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« MEGHA-TROPIQUES »

MEGHA-TROPIQUES
LEVEL 1 Products Handbook

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1 PURPOSE

This handbook provides the necessary information for the user to use Megha-Tropiques (MGT) data including information related to standard products. It introduces reference information such as the MGT spacecraft, on-board instruments, and ground systems.

This document is realized base on the work of the people involved in the Megha-Tropiques development at CNES, at CLS and out sourcing.

2 HANDBOOK OVERVIEW

In the second chapter, we describe the scientific context of the MGT mission, we describe the main features of the satellite and the orbit defined to achieve its mission. We also describe each scientific instrument.
The third one is dedicated to the description of the different evolutions of the Madras and Saphir products.
The fourth one describes the radiometer calibration procedure, including the corrections that where applied to data.
The fifth chapter goes deeper onto each parameter that is computed and available for the data user.
The last chapter gives information concerning the data format HDF 5 that was chosen to share MGT products. Here we describe all parameters that are recorded in hdf files and Quality Flags (QF) that were introduced into each data stream. These QF are important to discriminate Brightness Temperatures (BT) that were computed without difficulty with others that could be erroneous.

Information on the products description is more precise in the documents listed here below:

Document title
MEGHA-TROPIQUES Level 1 product definition
Product Definition MADRAS
Product Definition SAPHIR
Product Definition SCARAB

These documents are available in the current version on the Megha-Tropiques CNES website.

3 MEGHA-TROPIQUES MISSION OVERVIEW

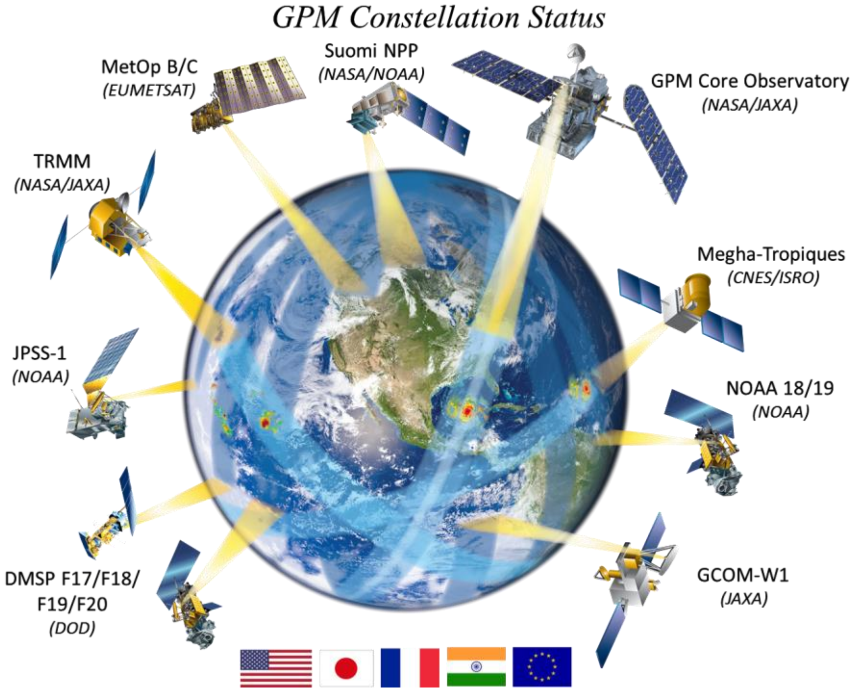
3.1 BACKGROUND

This mission was studied in France in the context of GEWEX (Global Energy and Water cycle Experiment). For understanding tropical meteorological and climatic processes, it appeared necessary to obtain reliable statistics on the water and energy budget of the tropical atmosphere and to describe the evolution of its systems (monsoons, cyclones …) at appropriate time scales. In parallel, tropical atmospheric and oceanic missions were also studied in India, which is directly concerned by these phenomena. The first originality of MEGHA-TROPIQUES is to associate three radiometric instruments allowing to observe simultaneously three interrelated components of the atmospheric engine: water vapor, condensed water (clouds and precipitations), and radiative fluxes. The second is to privilege the sampling of the intertropical zone, accounting for the large time-space variability of the tropical phenomena.

3.2 THE GPM CONSTELLATION

Initiated by NASA (US) and JAXA (Japan) space agencies, the GPM (Global Precipitation Measurement) aims achieving global coverage with a high sampling frequency by relying on both existing satellite programs and new mission opportunities from its partners [http://pmm.nasa.gov/GPM/constellation-partners].

The MEGHATROPIQUES mission is part of the GPM constellation through the bilateral Implementing Agreement signed between NASA and CNES and NASA and ISRO.



[source: http://pmm.nasa.gov/image-gallery/gpm-constellation]

The current composition of the constellation is the following:

- DPM and GMI compose the GPM Core Observatory
- The Multi-Frequency Microwave Scanning Radiometer (MADRAS) and the multi-channel microwave humidity sounder (SAPHIR) on the Megha-Tropiques satellite provided by the Centre National D'Etudes Spatiales (CNES) of France and the Indian Space Research Organisation (ISRO)
- Special Sensor Microwave Imager/Sounder (SSMIS) instruments on U.S. Defense Meteorological Satellite Program (DMSP) satellites
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- The Advanced Microwave Scanning Radiometer-2 (AMSR-2) on JAXA's Global Change Observation Mission - Water 1 (GCOM-W1) satellite
- The Microwave Humidity Sounder (MHS) instrument on the National Oceanic and Atmospheric Administration (NOAA)-19 satellite
- MHS instruments on the MetOp series of satellites launched by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)
- The Advanced Technology Microwave Sounder (ATMS) instruments on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP)
- ATMS instruments on the upcoming NOAA-NASA Joint Polar Satellite System (JPSS) satellites
- A microwave imager planned for the Defense Weather Satellite System (DWSS)

3.3 MEGHATROPIQUES IN THE GPM CONSTELLATION

Megha-tropiques mission combines the benefit from an original orbit to a unique suite of payloads. The following assets are extracted from a paper by Remy Roca et al. "*The Megha-Tropiques mission: a review after three years of orbit*", Frontiers In Earth Science, May 2015[1].

Its low inclination orbit and high altitude of flight greatly enhance the sampling of the tropical regions by the on-board instruments compared to typical low earth observing platforms. Megha-Tropiques (MT) flies a unique suite of payloads related to the elements of both the water and energy cycles in support of four main scientific objectives.

The MADRAS (Microwave Analysis and Detection of Rain and Atmospheric Structures) is a conical-scanning passive microwave imager primarily designed for cloud properties characterization and precipitation retrieval. Its channels are distributed optimally (18.7, 23.8, 36.5, 89.0, 157.0 GHz) to perform such retrievals over both land and ocean surfaces. Similar in concept to the previous generation of such instruments (SSMI, TMI), MADRAS has a number of specificities that arise from the MT objectives.
First, the 18.7, 23.8 and 36.5 GHz channels share a common (same feed-horn) spatial resolution in order to offer the best radiometric sensitivity possible (Table 1). Second, the 89 GHz channel pixels are overlapping by 10% in the along-track direction in order to offer a continuous coverage.

