χ_i, f_i and u_i are calculated once per day for each wave

$a_i = A_i \cos \varphi_i$ and $b_i = A_i \sin \varphi_i$ are linearly interpolated in latitude and longitude under the satellite track by using maps of the amplitude A_i tables and the phase φ_i calculated by Schwiderski (1980) for the first 8 waves (M2 to Q1) and by Le Provost et al. (1990) for the 5 last waves (L2 to μ2). In the Mediterranean sea, the tide is calculated for the first 8 waves using the maps given by Canceill et al. (1993). In some closed sea areas, (e.g. : the Japan sea), ocean tide is not computed. In this case, bit 9 of the measurement confidence data is set to 1 (cf. field 2).

Field 37 :

The correction of the tidal loading h37 is a correction induced by the loading effect of the ocean tide on the bottom of the ocean. It is calculated in a similar way to the ocean tide, using 8 main tide waves, in this order :

M2, S2, N2, K2, K1, O1, P1 and Q1

$$h37 = \sum_{i=1}^{8} f_i \left[c_i \cos(\sigma_i t + \chi_i + u_i) + d_i \sin(\sigma_i t + \chi_i + u_i) \right]$$

with :

h37 in mm

σ_i	:	frequency of the wave i (constant for each wave)
χ_i	:	astronomical argument for the wave i
f_i	:	amplitude nodal correction
u_i	:	phase nodal correction
t	:	time of the measurement in seconds per day.

χ_i, f_i and u_i are calculated once per day for each wave

$c_i = B_i \cos \psi_i$ and $d_i = B_i \sin \psi_i$ are linearly interpolated for latitude and longitude under the satellite track by using maps of amplitude B_i and the phase ψ_i calculated by Francis and Mazzega (1990).

Field 38 :

The body tide h38 is computed by adding four terms :

$$h38 = (h_L + h_S + h_W + h_P) \times 1000$$

with :

h38 in mm

h_L	:	moon contribution (including permanent deformation)
h_S	:	sun contribution (including permanent deformation)
h_W	:	Wahr's radial correction
h_P	:	is the opposite of the permanent deformation term

Consequently, the above body tide h38 does not include the permanent deformation term (see advices for using OPR in section 3.3).

A second order development of the potential is used to calculate the contributions due to the Moon and the Sun, for instance, for the Moon :

$$h_L = h_2 \ (M_L / M_T) \ (R_T^4 / D_L^3)[(3 \cos^2 \theta_L - 1) / 2]$$

with :

h_2 : Love number of second order= 0.609

M_L : mass of the Moon

M_T : mass of the Earth

R_T : local terrestrial radius

$D_L = (X_L^2 + Y_L^2 + Z_L^2)^{1/2}$

$\cos \theta_L = (xX_L^2 + yY_L^2 + zZ_L^2) / D_L$

X_L, Y_L, Z_L : are the coordinates of the Moon in the terrestrial reference frame at the time of the altimetric measurement.

x, y, z : are the coordinates of the point of the altimetric measurement in the terrestrial reference frame.

X_L, Y_L, Z_L : are calculated using the Moon ephemeris provided every 12 hours in the celestial reference frame in the following way :

- linear interpolation at the time of the ephemeris measurements :
- calculation of the sideral time θ_G at the time of measurement :
- conversion into the terrestrial reference frame by application of the θ_G rotation angle matrix.

h_s is calculated in an identical way using the Solar ephemeris.

Wahr's radial correction is calculated according to the expression :

$$h_w = -0.0253 \sin \phi \cos \phi \sin (\theta_G + \mu)$$

with :

h_w in m

ϕ : latitude of subsatellite point
μ : longitude of subsatellite point

The opposite of the permanent deformation term is calculated according to the expression :

$$hp = 0.198\ h_2\ [(3 \sin^2 \phi - 1) / 2]$$

with : hp in m

Field 39 :

The height of the geoid above the WGS84 ellipsoid at the subsatellite point is obtained by linear interpolation in latitude and longitude of the GRIM4_C2 geoid calculated on a grid of 1° x 1°.
Note that, as for the body tide, GRIM4_C2 does not include the permanent deformation.

