Ref : C1-EX-MUT-A22-01-CN
Issue 1 Revision 0
Date : 26.12.91

MICROWAVE RADIOMETER 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

QUALITY ASSESSMENT OF CERSAT MICROWAVE RADIOMETER PRODUCTS

MBT warning	22-DEC-1993

J STUM : CLS Argos
18 Avenue E. Belin - 31055 Toulouse cedex- France
FAX : (33) 61 75 10 14
INTERNET : stum@atlas.cnes.fr

CONTENTS

1 - BACKGROUND

The French processing and archiving facility (F-PAF: CERSAT centre) processes the ERS-1 microwave radiometer by using data recorded on-board the satellite and telemetered to the ground when the satellite flies over receiving stations.

The first step of the processing consists in transforming raw data in physical quantities (brightness temperatures), dated, located (over land and ocean), corrected for the instrumental effects, and storing them in a "microwave brightness temperatures product" (MBT). The second step of the processing consists in computing the geophysical parameters (vapour and liquid content) over ocean surfaces only, and storing them in a "vapour and liquid content product" (VLC) together with the altimeter surface windspeed used to correct for surface emissivity related effects.

Processing and products are described in CERSAT document : "Microwave Radiometer products, user manual" (C1-EX-MUT-A22-01-CN, issue 1.0).

2 - SOFTWARE VERSIONS

MBT products have been generated with software versions 2.8 and 2.9. These two versions are compatible. Version 2.9 only deals with removal of software bugs (case of bad handling of time between successive measurements when the infra-red radiometer is off).

3 - WARNING

Validation activities carried out at CRPE ("Centre de Recherches en Physique de l'Environnement"), indicates firstly that losses at the radiometer main antenna level have been overestimated during pre-launch calibration, and secondly that the radiative transfer model used to invert geophysical parameters from brightness temperatures, leads to an underestimation of water vapor absorption.

The consequence, for MBT users, is the following :

The simple linear corrections, recommended by CRPE, may be applied by users to all MBT products built up to now:

- 24 GHz brightness temperature [°K] : $Tb24_{corrected} = 0.960532 \cdot Tb24 + 12.235$
- 36 GHz brightness temperature [°K] : $Tb36_{corrected} = 0.96154 \cdot Tb36 + 11.81$

The consequence, for VLC users, is the following :

The simple linear correction, recommended by CRPE, may be applied by users to all VLC products built up to now:

- Water vapor content [g/cm^2] : $Wv_{corrected} = 0.80668 \cdot Wv + 0.32253$

There is no available a posteriori correction for cloud liquid content.

4 - ADVICE

After correcting the brightness temperatures, MBT users may themselves compute the water vapour and liquid contents from the brightness temperatures (over ocean only) by using simple formula given in the Microwave Radiometer Products User Manual, page 33. Coefficients a, b, c are the following :

- water vapour content (g/cm^2): a = 24.6795 b = -10.2242 c = 5.4746

- cloud liquid content (kg/m^2): a = 21.6779 b = 1.0567 c = -5.5446

It should be noted that the altimeter surface windspeed, used to correct the above geophysical parameters for surface emissivity related effects in VLC processing, brings very little correction to the radiometer-only estimates. The magnitude of the windspeed correction can be computed by using formula given in the Microwave Radiometer Products User Manual, page 34. Coefficient d is the following :

- water vapour content (g/cm^2): d = - 0.015

- cloud liquid content (kg/m^2): d = - 0.0093

Finally, the cloud liquid content estimation is presently considered by CRPE as being unreliable.

J STUM has been in charge of the definition and specification of ERS-1 radiometer and altimeter (geophysical level) off-line algorithms (since 1985), involved in the follow-up of the corresponding operational software development and acceptance testing, and in charge of the validation of the MBT and VLC processing and products.

List of changes

Issue	Date	Page	Comments
1.0	26.11.90		Creation

CONTENTS

Glossary

CLS/Argos	:	Collecte Localisation Satellite/Système Argos
CNES	:	Centre National d'Etudes Spatiales
CNET/CRPE	:	Centre National d'Etudes des Télécommunications/ Centre de Recherches en Physique de l'Environnement
ESA	:	European Space Agency
G-PAF	:	German Processing and archiving facility
IFREMER	:	Institut Français de Recherches pour l'Exploitation de la MER
MBT	:	Microwave Brightness Temperature
MCD	:	Measurement Confidence Data
MMCC	:	Mission management and control center (ERS-1 Mission and Control Center)
PAF	:	Processing and archiving facility (ERS-1 off-line processing center)
PCD	:	Product Confidence Data
T.B.C.	:	To be confirmed
UTC	:	Universal time coordinate
VLC	:	Water Vapour and Liquid water Content

Reference documents :

[R1] : CERSAT products, General Description
C1-EX-MUT-A2-07-CN   Issue 1.0   26/11/90

* **Authors addresses :**

Jacques Stum : CLS/Argos
18 avenue Edouard Belin, 31055 Toulouse Cédex, France

Alain Le Cornec : CNET-CRPE
& Laurence Eymard : 38-40 rue du Général Leclerc,
92131 Issy-les-Moulineaux Cédex, France

1. INSTRUMENT AND MISSION DESCRIPTION

1.1 Mission description

The ATSR-M microwave radiometer (Along Track Scanning Radiometer and Microwaver sounder) is part of the ATSR payload. It has been designed and built under the responsibility of CNET/CRPE, with the support of CNES, IFREMER and the Danish Ministry of Research.

The main purpose of the microwave radiometer is the measurement of the tropospheric path delay for the altimeter through the measurement of the atmospheric integrated water vapour content and the estimate of the attenuation of the altimetric signal by the liquid water content of the clouds. The radiometer also provides a continuous measurement of the water vapour and of the liquid water in the atmosphere above the oceans, as well as the brightness temperatures for both frequencies. This information can be used in radiation budget studies (e.g. surface energy budget associated with the surface temperature measured by the ATSR infrared channels and the scatterometer wind, ground humidity, surface emissivity etc.). It can also be used for studying ice formations (the limits of the ice, in association with the altimeter,) and for studying the properties of the continental ice pack.