The Sounder for Atmospheric Profiling of Humidity in the Intertropics by Radiometry (SAPHIR) radiometer is operating along the scan yield a pixel size of 14.5 × 22.7 km on the edges of the swath (Figure 3). The addition of three channels located closer to the absorption line and on its edge compared to operational 183 GHz radiometers like AMSU-B and MHS, improves the estimation of the relative humidity of the upper part of the troposphere and in its lowest layers.

The combination of SAPHIR and MADRAS observations, mainly through the 23.8 GHz and the 157 GHz channels brings additional information on the total water vapor content of the column and on the water vapor continuum that also improves the documentation of the humidity profile

ScaRaB (Scanner for Radiation Budget) is a four channel cross-track scanning radiometer. It is designed to determine the longwave (LW) and shortwave (SW) TOA instantaneous outgoing fluxes with an accuracy of 1% in the LW and 2% in the SW. Channels 2 and 3 are the broadband (BB) channels. The general concept of the instrument remains unchanged and is based on the two previous ScaRaB model flown on Meteor and Resurs satellites in 1994 and 1998, but most of the components (detectors, optics, mechanisms and electronics) have been updated.

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[1] Roca R, Brogniez H, Chambon P, Chomette O, Cloché S, Gosset ME, Mahfouf J-F, Raberanto P and Viltard N (2015) *The Megha-Tropiques mission: a review after three years in orbit*. Front. Earth Sci. 3:17. doi: 10.3389/feart.2015.00017

Figure 1 shows SAPHIR and MADRAS spectral bands compared to those of MHS (Microwave Humidity Sounder, a NASA/JAXA satellite) and AMSU-A (Advanced Microwave Sounding Unit-A). All spectral bands are related to water vapor and oxygen opacity spectrums.

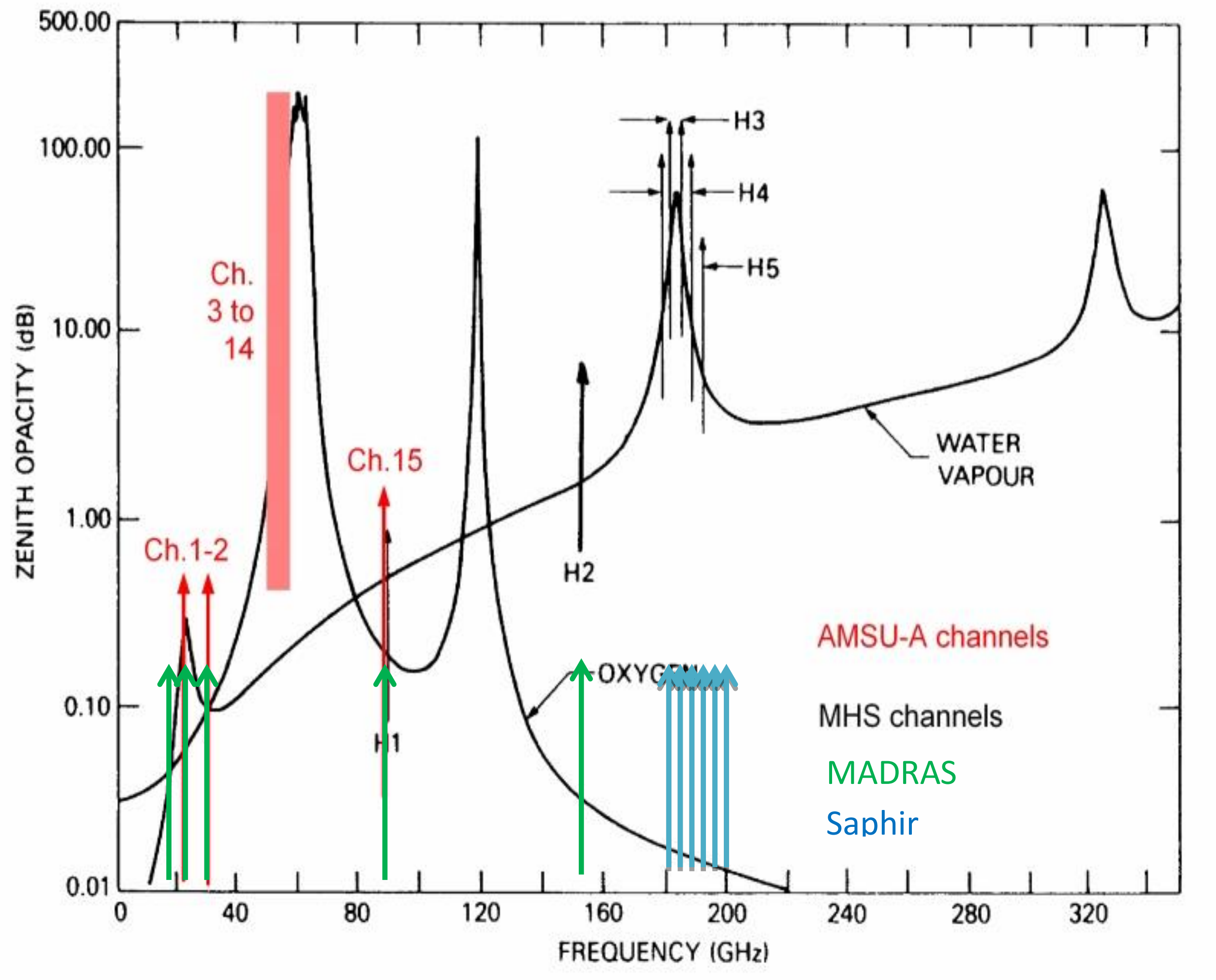


Figure 1 : Position of MADRAS and SAPHIR channels compared to position of AMSU-A and MHS ones.

3.4 MEGHA-TROPIQUES MISSION

Megha-Tropiques is a space mission to study the convective systems of the atmosphere and especially the analysis of the water cycle through the transmission and distribution of steam, lifecycle systems convective and energy exchanges in the equatorial belt. Tropical areas are where the most important energy exchanges appear: radiative exchange, latent heat exchanges, transport and energy components through dynamic processes. The challenge is to increase knowledge of water and energy processes in the tropics and their influence on the global circulation of the atmosphere, the oceans and climate variations. Although the main objectives of the development of a tropical database is to participate in the study of climate predictions, climate and validation weather patterns in tropical areas, the mission will also provide data relevant to the understanding of climate of the whole Earth where the climate is influenced by the tropical process.

3.4.1 MeghaTropiques Scientific Goals

The scientific objectives were divided into three classes:

- The collection of long-term measures with good temporal distribution and good coverage of tropical latitudes to better understand the processes related to large tropical convective systems and their life cycle.
- The improvement in the determination of water masses and amounts of energy at different spatial and temporal scales.

Obtaining meaningful statistics on the conditions in which the convective systems are formed and evolve, by analyzing their interaction with atmospheric circulation, the study of annual and seasonal and diurnal cycle of these systems. This will allow scientists to refine the weather and climate models and integrate data on convective systems in weather prediction models.

The ambition of the Megha-Tropiques mission is to achieve significant advances in understanding the effects of these convective systems over the tropical climate and increase our ability to predict at different spatial and temporal scales.

