Centre Spatial de Toulouse	**Réf. :**	**PIC-FDS-N1-SP-251-CNES**		
	Edition :	**4**		
	Révision :	**1**	**Date :**	**03/12/2014**

Direction du Centre de Toulouse

Sous-Direction Charges Utiles Scientifiques et Imagerie

Service "Physique de la Mesure Optique"

CALIPSO

Réf. secrétariat : DCT/SI/MO/04-378

IIR/CALIPSO Level 1 Processing Requirements

	Date	Signature
Préparé par : **T. Trémas**	**03 dec 2014**	
Approuvé par : **P.Ferrage**		
Pour application : **P.Ferrage**		

BORDEREAU D'INDEXATION

CONFIDENTIALITE : NON			**MOTS CLES :**	
TITRE : IIR/CALIPSO Level 1 Processing Requirements				
AUTEUR : T. Trémas				
RESUME :				
SITUATION DU DOCUMENT :				
Volume : 1	**Nbre de pages total : 63**	**dont pages liminaires : 7**	**nbre d'annexes : 4**	**LANGUE : GB**
DOCUMENT GERE EN CONFIGURATION		**A DATER DU :**	**RESPONSABLE :**	
SYSTEME HOTE :				

DIFFUSION

CNES		
DCT/PO/EV	DOC Projet CALIPSO	
DCT/ME/OT	P. FERRAGE A. LIFERMANN P. HENRY	
DCT/SI/MO	A. MEYGRET T. TREMAS	
DCT/SI/EM	T. BRET-DIBAT	
IPSL		
LMD	J. PELON A. GARNIER O. CHOMETTE	
NASA		
LARC	C. TREPTE D. WINKER M. ALVIN	
ICARE	J. DESCLOITRES N. PASCAL Doc Projet	

MODIFICATIONS
(REVISIONS)

Édition	**Révision**	**Date**	**Cause évolution**
1	0	28/05/01	Issue written by O. Hagolle
2	0	22/03/02	Issue written by O. Hagolle, P. Leroux, T .Bret-Dibat, A. Lifermann
3	0	29/01/04	Issue written by T. Trémas, P. Leroux - Quality parameters added - Input configuration file added (see annex A 3) - Correction of the image identifier length (§3.2) - Changes (slight) in time setting (annex A1.1, A1.2) - Add of radiometric tables in annex 4 - Interpolation of blind/dead pixels in IIR array - An averaged image per product (1/2 orbit) is created in the calibration output file
3	1	24/06/04	Change in the DQX Definition of the validation file Changes in the blind pixels algorithm Addition of on ground measured values in annex 4
3	2	27/09/04	§ 4.6 the headers of the input parameters files will be located in the metadata records § 5.4 additional data required in the validation file § 6.2 addition of Alert_BB_temp, Alert_CS, Blind_pixel_alert and Dead_pixel_alert in DQP § 6.3.1 in the R^k_E formula, "gain" has been changed to "1/gain" § 7.4 Dead and Blind pixel detection : if dead_pixel_detect is not set to 0, the dead_pixel matrix to take into account is the one loaded in the input parameters file (i.e blind pixels) § 7.4 Alert_BB_temp, Alert_CS, Blind_pixel_alert and Dead_pixel_alert loaded in DQP § 7.4 Blind Pixel detection : add "CS" to "IIR Blackbody Record" of RD1 §7.4, Blind Pixel Detection : inversion of the instruction : For each BB image /FOR each sequence s in [S0, S1]/FOR each spectral band k, in : For each spectral band k /FOR each sequence s in [S0, S1]/FOR each BB image § 7.6 correction of BB_status definition annex 3 : requested definition of the format of the "input parameters files" annex 3.2 : Default value of the scale factor

Édition	**Révision**	**Date**	**Cause évolution**
3	3	27/06/06	§ 6.1 the Moon_detect indicator is introduced in the DQP § 7.5 : add of the Moon detection and interpolation process
3	4	10/06/2014	Annex 3.3 : addition of tables : TARTAN_AFFECT_L0 Tartan_thres Tartan(3,64,145) IIR_Modis(3,64,145)
4	0	29/09/2014	§ 6, Quality control approach : DQX table has changed § 7: p47, Tartan and IIR_Modis issue correction § 8 : Bicubic interpolation : introduction of s_tartan, Taratan_Affect_L0, Tartan_thres. Update of the DQX
4	1	3/12/2014	P49 : "s_corr = (s-S0_corr) MOD 724" changed as "s_corr = (s-S0_corr) MOD 729" P55 : "s_tartan = s MOD 724" changed as "s_tartan = s MOD 729" All document : "TARTAN_AFFECT_L0(64, 3, 725)" replaced by "FLAG_TARTAN(64, 730)" All document : Tartan(3,64,725) changed as Tartan(3,64,730) All document : IIR_Modis(3,64,725) changed as IIR_Modis(3,64,730)

TABLE OF CONTENTS

ACRONYMS

ASDC	Atmospheric Science Data Center
ASE	Acquisition Start End
CALIPSO	Cloud Aerosol LIDAR Infrared Pathfinder Satellite Observations
CNES	Centre National d'Etudes Spatiales
IIR	Imageur Infra-Rouge (Infra Red Imager)
IPSL	Institut Pierre Simon Laplace
ISM	Infrared Sensor Module
LaRC	Langley Research Center
LIDAR	LIght Detection And Ranging
LMD	Laboratoire de de Météorologie Dynamique
NASA	National Aeronautics and Space Administration
RCI	Registre de Contrôle Individuel
TBC	To Be Confirmed
TBD	To Be Defined

1. Purpose of document

This document aims at describing the main features of the level 1b processing chain. It is based on the following hypotheses :

- No pre-processing is made on board of the satellite
- Level 0 data is not distributed to standard users (an exception is made for the IIR expertise center). Level 1b data is thus the most basic product.
- The level 1b data are expressed in physical units and not in digital numbers. They have been converted into radiance after being calibrated.
- The data of the three IIR spectral bands are registered, and localization information is given for every pixel in the product.
- Level 0 and level 1 data contain the data acquired during respectively one orbit and half an orbit. But the previous and the next product are available to process spectral registration and calibration data averaging.
- These requirements should be considered as functional requirement : the implementation and optimization of the processing are to be defined by NASA.

2. REFERENCE AND APPLICABLE DOCUMENTS

Reference Documents

Index	Reference	Title of document
RD 1	Data Products Catalog	PC-SCI-503

Applicable Documents

Index	Reference	Title of document
AD 1	PICASSO.ID.0070.SOD Issue: 1 Revision: A	IIR Interface Control Document
AD 2	PIC-DP-0209-SOD Iss 1	IIR RCI (Registre de Contrôle Individuel)
AD3	PIC-IIR-NT-246-CNES	Imaging Infrared Radiometer on ground pixels location
AD4	IN0110-DRD14	Payload Data Measurements and Analysis Document
AD 5	IN0110-DRD45	Payload Data Delivery System Interface Control Document

Index	Reference	Title of document
AD 6	13 May 03 *(Excel table)*	IIR optical axis Payload alignment
AD 7	PIC-IIR-SP-226-CNES, Iss. 3 rev. 0, 9 dec 200.	Imaging Infrared Radiometer Specification

3. Definitions

Geometrical reference frames

Figure 3-1 represents the CALIPSO satellite and its reference frame axes.

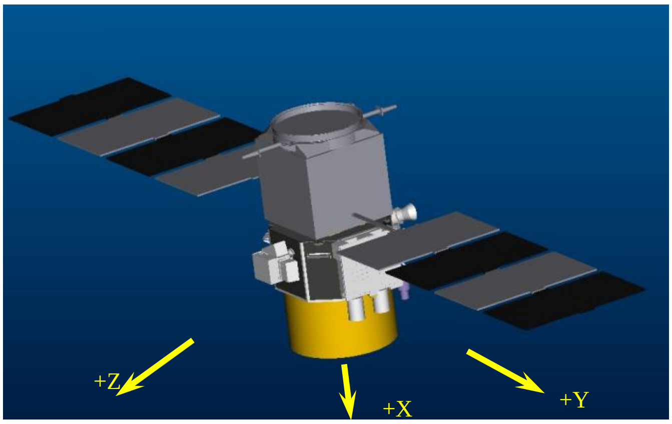


Figure 3-1: CALIPSO Satellite Reference Frame axes

The IIR, Payload and Satellite Reference Frames have common axes:

+X points to nadir.

+Y points to cold space.

+Z points to the anti-velocity vector.

Apart from the IIR, Payload and Satellite reference frames, another reference frame associated to the IIR image is defined and hereafter named as « Image Reference Frame». This frame is defined by the three vectors (**cols** , **rows** , **cols rows**), as illustrated on the Figure 3-2.

The dashed square represents the useful area on the detector array, ie the 64x64 pixels of the level 0 data.

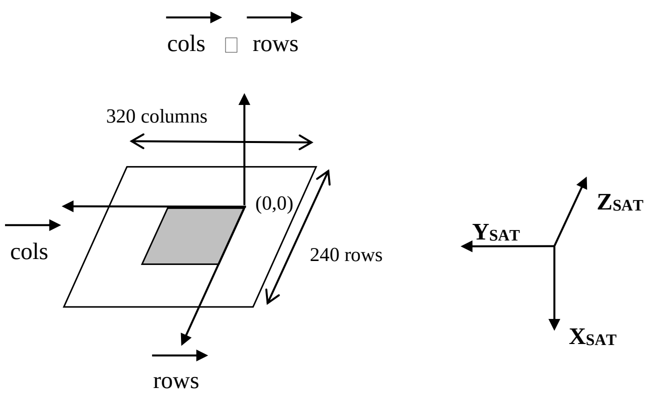


Figure 3-2: « Image Reference Frame».

The origin (coordinates (0;0)) of the Image Reference Frame is located at one edge of the useful 64 x 64 pixels² area. The coordinates of the center of the first pixel in the TeleMetry are (0.5;0.5).

The useful image format [cf AD3] comprises 64 pixels x 64 pixels provided in the order (column,row) [(1,1);…;(64,1);…..;(1,64);…..(64,64)].

The IIR pixels location on-ground [cf AD3], expressed in the CALIPSO reference frame is given in Figure 3-3.

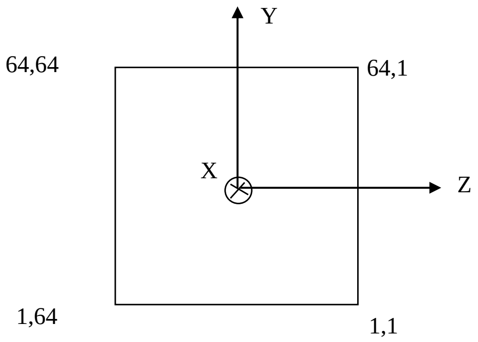


Figure 3-3: IIR pixels location on-ground

Sequences and cycles

The IIR acquisition **cycle** is made of 30 **images** organized into 5 **sequence**s of 6 images according to the following diagram.

A sequence is the period during which the IIR instrument looks at the Earth and at a calibration source (either BlackBody or Deep Space) for its 3 spectral bands. The duration of a sequence is approximately 8.184 seconds.

Cycle	40.92 s																													
Sequence	8.184 s						8.184 s						8.184 s						8.184 s						8.184 s					
View	Black Body			Earth			Deep Space			Earth			Deep Space			Earth			Deep Space			Earth			Deep Space			Earth		
Filter number	1	2	3	3	2	1	1	2	3	3	2	1	1	2	3	3	2	1	1	2	3	3	2	1	1	2	3	3	2	1
Image number + 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Image cycle description

In order to sort out the various IIR images, the IIR telemetry has been extended [AD1] to include :

- a **cycle number** (coded on 12 out of 16 bits) which counts the number of cycles performed during the last power on or reset.
- an **image identifier** (between 0 and 29, coded on 5 bits).

From the very beginning, the level 1 processing has been based on a **sequence number** to be incremented at each new sequence.

Since the level 0 product covers a finite time duration, the sequence number is also useful to find the last sequences in the previous level 0 file, and the first sequences of the next level 0 file.

This sequence number can be easily related to the cycle number and image identifier (cf §8 definition of the subroutine sequence).

4. Input data

Navigation data

Acquisition dates, orbit and attitude data

IIR level 0 data

See [AD4] . The data are provided through data packets, each packet being associated with one single IIR image. The IIR mode of operation (either normal, test or equalization) are identified from the “Science ancillary data” (“packet ID” never change).

For Normal mode of operation the packet includes:

- Equalization number (coded on 32 bits)
- Image data (according to the IIR chronogram: calibration (BlackBody or Deep Space) image, earth image)
- BlackBody temperature
- Cycle number (coded on 12 bits)
- Image identifier (coded on 5 bits, from 0 to 29)
- Datapacket_time

For Equalization mode of operation the packet includes:

- Equalization number (coded on 32 bits)
- BlackBody image at 8.65µm
- BlackBody temperature
- Cycle number (coded on 12 bits)
- Image identifier (coded on 5 bits, from 0 to 29)
- Datapacket_time

Geometric calibration parameters (see annex 3, Input Parameters Files)

4.1.1. Timing [see annex 1]

4.1.2. IIR geometrical parameters [from AD2]

4.1.3. Alignment of the IIR on the payload and lidar bore sight [from TBD, AD6]

4.1.4. Alignment of the payload on the satellite [from TBD, AD6]

Radiometric calibration parameters (see annex 3, Input Parameters Files)

Processing parameters (see annex 3, Input Parameters Files)

Management of input parameters files

All the input parameters files will be recorded in a data base with their date of application and their version number.

These files will be associated to the Metadata Record of the 3 output files (Level 1, Quality Control Product, Calibration) in order to recover the context in which level 1 data have been produced.