1.2 Instrument description

The ATSR-M microwave radiometer uses two frequencies at 23.8 GHz and 36.5 GHz, each with a bandwidth of ± 200 MHz. Each channel operates in the Dicke mode by comparing the antenna temperature to an internal reference source with a switching frequency of 1 KHz.

The output signal from the synchronous sensor is integrated and sampled every 150 ms (synchronized with the infrared radiometer scan rate) and is transmitted to the ground as a numerical count together with the reference load temperature and other internal temperatures.

Internal calibration is achieved by either connecting the receiver input to a skyhorn observing the cold temperature of space, or to a second internal reference load.

The main antenna is an offset antenna, with one feed horn for each frequency. Each channel is then pointing at an angle close to the nadir, with the channel 36.5 in the forward direction and the channel 23.8 in the backward direction. Each channel is linearly polarized in the orbit plane (vertical polarization). The measured antenna characteristics are given in table 1 and the measured antenna pattern in figure 1.

The skyhorn is a 7.5 cm. diameter corrugated horn, the channel separation being done by an orthomode transducer. Its characteristics are given in table 2.

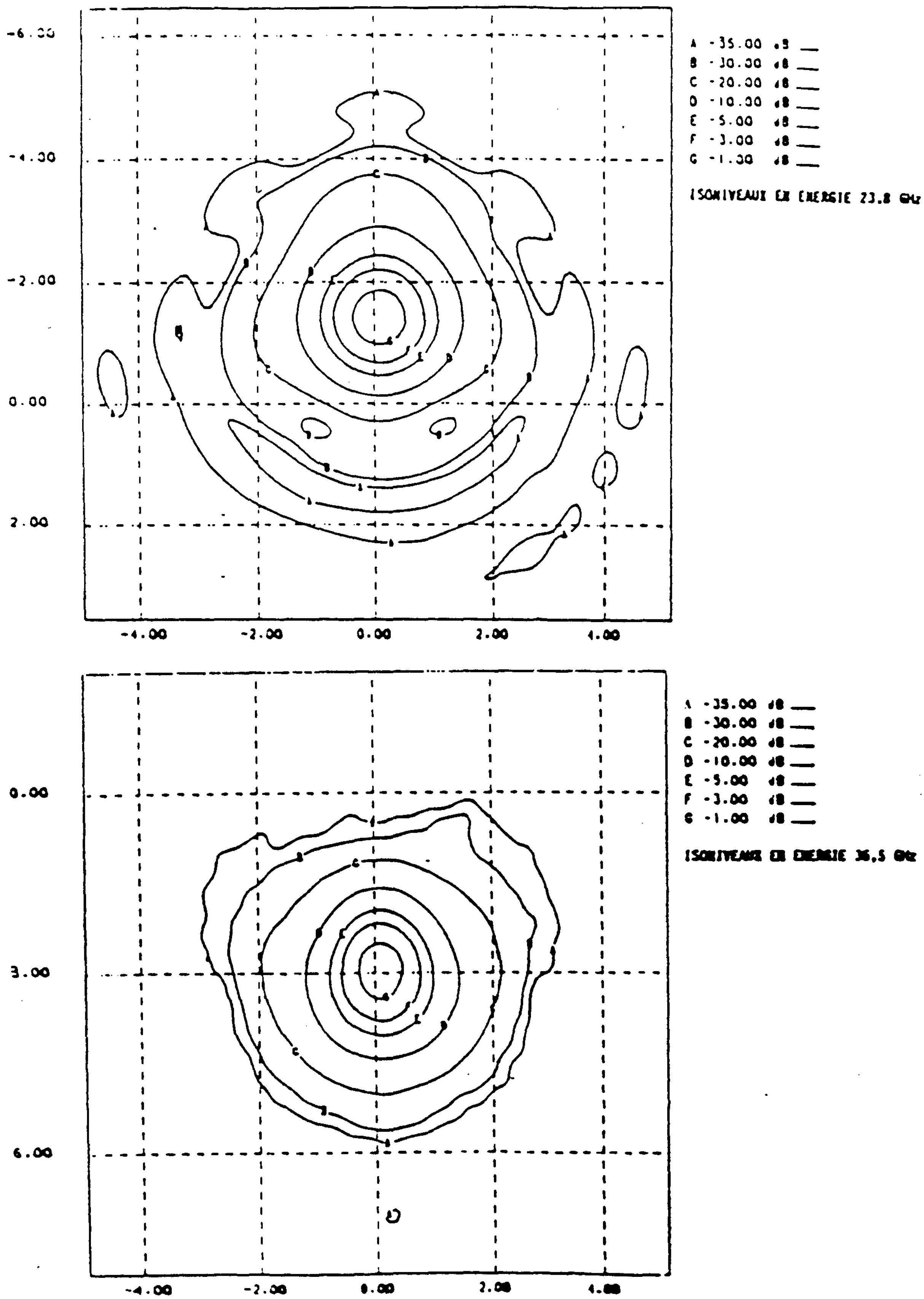
Reflector projected diameter	0.60 m	
Focal length	0.35 m	
Channel	**23.8**	**36.5**
Pointing angle	- 1.93 °	+ 2.50 °
Measured gain	40.62 dB	42.0 dB
3 dB aperture :		
along track	1.52 °	1.61 °
cross track	1.51 °	1.37 °
3 dB footprint diameter:		
along track	21.2 km	22.5 km
cross track	21.2 km	19.1 km
20 dB maximum aperture	4.2 °	4.1 °
Main beam efficiency	0.95	0.96
First side lobe	- 24.0 dB	- 35.0 dB

Table 1. Characteristics of the main atenna

Channel	**23.8**	**36.5**
3 dB aperture	15 ° x 15 °	14.1 ° x 19 °
Measured gain	21.2 dB	20.9 dB
20 dB aperture	50 °	50 ° x 36 °

Table 2. Skyhorn characteristics

Figure 1 Isolevels of energy from the antenna's main lobe



Each radiometer channel may be modelled as shown in figure 2, with a G' gain amplifier depending on its physical temperature T_g, a Dicke circulator at temperature T_d switching between the reference load T_{ref} and the antenna input. The antenna channel itself consists of a calibration circulator with temperature T_{cal} switching between the main antenna and the calibration channels. A last circulator at temperature $T_{h/c}$ switches the calibration input between the hot load T_c and the skyhorn.