3.4.2 Applied objectives

The objective is to to provide data about the processes leading to dramatic weather events affecting the Tropical countries, as hurricanes, systems producing heavy rainfalls, processes governing monsoons variability or droughts.

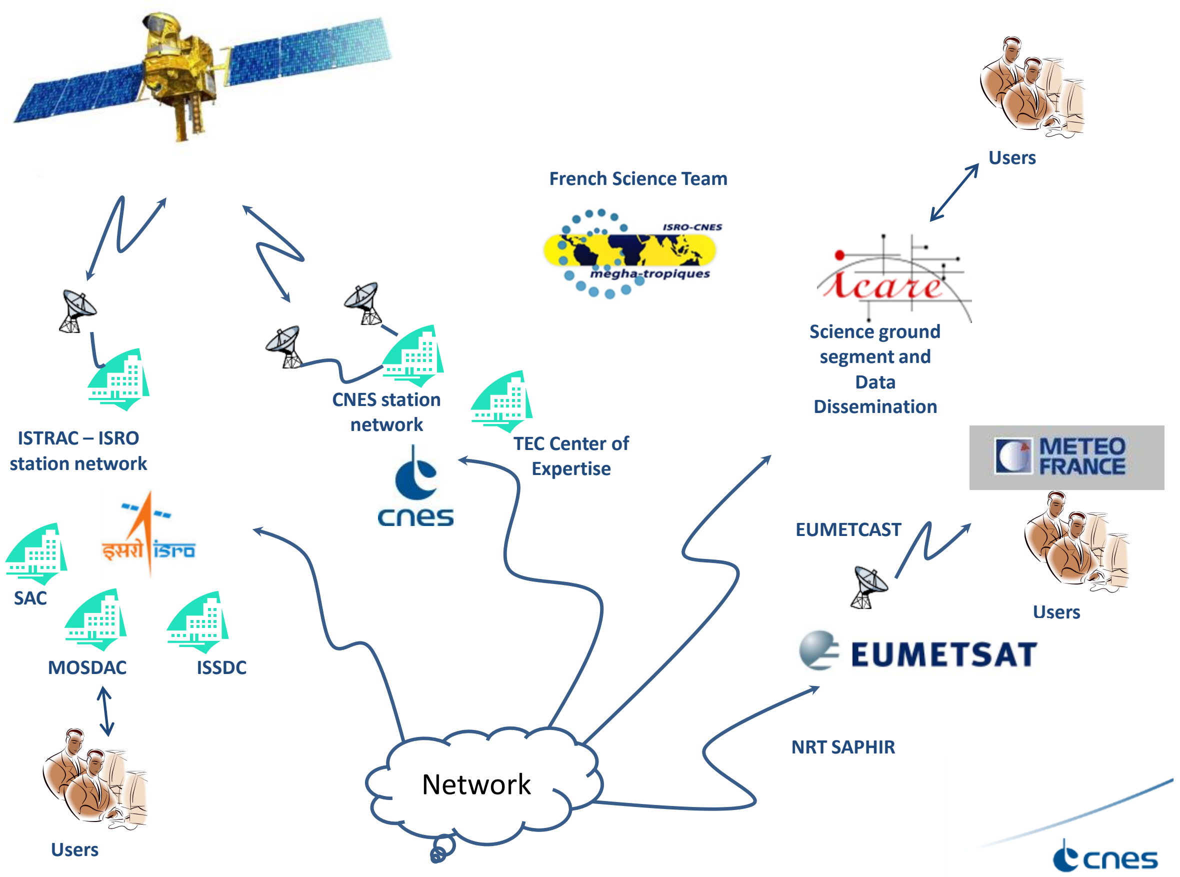
3.4.3 Mission Scenario

The key of this mission is the repetitively of the measurement in the Tropics. The orbit of the platform must be in a low inclination on the equatorial plane. The altitude of the orbit has to be high enough to allow a wide swath of the instruments.

3.4.4 Geophysical parameters to be retrieved:

Atmospheric water cycle elements: Water vapor (integrated and vertical distribution), cloud condensed water content, ice/water, precipitation.

3.5 MEGHA-TROPIQUES INVOLVED ENTITIES



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The ground segment Megha-Tropiques is complex and extensive. It consists of an aggregate of ground segment having also another function.
Data are collected by a network of three stations: Bangalore (ISRO), Kourou (CNES), and Hartbeesthoek (CNES).
ISRO is responsible for the mission center, located in Bangalore, which manages and processes the raw satellite data to level 1 and makes them available.
Scientist's treatment level above N1 products are made and distributed independently in India (MOSDAC) and France (CGTD ICARE).
The CGTD ICARE is responsible for the dissemination of N1 and production / distribution N2 and N4 on the basis of scientific codes.
The SAPHIR NRT data (N1 DUMP) produced in less than 3 hours are distributed by EUMETSAT via EUMETCast to Meteorological agencies.
CNES meanwhile manages the programming of the stations on the one hand (SER Operations and Supports for CNES Resorts Sol Networks) and ensures followed him SAPHIR SCARAB and control

instruments and instrument performance through the levels 0 and 1 (Completeness, data quality ...) (Technical Expertise Centre Megha-Tropiques).
The backbone for transfers of data is dedicating a network with multiple links between ISRO CNES and EUMETSAT CGTD ICARE. These are links of 2 Mbps with optimization and compression to achieve up to 8 Mbps. CNES is also responsible for managing the data network.

3.6 SATELLITE DESCRIPTION

3.6.1 Satellite Characteristics

The Megha-Tropiques system is composed by:

- A mini-satellite developed by France and India. This satellite is composed by:
- A platform derived by the IRS Indian platform with 4 payloads:
- MADRAS, developed by CNES and ISRO
- SAPHIR, developed by CNES
- SCARAB, developed by CNES
- A radio-occultation GPS receiver, provided by ISRO

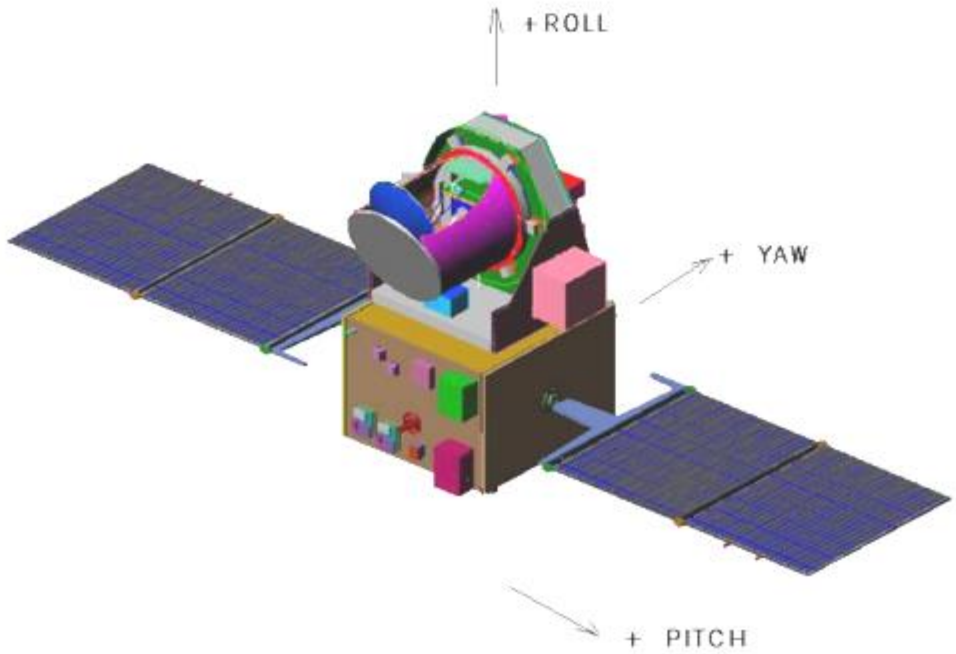


Figure 2 : General view of the MeghaTropiques Satellite.