Field 40 :

This concerns the orbit height of the satellite above the WGS84 reference ellipsoid, defined by

$$a = 6378.137 \text{ km}$$
$$f = 1/298.257223563$$

The satellite's orbit is calculated by the German Processing and Archiving Facility (GPAF). Two types of orbit are possible ; the information corresponding to the type of orbit used in the calculation is contained in bit17 of the Product Confidence Data (PCD).

The preliminary orbit is calculated with a limited set of satellite observations from less precise models. This orbit is available quickly (within a few hours). It represents an improvement of the initial orbit state but not its optimum adjustment. The data used for calculating it are tracking data, Laser quick look data, and altimeter Fast Delivery Products (FDP). The ephemeris are provided every two minutes.

The precise orbit is calculated using all of the available data, as well as the best models and numerical procedures . This orbit is available from 6 to 8 months after launch, as soon as the ERS-1 dedicated models of the gravity field have been calculated. The data used for their calculation are tracking data, normal Laser points, as well as OPR altimeter products provided by CERSAT. The ephemeris are calculated every 30 seconds.

In both cases, the ephemerides are interpolated at the altimeter time using Everett's formula. The height of the orbit above the ellipsoid is then calculated using an iterative method.
An estimation of the orbit error is also given every 30 seconds in the orbit files (see field 48)

Field 41 :

Average waveheight corrected for instrumental effects, including the external calibration correction (see OIP Secondary Header description). Negative values, when they exist, are set to zero.

Field 43 :

Average backscatter coefficient corrected for instrumental effects, including the external calibration correction (see OIP Secondary Header description)

Field 45:

The wind speed value is calculated using a table relating σ_0 to the wind: "Chelton and Wentz (1986)" up to version 2.5, "Witter and Chelton (1991)" from version 2.6.

Field 46:

The backscatter coefficient corrected for the liquid water attenuation is calculated using the backscatter coefficient corrected for instrumental effects (field 43) and the estimate of the liquid water content of the clouds made by the microwave radiometer, according to the expression:

$\sigma_C = \sigma_O + 2\beta$

with:

σ_C corrected coefficient in dB

σ_O measured coefficient in dB

β attenuation due to the liquid water of the clouds in a one-way trip.

The β expression is as follows:

$$\beta = \int_0^h \beta(z)\, dz$$

$$\beta(z) = \frac{3.55\ 10^2}{\lambda^2}\ 10^{-T(z)\ /\ 82} \times M(z) \qquad \text{(Staelin, 1970)}$$

with:

$\beta(z)$: absorption coefficient for the altitude z, in Néper/km.

λ : altimeter wave length in cm (= 2.2 cm)

$T(z)$: temperature of the cloud at altitude z in K

$M(z)$: liquid water content in g/m^3.

Assuming an average temperature of the cloud to be 280K constant with altitude, then integration gives the following expression:

$\beta = 0.12 \times L$ (with: β in dB)

L being the integrated liquid water content in kg/m^2.

The integrated liquid water content is calculated using microwave radiometer brightness temperatures, by means of a statistical algorithm identical in its principle to that described for correcting the wet troposphere 2 (field 32).

Field 47:

The corrected wind speed value is calculated using the corrected backscatter coefficient, in an identical way to the uncorrected wind speed value (field 45).