One has to add in the main antenna circuit the source and waveguide temperature T_r and likewise for the skyhorn circuit, where the contributions of the horn and the waveguide can be separated (T_{cc} for the horn, T_h for the guide).

The physical temperature of all of the components is monitored and transmitted as part of the science data.

The input temperature of the main antenna is the antenna temperature T_a , linked to the brightness temperature T_B of the scene observed in the main antenna lobe through antenna pattern correction.

The input temperature of the skyhorn is T_{sky}, which is in fact different from the very low cosmic background noise temperature mainly because of partial beam filling by the Earth disc.

Four different numerical counts are measured by the system:

C_a : Main antenna numerical count output
C_h : Hot load numerical count output
C_c : Cold load (skyhorn) numerical count output
C_{off} : Pre-adjusted offset numerical count output for the three previous measurements.

Each numerical count results from integration of the input signal over 150 ms. Each numerical calibration count (C_h,C_c and C_{off}) is measured every 38.4 seconds.

Three basic parameters can be retrieved from the above model : two calibration parameters (a gain G and a temperature bias TE) and the antenna temperature T_a. The two calibration parameters are calculated every 38.4 seconds. The gain G is the overall gain between the main antenna circuit and the amplifier output. It is given by equation (1) :

$$G = \frac{C_h - C_c}{\left[a_0 + a_1 T_{sky} + a_2 T_{cc} + a_3 T_h + a_4 T_c + a_5 T_{h/c} \right] \times f(T_g)} \qquad (1)$$

f (T_g) is a model function of the amplifier's physical temperature T_g :

$$f(T_g) = 1 + a (T_g - T_{g0}) + b (T_g - T_{g0})^2$$

with $T_{g0} \sim 290$ K

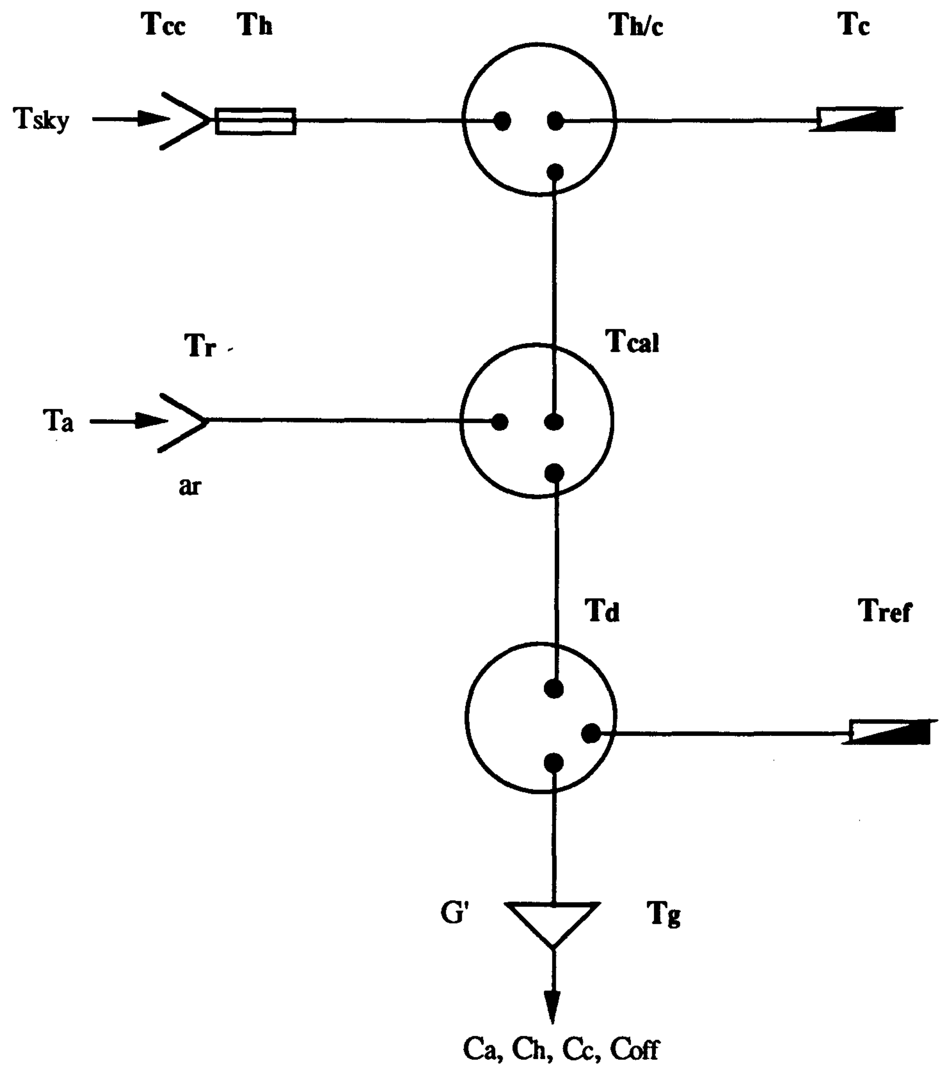


Figure 2. Model of radiometer channel

The temperature bias TE comes from residual temperature contributions due for instance to mismatches. This bias is assumed to be independant of the internal temperatures. It is given by equation (2) :

$$TE = \frac{C_h - C_{off}}{G \times f(T_g)} + a_6 T_{ref} + a_7 T_d + a_8 T_{sky} + a_9 T_{cc} + a_{10} T_h + a_{11} T_{h/c} + a_{12} T_c + a_{13} T_{cal} + a_{14} \quad (2)$$

The antenna temperature T_a is retrieved every 150 ms (except when internal calibration occurs) by means of equation (3) :

$$Ta = a_{15} T_{ref} + a_{16} T_d + a_{17} T_{cal} + a_{18} T_c + a_{19} T_{h/c} + a_{20} TE + a_{21} T_r + a_{22} \frac{C_a - C_{off}}{G \times f(T_g)} \quad (3)$$

Coefficients a_i are functions of transmission and/or isolation factors of the different microwave components and are determined by pre-launch laboratory measurements.