This mission is an experimental mission without plan for operational follow-up. In order to be able to study time scales from the scale of the large convective events to inter-annual variations, the duration of the mission should be 5 years. Figure 2 is an illustration of the MGT satellite; on the upper side of the satellite we can see MADRAS horn (violet) with a mirror presented in blue. SAPHIR is on the back of the satellite body and we can see a little part of it in red behind MADRAS. ScaRab is next to SAPHIR and not visible on this image.

3.6.1.1 Sampling, orbit, swath

As said above, the key of this mission is the repetitivity of the measurement in the Tropics. One has to combine the choice of the inclination of the orbit, the scanning capability of the instruments and the height of the orbit. The limitation of the swath is determined mainly by the microwave imager, which has a conical swath. Simulations have shown that it was possible to obtain a repetitivity of more than 3.5 visibilities per day of each point of the zone situated between 22°S and 22°N for an orbit inclination of 20° at 866-km height. The repetitivity reaches more than 5 per day around 13°N and 13°S.

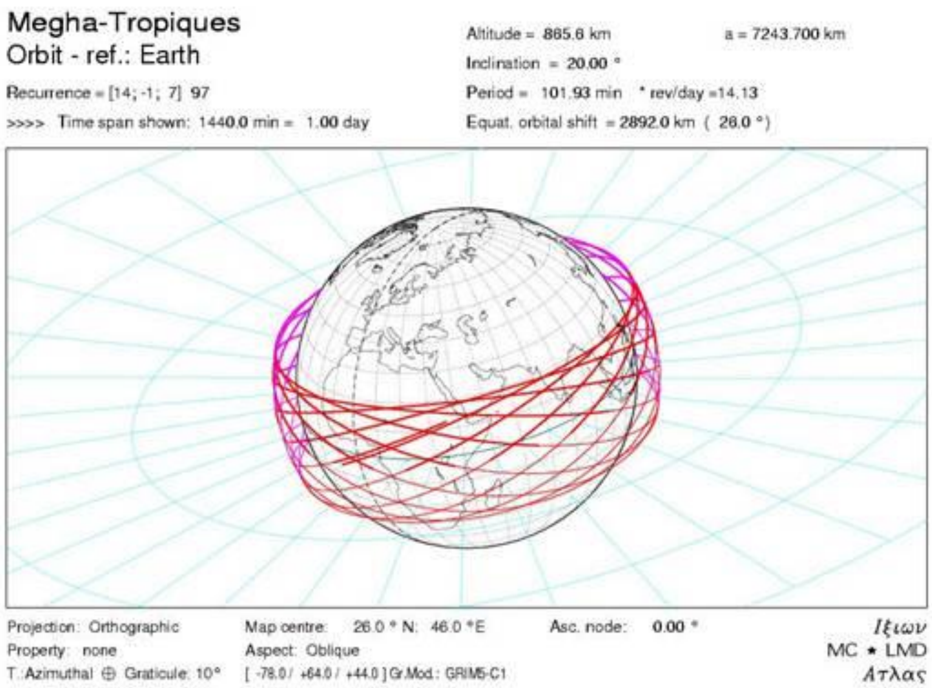


Figure 3 : Megha-Tropiques orbit for a 1-day period.

Megha-Tropiques (MGT) is a LEO satellite, with circular orbit, with the following characteristics:

- Semi-major axis a = 7243.679 km
- Altitude h = 866 km
- Recurrent cycle: 7 days
- 97 revolutions in the cycle (6.87 d)
- Grid interval: 3.711° or 413 km
- The precession cycle is short : 51 days

The originality of the MT orbit is its inclination of 20 degrees. Other particular point, resulting of the 20-degree inclination: for the latitudes between 10° and 25° (North and South), the temporal sampling is represented:

- by a « pack » of overpasses
- followed by a « lack » (without overpass)

3.6.1.2 Space resolution, geometry of observation:

The space resolution should be adapted to the scale of the main objects studied, the large convective complexes of the Tropical areas. The requirements do not call for resolution of individual convective cells, which can be smaller than 10 km in horizontal extent. A resolution of 10 km is estimated sufficient for localizing the active convective parts of the systems with the microwave imager. It also appears reasonable obtaining clear enough air measurements, between the clouds, with the humidity-profiling instrument. A still lower resolution (40 km) appears acceptable for the determination of other parameters: liquid water content, radiative budget components at Top of the Atmosphere. The geometry of observation has to be conical scanning for the microwave imager, as the incidence has to be constant in order to use the polarization information. For the other instruments (sounder and radiative budget), a cross track scanning is acceptable. The general Geometry of scanning of the three instruments of the mission is represented on Figure 4.