An input parameter file will be use as long as a new parameter file will be requested for application.

A input parameter file could be re-activated on past data (for comparisons with another way, i.e another input parameter file, of calibrating IIR).

Geometric and radiometric calibration files can be modify independently from each other. Both have their own application date and version number.

5. Output data

IIR level 1B product

See detailed content in §6.5

- Calibrated radiances
- Re-sampled and registered on a "system" projection
- Localization data and angles added
- Quality flags

Quality Control Product

This file (TBD by NASA) provides the processing report including:

Version of the processing

Input parameters file version

Name of input data files

Name of annex & exogen data files

Name of output files

IIR calibration product

See detailed content in §6.5.2

- Calibration data (time, blackbody temperature, blackbody & deep space images)
- Mean and standard deviation over images (blackbody, deep space images)
- Gain for each BB view
- Dead pixels
- Blind pixels
- Earth average record

- Equalization number code (the same as in Input)

Validation file

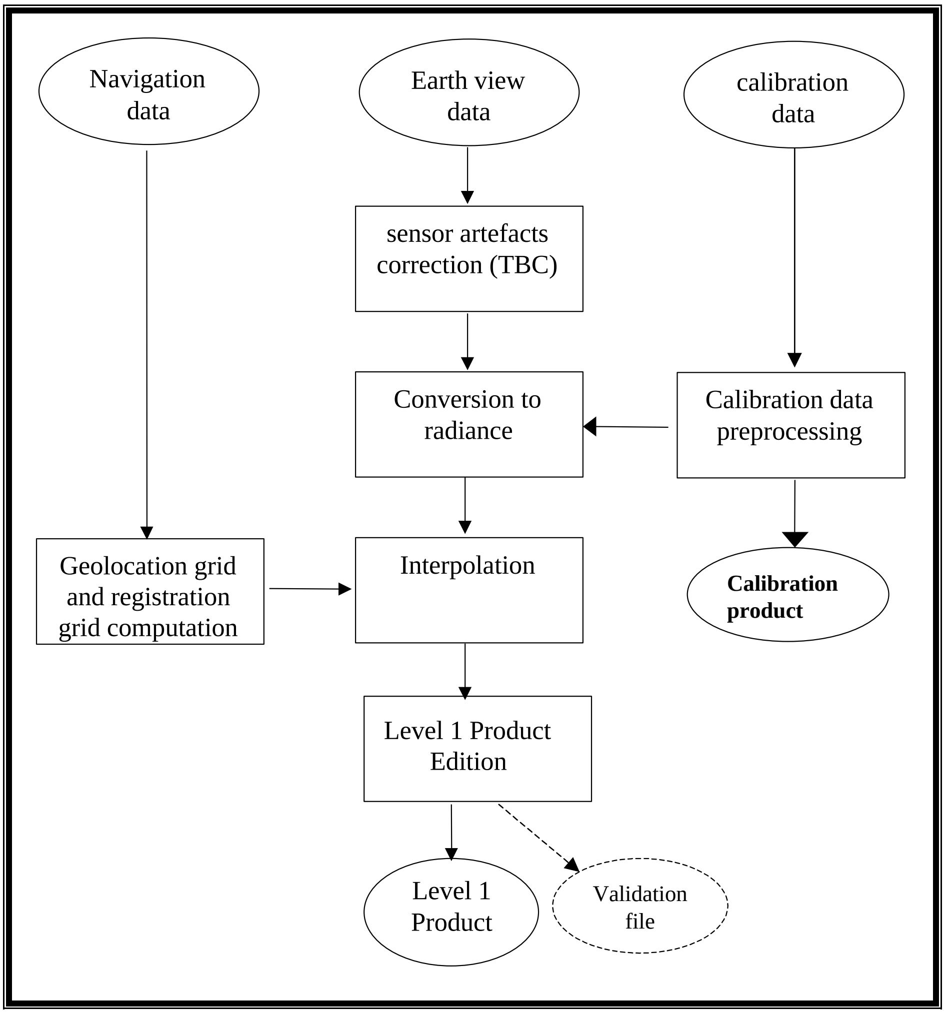
This optional file is for internal use only and should not be archived nor distributed by the ASDC. It provides additional intermediate results of the processing which are not included in the level 1 products and which will be useful for the purpose of validating the processing algorithms.

This file will be produced on requirement when Valid_file_issue = 1

In this file will be include :

- Product_ID
- the Header for radiometry of Input parameters (see annex 3)
- the Header for geometry of Input parameters (see annex 3)
- all the images 64*64 filled with L_raw_geo(l,p,k,s) associated to the corresponding (l,p,k,s) processed during the level 1 product elaboration (see § 7.6).
- the images date and cycle number
- for each above L_raw_geo image : the list of the Cold Space sequences that should have been interpolated in the $\overline{Cold\_space}$ computation (see § 7.4 "Interpolation of missing calibration data")
- for each above L_raw_geo image : the list of the Black Body sequences (or gains) that should have been interpolated in the $\overline{BB}$ (or $\overline{gain}$) computation (see § 7.4 "Interpolation of missing calibration data")

6. Processing description



Quality control approach

The proposed approach combines 2 quality indices: one at pixel level DQX (Pixel Quality Index) and one at product level DQP (Product Quality Index).

The Pixel Quality Index is an indicator provided for each pixel in the level 1 product. DQX is related to a specific step in the processing that may be flagged as good or bad.

The Product Quality Index is an indicator (TBD with NASA according to the general approach for CALIPSO products) at product level providing an overall estimate of the product quality .

DQX is a flag, associated with each pixel of the grid. The flag will take one of the following values (the idea is to create a DQX as an indicator of the pixel reliability on the grid. Several possible occurrences have been listed :

- the ideal case happens when no problem have had to be solved to built the pixel.
- another case arises when a calibration problem occurs but is solved before building the pixel. If the number of missing calibration images (for instance) is lower enough to be interpolated, the final pixel will not be significantly affected by this incident
- a last case arises when a detector of the IIR matrix fails and has to be interpolated with its closest neighbors before computing the radiometry.

These two last cases are not exclusive.

Thus, DQX is split in 3 channels, each channel is split in 3 fields :

<table>
<tr><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td><td>0 / 1</td></tr>
<tr><td>Indicates if the pixel is affected by tartan effect</td><td>Indicates if the pixel is affected by tartan effect</td><td>Indicates if the pixel is affected by tartan effect</td><td>Indicates if the pixel is saturated, missing or had have calibration problems</td><td colspan="5">Number of interpolated pixel in the IIR matrix, used in the bi-cubic interpolation (from 0 to 16)</td><td>Indicates if the pixel is saturated, missing or had have calibration problems</td><td colspan="5">Number of interpolated pixel in the IIR matrix, used in the bi-cubic interpolation (from 0 to 16)</td><td>Indicates if the pixel is saturated, missing or had have calibration problems</td><td colspan="5">Number of interpolated pixel in the IIR matrix, used in the bi-cubic interpolation (from 0 to 16)</td><td colspan="3">Status of the pixel of the grid in channel 8.6;10.5; 12.05 : 0=OK, 1=BAD</td></tr>
<tr><td>Band 8.6</td><td>Band 10.5</td><td>Band 12.05</td><td colspan="6">Band 8.6</td><td colspan="6">Band 10.5</td><td colspan="6">Band 12.05</td><td colspan="3">All 3 bands</td></tr>
</table>

From left to right :

-
- Bit 1 : indicates the pixel is affected by tartan issue on channel 8.6
- Bit 2 : indicates the pixel is affected by tartan issue on channel 10.5
- Bit 3 : indicates the pixel is affected by tartan issue on channel 12.05
- Bit 4 : indicates the quality of the calibration that have contributed to the pixel, or the qualitative status of the pixel on the grid (i.e : missing or saturated), for channel 8.6
- Bits 5 to 9 : give information on the reliability of the detectors of the IIR matrix that have contributed to the pixel on the grid, for channel 8.6
- Bit 10 : indicates the quality of the calibration that have contributed to the pixel, or the qualitative status of the pixel on the grid (i.e : missing or saturated), for channel 10.5
- Bits 11 to 15 : give information on the reliability of the detectors of the IIR matrix that have contributed to the pixel on the grid, for channel 10.5
- Bit 16 : indicates the quality of the calibration that have contributed to the pixel, or the qualitative status of the pixel on the grid (i.e : missing or saturated), for channel 12.05
- Bits 17 to 21 : give information on the reliability of the detectors of the IIR matrix that have contributed to the pixel on the grid, for channel 12.05
- Bits 21 to 24 : (one bit per channel) are a flag indicating if a pixel on the grid is usable or not (convention of level 2 process). A bit is set to 0 if the 6 previous bits corresponding to the same channel (bits 1 to 6 for channel 8.6 for instance), are under or equal to Pixel_threshold_k (see annex 3.9). A good pixel has a DQX of 0.

0 *(0 in Binary)* : no problem on the pixel

n : n in {1,..,16}*({*0,..,10000*}in Binary)*. The pixel has been interpolated with n re-created pixels in the IIR matrix array

16 + [one of the above value]

(10000 + [one of the above value] in Binary) : at least one of the 16 pixels of the IIR matrix used in the interpolation had a corrected calibration value (the Cold Space or Gain value has been interpolated)

33 *(100001 in Binary)* : saturated pixel

34 *(100010 in Binary)* : missing pixel

DQX is included in the Earth View Record (RD 1 Table 14)

DQP gathers a set of values to be included in the IIR Metadata record (table 12 of RD 1) or/and in the IIR Calibration Metadata record (table 67 of RD 1) :

Function of the field	Range or size	Location in RD 1
percentage of missing cycles in a product	[0, 100]	Table 67 (request for addition)
percentage of missing sequences in a product	[0, 100]	Table 67 (request for addition)
percentage of missing single images in a product	[0, 100]	Table 12 & Table 67 (request for addition)
Number of equalization in a product	Integer 16	Table 12 & Table 67 (request for addition)
percentage of missing pixels in a product	[0, 100]	Table 12 (request for addition)
Alert_BB_temp	0 or 1	See § 7.4 dead and blind pixels detection
Alert_CS	0 or 1	See § 7.4 dead and blind pixels detection
Blind_pixel_alert	0 or 1	See § 7.4 dead and blind pixels detection
Dead_pixel_alert	0 or 1	See § 7.4 dead and blind pixels detection
Moon_detect	Integer : # of the first cycle in which Moon has been detected and interpolated	

Note : in addition, it is requested that parameters of table 12 of RD1 called "Percentage_of_*channelk*_Bad_Pixels " are changed into "Percentage_of_*channelk*_Good_Pixels "

Sensor artifact removal

No sensor artifacts have been detected up to now (i.e during on-ground tests).

Radiometric calibration

6.1.1. Basic Principle

For each spectral band (index k = 1 for 8.65 µm, 2 for 12.05 µm and 3 for 10.6 µm)

$$R_E^k = \underbrace{(X_E^k - \hat{X}_{DSE}^k)}_{\text{offset}} . \frac{R_{BB}^k(T_{BB}^k)}{\underbrace{(X_{BB}^k - \hat{X}_{DSBB}^k)}_{\text{1/gain}}} . l^k[X_E^k - \hat{X}_{DSE}^k]$$

with

X_E^k	scene measurement
$\hat{X}_{DSE}^k$	average on N_{DSE}^k Deep Space measurements around X_E^k
$\hat{X}_{DSBB}^k$	average on N_{DSBB}^k Deep Space measurements around X_{BB}^k
X_{BB}^k	Blackbody measurement
$R_{BB}^k(T_{BB}^k)$	computed Blackbody radiance at measured T_{BB}^k

$l[X_E^k - \hat{X}_{DSE}^k]$ non linearity function depending on the input radiance (a table, LINEAR(k,s), in the processing, with $[X_E^k - \hat{X}_{DSE}^k]$ rounded to the closest value)

The Gain is averaged on N_{BB}^k Blackbody measurements around X_E^k

6.1.2. Pre-processing of calibration data

For each sequence of the instrument, a calibration image is acquired and transmitted for each spectral band. Depending on the sequence number, this image is either a cold view image or a blackbody image. The cold view images are acquired more frequently due to the more probable variation of the offset than of the gain of the instrument. Interpolation is necessary to replace the values of the missing data.

As for every instrument data, the calibration data are not perfect. Using them directly would increase the noise on the earth view images. But, because of the thermal variations of the instrument and of the detectors, it is likely that the sensor calibration will change quite quickly with time. The calibration data (black body and cold views) are smoothed in order to reduce the noise, without eliminating the low frequency variations of the calibration.

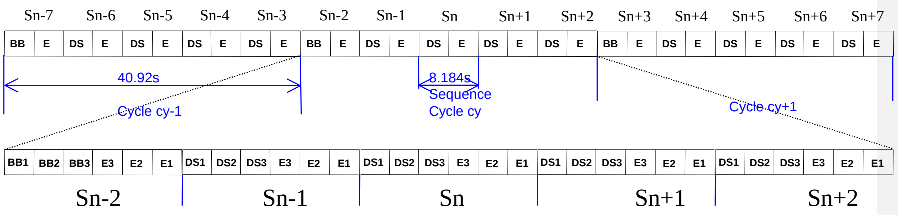
Two antagonistic phenomena are driving the averaging philosophy:

- noise reduction : the more you average, the more you reduce noise;
- IIR thermal drift introducing thermal offset : the more you average, the more you may introduce thermal offset error

The Deep Space view enables to determine the global offset of the IIR. This measure shall be performed as often as possible in order to take into account thermal offset error.

The Blackbody view enables to determine the gain (sensitivity) of the IIR. The gain has a slow rate variation.