Field 48:

The radial orbit error is computed by simple linear interpolation of the orbit error field provided every 30 seconds in the D-PAF orbit files. The orbit error estimation performed at D-PAF is based on the minimization of crossover sea surface height differences, by the way of least squares polynomial adjustment, using the orbit altitude together with Quick-Look OPR (ERS.ALT.QLOPR) data (Fast Delivery altimeter data corrected for ocean and earth tides, and wet and dry troposphere from ECMWF meteorological fields when available). The orbit error field provided by D-PAF is set to undefined (default) value in the following cases :

- missing QLOPR data (value = 9999),
- orbit state vector on land (value = 9998),
- radial orbit error exceeds 60 cm (value = 9997).

In the presence of such an undefined value, the interpolation at OPR altimeter time simply propagates the previous valid radial orbit correction field if available within the 30 seconds time interval. If no valid radial orbit error field is available within the 30 seconds time interval, the radial orbit correction is set to the undefined value of the orbit error field preceeding the altimeter time.

Field 49:

The height of the mean sea surface at the subsatellite point is obtained by linear interpolation in latitude and longitude of the MSS93A mean sea surface provided on a grid of 10' x 10' by GPAF. This mean sea surface has been computed using upgraded ERS-1 Fast Delivery data from April 14, 1992 to April 14, 1993 together with the operational ERS-1 preliminary orbit based on the PGM009 gravity model (radial accuracy of about 55cm), and GEOSAT altimeter data from January 1, 1987 to January 1, 1988 (GEMT2 gravity model, radial accuracy of about 45 cm). Computation of the MSS93A mean sea surface consisted in the following steps:

- generate a sea surface height model from upgraded ERS-1 fast delivery altimeter data and store normal equations of every single grid node.
- read normal equations file and GEOSAT data, take the above mentionned sea surface as a reference and remove systematics from difference subsatellite track minus reference surface, accumulate normal equations of every single grid node, solve normal equation system.

3.3 Advices for using OPR

The advices given for using OIP (see 2-3) are applicable to OPR products.

When computing the altitude corrected for environmental effects, all the OPR corrections have to be added to the altitude.

The corrected sigma-naught and windspeed (for cloud attenuation) have to be considered with caution, due to the absence of validation of the radiometer cloud liquid water content up to now.

Bit 11 of MCD indicates the presence or absence of rain or ice in the radiometer footprint, but is not reliable to reject the corresponding overestimated values of the radiometer wet tropospheric correction. One may use thresholds on the wet tropospheric correction itself to reject them.

A wrong sign in the application of the DOPPLER correction on the altimeter range at the OIP level leads to an error on the OPR altimeter range for OIP software version number up to 2.8. The OPR altimeter range can however been corrected with the following equation :

if OIP software version number is smaller or equal to 2.8, then :
    corrected range (mm) = range (mm) + 0.0017 x range time derivative (mm/s);
end if.

where the range time derivative is obtained with good accuracy from the orbit height time derivative. The OIP software version number can be found in the Main Header of the products (see Annex 1).
This error has been corrected in the OIP software version number 2.9.

The body tide is computed in page 39 as being the sum of four terms : moon contribution h_L, sun contribution h_S, Wahr's radial correction h_W and opposite of permanent deformation term h_P. It was recently recognized that the computation of h_L and h_S implicitly included the permanent deformation term and that the h_P term was in fact the opposite of the permanent deformation term, so that the permanent deformation is removed from the OPR body tide. Independantly, an OPR software bug set h_P to 0 from version 2.6 to 2.7 included, which means that the body tide for OPR products corresponding to version 2.6 and 2.7 does include the permanent deformation. As far as the GRIM4-C2 geoid is concerned, it does'nt include the permanent deformation . So, users who intend to compute some sea surface topography by substracting geoid height from altimeter sea surface height should have to add the h_P term to their sea surface topography (with OPR products corresponding to version 3.0).

Starting from OPR software version 3.0, the following changes have been made :

First, new fields are available in the OPR products :

- field 48 gives an orbit error estimate ; it replaces the older field 48 (2 bytes spare)
- field 49 gives the mean sea surface height ; it replaces the older fields 49 (2 bytes spare) and 50 (corrected instrument mispointing, which was not computed). Bit 15 of measurement confidence data indicates if the mean sea surface height is computed or not.
- field 14 of the Main Header contains the orbit version number.