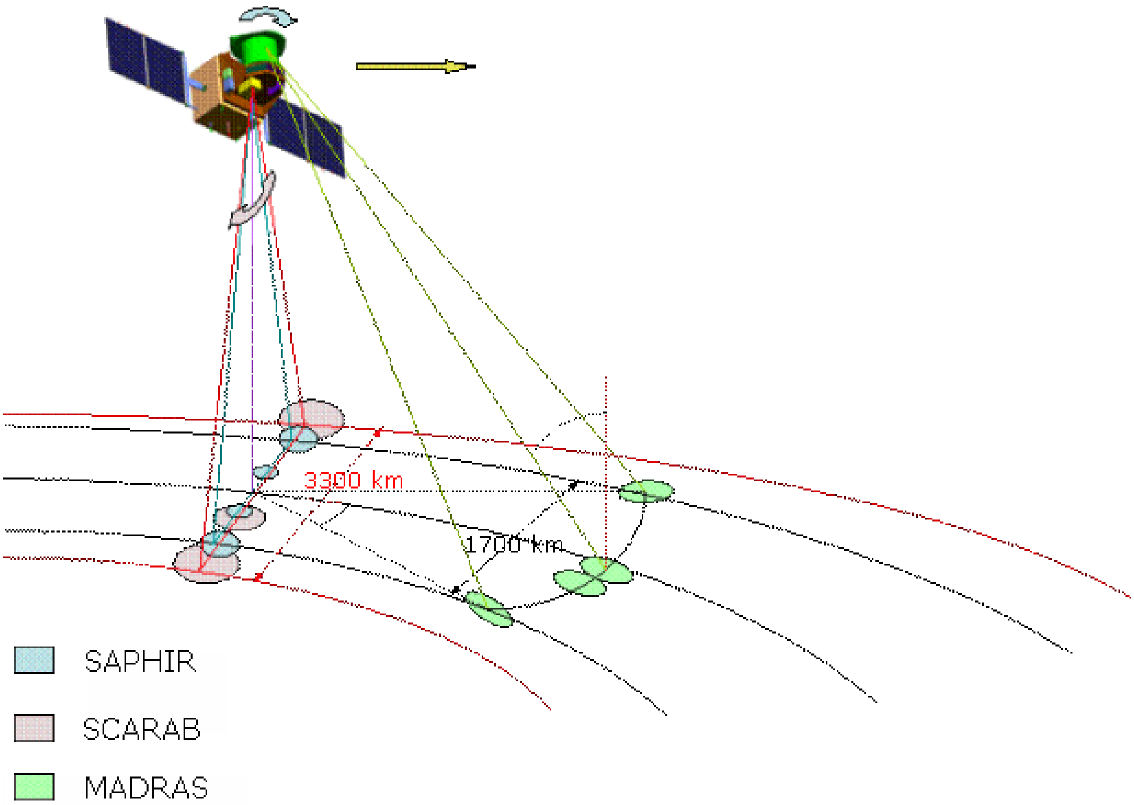


Figure 4 : General configuration of the swath of the three instruments of MeghaTropiques. Size of the footprints has been enhanced in order to show their geometric behavior

3.6.1.3 Satellite modes

Satellite is required to flip around yaw axis by 180° in order to avoid sun entry in some platform equipment, typically a few times per year. Duration of a maneuver is approximately 20 minutes.

3.6.1.4 Scanning Direction

The MADRAS instrument scanning direction is anti-clockwise around yaw direction as observed from "–Yaw "SAPHIR and SCARAB instruments scanning from "+Pitch" to "+Yaw" as observed from "+Roll". The sequence in which samples will be acquired depends on flip status and scan direction. The imaging geometry is termed as forward or backward as explained in Figure 5 for MADRAS payload and in Figure 6 for SCARAB & SAPHIR payloads.