Sequences/Images definition on a three cycles example



6.1.2.1. Interpolation of DS images

Missing Deep Space views have to be interpolated in order to have a regular period between images

Example: available measurements: Sn-6, Sn-5, Sn-4, Sn-3, Sn-1, Sn, Sn+1, Sn+2, Sn+4, Sn+5, Sn+6, Sn+7

Missing Deep Space views for Sn-2 and Sn+3 .

6.1.2.2. NDSE averaging

The Deep Space sliding averaging shall be as well as possible centered around the Earth measurements. According to the chronogram, the averaging can be optimized depending on the spectral channel.

For E_1: E_1 for Sn is close to DS_1 for Sn+1

The Deep Space averaging shall be centered on DS_1 for Sn+1

N^{1}_{DSE} is an odd number (typically 9)

For E_2: Deep Space measurements for spectral channel 2 are centered around E_2

N^{2}_{DSE} is an even number (typically 8)

For E_3: E_3 for Sn is close to DS_3 for Sn

The Deep Space averaging shall be centered on DS_3 for Sn

N^{3}_{DSE} is an odd number (typically 9)

6.1.2.3. NDSBB averaging

Deep Space measurements are symmetrical wrt Blackbody measurements.

$\hat{X}^{k}_{DSBB}$ shall use the Deep Space interpolated measurements.

For each spectral band, N^{k}_{DSBB} is an even number (typically 8).

6.1.2.4. *Gain computation and averaging*

6.1.2.4.1. Blackbody temperature to radiance conversion

$R^{k}_{BB}(T^{k}_{BB})$ is a table (for the 3 spectral bands) determined during on-ground calibration.

Size : 256 x 4 (1 column for temperature lead, 3 column for the 3 channels)

6.1.2.4.2. Gain computation

One Gain $(Gain^{k})_{j}$ is computed for every Blackbody measurement (for each cycle j) and for each channel k.

The T^{k}_{BB} temperature is the one included in the Payload data Packet with the Blackbody view.

6.1.2.4.3. Gain averaging

The sliding averaging of the Gain is performed on N^{k}_{BB} consecutive cycles (typically N^{k}_{BB} = 4).

$$(\hat{Gain}^{k})_{cy} = \frac{1}{N^{k}_{BB}} \sum_{cy-\frac{N^{k}_{BB}}{2}+1}^{cy+\frac{N^{k}_{BB}}{2}} (Gain^{k})_{j}$$

The associated σ is computed as well.

The averaged $Gain^{k}$ is applied for all Earth images of the cycle number cy.

In case of a missing Blackbody image (resp.a missing temperature measurement), the corresponding Gain image for the cycle shall be linearly interpolated using the other existing Gain data (resp.the temperature with other temperature measurements)

Degraded cases

More generally, all missing Deep Space images shall be interpolated using the existing data in order to provide complete series of Deep Space images for offset sliding averages computations.

6.1.3. Dead & blind pixels detection

Analysis of the calibration images allows the detection of dead/blind pixels and comparison with the tables provided after on-ground calibration of the IIR. If significant degradation of the detector has occurred the dead/blind pixels table may also be updated upon request by the IIR expertise centre.

6.1.4. Conversion to radiance

After Offset and Gain computations, the last term in the calibration equation accounts for the instrument non-linearity function.

$l^k[X_E^k - \hat{X}_{DSE}^k]$ is a table (for the 3 spectral bands) measured during on-ground calibration. See Annex 4, variable : LINEAR.

Size : 4096 x 4 (a column for the input level, 3 columns for the channels)

At this final stage an interpolation of the dead pixels on the Earth radiance image is done.

6.1.5. Statistics over calibration (DS or BB) images

- Computation of the mean and standard deviation over the whole image for every (DS or BB) calibration image.
- Computation of the average Gain image and standard deviation image.

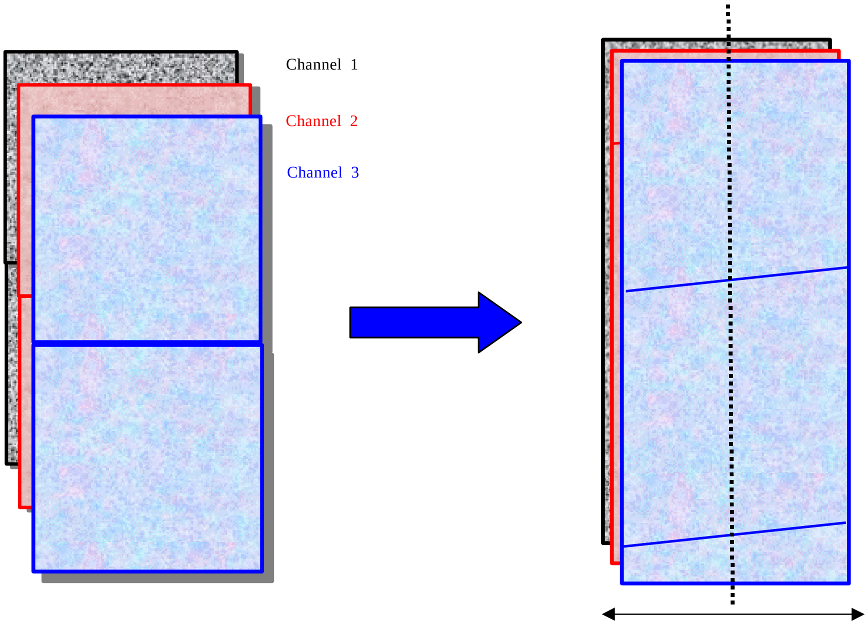
Comparison with predefined values : TBC/TBD

Geometrical processing

IIR data geometrical processing has two goals :

- to register the data from the 3 spectral bands

- to provide the geometrical coordinates (longitude, latitude) of each pixel (+ viewing angles)



One of the concerns for the definition of the geometrical processing is to minimize the number of resampling needed to produce the level 2 data. The raw data of the 3 spectral bands are mis-registered since they are not acquired simultaneously, because of the filter wheel concept of the instrument. To produce accurate level 2 data, it is necessary to register the spectral bands and this must done in the level 1 product, so that this product is easy to use. At least a resampling for 2 of the 3 spectral bands is necessary to perform this task.

However, if the product projection is not convenient for the users, they will have to re-project the data to another grid, adding another resampling to the ones performed for the level 1. The level 1 users prefer to have a product with a continuous projection, rather than having a projection changing every 64 kilometers, but this implies to resample all of the 3 spectral bands. Given the narrow footprint of the data on the earth, registering data from different orbits is not a priority. It is thus possible to have a different projection for each orbit.

Most of the IIR product users will need to register the lidar data with the IIR data. It is possible to define a projection for which the center column is the lidar track, and the lines are orthogonal to this track. The only drawback is that this projection needs to be computed just before the geometrical rectification, and this increases slightly the amount of numerical operations that have to be performed in the level 1 processing.

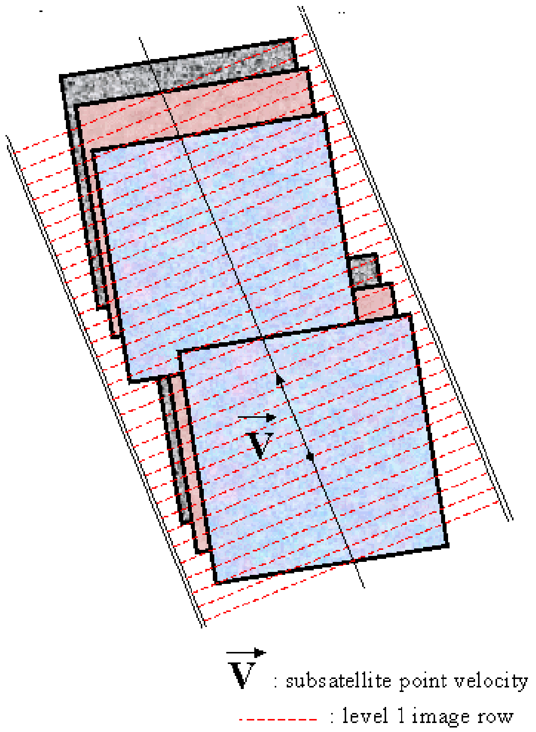
The IIR Mission Working Group has decided to define the geometrical projection as follows :

- The lines in the product are orthogonal to the lidar track
- The center column is the lidar track (not taking into account the fluctuations of this track related to the pointing errors of the satellite)
- For each line, the projection is defined so that the center pixel of the line is registered with a lidar shot (the time of acquisition of the lidar shot is used as a parameter of the projection definition)
- The lines are separated by about 1 km, but the sampling is exactly determined by the translation of the sub-satellite point during a time Δt equivalent to 3 lidar shots, ie about 148 ms.
- It is not necessary to resample the product with each lidar shot (about 300m), since the IIR geometrical resolution is about 1 km. Only one lidar shot out of three will be chosen. If the lidar shots are averaged by groups of three in the lidar processing,: the idea is to use the center lidar shot as parameter for the computation of the projection for a line of the IIR product.

For each point of the grid to be built, for each channel, 2 level 0 images are potentially convenient to interpolate the radiance in the level 1 image (i.e both images of which dates flank the date when the line of the grid is built)

Several cases can occur :

- The point on the grid belongs to none of this 2 images (point on the edge of the grid): no interpolated radiance for this point
- The point belongs to only one of these images : this image is used to compute the radiance, watching the point is not to close to the edge of the image (4x4 neighboring points are required for the interpolation)
- The point belongs to both images an can be interpolated on one or the other as well : the image on which the point is the farthest from the edge of the image is preferred..



Level 1 output products content

The IIR level 1 output products format is to be defined by NASA in order to have a consistency between all the products of the CALIPSO platform, but this paragraph gives the required content of the products :

6.1.6. Level 1 product

FOR each line

- Lidar shot time

FOR every pixel in the line (<70 per line) :

- longitude, latitude (2* 4 bytes)
- quality indexes (4 bytes) of which :
  - DQX 21 bits

- FOR each spectral band
  - radiance (2 bytes)
  - sequence number (2 bytes)
  - viewing angles (2 * 2 bytes)

ENDFOR
ENDFOR
ENDFOR

FOR each sequence in the product

FOR each Earth view image

- Image date (see annex 1)
- Satellite position in ECR
- Satellite velocity
- Satellite attitude
- Subsatellite latitude, longitude

- ENDFOR

ENDFOR

FOR each product

DQP 4* 7 Bits and 2 bytes

6.1.7. Calibration product

IIR calibration record summary

IIR calibration metadata record

IIR space view record

IIR black body view record

IIR dead pixel matrix

IIR blind pixel matrix (to be added in Tab 66)

IIR equalization image

IIR test image

IIR Earth Averaging Record

Calibration metadata record

FOR each product

Dates

Initial and final subsatellite coordinates in the product

Number of blackbody records

Number of BB images interpolated or missing (request for addition to RD 1)

Number of cold space records

Number of cold space images interpolated or missing (request for addition to RD 1)

Dead pixels alert (request for addition to RD 1)

Blind pixels alert (request for addition to RD 1)

Alert BB temperature (request for addition to RD 1)

Radiance scale factor and offset *(note : for the Earth Average product)*

Intial and final sequence numbers *(note : for the Earth Average product)*

ENDFOR

Deep Space record

FOR each Deep Space image

Cycle number, Sequence number

FOR each channel

Image time

Space view image

Black body temperature

Mean & standard deviation over the images

ENDFOR

ENDFOR

Blackbody record

FOR each Blackbody image

Cycle number, Sequence number

FOR each channel

Image time

Black body image

Black body temperature

Mean & standard deviation over the BB image

Gain image

Mean & standard deviation over the Gain image

ENDFOR
ENDFOR

Equalization record

FOR every equalization process (see data packet ID)

Equalization number

Cycle, Sequence number

Image time

BB temperature

Blackbody image for 8.65µm (BB1)

Mean & standard deviation over the image

ENDFOR

Test record

FOR every test process (see data packet ID)

Equalization number

Cycle, Sequence number

Image time

BB temperature

Test image

ENDFOR

Dead pixel matrix

Dead_pixel

Blind pixel matrix *(note : request for addition to RD1)*

Blind_pixel

Earth Averaging Record *(note : request for addition to RD1)*

For each product (i.e each half orbit) an average of all the earth images, for each channel, is computed.

- FOR each channel

64*64 image, average of all the Earth images of the channel in this product

ENDFOR

6.1.8. Validation file

See § 5.4

6.1.9. Quality Control Product

Cf §5.2

TBD (NASA)

7. Pseudo-code

Notations :

l : line number of a pixel

p : column number of a pixel

k : spectral band number

k0 : reference band number for the geometrical processing

s : sequence number (the sequence number is incremented at each sequence of the instrument (acquiring the 3 spectral bands and the calibration data)

S0 : sequence number of the first sequence in the product

S1 : sequence number of the last sequence in the product

CY0 : cycle number of the first cycle in the product

CY1 : cycle number of the last cycle in the product

N_cal : number of calibration images from previous and next level 0 products necessary to perform calibration

Set of sequence bounds of the product

Principle

The purpose is to determine the number of the first (S0) and last (S1) sequences of the incoming level 0 product. Although the products are likely to be composed of entire cycles, this procedure prevent the sequence counting from missing cycles and/or sequences from a product to another.