Second, algorithm refinements have been performed :

- the reference ellipsoid is WGS84 (ESA request);
- the GRIM4C2 geoid height is computed above this reference ellipsoid (this was not the case before OPR version 3.0);
- the radial orbit height is computed above this reference ellipsoid;
- the ocean tide is computed using 13 tides constituents (instead of 16 before OPR version 3.0, for sake of comparison with TOPEX-POSEIDON GDR's), and the Mediterranean tide is included.

3.4 References

Barrick, D.E., and B.J. Lipa, 1985 : in Satellite Oceanic remote Sensing, Advances in Geophysics, Vol. 27, pp 86 - 93

Canceill, P., P. Agelou and P. Vincent, 1993 : Barotropic tides in the Mediterranean sea using a finite element numerical model, submitted to J. Geophys Res (Oceans).

Chelton, D.B., and F.J. Wentz, 1986 : Further development of an improved windspeed algorithm, J. Geophys. Res., vol. 91, pp 14250 - 14260

Francis, O. and P. Mazzega, 1990 : Global Charts of Ocean Tide Loading Effects, J. Geophys. Res., vol. 95, pp 11411 - 11424

Jones, W.B. and R.M. Gallet, 1960 : Ionospheric mapping by numerical methods, ITU Telecomm. Journal, vol. 12, pp 260 - 264

Le Provost, C., F. Lyard and J.M. Molines, 1990 : Improving ocean tide prediction by increasing the number of semi-diurnal constituents, submitted to Geophys. Res. Letters.

Llewellyn, S.K. and R.B. Bent, 1973 : Documentation and Description of the Bent ionospheric model, AFCRL-TR-73-0657

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

Schwiderski, E.W., 1980 : On charting global tides, Rev. of Geophys. Space Phys., vol. 18 (1), pp 243 - 268

Staelin, D.H. , A.L. Cassel, K.F. Kunzi, R.L. Pettyjohn, R.K.L. Poon, P.W. Rosenkranz and J.W. Waters, 1975 : Microwave atmospheric temperature sounding : effects of clouds on the Nimbus 5 satellite data, J. Atmos. Sci., vol. 32, pp 1970 - 1976

Witter D.L. ,Chelton D.B., 1991 : A geosat altimeter wind speed algorithm and a method for altimeter wind speed algorithm development, J. geophys. Res., 96, 8853-8860

ANNEX 1: MAIN HEADER

Field no.	No. bytes	Type	Position (bytes)	Description
1	4	I4	1	Product label
2	1	I1	5	Type of product (instrument - level)
3	1	I1	6	Satellite
4	1	I1	7	Orbital cycle
5	2	I2	8	Orbit number
6	1	I1	10	Ascending or descending pass
7	24	A	11	Subsatellite point at beginning of product (code T1)
8	2	A	35	Data acquisition station
9	24	A	37	UTC product generation time (see note 1)
10	2	A	61	Software version
11	4	I4	63	Size of specific header (in bytes)
12	4	I4	67	Number of data records
13	4	I4	71	Size of a data record(in bytes)
14	24	A	75	UTC reference time, used in on board time-ground time relationship, with the two following parameters (see note 2) :
15	4	I4	99	On board time (binary counter)
16	4	I4	103	On board clock interval (see note 2)

Note 1 : Code T2 (20 bytes). The four remaining bytes are filled with software version number of level 1.5 altimeter and level 1.5 radiometer processings, copied from level 1.5 products.