The temperatures of the microwave components are monitored every 4.8 s using precise resistance measurements of platinum thermistances. As some drift of the resistance measurement system may occur with temperature variations, four precisely calibrated reference resistances are measured to calibrate the system. Actually, as the theoretical relationship between resistance and temperature is nearly linear, any temperature can be determined directly by linear interpolation between the two closest reference resistances, according to the following equation (4) :

$$T = Tj + (Tj+1 - Tj) \times \frac{R - Rj}{Rj+1 - Rj}$$

with :

R	:	resistance measurement
T	:	corresponding temperature ;
Rj and Rj+1	:	are the measured reference resistance measurements that verify : $Rj \leq R \leq Rj+1$;
Tj and Tj+1	:	are the corresponding reference temperatures.

2. LEVEL 1.5 PRODUCT

2.1. General description of level 1.5 processing(MBT processing)

The processing generates MBT products from the radiometer telemetry. Each Radiometer MBT product nominally contains 64 brightness temperatures for each channel, averaged over 1.2 s, colocated at the satellite's nadir over sea, land, and ice surfaces.

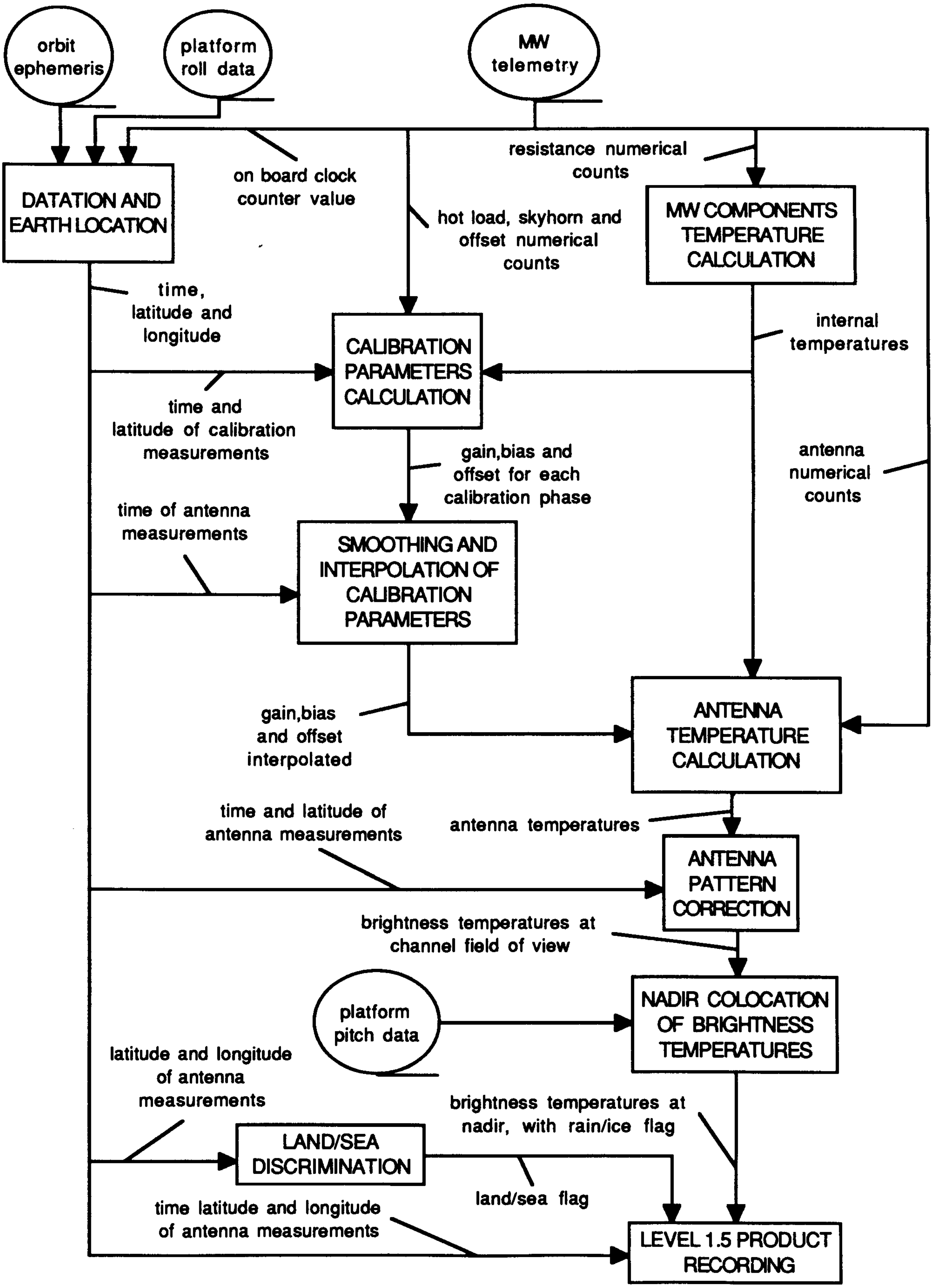
The block diagram describing the main steps of the processing is shown in figure 3. The quantity of telemetry processed each time processing is initialized will henceforth be referred to as the orbit segment . Nominally, an orbit segment contains approximately half a revolution of the satellite. The restituted orbit ephemeris and the platform attitude information (roll, pitch) are also part of the processing input data. About 47 Radiometer MBT products are generated per orbit segment.

Quality control is performed during most of the processing steps. The results of this quality control are given for each product in the form of Product Confidence Data (PCD) and, for each measurement of the product, in the form of Measurement Confidence Data (MCD).

2.2 Definition of level 1.5 radiometer product (MTB product)

The radiometer MBT product consists of a general header record, of a secondary header record and of a 64 measurements record. The general header is described in document [R1] and is similar for all of the instruments.