Input

CY0	the first cycle number of the incoming product
IM0	the number (∈[0,29]) of the first image of the incoming product
CY1	the last cycle number of the incoming product
IM1	the number (∈[0,29]) of the last image of the incoming product
CY1_previous	the last cycle number of the previous product
S1_previous	the last sequence number of the previous product
IM1_previous	the last image number (∈[0,29]) of the previous product

Output

S0	the first sequence number of the incoming product
S1	the last sequence number of the incoming product

Parameters

Internal data

Seq	sequence rank of the first image in the first cycle of the current product
Seq_prev	sequence rank of the last image in the last cycle of the previous product
Seq_last	sequence rank of the last image in the last cycle of the current product
S1_previous	the last sequence number of the previous product

Description

FOR each Data_packet

IF packetID=Normal then

Check that equalization number=equalization number_current (if not apply equalization packet procedure)

IF IM0 ∈[0,5] THEN seq = 1

IF IM0 ∈[6,11] THEN seq = 2

IF IM0 ∈[12,17] THEN seq = 3

IF IM0 ∈[18,23] THEN seq = 4

```
        IF IM0 ∈[24,29] THEN seq = 5
        IF IM1_previous ∈[0,5] THEN seq_prev = 1
        IF IM1_previous ∈[6,11] THEN seq_prev = 2
        IF IM1_previous ∈[12,17] THEN seq_prev = 3
        IF IM1_previous ∈[18,23] THEN seq_prev = 4
        IF IM1_previous ∈[24,29] THEN seq_prev = 5
        S1_previous = CY1_previous * 5 + GROUND(IM1_previous/6)
        IF CY0 = CY1_previous THEN
              S0 = S1_previous+(seq-seq_prev)
              ELSE
              S0 = S1_previous + (5-seq_prev) + seq +5*(CY0- CY1_previous-1)
        ENDIF
        IF IM1 ∈[0,5] THEN seq_last = 1
        IF IM1 ∈[6,11] THEN seq_last = 2
        IF IM1 ∈[12,17] THEN seq_last = 3
        IF IM1 ∈[18,23] THEN seq_last = 4
        IF IM1 ∈[24,29] THEN seq_last = 5

        S1 = 5*(CY1-CY0) – seq - (5-seq_last)
  ENDIF
ENDFOR
```

Check of level 0 data

Principle

The goal of this function is to read the level 0 data of the IIR, to check its consistency, to sort the 3 types of incoming products, and to update the sequence numbers.

In this function, the Cold space view data are checked to detect saturated pixels.

Input

Level 0 data containing :

FOR each sequence s in [S0-N_cal, S1+N_ cal]

FOR each spectral band k

DN (l,p,k,s) : Digital numbers from Earth view acquisition

CAL(l,p,k,s) : calibration image

Cal_type(s) : type of calibration image (black body or cold space)

Output

checked level 0 data

Quality Control Product information

Parameters

Internal data

Description

Equalization number_current = 0

For each datapacket

If equalization number has changed THEN

Equalization number_current=equalization number

no processing; add calibration image to calibration file;

RESET sequence number

GOTO next packet untill (N_{DSBB}/2) cycles (starting with this packet)

(in other words, after an equalization, the first images will not be processed. A sufficient number of calibration image is not reached)

IF packetID=Normal then

Check that equalization number=equalization number_current (if not apply equalization packet procedure)

Detection of missing image packets (check of packet quality flag)

Determine the sequence number for this image

Determine the type of the image from image identifier

Sort of images by type (Earth, DS, BB)

Continue the processing

ENDIF

ENDFOR

Perform statistics for the Product Quality index DQP

Subroutines

- Sequence (cycle; image_identifier) : computes the sequence number associated with the cycle number and image identifier

Ancillary data processing

7.1.1. Timing

A detailed description of the IIR timing is given in Annex 1.

All types of images and temperatures may be tagged according to this description through a table of parameters Timing[image number] by:

IIR_Time [cycle, image number] = Datapacket_time + Timing[image number]

The lidar shots may be time tagged by a similar algorithm as for the IIR:

Lidar_Time [] = TBD (NASA)

7.1.2. Attitude and orbit interpolation (TBD NASA)

Principle

The goal of this function is to prepare the auxiliary data processing (transform attitude and position data in the right reference frame, interpolate them for the image acquisition dates).

Calibration data pre-processing

Commented [H1]: Page: 28
Est-il nécessaire de prétraiter les données de température (interpolation à la bonne date, lissage ?) (AL,TB)

Input

Calibration data :

FOR each sequence s in [S0-N_cal, S1+N_ cal]

FOR each spectral band k

CAL(l,p,k,s) : calibration image

Cal_type(s) : type of calibration image (black body or cold space)

Dead_pixels(l,p) = image with 0 when pixel is OK, 1 when pixel is dead

Output

FOR each sequence s in [S0-N_cal, S1+N_ cal]

FOR each spectral band k

CS (l,p,k,s) : averaged cold space observation image

Gain

BB (l,p,k,s) : averaged black body observation image

Sigma_CS(l,p,k,s)= Standart deviation on averaged cold space observation image

Sigma_BB(l,p,k,s)= Standart deviation on averaged Black body observation image

CS_status(l,p,k,s) : status of cold space averaged image

BB_status(l,p,k,s) : status of cold space averaged image

Parameters

N_{DSBB} : Number of black body images to average (ref § 6.3.2.3)

N_{CS}: Number of cold view images to average (ref § 6.3.2.2)

CS_Interp_Threshold : integer, the maximum acceptable number of missing Deep Space sequence around an odd Deep Space sequence that have to be interpolated

BB_Interp_Threshold : integer, the maximum acceptable number of missing Blackbody sequence around an odd Blackbody sequence that have to be interpolated

CS_OK_Threshold

BB_OK_Threshold

N_cal : number of calibration images from previous and next level 0 products necessary to perform calibration

Internal data

FOR each sequence s in [S0-N_cal, S1+N_ cal]

FOR each spectral band k

CS_interm(l,p,k,s) : array containing the raw cold space calibration data

BB_interm(l,p,k,s) : array containing the raw black body calibration data

CS_interm_status(k,s) : 'OK' if the cold space data is present

BB_interm_status(k,s) : 'OK' if the black body data is present

CS_average_status : a flag indicating that there is not enough neighboring Deep Space sequences to perform an interpolation

BB_average_status : a flag indicating that there is not enough neighboring Blackbody sequences to perform an interpolation

Description

Sorting and counting of calibration data

```
FOR each sequence s in [S0-N_cal, S1+N_ cal]
    FOR each spectral band k
        read CAL(l,p,k,s) and cal_type(s)
        IF (cal_type(s) = 'cold_space') THEN
            CS_interm(l,p,k,s) = CAL(l,p,k,s)
            CS_interm_status(k,s) = 'OK'
        ENDIF
        IF (cal_type(s) = 'black body') THEN
            BB_interm(l,p,k,s) = CAL(l,p,k,s)
            BB_interm_status(k,s) = 'OK'
        ENDIF
    ENDFOR
ENDFOR

IF number of OK CS sequences  < CS_OK_Threshold then
    Stop processing : not enough CS calibration data
ENDIF
IF number of OK BB sequences  < BB_OK_Threshold then
    Stop processing : not enough BB calibration data
```

ENDIF

***Interpolation of missing calibration data** : in case some sequences of the calibration data would be missing,(for instance, one cold space calibration out of 5 is missing) averaging of calibration cannot be performed without an interpolation of the missing data (otherwise there might be a bias).*

If too much sequences are missing, the interpolation is not performed and a "bad" status is put forward. The corresponding earth image will not be available.

<u>Description</u>

```
FOR each sequence s [S0-N_cal+1, S1+N_ cal-1]
    FOR each spectral band k
        IF CS_stat(k,s) ≠ 'OK' THEN
            Search for the previous sequence Sp for which CS_stat(k,s) is OK
            Search for the next sequence Sn for which CS_stat(k,s) is OK
            IF s-Sp > CS_Interp_Threshold OR Sn-s > CS_Interp_Threshold THEN
                CS_average_status= 'bad'
            ENDIF
            CS_interm(l,p,k,s)= linear interpolation (CS_interm(l,p,k,Sp), CS_interm(l,p,k,Sn))
        ENDIF
        IF BB_stat(k,s) ≠ 'OK' THEN
            Search for the previous sequence Sp for which BB_stat(k,s) is OK
            Search for the next sequence Sn for which BB_stat(k,s) is OK
            IF s-Sp > BB_Interp_Threshold OR Sn-s > BB_Interp_Threshold THEN
                BB_average_status= 'bad'
            ENDIF
            Gain(l,p,k,s)= linear interpolation (Gain(l,p,k,Sp), Gain(l,p,k,Sn))
        ENDIF
    ENDFOR
ENDFOR
```

Commented [H2]: Page: 30
vérifier que cela marche à l'initialisation (OH)

Commented [H3]: Page: 30
A détailler ?

Blind pixels detection (blind pixels are characterized according to 2 critirias :

- a value of the signal of the pixel is much higher or lower than the average value of all the pixels when a black body is seen [AD 7]
- the noise equivalent temperature (i.e the signal of the pixel divided by the gain when a black body is seen) is higher than a specified value).

Detection of blind pixels is activated if required (see "Blind_pixel_detect" in the Input parameters file))

Inputs

BB_temp (k,s) : blackbody temperature

CS(l,p,k,s) : Average Cold Space

Sigma_CS(l,p,k,s)= Standart deviation on Cold Space

BB_interm(l,p,k,s)= Black Body image in a cycle

Sigma_BB(l,p,k,s)= Standart deviation on Black Body

Outputs

NEDT (l,p,k,s) : the noise equivalent temperature for each pixel of the matrix

Parameters

Conf_BB_Temp interval of temperature in which should stand the BB temperature

Alert_BB_temp 0 : BB temperature is OK, 1 : BB temperature is out of range

Conf_CS interval in which should stand the average CS count on one CS image

Alert_CS 0 : CS image is OK, 1 : CS image is out of range

Blind_pixel_grd [64*64] 1 bit array. Updated from Black Body image. Value is "0" when the pixel is OK, "1" when it is blind

Description

IF Blind_pixel_detect = 0 THEN

For each spectral band k

FOR each sequence s in [S0, S1]

FOR each BB image

IF BB_temp(k,s) $\in$ Conf_BB_Temp THEN

IF Average of CS_image(k,s) $\in$ Conf_CS THEN

(Note : First criteria of blind pixel detection)

CS(l,p,k,s)=Average(CS_interm(l,p,k,s), s in [s-N^k_{DSBB}, s+ N^k_{DSBB}])

WRITE CS to “IIR Blackbody Record” of RD1

Compute the average value of the [64*64] [BB_interm (l,p,k,s)-CS(l,p,k,s)]

Sort the 10% pixels with the highest absolute value

Compute (again) the average value “m_BB_response” with the 90% remaining [BB_interm (l,p,k,s)-CS(l,p,k,s)] *(note : “m_BB_response” is a real)*

Compute the standart deviation “Sigma_BB_response” of these 90% remaining values

FOR each 4096 pixels of the [64*64] [BB_interm(l,p,k,s)-CS(l,p,k,s)]

IF | [BB_interm(l,p,k,s)-CS(l,p,k,s)]- m_BB_response| > 5*Sigma_BB_response

THEN

Blind_pixel(l,p) = 1

ELSE

Blind_pixel(l,p) = 0

ENDIF

ENDFOR

(Note : Secondt criteria of blind pixel detection)

compute the temporal average and σ (Sigma_BB(l,p)) value of each BB_interm(l,p,k,s) on [S0, S1]

Compute the temporally averaged gains NedT_Gain(l,p) *(note : 4096 gains to find)* corresponding to the temporal average of each gain computed from BB_interm(l,p,k,s) on [S0, S1]

Sort the 10% pixels with the highest σ absolute value

Compute the mean gain “mean_NedT_Gain” *(note : a real)* from all the 90% remaining temporally averaged gains

Compute the mean standart deviation “Sigma_BB_response” from all the 90% remaining σ values

FOR each pixel and each channel compute

NEDT(l,p)= ABSOLUTE VALUE(Sigma_BB(l,p)/ NedT_Gain(l,p))

$$(\textit{note} \; : \; L_{equiv\_noise}^{l,p} = \left| \frac{\sum_{[S0;S1]}^{average} \sigma_{l,p}}{\sum_{[S0;S1]}^{average} G_{l,p}} \right|)$$

IF NEDT(l,p) > |5*Sigma_BB_response/ mean_NedT_Gain| THEN

Blind_pixel(l,p) = 1

ENDIF

ENDFOR

ENDFOR

ENDFOR

ELSE Alert_BB_temp = 1

ELSE Alert_CS = 1

ENDFOR

Compare Blind_pixel and Blind-pixel_grd

IF Blind_pixel ≠ Blind-pixel_grd THEN Blind_pixel_alert =1

ENDFOR

ENDIF

ELSE Blind_pixel = Blind-pixel_grd

WRITE Alert_BB_temp, Alert_CS, Blind_pixel_alert in DQP

(note : request for addition to RD1)

Dead pixels detection (dead pixels are characterized by 0 or 4096 value. Detection is activated if required in Dead_pixel_detect (see the Input parameters framework))

Parameters

Dead_pixel_grd [64*64] 1 bit array. Updated from Cold Space image and associated to each cold space image. Value is “0” when the pixel is OK, “1” when it is dead

Description

IF Dead_pixel_detect = 0 THEN

```
For each DS image
    For each spectral channel
        For each pixel (l,p)
            If value=0 or 4096 then Dead_pixel(l,p) = 1
            Else Dead_pixel(l,p) = 0
        Endfor
        Compare Dead_pixel and Dead_pixel_grd
            IF Dead_pixel ≠ Dead_pixel_grd THEN Dead_pixel_alert =1
    Endfor
Endfor
ENDIF
ELSE Dead_pixel = Dead_pixel_grd
WRITE Dead_pixel_alert in DQP
```

Moon detection and interpolation

The Moon is seen in the space view every 4 weeks. It appears as a 7 pixel large bright spot in the Cold Space image. Because this spot is not present on the Earth and Black Body views, it cannot be compensated when computing the gain of the concerned pixels.