Note 2 : For OIP up to version 2.4, and OPR up to version 2.5 :
UTC reference time : code T1; On board clock interval: nanoseconds

For OIP beyond version 2.4, and for OPR version 2.6 up to version 2.8 :
UTC reference time : 7 spare bytes and code T5; On board clock interval: picoseconds

For OPR beyond version 2.8 :
UTC reference time : 2 bytes for orbit version number, 5 spare bytes and code T5

Description of main header fields :

1. Product identifier

2. Type of product

   12 : Level 1.5 Altimeter product (OIP)
   14 : Level 2 Altimeter product with preliminary orbit (OPRO1)
   15 : Level 2 Altimeter product with precise orbit (OPRO2)
   22 : Level 1.5 Microwave radiometer product (MBT)
   24 : Level 2 Microwave radiometer product (VLC)
   32 : Level 1.5 Scatterometer product (SNT)
   34 : Level 2 Scatterometer product (Fast Delivery Product generated in station)
   35 : Level 2A Scatterometer product (WNF)
   37 : Level 2 i Scatterometer product (WNF)
   42 : Level 1.5. SAR wave product (DIS)
   44 : Complex imagettes (CIT)
   45 : Level 2 SAR waves product (IPS)

3. Satellite : 1 for ERS-1

4. Orbit cycle : number of days

5. Orbit number

6. Orbit pass :

   1 : ascending
   2 : descending

7. UTC time of sub-satellite point at beginning of product : code T1 (cf. annex 2)

8. Data acquisition station :

   KS : Kiruna
   MS : Maspalomas
   GS : Gatineau
   FS : Fucino
   PS : Prince Albert

9. UTC time of product generation : code T1 for OIP, T2 for OPR

   Note that code T2 fills only 20 bytes. Remaining 4 bytes are used to store software version numbers of original products OIP and MBT. Each software version number is coded on 2 bytes.

10. Software version : two-digit number coded in ASCII

    This number is increased each time the software or the internal files are changed.

11. Size of specific header : in number of bytes

12. Number of data records

This number corresponds to the size of the product. It is necessary to refer to the specific header to find the number of measurements present in the product.

13 : Size of a data record : in number of bytes

14,15,16 : Parameters of satellite on board time-universal time relationship, used for generating the product. In field 14, the first two bytes are devoted to the orbit version number, from OPR software version 3.0.

ANNEX 2

A1. - DATA CODING AND TYPE

The types of data used are :

In : binary integer coded using n bytes

Sin : binary integer coded using n bytes with possible negative value (complement value of two)

blc : b binary integers each coded using c bytes

A : ASCII

B : Binary (Group of bits).

The bit 0 and the bit 7 are respectively the left-hand and right-hand bits of the byte in its binary representation. The bits 8 and 15 are the bits 0 and 7 (as defined above) of the following byte, etc.
The following coding convention has been adopted (ci for the i^{th} convention):

- c1 : Bit relative to a condition is positioned at 1 if the condition is satisfied
- c2 : bit relative to the quality : 0 if nominal, 1 if downgraded
- c3 : Bit relative to orbit data used : MMCC : 1, G-PAF : 0
- c4 : Bit relative to a measurement : 0 if valid, 1 if downgraded or outside of norms
- c5 : Bit indicator of measurement over land or over sea : Land : 1, Sea : 0
- c6 : Bit relative to the amount of data used to generate a product : 0 : nominal, 1 : insufficient
- c7 : Bit indicator of state of sensor : 0 : on, 1 : off
- c8 : Bit indicator for presence of auxiliary data : 1 : absence, 0 : presence
- c9 : Bit relative to data used : 0 : current, 1 : by default
- c10 : Bit indicating the type of G-PAF orbit : 0 : preliminary, 1 : precise
- c11 : Bit indicating Scatterometer's operating mode : 0 : Wind, 1 : Wind/wave
- c12 : Bit indicating type of 1.5 product input : 0 : Intermediary ESA product, 1 : CERSAT
- c13 : Bit relative to the result of a processing run : 0 : succeeded, 1 : failure
- c14 : Bit relative to application of a correction : 0 : applied, 1 : not applied