This document describes the secondary header and the measurements.


orbit ephemeris
platform roll data
MW telemetry
DATATION AND EARTH LOCATION
on board clock counter value
resistance numerical counts
MW COMPONENTS TEMPERATURE CALCULATION
hot load, skyhorn and offset numerical counts
time, latitude and longitude
CALIBRATION PARAMETERS CALCULATION
internal temperatures
time and latitude of calibration measurements
gain,bias and offset for each calibration phase
antenna numerical counts
time of antenna measurements
SMOOTHING AND INTERPOLATION OF CALIBRATION PARAMETERS
gain,bias and offset interpolated
ANTENNA TEMPERATURE CALCULATION
time and latitude of antenna measurements
antenna temperatures
ANTENNA PATTERN CORRECTION
brightness temperatures at channel field of view
platform pitch data
NADIR COLOCATION OF BRIGHTNESS TEMPERATURES
latitude and longitude of antenna measurements
brightness temperatures at nadir, with rain/ice flag
LAND/SEA DISCRIMINATION
land/sea flag
time latitude and longitude of antenna measurements
LEVEL 1.5 PRODUCT RECORDING

2.2.1. Secondary header

Field number	Number of bytes	Type	Description	Units
1	1	I1	Number of measurements present in the product	
2	4	SI4	Latitude of subsatellite point for the first valid measurement	1.E-4 deg
3	4	I4	Longitude of subsatellite point for the first valid measurement	1.E-4 deg
4	4	SI4	Latitude of subsatellite point for the last valid measurement	1.E-4 deg
5	4	I4	Longitude of subsatellite point for the last valid measurement	1.E-4 deg
6	1	I1	Number of invalid measurements	
7	1	I1	Number of measurements on sea	
8	1	I1	Number of measurements on land	
9	2	I2	Bias on Tb 23.8	0.1 °K
10	2	I2	Bias on Tb 36.5	0.1 °K
11	2	I2	Mean Tb 23.8	0.1 °K
12	2	I2	Tb 23.8 standard deviation	0.1 °K
13	2	I2	Tb 23.8 minimum value	0.1 °K
14	2	I2	Tb 23.8 maximum value	0.1 °K
15	2	I2	Mean Tb 36.5	0.1 °K
16	2	I2	Tb 36.5 standard deviation	0.1 °K
17	2	I2	Tb 36.5 minimum value	0.1 °K
18	2	I2	Tb 36.5 maximum value	0.1 °K
19	2	B	Product confidence data	

Comments :

Field 1 :

The nominal value is 64.

Fields 9 and 10 :

These biases are always 0 and are never taken into account in the actual processing.

Field 19:

The product confidence data for level l.5 is a 16 bit field made up as follows :

bits	0	...	...7	8	...	...	15
	<-------byte41		---->	<------byte 42--------->			

bit 0 : 0 if there is at least one measurement in the product.
1 otherwise : the product is called a "blank product".

bit 1 : 0 if there is no discontinuity with the previous product.
1 otherwise.

bit 2 : 0 if there is at least one measurement over the sea.
1 if all of product's measurements are over land.

bit 3 and 4 : These describe the processing option used for the calibration data :

0 0 if the temperature observed by the skyhorn is given by a function of latitude.

As a matter of fact the skyhorn does not only capture the 2.7 K coming from the cosmic background noise, but rather a temperature of approximately 3.1 K, because of partial beam filling of the main lobe by the Earth disc and parasite radiation by the satellite platform; a small variation of this temperature has been taken into account, in relation to the latitude.

0 1 if the temperature observed by the skyhorn is given by a constant value : this case indicates that there is no skyhorn temperature variation along the orbit track.

1 0 if the skyhorn measurement has not been used.

This case would occur if it were established that the skyhorn was not a sufficiently precise calibration point to be able to be used in calculating the calibration data : in this case, the overall radiometer gain is frozen in the processing and the hot load measurements are only used to calculate the temperature bias.

1 1 if none of either the cold load or the hot load measurements have been used.

This case would occur if there were a major problem in the instrument thus preventing in-flight calibration of the radiometer. In this case the gain, temperature bias and offset values are set to predetermined values in the processing.

most probable values : 00

bit 5: this describes the processing option used for calculating the brightness temperatures from the antenna temperatures.

0 if the temperature observed through the side lobes of the main antenna is given by a tabulation according to the month and the latitude. The temperature seen through the side lobes is calculated by linear interpolation in the table.

1 if the temperature observed through the side lobes of the main antenna is given by a constant value.

most probable value : 0

bit 6 : indicates whether it was necessary, for at least one product measurement, to extrapolate the calibration data, i.e. that the calibration data is missing after the measuring point or before the measuring point.

0 interpolation was possible.

1 extrapolation was carried out.

Extrapolation may occur if the calibration data are missing in the telemetry at the beginning or end of the orbit segment processed. This may happen only rarely and does not alter the accuracy of the brightness temperature for the measurement(s) involved.

most probable value : 0

bit 7 : indicates whether a temperature variation greater than a certain threshold has been observed in one of the microwave components for at least one product measurement.

0 no variation.

1 at least one variation.

This bit is only a piece of information on spurious resistance measurements that may occur. The processing eliminates the spurious measurements so the accuracy of the corresponding brightness temperatures is not altered.

most probable value : 0

bit 8 : indicates whether, among the four reference resistances used to calculate the component temperatures by means of resistance measurements, at least one of them has a value which is out of range.

0 no out of range value.

1 value out of range.

This bit may be set to 1 at the beginning of the orbit segment or after telemetry gaps. It does not mean that the accuracy of the brightness temperatures is altered: two valid reference resistances out of four are sufficient for calculating the microwave component temperatures from their measured resistances.

bit 9 : indicates whether less than N calibration parameters (gain, bias or offset) were available in the orbit segment to which the product belongs.

0 more than N.

1 less than N.

At least N values are required for the processing (N= at least 6, TBD) as each calibration parameter is smoothed by calculating a running linear regression line for N consecutive values.
If less than N parameters are available, then all of the orbit segment products are processed with predetermined values of the calibration parameters . This bit is partly redundant with the value 11 of bits 3 and 4.

bit 10 : indicates whether blanking pulses have been received and processed during signal integration.

- 0 no blanking pulses received and processed.
- 1 blanking pulses have been received and processed.