As a result, the part of the CS images impacted by the Moon should be removed. To avoid from creating a hole in the level 1 products, the “faulty” pixels are replaced by an interpolation of the same pixels of the previous and next images, from which the Moon is absent.

The algorithm should include the following steps :

- on each CS images of each channel : to detect pixels containing the Moon, these pixels being higher than a known threshold value. This threshold has to be set as an input parameter (Radiometry parameters or cfg parameter list)
- in the set of pixels to be interpolated should be included the pixels neighboring the “moon pixels” (indeed, these neighbors pixels can be affected partially covered by the moon without trespassing the critical threshold)
- to check (by means of the blind and dead pixels tables) that the pixels impacted by the Moon are not dead or blind
- in the four previous CS images, look for the closest CS image in which the same pixels are not impacted by the Moon. To check that these pixels are not dead or blind
- in the four next CS images, look for the closest CS image in which the same pixels are not impacted by the Moon. To check that these pixels are not dead or blind

- to interpolate the pixel containing the Moon by means of those from the previous and next images found.
- The interpolation is linear but a weight is affected to the next and previous pixel, depending on the number of sequences they are far from the pixel to be replaced
- To indicate in the DQP that the CS image has been impacted by the Moon and interpolated.

Threshold_Moon is set to 1400 for channel 1, 2 and 3

```
FOR each spectral band k
  FOR each sequence s in [S0, S1] DO BEGIN
      lower_bound= 0
      upper_bound = 0
      lower_bound_detect = FALSE
      upper_bound_detect = FALSE
          FOR each CS image
            IF (CS(l,p,k,s) > Threshold_Moon) AND (dead_pixel(l,p,k,s) <> 1) AND
          (blind_pixel(l,p,k,s) <> 1) THEN
              I=0
              WHILE lower_bound_detect<>TRUE AND I< 5 DO BEGIN
                  IF (CS(l,p,k,s-I) < Threshold_Moon) AND (dead_pixel(l,p,k,s-I) <> 1)
          AND (blind_pixel(l,p,k,s-I) <> 1) THEN
                      lower_bound= I
                      lower_bound_detect=TRUE
                  ELSE I=I+1
                  ENDIF
              ENDWHILE
              I=0
              WHILE upper_bound_detect<>TRUE AND I< 5 DO BEGIN
                  IF (CS(l,p,k,s+I) > Threshold_Moon) AND (dead_pixel(l,p,k,s+I) <> 1)
          AND (blind_pixel(l,p,k,s+I) <> 1) THEN
                      upper_bound = I
                      upper_bound_detect=TRUE
```

ENDIF

ELSE I=I+1

ENDWHILE

IF lower_bound* upper_bound =0 DO BEGIN

The Moon view is replaced by « no data » (a hole will be generated in level 1)

ENDIF

ELSE

CS(l,p,k,s) = (lower_bound/(lower_bound+upper_bound))*CS(l,p,k,s-lower_bound) +(upper_bound/(lower_bound+ upper_bound))*CS(l,p,k,s+ upper_bound)

Apply the same procedure of interpolation (including dead and blind pixels detection) to neighboring pixels : CS(l-1,p-1,k,s); CS(l-1,p,k,s); CS(l-1,p+1,k,s); CS(l,p-1,k,s); CS(l,p,k,s); CS(l,p+1,k,s); CS(l+1,p-1,k,s); CS(l+1,p,k,s); CS(l+1,p+1,k,s)

Update the DQP with the first cycle number in which Moon is detected

ENDIF

ENDFOR

ENDFOR

Sensor artifacts correction

No artifacts have been detected during on-ground test. However, a place for this function should be kept in the level 1 software.

Conversion to radiances

<u>Input</u>

FOR each sequence s in [S0-N_cal, S1+N_ cal]

FOR each spectral band k

CS (l,p,k,s) : averaged cold space observation image

BB (l,p,k,s) : averaged black body observation image

CS_status(l,p,k,s) : status of cold space averaged image

BB_status(l,p,k,s) : status of black body averaged image

DN (l,p,k,s) : Digital numbers from earth view acquisition

BB_temp (k,s) : blackbody temperature

TAB_BB(BB_temp(k,s), k) : table providing BB radiance (W.m-2.sr-1) in channel k, from blackbody temperature

LINAR(k,s) : linearity of channel k at sequence s

Output

FOR each sequence s in [S0-N_cal, S1+N_ cal]

FOR each spectral band k

L_raw_geo (l,p,k,s) : radiance

Commented [H4]: Page: 32
quelle unité (AL)

Parameters

Internal data

FOR each spectral band k

BB_rad (k,s) : black body radiance

Description

FOR each sequence s in [S0, S1]

FOR each spectral band k

Black body radiance estimation

BB_rad(k,s) = TAB_BB(BB_temp(k,s), k)

calibration

IF L_raw_geo(l,p,k,s)≠0 or 4096 THEN

$$\text{L\_raw\_geo (l,p,k,s)} = BB\_rad(k,s) * \frac{DN(l,p,k,s) - CS(l,p,k,s)}{BB(l,p,k,s) - CS(l,p,k,s)} .\text{LINAR(k,s)}$$

ENDIF

Update the Validation file (see § 5.4)

ENDFOR

ENDFOR

Dead and Blind Pixels interpolation

(once radiances are computed, dead and blind pixels in the matrix are interpolated by the average of their closest safe neighbors)

Input

L_raw_geo (l,p,k,s) : radiance with uncorrected blind/dead pixels

Dead_Pixel(l,p) = image with 0 when pixel is OK, 1 when pixel is dead

Blind_Pixel(l,p) = image with 0 when pixel is OK, 1 when pixel is dead

Output

L_raw_geo (l,p,k,s) : radiance with interpolated missing pixels

Parameters

Internal data

Description

FOR each sequence s in [S0, S1]

FOR each channel k

IF Dead_Pixel(l,p) or Blind_Pixel(l,p) = 1 THEN

L_raw_geo (l,p,k,s) = average of the surrounding pixels of which the (Dead_Pixels (l+n,p+m) + Blind_Pixels (l+n,p+m)) is 0 with{n,m}$\in$ {(-1,1), (-1,1)}

IF no available surrounding pixel THEN L_raw_geo (l,p,k,s) = "saturated"

ENDIF

ENDFOR

ENDFOR

Tartan and IIR_Modis issue corrections

Input

L_raw_geo (l,p,k,s) : radiance with corrected blind/dead pixels

Commented [H5]: Page: 32
quelle unité (AL)

Commented [H6]: Page: 32
quelle unité (AL)

Commented [H7]: Page: 32
quelle unité (AL)

Output

L_raw_geo (l,p,k,s) : radiance with pixels corrected from tartan issue

Commented [H8]: Page: 32
quelle unité (AL)

Parameters

Tartan(3,64,730)

IIR_Modis(3,64,730)

Internal data

S_ND ; *the sequence in [S0, S1] that corresponds to the night-day transition. This variable can be deduced from the ephemeris file.*

S0_corr : *the first sequence of the cycle following the cycle in which S_ND has been found*

Description

Find S_ND in [S0, S1]

Find S0_corr

FOR each sequence s in [S0, S1]

s_corr = (s-S0_corr) MOD 729

FOR each channel k

L_raw_geo (l,p,k,s) = L_raw_geo (l,p,k,s)*Tartan(k, l, s_corr)*IIR_Modis(k, l, s_corr)

ENDFOR

ENDFOR

Product Earth average *(this task will help to detect slow drifts – at a scale of an orbit – introduced by calibration. This task will also detect slopes created during equalization)*

Input

L_raw_geo (l,p,k,s) : radiance with interpolated missing pixels

Commented [H9]: Page: 32
quelle unité (AL)

Output

L_average_geo (l,p,k) : radiance with averaged pixels on half orbit (a product)

Commented [H10]: Page: 32
quelle unité (AL)

Parameters

Internal data

Description

FOR all sequences s in [S0, S1]

FOR each channel k

L_average_geo (l,p,k) = AVERAGE (L_raw_geo (l,p,k,s))

ENDFOR

ENDFOR

WRITE to Earth Average Record in the Calibration File *(request for addition to RD 1)*

Geometrical processing (this module computes and projects on the grid the calibrated Earth images)

Input

FOR each sequence s in [S0, S1]

type of image cycle : Black Body or Deep Space (1st, 2nd, 3rd or 4th one)

FOR each spectral band k

L_raw_geo (l,p,k,s) : radiance (W.m-2.sr-1)

Navigation data : satellite position, attitude, acquisition dates (from 7.1.1)

Output

latitude(l,p), longitude(l,p) : geolocation grid

L_geo(l,p) : geolocated radiance

nrows, ncols : number of rows and columns of L_geo(l,p)

Parameters

Δt : duration of 3 lidar shots

h_proj : geodetic altitude of projection

dmax : the number of columns in an IIR level 1 line is 2* dmax +1

Internal data

Subroutines (subroutines are described in §8)

- atan2 (x , y) : returns the arctangent of coordinates x et y in [$-\pi$; π [

- abs : returns the absolute value of its argument

- SubSatPointVelocity(t , Vnorth , Veast) : returns the North and East components of the sub-satellite point velocity at the input time t (see PGS_CSC_SubSatPoint)

- GEO_To_ECR (λ, ϕ, h, X, Y, Z) : converts from geodetic to ECR coordinates

(see PGS_CSC_GEOtoECR)

- lidar_geolocate (t , λ_{lidar}, ϕ_{lidar}) : returns the geodetic coordinates of the lidar point at time t

- sequences (t, k, s_0, s_1) : returns the 2 sequence numbers (s_0, s_1) that are closest to the date t for spectral band k ($s_1 = s_0 + 1$).

- inv_geolocate (λ, ϕ, h, s, k, l, p) : given a point with geodetic coordinates (λ, ϕ, h), returns the coordinates (l,p) of the pixel from the sequence number s or spectral band k that corresponds to it. These coordinates are floating point numbers.

- interpolation : see § 8.1

- choose_sequence(s_0, l_0, p_0, s_1, l_1, p_1) : chooses the best sequence to interpolate a point which image coordinates are (l_0,p_0) in sequence s_0 and (l_1,p_1) in sequence s_1 (see § 8.5)

Description

l = 0

IF (sequence S0 is a "Deep Space" sequence)

THEN

    time_offset = Te_ds_3 (4.1134 s, see Annex 1.2.1)

ELSE

time_offset = Te_b_3 (4.3233 s, see Annex 1.2.1)

END IF

t = acquisition time of the first Earth image of the sequence S0 – time_ offset – start_margin

(the time_offset makes possible to turn back to the beginning of the sequence, the start_margin – a multiple of 3 lidar shots- makes possible to coordinate the beginning of the image with the lidar timing)

t_{end} = acquisition time of the first image of the sequence S1 + end_margin

DO

SubSatPointVelocity(t , V_{north} , V_{east})

α = atan2 (V_{east} , V_{north}) + $\pi/2$

lidar_geolocate (t , λ_{lidar} , ϕ_{lidar})

GEO_To_ECR (λ_{lidar} , ϕ_{lidar} , h_proj , X_{lidar} , Y_{lidar} , Z_{lidar})

p = 0

FOR each d in [- d_{max} , d_{max}] with step = 1km

$X_{cur} = X_{lidar} – d.(\cos(\alpha).\sin(\lambda_{lidar})+\sin(\alpha).\sin(\phi_{lidar}).\cos(\lambda_{lidar}))$

$Y_{cur} = Y_{lidar}+d.(\cos(\alpha).\cos(\lambda_{lidar})-\sin(\alpha).\sin(\phi_{lidar}).\sin(\lambda_{lidar}))$

$Z_{cur} = Z_{lidar}+d.\sin(\alpha).\cos(\phi_{lidar})$

ECR_To_GEO(X_{cur} , Y_{cur} , Z_{cur} , longitude[l][p] , latitude[l][p] , alt)

λ = longitude[l][p]

ϕ = latitude[l][p]

FOR each k in [1 , 3]

sequences (t , k , s_0 , s_1)

inv_geolocate(λ, ϕ, h_proj, s_0, k, l_0, p_0)

inv_geolocate(λ, ϕ, h_proj, s_1, k, l_1, p_1)

s = choose_sequence(s_0, l_0, p_0, s_1, l_1, p_1)

IF (s = undefined) THEN

L_geo(l,p) = undefined

ELSE IF (s = s_0)

L_geo(l,p) = interpolation (L_raw_geo(l_0 , p_0, k , s_0))

ELSE

L_geo(l,p) = interpolation (L_raw_geo(l_1 , p_1, k , s_1))

END IF

END FOR

p = p + 1

END FOR

(a line of the grid is generated at each 3 lidar shots. 165 lidar shots match to 55 lines and to 1 sequence as well. During a whole sequence, each line of the grid is dated referring to 3 lidar shots. Each time a new sequence is detected, the dating is wedged on the start of this new sequence)

l = l + 1

IF (modulo(l, 165/3) = 0) # 165 lidar shots per sequence, 1 grid row every 3 lidar shots

THEN

current_sequence = current_sequence+1

IF (current_sequence is a "Deep Space" sequence)

THEN

time_offset = Te_ds_3

ELSE

time_offset = Te_b_3

ENDIF

t = acquisition time of the first image of the current sequence – time_offset

ELSE

t = t + Δt

ENDIF

WHILE t < t_{end}

nrows = l

ncols = p

Level 1 output files edition

7.1.3. Level 1B product

Spacecraft position, attitude, velocity

Earth view records

7.1.4. Calibration products

IIR calibration record summary

IIR calibration metadata record

IIR space view record

IIR blackbody record

IIR Dead pixel image

IIR Blind pixel image *(note : request for addition to RD1)*

IIR equalization image

Earth Average Record *(note : request for addition to RD1)*

7.1.5. Validation file

Produced on request. See §5.4

8. Subroutines

Sequence numbering

Anytime an equalization occurs, the cycle number is set to "zero"

```
FOR each cycle number
    FOR each image identifier
        Sequence number = 5* cycle number + INT(image number/6)
    ENDFOR
ENDFOR
```

Bicubic interpolation *(this subroutine is used to fill the level 1 grid by interpolating measurements collected by the IIR matrix)*

Input

k spectral band

s sequence

l line number (floating point number)

p column number (floating point number)

L_raw_geo (k,s) : radiance ($W.m^{-2}.sr^{-1}$) in matrix array

s_tartan

FLAG_TARTAN (l,s_tartan)

Output

L_geo(l,p,k,s) : interpolated for (l,p,k,s)

Tartan_thres

DQX

Parameters

"Missing & saturated values", i.e. pixels in the projection that fall outside the IIR images, will be coded with a value specified in the hdf of the corresponding file. This figure will indicate that no value is associated to the pixel.