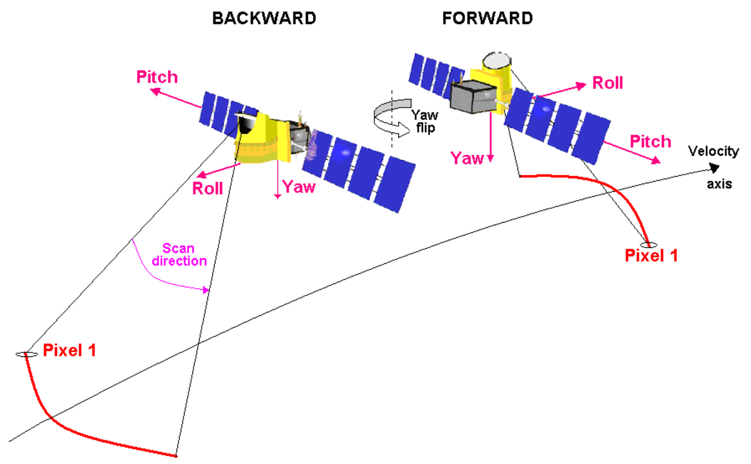


Figure 5 : MADRAS scans line geometry: forward and backward definition

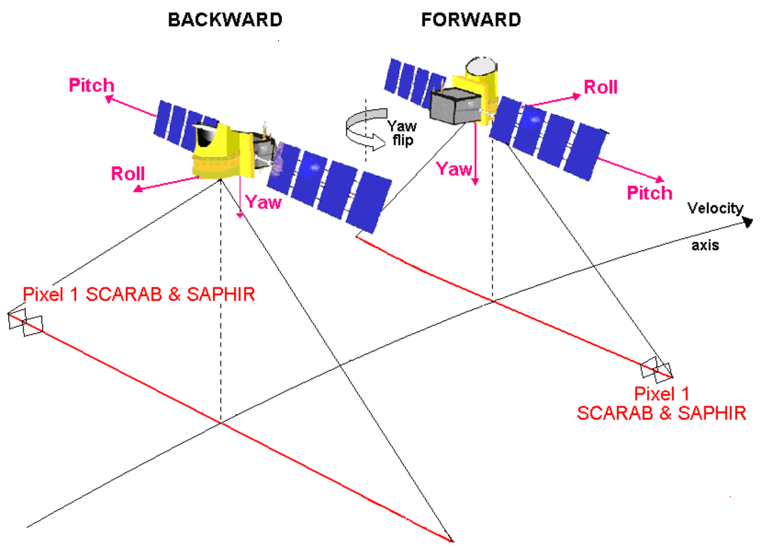


Figure 6 : SAPHIR and SCARAB scan line geometry: forward and backward definition

4 SENSORS

4.1 SAPHIR

4.1.1 Characteristics

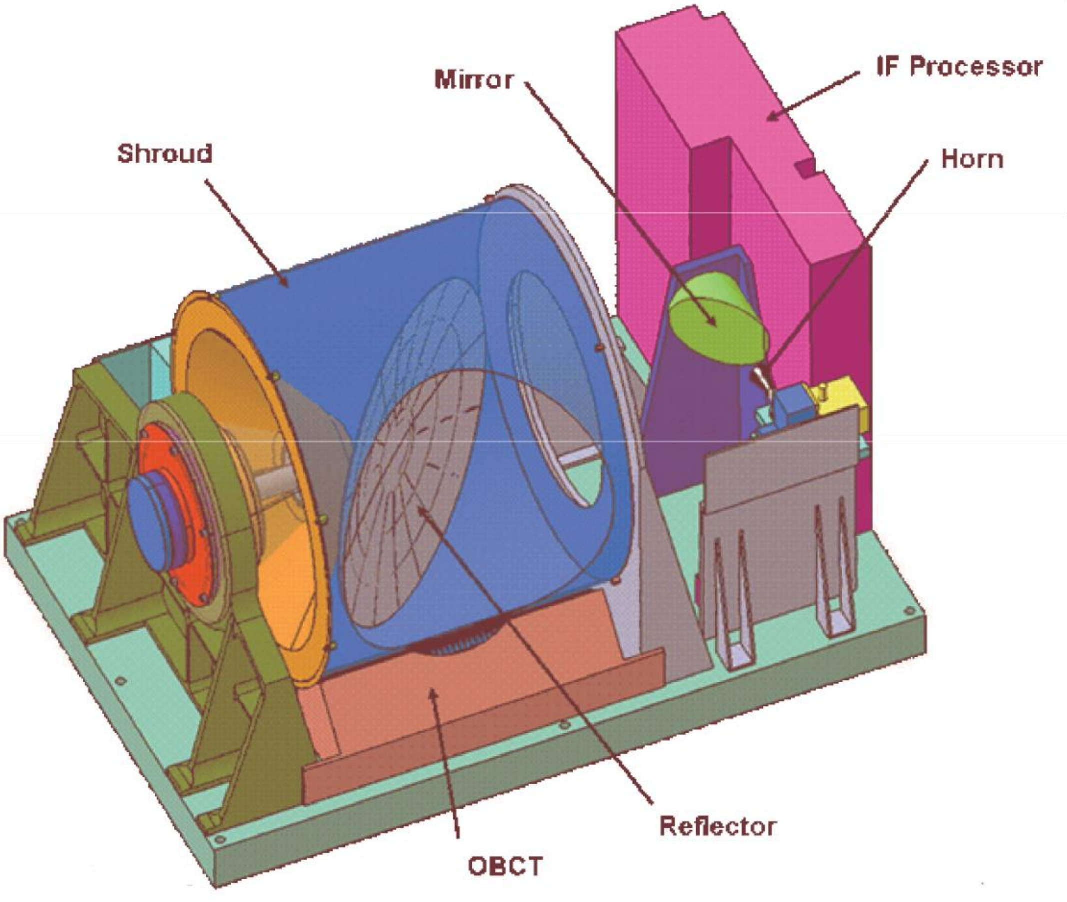


Figure 7 : SAPHIR instrument

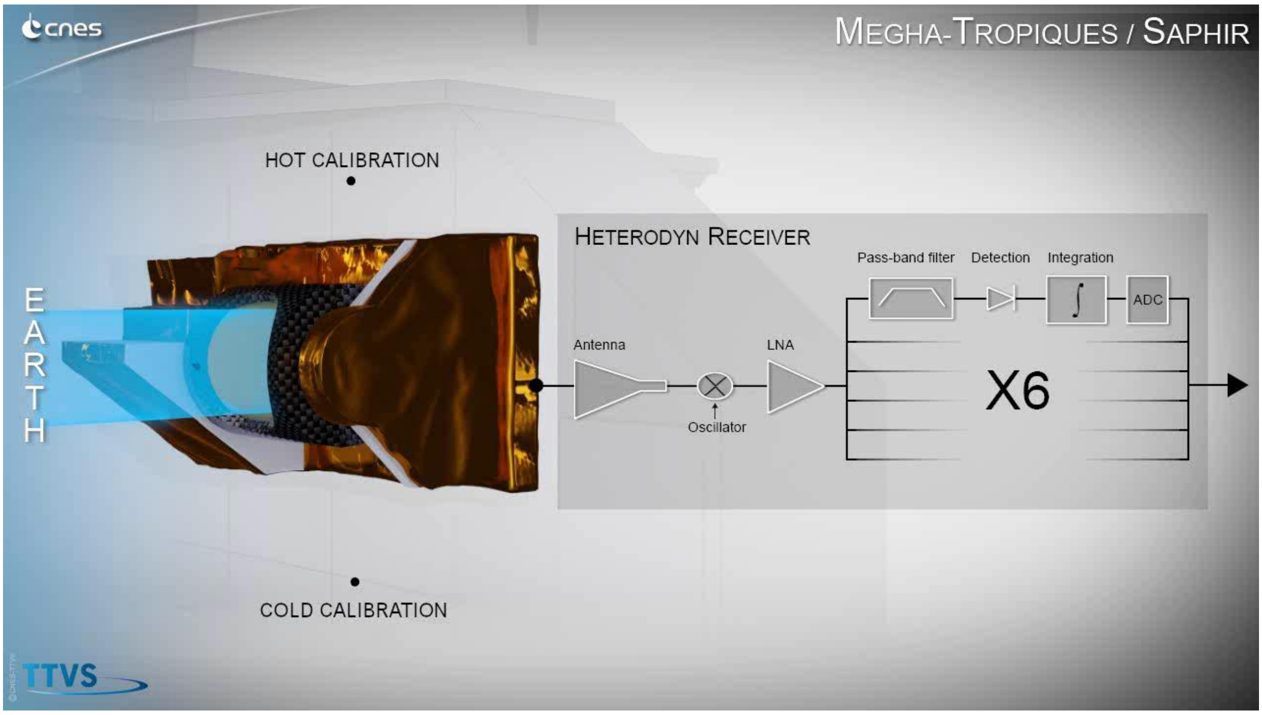


Figure 8 : Schematic SAPHIR instrument illustration

The SAPHIR instrument (see Figure 7 and Figure 8 for instrument illustration) is multi-channel passive microwave humidity sounder. Atmospheric humidity profiles can be obtained by measuring brightness temperatures in different channels situated close to the 183.31 GHz water vapor absorption line.
The channels characteristics are specified in the following table:

Table 1 : SAPHIR Channel definition

Channels	Central nominal frequencies (GHz)	Channels bandwidth
C1	183,31 ± 0,2	200MHz
C2	183,31 ± 1,1	350MHz
C3	183,31 ± 2,8	500MHz
C4	183,31 ± 4,2	700MHz
C5	183,31 ± 6,8	1200MHz
C6	183,31 ± 11	2000MHZ

Next figures (Figure 9 and Figure 10) we plotted all SAPHIR channels for the same 187 orbit, together first (Figure 9) and then each channel projected on earth surface. Small influence of solid surface is clearly visible. Nevertheless contribution of different layers of atmosphere is illustrated with the zoom on the hurricane: each channel shows different shapes which could be related to different atmospheric layers.