The microwave receivers may be blocked during ERS-1 radar transmission if necessary. During the blocking time, the integrator input value is conserved but decreases slightly over time, this being equivalent to a decrease in gain or in integration time. A correction can be made to the numerical counts in the ground processing, according to the type of transmitting instrument (SAR, SCATT or RA). The occurrence of blanking pulses does not affect the resulting precision of the measurement.

most probable value : 0

bit 11 :

- 0 if, for more than half of the product valid measurements, there is simultaneous functioning of the infrared radiometer.
- 1 otherwise.

bit 12 :

- 0 if it is the G-PAF orbit which has been used for locating the measurements.
- 1 If its the MMCC orbit.

bit 13 :

- 0 if the orbit quality is nominal.
- 1 if the orbit quality is altered (case of satellite being in manoeuvering mode).

bit 14 :

- 0 if the platform altitude data were available for the processing.
- 1 otherwise.

this bit will probably be set to 1 for the whole duration of the mission.

bit 15 : not used (value 0)

2.2.2. The data set

This is a record of 64 x 29 bytes corresponding to the 64 measurements present in the product. The details of the 29 bytes corresponding to one measurement are given below. the time interval separating each measurement is about 1.2 s, resulting from the average of eight elementary measurements in nominal.

Field number	Number of bytes	Type	Description	Units
1	1	I1	Number of the measurement in the product	
2	2	B	Measurement confidence data	
3	8	2I4	Time of measurement (UTC)	sec, msec
4	4	SI4	Latitude of subsatellite point	1.E-4 deg
5	4	I4	Longitude of subsatellite point	1.E-4 deg
6	1	I1	Number of 23.8 GHz elementary measurements	
7	2	I2	23.8 GHz brightness temperature	0.1 °K
8	1	I1	23.8 GHz brighness temperature standard deviation	0.1 °K
9	1	I1	"Blanking pulses" number for the 23.8 GHz channel	
10	1	I1	Number of 36.5 GHz elementary measurements	
11	2	I2	36.5 GHz brightness temperature	0.1 °K
12	1	I1	36.5 GHz brightness temperature Standard deviation	0.1 °K
13	1	I1	"Blanking pulses" number for the 36.5 GHz channel	

Comments :

Field 2 :

The MBT measurement confidence data (MCD) is a 16 bit field made up as follows :

bits	0	... ...	7	8	... ...	15

<-------byte 2--------><-------byte 3----------->

bits 0 and 1 : describe the validity of the measurement.

- 0 0 if the measurement is valid for both channels.
- 0 1 if the 23.8 GHz measurement is not valid.
- 1 0 if the 36.5 GHz measurement is not valid.
- 1 1 if the measurement is invalid for both channels.

bits 2 and 3 : describe the reason for invalidity reported in states 01, 10 and 11 of the bits 0 and 1.

- 0 0 if the radiometer has been switched off.
- 0 1 if the radiometer is operating with an anomalous temperature range or if it was not possible to calculate the component temperatures (case which occurs when the reference resistances are out of range).
- 1 0 if the radiometer is in special test operation mode (for example, if the output is permanently connected to the skyhorn).
- 1 1 if there is a telemetry gap.

The most likely case of invalidity is a telemetry gap . The others concern events which have been predicted, but which should not occur in flight during radiometer operation.

bit 4 :

0 if the infrared radiometer is active.

1 otherwise.

This bit indicates for each measurement whether infrared radiometer data is available. In addition, when the infrared radiometer is active, the integration time for the microwave signals is governed by the rotation period of the infrared radiometer mirror, i.e. 150 ms ; when the infrared radiometer is off, the integration time is set by the microwave radiometer's internal clock the period of which is slightly different (157 ms).

bit 5 :

0 if the measurement is over the sea.

1 if the measurement is over land.

The sea/land discrimination is done by using a US Navy file which was corrected and reorganized for the ECMWF requirements and then adapted for the present study. The file has a resolution of 10' x 10' and contains a flag representative of a 74 x 74 km^2 squared area : if there is 100% sea within this area the flag indicates "sea", if there is less than 100% of sea within the area, the flag indicates "land".

Bit 5 is set to "sea" or "land" for each 1.2 s radiometer measurement, according to the value given by the file grid point which is the closest to the measurement

bit 6 :

0 absence of rain or ice.

1 presence of rain or ice.

A test is carried out for each average measurement, using the brightness temperatures :

$$\text{if } TB36 > 0.25\ TB23 + 195,$$

then bit 6 is set to 1.

This bit indicates more the possiblity than the probability of rain or ice in the main lobe. The brightness temperature measurements should be taken with caution.

In level 2 processing, the brightness temperatures for which there is a presence of rain or ice are nevertheless used to calculate the geophysical parameters. Bit 6 is copied in the measurement confidence data of level 2 product.

bit 7 : indicates for the 23.8 GHz channel whether a temperature variation greater than a certain threshold has been observed in one of the components for the measurement involved.

0 no anomalous variation.

1 at least one anomalous variation.

When anomalous variation occurs, the value of the temperature is set to its previous value. Anomalous behaviour of a component has no significant impact on the accuracy of the brightness temperature for the measurement concerned.

bit 8 : same as bit 7 for the 36.5 GHz channel.

bit 9 : indicates if it was necessary to extrapolate the calibration data for the 23.8 GHz channel measurement in question. This bit gives, for each measurement, detailed information for bit 6 of the PCD .

bit 10 : Same as bit 9 for the 36.5 GHz channel.

bits 11 to 15: not used (value 0)

Field 3 :

Date of the measurement : this is provided in the form of 2 4-byte integers. The first integer is the number of seconds elapsed since 1/1/1990 at Oh UTC. The second integer is the number of milliseconds in the second.

Field 4 :

This gives the latitude in units of 10^{-4} degrees, positive in the northern hemisphere, negative in the southern hemisphere.

Field 5 :

This gives the longitude in units of 10^{-4} degrees, (positive towards East).

The latitude and longitude are calculated either from the orbit ephemeris provided by the MMCC, or from the orbit ephemeris provided by the G-PAF (see bit 12 of the PCD).

The MMCC orbit ephemeris contains the position of the satellite calculated every minute, whereas the G-PAF orbit ephemeris gives the position once every two minutes.

The orbit is interpolated at the time of radiometer measurement using Everett's formula. The position of the interpolated satellite is projected on the reference elipsoid, defined by :

$$a = 6378.1364 \text{ km}$$
$$f = 1/298.2564 \text{ km}$$

and the latitude and longitude are calculated by iterative processing. They are then corrected to take into account the platform roll, by using the restituted attitude data provided by the MMCC, when this is available.