Tabulated interpolation coefficients : a priori, use of bicubic interpolation, defined with

Commented [H11]: Page: 37
fournis en paramètres de la chaîne (OH) ?

$C_u(k)$, with $1 \leq k \leq 4$,

Tabulated for $0 \leq u \leq 1$, with a step of 0.01

Internal data

Subroutines

INT : returns the closest integer less than or equal to its argument.

Description

l_frac = l-INT(l)

p_frac=p-INT(p)

read the interpolation coefficients $C_{l\_frac}(h)$, $C_{p\_frac}(k)$, $1 \leq h,k \leq 4$,

find the 4*4 neighbours of (l, p) in L_raw_geo (k,s)

s_tartan = s MOD 729

find the corresponding 4*4 FLAG_TARTAN (l, s_tartan)

    IF at least Tartan_thres of them = 1

        Update DQX (the 3 first pixels of DQX are dedicated to tartan issue. See Table 1)

    ENDIF

IF the 4*4 neighbours exist

    Check Dead_pixel and Blind_pixel for the 4*4 neighbours

    IF one of the neighbours is saturated

        L_geo (l,p,k) = "saturated"

        Update DQX

    ELSE

        L_geo (l,p,k) = interpolation of the radiance for pixel (l, p) in the grid, with $C_{l\_frac}(h)$, $C_{p\_frac}(k)$ coefficients

        Update DQX

    ENDIF

ELSE

    L_geo(l,p,k) = "missing"

    Update DQX

ENDIF

Update DQP

sequences

Input

- t : date
- k : spectral band
- dates(k,s) : acquisition dates for sequence s in $[S_0,S_1]$ and spectral band k

Output

s_0 , s_1 : sequence numbers that are closest to the date t

Description

search s_0 and s_1 for which acquisition date for $(s_0, k) \leq t <$ acquisition date for (s_1, k)

s1 = s0 + 1 (except boundary effects. In these cases, s_0 and/or s_1 may be undefined).

lidar_geolocate

Input

t : date

Output

$(\lambda_{lidar}, \phi_{lidar})$: geodetic coordinates of lidar spot

Parameters

Internal data

line of sight of the lidar in the spacecraft reference frame.

Subroutines

PGS_CSC_GetFOV_Pixel

Description

localization (PGS_CSC_GetFOV_Pixel) for the line of sight of the lidar at the input time t.

inv_geolocate

Input

(λ , ϕ , h) : geodetic coordinates of a ground point

s : sequence number

k : spectral band

Output

(l , p) : coordinates of the corresponding pixel (floating point numbers)

Parameters

Internal data

Subroutines

PGS_CSC_Earthpt_FOV

Description

- t is the acquisition date of spectral band k for sequence s
- PGS_CSC_Earthpt_FOV gives the line of sight in the spacecraft reference frame at the input time t (input : λ, ϕ, h, ... output : (Vx_{Sat}, Vy_{Sat}, Vy_{Sat},) ...)

choose_sequence

Input

s_0 : sequence number

(l_0,p_0) : image coordinates of the point in the sequence s0

s_1 : sequence number

(l_1,p_1) : image coordinates of the point in the sequence s1

Output

s : best sequence for interpolation (s_0, s_1 or undefined)

Parameters

nrows : number of rows in a level 0 image
ncols : number of columns in a level 0 image

Internal data

Subroutines

Description

\# *Is interpolation possible in sequence s0 ?*
IF (s_0 = undefined OR l_0 < 1.5 OR nrows-1.5<l_0 OR p_0 < 1.5 OR ncols-1.5 < p_0) THEN
    flag_s0 = FALSE
ELSE
    flag_s0 = TRUE
ENDIF

\# *Is interpolation possible in sequence s1 ?*
IF (s_1 = undefined OR l_1 < 1.5 OR nrows-1.5<l_1 OR p_1 < 1.5 OR ncols-1.5 < p_1) THEN
    flag_s1 = FALSE
ELSE
    flag_s1 = TRUE
ENDIF

if (flag_s0 = FALSE AND flag_s1 = FALSE) THEN
    RETURN undefined
END IF

```
IF (flag_s0 = TRUE AND flag_s1 = FALSE) THEN
        RETURN s0
END IF

IF (flag_s0 = FALSE AND flag_s1 = TRUE) THEN
        RETURN s1
END IF
distance_0 = max(abs(nrows/2-l0), abs(ncols/2-p0));
distance_1 = max(abs(nrows/2-l1), abs(ncols/2-p1));

IF (distance_0 < distance_1) THEN
        RETURN s0
ELSE
        RETURN s1
END IF
```

ANNEX 1 IIR TIMING

AD1 DRD14 Payload Data Measurements

AD2 SER-SYS-2378B Payload Data Synchronization and Time Tag methods

AD3 Rapport d'étude électronique de l'IIS – IA.AR.1600.0029.SOD Issue 2

The IIR timing knowledge is based on the time tag by the Payload software of the signal used to command the IIR and on IIR the internal timing.

Annex 1.1. Payload Time Tag

Two physical clocks are involved in the image datations :

T_{PL} the time tag by the Payload on which are synchronized Sequence and Cycle periods (see below)

ASE Acquisition Start End on which are synchronized the image snapshots (see below)

The IIR operates on the IIR_Cycle_Synchro period.
For each IIR_Cycle_Synchro period, there are 5 IIR_Sequence_Synchro periods.
For each IIR_Sequence_Synchro period, there are 6 IIR images collected (two views and three filter positions for each view (see Table 1).
Each image is stored as an individual Payload Data packet with the appropriate APID and Packet Id (see AD1). The time tag for each packet is the time of the snapshot clock, with which the IIR_Sequence_Synchro signal is synchronized.
The IIR_Cycle_Synchro signal is also synchronized with the snapshot clock.
There are 5 sequences collected during an IIR_Cycle_Synchro period, for a total of thirty packets. Each of these packets are identified with a count ranging from 0 to 29, to indicate where it occurred within the IIR_Cycle_Synchro period.

Cycle	40.92 s																													
Sequence	8.184 s						8.184 s						8.184 s						8.184 s						8.184 s					
View	Black Body			Earth			Deep Space			Earth			Deep Space			Earth			Deep Space			Earth			Deep Space			Earth		
Filter number	1	2	3	3	2	1	1	2	3	3	2	1	1	2	3	3	2	1	1	2	3	3	2	1	1	2	3	3	2	1
Image Identifier	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

Table 1: ***Image cycle description***

Annex 1.2. IIR internal timing

The IIR internal timing takes into account two phases:

The beginning of the image acquisition, which corresponds to the rising edge of the Acquisition Start End (ASE) signal commanding the ISM. Depending on the type of sequence (Blackbody or Deep Space), the rising edge of the ASE signal can be related to the time tagged synchronization signals sent by the Payload (T_{PL})

The IIR image being the average of several elementary frames, the timing is determined as the center of the acquisition duration.

Annex 1.2.1. ASE beginning

Blackbody sequence timing

This is the first sequence performed inside the cycle.

The corresponding timings Tb_k for Blackbody views and Te_b_k for Earth views (k for the spectral channel) are described in table 2. The values are defined with regard to the IIR_**Cycle**_Synchro signal rising edge.

			Image Acquisition Beginning*	
			Typical	Tolerance
Unit	Image Identifier	Parameter	*ms*	*ms*
Black Body (Filter n°1)	0	Tb_1	350.1	±1.0
Black Body (Filter n°2)	1	Tb_2	1484.7	±1.0
Black body (Filter n°3)	2	Tb_3	2619.2	±1.0
Earth (Filter n°3)	3	Te_b_3	4323.3	±1.0
Earth (Filter n°2)	4	Te_b_2	5457.8	±1.0
Earth (Filter n°1)	5	Te_b_1	6592.4	±1.0

***** laps of time between the IIR_Cycle_Synchro and the rising edge of the ASE

Table 2: Black body sequence timing

Deep Space sequence timing

Deep Space sequence timings Tds_k for Deep Space views and Te_ds_k for Earth views (k for the spectral channel) are described in table 3. The values are defined with regard to the IIR_**Sequence**_Synchro signal rising edge.

			Image Acquisition Beginning*	
			Typical	Tolerance
Unit	Image Identifier	Parameter	*ms*	*ms*
Deep Space (Filter n°1)	6, 12, 18, 24	Tds_1	350.1	±1.0
Deep Space (Filter n°2)	7, 13, 19, 25	Tds_2	1484.7	±1.0
Deep Space (Filter n°3)	8, 14, 20, 26	Tds_3	2619.2	±1.0
Earth (Filter n°3)	9, 15, 21, 27	Te_ds_3	4113.4	±1.0
Earth (Filter n°2)	10, 16, 22, 28	Te_ds_2	5248.0	±1.0
Earth (Filter n°1)	11, 17, 23, 29	Te_ds_1	6382.5	±1.0

* laps of time between the IIR_Cycle_Synchro and the rising edge of the ASE

Table 3: Deep space sequence timing

Annex 1.2.2. ASE internal timing

During the ASE period, 5 frames are acquired. The actual integration time for each frame is 111 µs. The IIR composite image is made by averaging the 4 last frames.

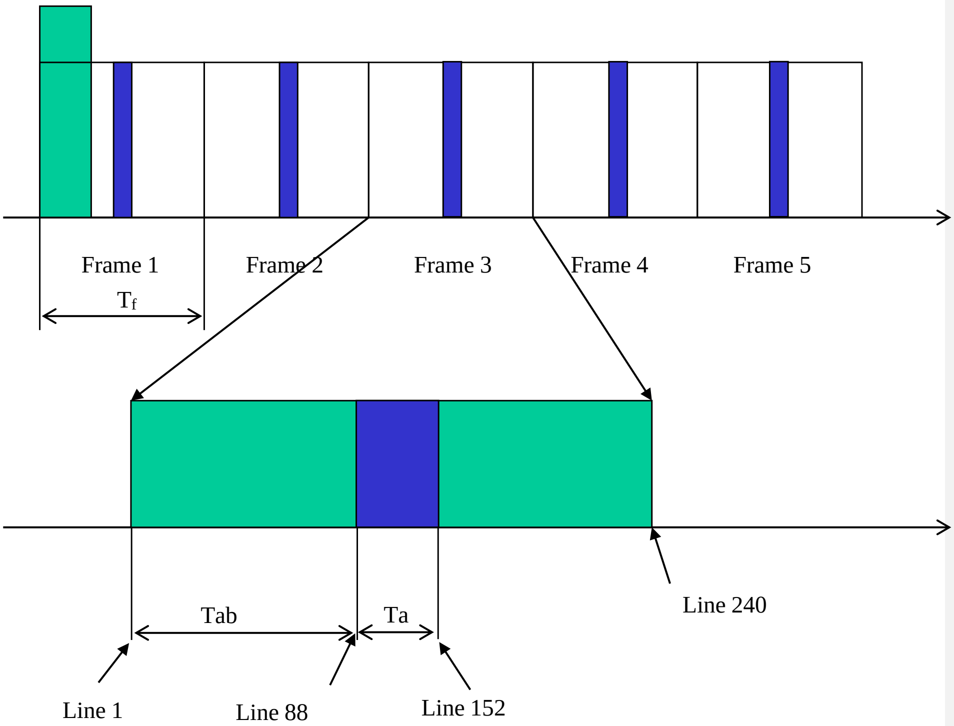


Figure 0-1: IIR internal timing

Note that the µbolometer device comprises 240 lines of 320 pixels. Each pixel value has to be read in order to acquire the 64 x 64 pixels² useful area.

T_{ab} Acquisition beginning time corresponds to the beginning of the useful area acquisition

T_a corresponds to the duration of the useful area acquisition

T_f corresponds to the duration of a frame

Ti image acquisition IIR internal timing wrt the ASE front end is defined as the center of the acquisition frames for the center of the Field Of View.

$$T_i = \frac{5}{2}.T_f + T_{ab} + \frac{1}{2}T_a$$

<u>Nominal values</u>

T_f = 28.5344 ms

T_a = 7.5776 ms

T_{ab} = 10.4192 ms in case of a useful area centered wrt the total µbolometer device (this corresponds to an acquisition beginning at line 89 and end at line 152)

T_i = 85.544 ms

Annex 1.3. Total timing

T_{PL} being the time tag by the Payload included in the Payload Data Packet for each image, the image timing shall be calculated by :

$Ti\min g = T_{PL} + T_{e\_b\_k} + T_i$ for an Earth view during a Blackbody sequence

$Ti\min g = T_{PL} + T_{e\_ds\_k} + T_i$ for an Earth view during a Deep Space sequence

Blackbody sequence or Deep Space sequences can be identified by the image identifier included in the Payload Data Packet (2 to 5 for Blackbody sequence; 9 to 11 or 15 to 17 or 21 to 23 or 27 to 29 for deep Space sequence).