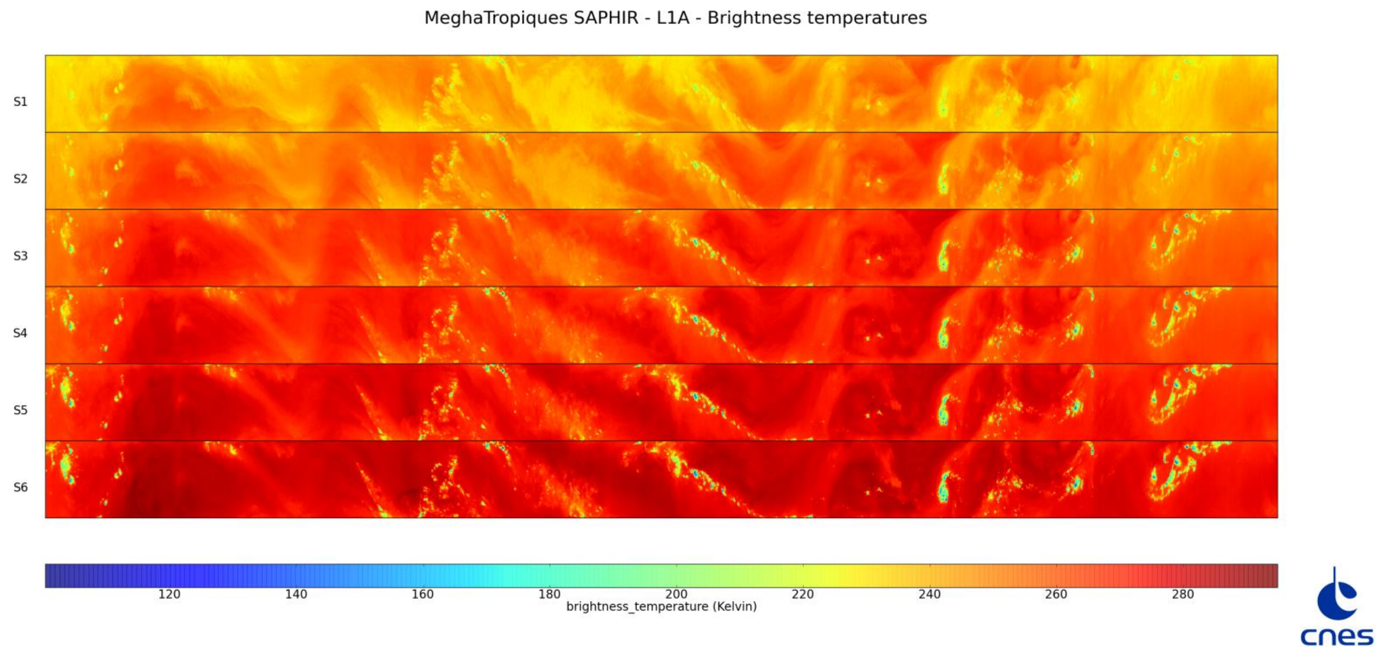
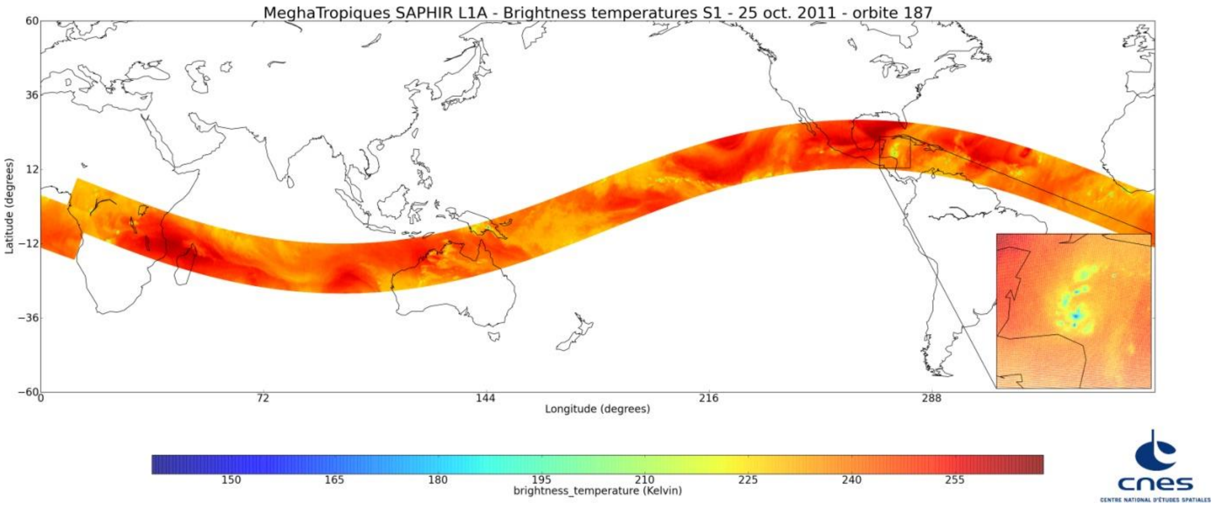
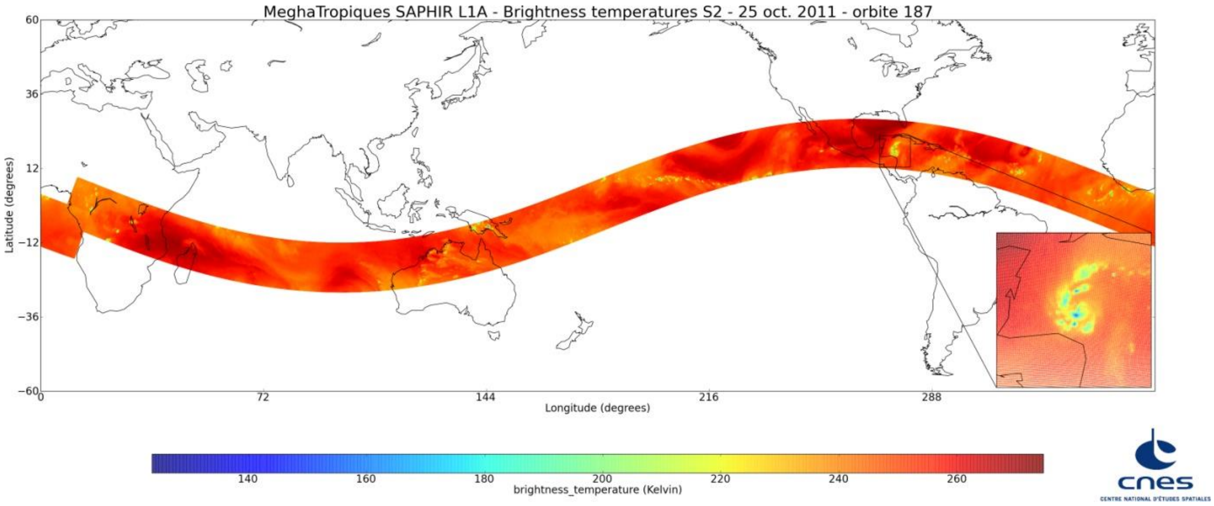


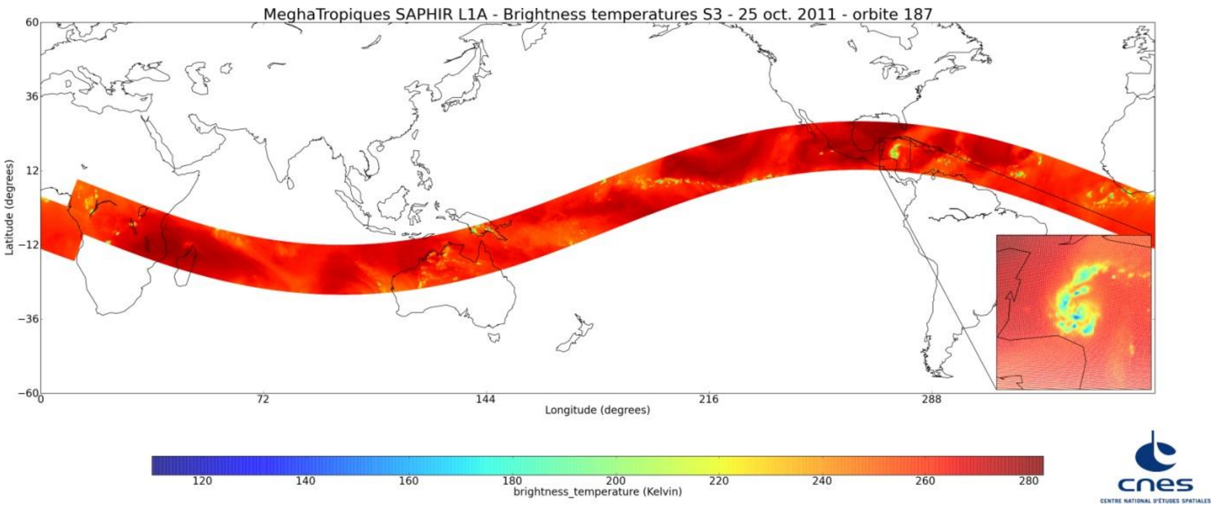
Figure 9 : Illustration of the SAPHIR BT values for the orbit 187. All values for all 6 channels are plotted together, from channel S1 to S6