Fields 6 and 10 :

These fields give the number of 150 ms elementary measurements used to calculate the mean (1.2 s) brightness temperature.

The nominal value is 8, except every 38.4 seconds (at each calibration phase) when it is 1 : only a single elementary measurement is available for constructing the mean.

Field 7 and 11 :

The brightness temperatures for each channel are calculated according to the following steps :

1 - calculation of the brightness temperatures from the antenna temperatures ;
2 - colocation of brightness temperatures at nadir.

1 - The brightness temperatures are calculated with the equation :

$$T_B = (T_a - T_{SL})/W$$

with :

T_a : antenna temperature

W : global efficiency of the main lobe

The global efficiency of the main lobe is the product of the main beam efficiency by the antenna radiation efficiency. Values are 0.933 for 23.8 GHz, 0.938 for 36.5 GHz.

T_{SL} : average temperature seen through the side lobes

T_{SL} is about 11K ; it takes into account radiation coming from the satellite platform, the SAR antenna and the Earth surface. The main contribution however is from the Earth surface and is given as a function of latitude.

The antenna temperature is calculated by means of equation (3) in paragraph 1.2 using the antenna numerical counts averaged every 1.2 s and the calibration parameters (gain, bias and offset) that have been smoothed and interpolated at the date of the average measurement.

2 - The 23.8 GHz channel footprint is located approximately 27 km behind the nadir ; the 36.5 GHz channel footprint is located 35 km in front of the nadir. The brightness temperatures have to be reset for colocation of the measurements to the nadir.

In order to do this, the number of average measurements corresponding to this difference is calculated by taking into acount the channel mispointing values given in table 1 of paragraph 1.2, as well as the platform pitch if this is available. This number has the value 3 for the 23.8 GHz channel and 4 for the 36.5 GHz channel (if pitch is neglected).

For each average measurement identified by its number N, the brightness temperature for the 23.8 GHz channel is replaced by that of the measurement number N +3 and the brightness temperature for the 36.5 GHz channel is replaced by that of the measurement number N - 4.

Fields 8 and 12 :

The standard deviations for each average measurement are calculated using the elementary measurements (nominally 8) used to calculate the average measurement.

If the average measurement has only been constructed using a single elementary measurement, the standard deviation is not calculated.

Fields 9 and 13 :

The blanking pulses number varies between 0 and 8. It is 0 if no blanking pulses have been received and processed for any elementary measurement used to calculate the average measurement . It has the value 8 if blanking pulses have been received and processed for each of the 8 elementary measurements used to calculate the average measurement .

3 LEVEL 2 PRODUCT (radiometer VLC product)

3.1. General description of level 2 processing

Radiometer processing from level 1.5 (MBT) to level 2 (VLC) is performed together with the altimeter one. It consists in calculating the geophysical parameters (water vapour content, liquid water content, and wet tropospheric correction for the altimeter) by using the brightness temperatures over the ocean.

The interaction between the two instruments in the processing is as follows : the liquid water content of the clouds calculated from the radiometer brightness temperatures is used to calculate a sigma 0 and a wind value corrected for cloud attenuation. The altimeter wind value is then used to improve the estimate of the radiometer product parameters for level 2. For each simultaneous processing of the two instruments, the radiometer measurements are resampled over time according to the altimeter sampling (i.e. 0.98 s instead of 1.2 s). A simultaneous altimeter and radiometer measurement is defined as being an altimeter measurement for which there is a radiometer measurement within an interval of about 0.6 s centered on the time of the altimeter measurement.

3.2. Definition of level 2 radiometer product (VLC)

The product consists of a general header, a secondary header record and a 64 measurements record.

The general header has been described in chapter 1 and is similar for all of the instruments. We shall now describe the secondary header record and the 64 measurements record.

3.2.1. Secondary header

Field number	Number of bytes	Type	Description	Units
1	1	I1	Number of measurements present in the product	
2	4	SI4	Latitude of subsatellite point for the first valid measurement	1.E-4 deg
3	4	I4	Longitude of the subsatellite point for the first valid measurement	1.E-4 deg
4	4	SI4	Latitude of the subsatellite point for the last valid measurement	1.E-4 deg
5	4	I4	Longitude of the subsatellite point for the last valid measurement	1.E-4 deg
6	1	I1	Number of invalid measurements	
7	1	I1	Number of measurements on sea	
8	1	I1	Number of simultaneouradiometer and altimeter measurements	
9	2	I2	Mean water vapour content	10^{-2} g/cm^2
10	2	I2	water vapour content standard deviation	10^{-2} g/cm^2
11	2	I2	Water vapour content minimum value	10^{-2} g/cm^2
12	2	I2	Water vapour content maximum value	10^{-2} g/cm^2
13	2	I2	Mean liquid water content	10^{-2} g/cm^2
14	2	I2	Liquid content standard deviation	10^{-2} g/cm^2
15	2	I2	Liquid water content minimum value	10^{-2} g/cm^2
16	2	I2	Liquid water content maximum value	10^{-2} g/cm^2
17	2	B	Product confidence data	

Comments :

Field 8 :

This field describes the number of product measurements for which the altimeter wind value was used to correct for the water vapour and liquid water contents.

Fields 9 to 16 :

Negative values may occur due to the statistical nature of the inversion algorithm used for retrieving the contents by means of the brightness temperatures. The inversion method can be found in Lojou (1990).