In summary, the IIR timing can be computed as:

Timing(Im_Id) = T_{PL} + T_i(Im_Id)

With Im_Id Image Identifier (0 to 29)

And T_i(Im_Id) table (29 x 1) depending on the image (see annex 4)

Annex 1.4. Lidar timing

The snapshot clock starts a major frame of lidar data collection corresponding to 165 lidar shots devided into 11 sequences of 15 pulses.

Lidar data are collected and packetized into Lidar Major Profiles. The time tag associated with the first sequence of the Lidar Major Profile will be the time of the snapshot clock. The time tags for the remaining sequences will have a fixed time added to the snapshot clock.

The detailed algorithm for the lidar time tag is TBD by NASA.

ANNEX 2 Change of reference frame – Account for alignment measurements

Annex 2.1. Distortion model

The distortion of the optics (for each channel k) is fitted by a radial model expressed in terms of the distance “dist” between the current pixel and a central point D^k with ($D^k{}_l$, $D^k{}_p$) =(row, column) coordinates. The distorsion value is computed as:

$\text{Distortion}^k = R^k{}_3.\text{dist}^3+R^k{}_5.\text{dist}^5+R^k{}_7.\text{dist}^7$

So the distorsion law parameters [to be found in AD2] are:

[$R^k{}_3$,$R^k{}_5$, $R^k{}_7$] for k=1,2,3

($D^k{}_l$, $D^k{}_p$) for k=1,2,3

Annex 2.2. Transfer from image coordinates (l,p) to a viewing vector in image reference frame

Iterative method to calculate the undistorted coordinates (x,y) corresponding to the coordinates (l,p)

$$last\_dist = \sqrt{\left(p - D^k{}_p\right)^2 + \left(l - D^k{}_l\right)^2}$$

$$\alpha = R^3{}_k \cdot last\_dist^2 + R^5{}_k \cdot last\_dist^4 + R^7{}_k \cdot last\_dist^6$$

$$iter = 0$$

$$DO$$

$$dist = \sqrt{\left(\frac{p - D^k{}_p}{1+\alpha}\right)^2 + \left(\frac{l - D^k{}_l}{1+\alpha}\right)^2}$$

$$\alpha = R^k{}_3 \cdot dist^2 + R^k{}_5 \cdot dist^4 + R^k{}_7 \cdot dist^6$$

$$\Delta = \left| \, dist - last\_dist \, \right|$$

$$last\_dist = dist$$

$$iter = iter + 1$$

$$WHILE\left(\Delta > \varepsilon \ AND \ iter \leq NITER\_MAX\right)$$

$$x = \frac{p + \alpha \cdot D^k{}_p}{1+\alpha} \qquad y = \frac{l + \alpha \cdot D^k{}_l}{1+\alpha}$$

where $\varepsilon = 10^{-3}$ (pixel) and NITER_MAX = 10 (TBC).

Then

$$\vec{V}_{image} = \begin{bmatrix} x - \dfrac{ncols}{2} \\ y - \dfrac{nrows}{2} \\ -\ focal_k \end{bmatrix}$$

Annex 2.3. Transfer from a viewing vector (VX,VY,VZ) to image coordinates in image reference frame

$$\begin{cases} l = (1+\alpha)\cdot\left(\dfrac{nrows}{2} - focal_k \cdot \dfrac{V_Y}{V_Z}\right) - \alpha \cdot D^k{}_l \\ p = (1+\alpha)\cdot\left(\dfrac{ncols}{2} - focal_k \cdot \dfrac{V_X}{V_Z}\right) - \alpha \cdot D^k{}_p \end{cases}$$

with

$$\text{dist} = \sqrt{\left(\frac{ncols}{2} - D^k{}_p - focal_k \cdot \frac{V_X}{V_Z}\right)^2 + \left(\frac{nrows}{2} - D^k{}_l - focal_k \cdot \frac{V_Y}{V_Z}\right)^2}$$

$\alpha = R^k{}_3.\text{dist}^2 + R^k{}_5.\text{dist}^4 + R^k{}_7.\text{dist}^6$

Annex 2.4. Transfer from the image reference frame to the IIR reference frame

For spectral channel number k

Assume a viewing vector given in the image reference frame as $\begin{pmatrix} Vx_{image} \\ Vy_{image} \\ Vz_{image} \end{pmatrix}$,

Assume the same viewing vector expressed in the IIR reference frame as: $\begin{pmatrix} Vx_{IIR} \\ Vy_{IIR} \\ Vz_{IIR} \end{pmatrix}$

We have the following relations:

$$\begin{pmatrix} Vx_{IIR} \\ Vy_{IIR} \\ Vz_{IIR} \end{pmatrix} = [\ \mathrm{MAT}_{\mathrm{IIR}\rightarrow\mathrm{image},k}\ ] \,.\, \begin{pmatrix} Vx_{image} \\ Vy_{image} \\ Vz_{image} \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} Vx_{image} \\ Vy_{image} \\ Vz_{image} \end{pmatrix} = [\ \mathrm{MAT}_{\mathrm{IIR}\rightarrow\mathrm{image},k}\ ]^{-1} \,.\, \begin{pmatrix} Vx_{IIR} \\ Vy_{IIR} \\ Vz_{IIR} \end{pmatrix}$$

Annex 2.5. Transfer from IIR reference frame to Payload reference frame

Assume a viewing vector expressed in the IIR reference frame as: $\begin{pmatrix} Vx_{IIR} \\ Vy_{IIR} \\ Vz_{IIR} \end{pmatrix}$

This vector is expressed in the payload reference frame as: $\begin{pmatrix} Vx_{payload} \\ Vy_{payload} \\ Vz_{payload} \end{pmatrix}$

$$\begin{pmatrix} Vx_{Payload} \\ Vy_{Payload} \\ Vz_{Payload} \end{pmatrix} = [\ \mathrm{MAT}_{\mathrm{Payload}\to\mathrm{IIR}}\ ] \cdot \begin{pmatrix} Vx_{IIR} \\ Vy_{IIR} \\ Vz_{IIR} \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} Vx_{IIR} \\ Vy_{IIR} \\ Vz_{IIR} \end{pmatrix} = [\ \mathrm{MAT}_{\mathrm{Payload}\to\mathrm{IIR}}\ ]^{-1} \cdot \begin{pmatrix} Vx_{Payload} \\ Vy_{Payload} \\ Vz_{Payload} \end{pmatrix}$$

Annex 2.6. Transfer from the payload reference frame to the Satellite reference frame

Assume a viewing vector which coordinates in the payload reference frame are: $\begin{pmatrix} Vx_{Payload} \\ Vy_{Payload} \\ Vz_{Payload} \end{pmatrix}$

This vector is expressed in the satellite reference frame as: $\begin{pmatrix} Vx_{sat} \\ Vy_{sat} \\ Vz_{sat} \end{pmatrix}$

$$\begin{pmatrix} Vx_{Sat} \\ Vy_{Sat} \\ Vz_{Sat} \end{pmatrix} = [\ \mathrm{MAT}_{\mathrm{Sat}\to\mathrm{Payload}}\ ] \cdot \begin{pmatrix} Vx_{Payload} \\ Vy_{Payload} \\ Vz_{Payload} \end{pmatrix} \quad \text{et} \quad \begin{pmatrix} Vx_{Payload} \\ Vy_{Payload} \\ Vz_{Payload} \end{pmatrix} = [\ \mathrm{MAT}_{\mathrm{Sat}\to\mathrm{Payload}}\ ]^{-1} \cdot \begin{pmatrix} Vx_{Sat} \\ Vy_{Sat} \\ Vz_{Sat} \end{pmatrix}$$

ANNEX 3 Input parameters file for level 1 processing

Note *: the format has to be defined by NASA. This file will be edited in this format at the TEC and sent to ASDC during in-flight operation*

Annex 3.1. Header for Radiometry

Function of the parameter	Name	Value
Version number	Vers_num_rad	integer
Date of application	Appl_date_rad	

Annex 3.2. Constants for Radiometry

Function of the parameter	Name	Value
Physics		
conversion factor from degree celsius to Kelvin		273.15
	k	$1{,}38.10^{-23}$ JK^{-1}
	h	$6{,}62607.10^{-34}$ Js
Stefan Boltzmann constant		$5.67040.10^{-8}$ $J.K^{-4}.m^{-2}.s^{-1}$
Light speed	C	$2{,}99792.10^{8}$ ms^{-1}
Instrument		

number of pixels in the matrix		64*64
Scale factor for radiance	Scale_Factor_for_Packed_Radiance	Float 32; default value = 100
Radiance offset	Radiance_offset	Float 32; default value = 0
On-ground measurements		
BB emissivity		0.994
BB_T° to Radiance table	TAB_BB	(see annexe 4)
Linearity table for each channel	LINAR	(see annexe 4)

Annex 3.3. Radiometry

Function of the parameter	**Name**	**Value**
Map of dead pixels of the matrix before flight	Dead_pixel_grd	64*64 array of 1 byte (default value = 0)
Map of blind pixels of the matrix before flight	Blind_pixel_grd	64*64 array of 1 byte (default value = 0)
Typical σ value for DS image		TBD after launch
Typical σ value for BB image		TBD after launch
number of calibration image from previous and next to perform calibration	N_cal	4

For the 3 channels, for the 730 sequences (146 cycles) over which is described the cycle of Tartan effect, a "1" indicates that the row in the image is affected by tartan	Flag_Tartan	64*730 array of 1 byte (default value = 0)
The number of pixels affected by tartan and contributing to the interpolation	Tartan_thres	1≤ Tartan_thres ≤16
The table to correct tartan effect	Tartan(3,64,730)	3*64*730 array of 2 bytes
The table to correct IIR_Modis difference	IIR_Modis(3,64,730)	3*64*730 array of 2 bytes

Annex 3.4. Header for Geometry

Function of the parameter	**Name**	**Value**
Version number	Vers_num_geo	integer
Date of application	Appl_date_geo	

Annex 3.5. Constants for geometry

Function of the parameter	**Name**	**Value**
Half the number of columns in an IIR level	Dmax	34

1 product *(numbers of columns=2*dmax+1)*		

Annex 3.6. Geometry

Function of the parameter	**Name**	**Value**
Geodetic altitude of projection	h_proj	0 (km)
Distorsion		
Coordinates (raw, columns) of the central point of symmetry for each band k	(D^{k}_{l}, D^{k}_{p})	(0,0)
Coefficients R_x for each spectral band k	R^k_3 , R^k_5 , R^k_7	*Mesures d'alignement TBD*
Maximum iteration to calculate undistorted coordinates	NITERMAX	10
Focals		
Focal length for each band k	$focal_k$	35.96 mm
Matrix		
Transfer from satellite reference frame to payload	$MAT_{sat\_payload}$	See Annex 5
Transfer from payload reference frame to IIR	$MAT_{payload\_IIR}$	See Annex 5
Transfer from IIR reference frame to image for each spectral band 8.65	$MAT_{IIR\_imageB1}$	See Annex 5
Transfer from IIR reference frame to image for each spectral band 12.05	$MAT_{IIR\_imageB2}$	See Annex 5

Transfer from IIR reference frame to image for each spectral band 10.6	$MAT_{IIR\_imageB3}$	See Annex 5
Time		
Duration of 3 Lidar shots	Δt	
the start_margin – a multiple of 3 lidar shots- makes possible to coordinate the beginning of the image on the grid with the lidar timing	start_margin	0.0496s
the end_margin – a multiple of 3 lidar shots- makes possible to coordinate the end of the image on the grid with the lidar timing	end_margin	0s

Annex 3.7. Configuration parameters *(these parameters allow or not the activation of specific procedures)*

Function of the parameter	**Name**	**Value**
Perform detection of a change in the dead pixel matrix	Dead_pixel_detect	1 or 0 (default value)
Perform detection of a change in the blind pixel matrix	Blind_pixel_detect	1 or 0 (default value)
Production of a validation file required	Valid_file_issue	1 or 0 (default value)

Annex 3.8. Processing parameters

Function of the parameter	**Name**	**Value**

The maximum acceptable number of missing Deep Space sequence around an missing Deep Space sequence that have to be interpolated	CS_Interp_Threshold	6
The maximum acceptable number of missing Blackbody sequence around an missing Blackbody sequence that have to be interpolated	BB_Interp_Threshold	6
Number of deep space images to average in the calibration process for channel 1	N^{1}_{DSE}	9
Number of deep space images to average in the calibration process for channel 2	N^{2}_{DSE}	8
Number of deep space images to average in the calibration process for channel 3	N^{3}_{DSE}	9
Number of calibration images to average in the calibration process for each channel	N^{k}_{DSBB}	8
Number of gain values to average in the calibration process	N^{k}_{BB}	4
Bicubic interpolation parameter	$C_u(k)$	$1 \leq k \leq 4$

Annex 3.9. Alert parameters

Function of the parameter	Name	Value
Confidence range for BB T°	Conf_BB_Temp	[287K,298K]
Confidence range for space values	Conf_CS	[value TBD in flight, value TBD in flight]
Confidence range for each pixel averaged on a full orbit	Conf_full_orb	[value TBD in flight, value TBD in flight]

Maximum acceptable number of interpolated pixels in the IIR matrix required to compute the corresponding grid pixel of channel 8.5 with no significant degradation	Pixel_threshold_1	3
Maximum acceptable number of interpolated pixels in the IIR matrix required to compute the corresponding grid pixel of channel 10.5 with no significant degradation	Pixel_threshold_2	3
Maximum acceptable number of interpolated pixels in the IIR matrix required to compute the corresponding grid pixel of channel 12.05 with no significant degradation	Pixel_threshold_3	3

Ti

times to add to the Time_payload, to get the image time (depends on the Image identifier)

Image Identifier	**Image Acquisition Beginning (Typical) in ms**
0	435.644
1	1570.244
2	2704.744
3	4408.844
4	5543.344

5	6677.944
6	435.644
7	1570.244
8	2704.744
9	4198.944
10	5333.544
11	6468.044
12	435.644
13	1570.244
14	2704.744
15	4198.944
16	5333.544
17	6468.044
18	435.644
19	1570.244
20	2704.744
21	4198.944
22	5333.544

23	6468.044
24	435.644
25	1570.244
26	2704.744
27	4198.944
28	5333.544
29	6468.044

ANNEX 4 Radiometric tables

BB_T° to Radiance table **TAB_BB**

Temperature (TM HEXA count)	Radiance F1 (W.m-2.sr-1)	Radiance F2 (W.m-2.sr-1)	Radiance F3 (W.m-2.sr-1)
0	6,0585	7,3938	4,9198
1	6,0634	7,3982	4,9231
2	6,0683	7,4025	4,9263
3	6,0732	7,4068	4,9296
4	6,0781	7,4112	4,9328
5	6,0831	7,4155	4,9361
6	6,0880	7,4199	4,9393
7	6,0929	7,4242	4,9426
8	6,0978	7,4286	4,9459
9	6,1027	7,4329	4,9491
A	6,1076	7,4373	4,9524

B	6,1126	7,4416	4,9557
C	6,1175	7,4460	4,9589
D	6,1224	7,4503	4,9622
E	6,1274	7,4547	4,9654
F	6,1323	7,4590	4,9687
10	6,1372	7,4634	4,9720
11	6,1422	7,4678	4,9753
12	6,1471	7,4721	4,9785
13	6,1521	7,4765	4,9818
14	6,1570	7,4809	4,9851
15	6,1620	7,4852	4,9884
16	6,1669	7,4896	4,9916
17	6,1719	7,4940	4,9949
18	6,1768	7,4983	4,9982
19	6,1818	7,5027	5,0015
1A	6,1867	7,5071	5,0048
1B	6,1917	7,5114	5,0080
1C	6,1967	7,5158	5,0113
1D	6,2017	7,5202	5,0146
1E	6,2066	7,5246	5,0179
1F	6,2116	7,5289	5,0212
20	6,2166	7,5333	5,0245
21	6,2216	7,5377	5,0278
22	6,2266	7,5421	5,0311
23	6,2315	7,5465	5,0344
24	6,2365	7,5509	5,0377
25	6,2415	7,5553	5,0410
26	6,2465	7,5596	5,0442
27	6,2515	7,5640	5,0475
28	6,2565	7,5684	5,0508
29	6,2615	7,5728	5,0542
2A	6,2665	7,5772	5,0575
2B	6,2715	7,5816	5,0608
2C	6,2765	7,5860	5,0641

2D	6,2816	7,5904	5,0674
2E	6,2866	7,5948	5,0707
2F	6,2916	7,5992	5,0740
30	6,2966	7,6036	5,0773
31	6,3016	7,6080	5,0806
32	6,3067	7,6124	5,0839
33	6,3117	7,6168	5,0872
34	6,3167	7,6212	5,0906
35	6,3218	7,6256	5,0939
36	6,3268	7,6301	5,0972
37	6,3318	7,6345	5,1005
38	6,3369	7,6389	5,1038
39	6,3419	7,6433	5,1071
3A	6,3470	7,6477	5,1105
3B	6,3520	7,6521	5,1138
3C	6,3571	7,6565	5,1171
3D	6,3621	7,6610	5,1204
3E	6,3672	7,6654	5,1238
3F	6,3723	7,6698	5,1271
40	6,3773	7,6742	5,1304
41	6,3824	7,6787	5,1338
42	6,3875	7,6831	5,1371
43	6,3925	7,6875	5,1404
44	6,3976	7,6920	5,1438
45	6,4027	7,6964	5,1471
46	6,4078	7,7008	5,1504
47	6,4128	7,7052	5,1538
48	6,4179	7,7097	5,1571
49	6,4230	7,7141	5,1605
4A	6,4281	7,7186	5,1638
4B	6,4332	7,7230	5,1672
4C	6,4383	7,7274	5,1705
4D	6,4434	7,7319	5,1739
4E	6,4485	7,7363	5,1772

4F	6,4536	7,7408	5,1806
50	6,4587	7,7452	5,1839
51	6,4638	7,7497	5,1873
52	6,4689	7,7541	5,1906
53	6,4740	7,7586	5,1940
54	6,4792	7,7630	5,1973
55	6,4843	7,7675	5,2007
56	6,4894	7,7719	5,2040
57	6,4945	7,7764	5,2074
58	6,4997	7,7808	5,2108
59	6,5048	7,7853	5,2141
5A	6,5099	7,7898	5,2175
5B	6,5150	7,7942	5,2208
5C	6,5202	7,7987	5,2242
5D	6,5253	7,8032	5,2276
5E	6,5305	7,8076	5,2309
5F	6,5356	7,8121	5,2343
60	6,5408	7,8166	5,2377
61	6,5459	7,8210	5,2411
62	6,5511	7,8255	5,2444
63	6,5562	7,8300	5,2478
64	6,5614	7,8344	5,2512
65	6,5665	7,8389	5,2546
66	6,5717	7,8434	5,2579
67	6,5769	7,8479	5,2613
68	6,5821	7,8524	5,2647
69	6,5872	7,8568	5,2681
6A	6,5924	7,8613	5,2715
6B	6,5976	7,8658	5,2749
6C	6,6028	7,8703	5,2782
6D	6,6079	7,8748	5,2816
6E	6,6131	7,8793	5,2850
6F	6,6183	7,8837	5,2884
70	6,6235	7,8882	5,2918

71	6,6287	7,8927	5,2952
72	6,6339	7,8972	5,2986
73	6,6391	7,9017	5,3020
74	6,6443	7,9062	5,3054
75	6,6495	7,9107	5,3088
76	6,6547	7,9152	5,3122
77	6,6599	7,9197	5,3156
78	6,6651	7,9242	5,3190
79	6,6703	7,9287	5,3224
7A	6,6756	7,9332	5,3258
7B	6,6808	7,9377	5,3292
7C	6,6860	7,9422	5,3326
7D	6,6912	7,9467	5,3360
7E	6,6965	7,9513	5,3394
7F	6,7017	7,9558	5,3428
80	6,7069	7,9603	5,3462
81	6,7122	7,9648	5,3496
82	6,7174	7,9693	5,3531
83	6,7226	7,9738	5,3565
84	6,7279	7,9783	5,3599
85	6,7331	7,9829	5,3633
86	6,7384	7,9874	5,3667
87	6,7436	7,9919	5,3702
88	6,7489	7,9964	5,3736
89	6,7542	8,0009	5,3770
8A	6,7594	8,0055	5,3804
8B	6,7647	8,0100	5,3838
8C	6,7699	8,0145	5,3873
8D	6,7752	8,0191	5,3907
8E	6,7805	8,0236	5,3941
8F	6,7858	8,0281	5,3976
90	6,7910	8,0327	5,4010
91	6,7963	8,0372	5,4044
92	6,8016	8,0417	5,4079

93	6,8069	8,0463	5,4113
94	6,8122	8,0508	5,4147
95	6,8175	8,0554	5,4182
96	6,8228	8,0599	5,4216
97	6,8280	8,0644	5,4251
98	6,8333	8,0690	5,4285
99	6,8386	8,0735	5,4319
9A	6,8439	8,0781	5,4354
9B	6,8493	8,0826	5,4388
9C	6,8546	8,0872	5,4423
9D	6,8599	8,0917	5,4457
9E	6,8652	8,0963	5,4492
9F	6,8705	8,1008	5,4526
A0	6,8758	8,1054	5,4561
A1	6,8811	8,1100	5,4595
A2	6,8865	8,1145	5,4630
A3	6,8918	8,1191	5,4664
A4	6,8971	8,1236	5,4699
A5	6,9025	8,1282	5,4734
A6	6,9078	8,1328	5,4768
A7	6,9131	8,1373	5,4803
A8	6,9185	8,1419	5,4837
A9	6,9238	8,1465	5,4872
AA	6,9292	8,1510	5,4907
AB	6,9345	8,1556	5,4941
AC	6,9399	8,1602	5,4976
AD	6,9452	8,1648	5,5011
AE	6,9506	8,1693	5,5045
AF	6,9559	8,1739	5,5080
B0	6,9613	8,1785	5,5115
B1	6,9667	8,1831	5,5150
B2	6,9720	8,1876	5,5184
B3	6,9774	8,1922	5,5219
B4	6,9828	8,1968	5,5254

B5	6,9882	8,2014	5,5289
B6	6,9935	8,2060	5,5324
B7	6,9989	8,2106	5,5358
B8	7,0043	8,2152	5,5393
B9	7,0097	8,2197	5,5428
BA	7,0151	8,2243	5,5463
BB	7,0205	8,2289	5,5498
BC	7,0259	8,2335	5,5533
BD	7,0313	8,2381	5,5567
BE	7,0367	8,2427	5,5602
BF	7,0421	8,2473	5,5637
C0	7,0475	8,2519	5,5672
C1	7,0529	8,2565	5,5707
C2	7,0583	8,2611	5,5742
C3	7,0637	8,2657	5,5777
C4	7,0691	8,2703	5,5812
C5	7,0745	8,2749	5,5847
C6	7,0800	8,2795	5,5882
C7	7,0854	8,2842	5,5917
C8	7,0908	8,2888	5,5952
C9	7,0962	8,2934	5,5987
CA	7,1017	8,2980	5,6022
CB	7,1071	8,3026	5,6057
CC	7,1126	8,3072	5,6092
CD	7,1180	8,3118	5,6127
CE	7,1234	8,3165	5,6163
CF	7,1289	8,3211	5,6198
D0	7,1343	8,3257	5,6233
D1	7,1398	8,3303	5,6268
D2	7,1452	8,3349	5,6303
D3	7,1507	8,3396	5,6338
D4	7,1562	8,3442	5,6373
D5	7,1616	8,3488	5,6409
D6	7,1671	8,3535	5,6444

D7	7,1726	8,3581	5,6479
D8	7,1780	8,3627	5,6514
D9	7,1835	8,3674	5,6550
DA	7,1890	8,3720	5,6585
DB	7,1945	8,3766	5,6620
DC	7,1999	8,3813	5,6655
DD	7,2054	8,3859	5,6691
DE	7,2109	8,3905	5,6726
DF	7,2164	8,3952	5,6761
E0	7,2219	8,3998	5,6797
E1	7,2274	8,4045	5,6832
E2	7,2329	8,4091	5,6867
E3	7,2384	8,4138	5,6903
E4	7,2439	8,4184	5,6938
E5	7,2494	8,4231	5,6973
E6	7,2549	8,4277	5,7009
E7	7,2604	8,4324	5,7044
E8	7,2659	8,4370	5,7080
E9	7,2714	8,4417	5,7115
EA	7,2770	8,4463	5,7151
EB	7,2825	8,4510	5,7186
EC	7,2880	8,4557	5,7222
ED	7,2935	8,4603	5,7257
EE	7,2991	8,4650	5,7293
EF	7,3046	8,4696	5,7328
F0	7,3101	8,4743	5,7364
F1	7,3157	8,4790	5,7399
F2	7,3212	8,4836	5,7435
F3	7,3268	8,4883	5,7470
F4	7,3323	8,4930	5,7506
F5	7,3379	8,4977	5,7542
F6	7,3434	8,5023	5,7577
F7	7,3490	8,5070	5,7613
F8	7,3545	8,5117	5,7648

F9	7,3601	8,5164	5,7684
FA	7,3656	8,5210	5,7720
FB	7,3712	8,5257	5,7755
FC	7,3768	8,5304	5,7791
FD	7,3824	8,5351	5,7827
FE	7,3879	8,5398	5,7863
FF	7,3935	8,5445	5,7898

Linearity table for each channel : **LINAR**

	channel 1; 8.65 µm	channel 2; 12.05 µm	channel 3; 10.6 µm
$X^1_E\text{-}X^1_{DSE}$	$I^1[X^1_E\text{-}X^1_{DSE}]$	$I^2[X^2_E\text{-}X^2_{DSE}]$	$I^3[X^3_E\text{-}X^3_{DSE}]$
0	1	1	1
1	1	1	1
2	1	1	1
…	…	…	…
1999	1	1	1
2000	1	1	1

ANNEX 5 Geometric tables

$MAT_{sat\_payload}$

1	0	0
0	1	0
0	0	1

$MAT_{payload\_IIR}$

0.99999937	0.00109956	-0.00022689
0.00109988	0.9999984	0.00141372
0.00022534	-0.00141347	0.99999897

$MAT_{IIR\_imageB1}$

0.99999996	-0.0002	0.000183
0.00020003	0.99999997	-0.00017

-0.00018297	0.00017004	0.99999997

MAT$_{IIR_imageB2}$

0.99999996	-0.000183	0.000207
0.00018304	0.99999997	-0.00017
-0.00020697	0.00017004	0.99999996

MAT$_{IIR_imageB3}$

0.99999996	-0.00019	0.0002
0.00019003	0.99999997	-0.00017
-0.00019997	0.00017004	0.99999997