Field 17 :

The VLC quality confidence data is a 16 bit field made up as follows :

bits	0	... ...	7	8	... ...	15

<------byte 35 ------><-------byte 36---------->

bit 0 : blank product (cf. bit 0 of radiometer MBT product PCD)

bit 1 : discontinuity with the previous product (cf. bit 1 of radiometer MBT product PCD)

bit 2 :
- 0 if there is at least one simultaneous altimeter and microwave sounder measurement in the product (see field 7 of the secondary header for the altimeter VLC).
- 1 otherwise.

bits 4 and 5 : calibration data processing option (cf. bits 3 and 4 of radiometer MBT product PCD)

bit 6 : processing option for correction of side lobes (cf. bit 5 of radiometer MBT product PCD).

bit 7 : quality of calibration data (cf. bit 6 of radiometer MBT product PCD).

bit 8 : quality of microwave components (cf. bit 7 of radiometer MBT product PCD).

bit 9 : blanking pulses (cf. bit 10 of radiometer MBT product PCD).

bit 10 : out of range reference resistances (cf. bit 8 of radiometer MBT product PCD).

bit 11 : insufficient number of calibration data (cf. bit 9 of radiometer MBT product PCD).

bit 12 : orbit type for location (cf. bit 12 of radiometer MBT product PCD).

bit 13 : quality of location (cf. bit 13 of radiometer MBT product PCD).

bit 14 : attitude (cf. bit 14 of radiometer MBT product PCD).

bit 15 : not used (value 0.)

3.2.2. Data set

This consist of a 64 x 31 byte record corresponding to the 64 measurements present in the product. The details of the 31 bytes corresponding to one measurement are given below.

Field number	Number of bytes	Type	Description	Units
1	1	I1	Number of the measurement in the product	
2	2	B	Measurement confidence data	
3	8	2I4	Time of the measurement (UTC)	sec, msec
4	4	SI4	Latitude of subsatellite point	1.E-4 deg
5	4	I4	Longitude of subsatellite point	1.E-4 deg
6	1	I1	Number of 23.8 GHz elementary measurements	
7	1	I2	Number of 36.5 GHz elementary measurements	
8	2	I2	Water vapour content	10^{-2} g/cm^2
9	2	I2	Liquid water content	10^{-2} g/cm^2
10	2	I2	Precise water vapour content	10^{-2} g/cm^2
11	2	I2	Precise liquid water content	10^{-2} g/cm^2
12	2	I1	Wind speed value	1.E-2 m/s

Comments :

Field 2 :

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

bits	0	... ...	7	8	... ...	15

<-------byte 2---- ---><-------byte 3---------->

bit 0 : 0 if the measurement is valid.

1 otherwise.

bits 1,2 & 3 : indicate the reason for invalidity reported in state 1 of bit 0.

bits 1 and 2 are a copy of the bits corresponding to the reason for invalidity reported in the Radiometer MBT product.

0 0 if the radiometer has been switched off.

0 1 if the radiometer is operating with an anomalous temperature range or if it was not possible to calculate the component temperatures (case which occurs when the reference resistances are out of range).

1 0 if the radiometer is in special test operation mode (for example, if the output is permanently connected to the skyhorn).

1 1 if there is a telemetry gap.

bit 3 set to 1 indicates that the measurement was taken over land.

The two most likely reasons for invalidity are the presence of land and telemetry gap . The others concern events which have been predicted, but which should not occur in flight during radiometer operation.

bit 4 : 0 if for the microwave sounder measurement in question there is a simultaneous altimeter measurement

1 otherwise.

bit 5 : value of 1 if the 23.8 GHz channel brightness temperature is such that :

$$T_B < 130 \text{ K or } T_B > 280 \text{ K}.$$

The geophysical parameters are calculated by linear interpolation in a table whose input consists of the brightness temperatures for each channel. This table is specified for :

$$130 \leq T_B \leq 280$$

value of 0 otherwise.

bit 6 : As for bit 5 for the 36.5 GHz channel.

bit 7 : value of 1 if the altimeter backscatter coefficient that was used for calculating the altimeter wind is out of range (smaller than 8 dB or greater than 20 dB, TBC). This may indicate the presence of ice.

otherwise value of 0.

bit 8 : presence/absence of rain or ice (cf. bit 6 of Radiometer MBT Product MCD).

bit 9 : quality of 23.8 GHz channel microwave components (cf. bit 8 of Radiometer MBT Product MCD).

bit 10 : quality of 36.5 GHz channel microwave components (cf. bit 9 of Radiometer MBT Product MCD).

bit 11 : quality of 23.8 GHz channel calibration data (cf. bit 9 of Radiometer MBT Product MCD).

bit 12 : quality of 36.5 GHz channel calibration data(cf. bit 10 of Radiometer MBT Product MCD).

bit 13,14 & 15 : not used (value 0).

Field 3 :

Time of measurement : this is provided in the form of 2 4-byte integers. The first integer is the number of seconds elapsed since 1/1/1990 at 0h UTC. The second integer is the number of milliseconds in the second.

Fields 4,5,6, 7 :

Identical to fields 4,5,6,10 respectively of radiometer MBT product.

Field 8 :

This concerns the uncorrected water vapour content of the altimeter wind. It is calculated from the brightness temperatures by means of the following algorithm :

$$V = a + b \text{ Log } (280 - T23) + c \text{ Log } (280 - T36)$$

with :

T23 : 23.8 GHz channel brightness temperature in K
T36 : 36.5 GHz channel brightness temperature in K
V : integrated water vapour content in 10-2 g cm^{-2}.

a,b and c are calculated by regression between a statistically representative set of atmospheric and surface situations and their corresponding brightness temperatures simulated by a radiative transfer model.

The above expression used to find V has been tabulated every 5K for T23 and T36, for brightness temperatures taken between 130 and 280 K. The water vapour content is calculated by linear interpolation in the table.

Field 9 :

The liquid water content is calculated in the same way (only the coefficients a,b and c are different). Negative values may occur in a clear sky situation (where the real integrated content of liquid water is zero) due to the statistical nature of the algorithm. Such values should be understood as being zero values for liquid water content.

Field 10 :

The precise water vapour content is calculated from the water vapour content given in field 8 by the equation :

$$V_p = V + d\,(U - 7)$$

with :

V_p : precise content
V : calculated content of field 8 (corresponds to a wind of 7 m/s)
U : altimeter wind speed value
d : regression coefficient.

This *à posteriori* correction is used to take into account the emissivity variations due to the wind.

Field 11 :

The precise liquid water content is calculated in the same way (only the coefficient d is different). As for field 9, negative values may occur.

Field 12 :

This is the altimeter wind speed value. (corrected for cloud liquid water attenuation).

The fields 10,11 and 12 are filled only in the event of a simultaneous radiometer and altimeter measurement.