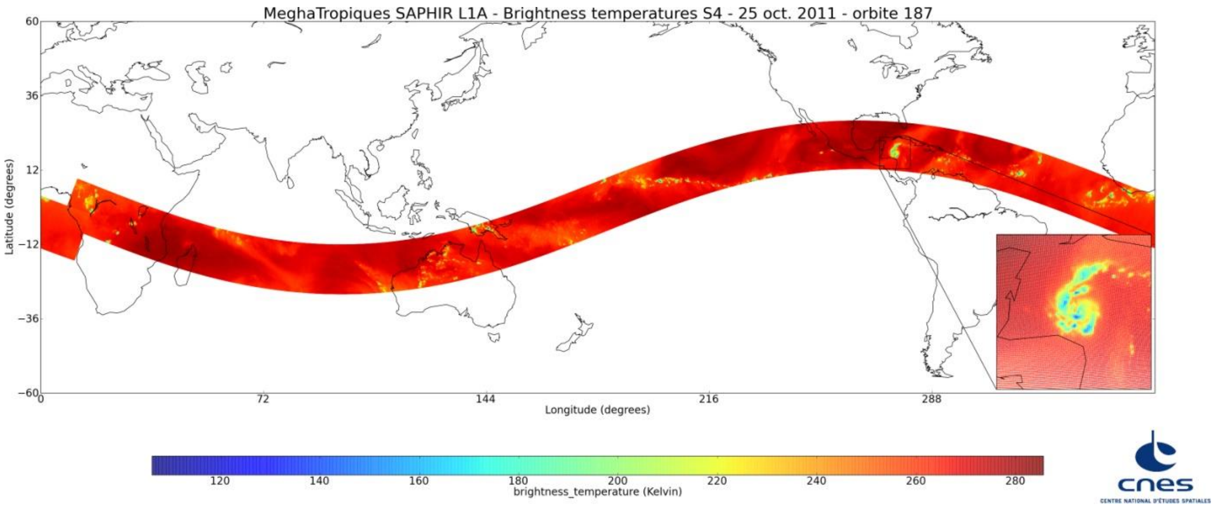
Channel 1 : 183,31 ± 0,2



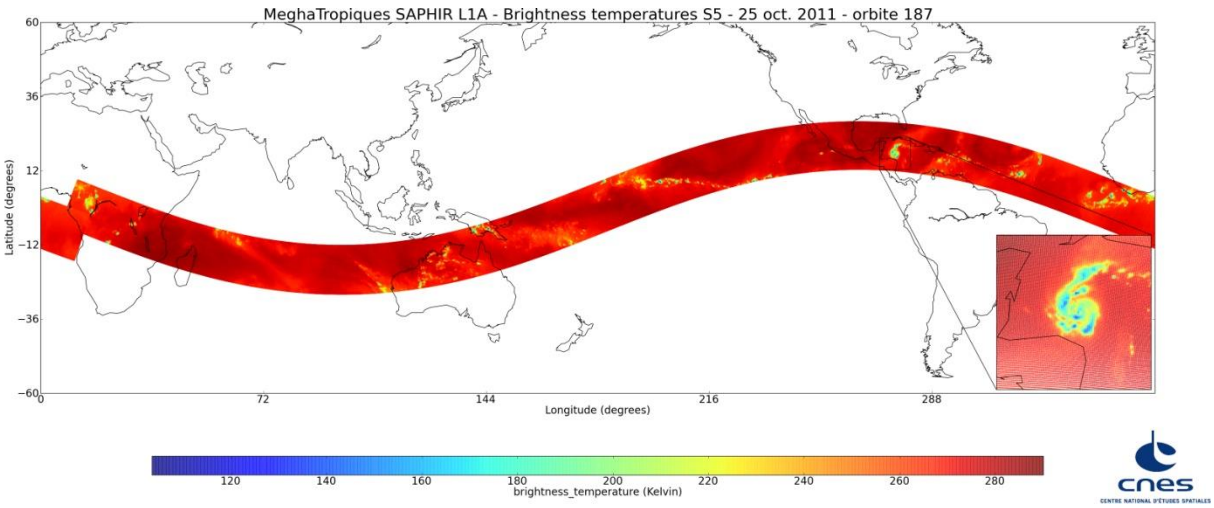
Channel 2 : 183,31 ± 1,1



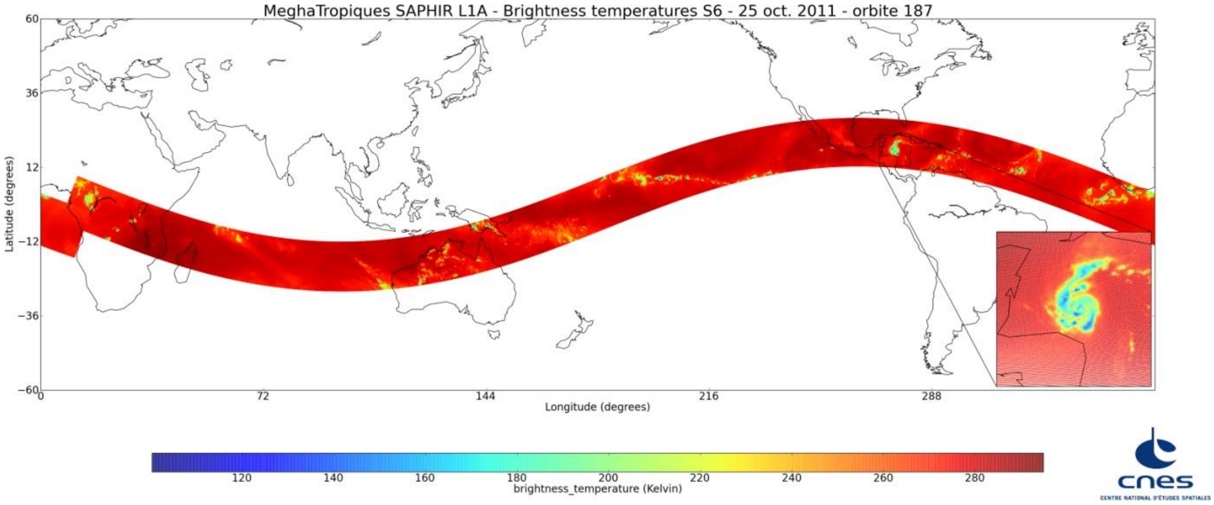
Channel 3 : 183,31 ± 2,8



Channel 4 : 183,31 ± 4,2



Channel 5 : 183,31 ± 6,8



Channel 6 : 183,31 ± 11

Figure 10 : BT projection on earth surface for the orbit 187. All channels are projected

The dynamic range of SAPHIR radiometer brightness temperature is 4K to 313K.
To ensure large swath coverage, the narrow beam of the antenna is performing a Nadir across track scanning when the satellite is moving ahead. The following illustration (Figure 11) shows the imaging geometry.

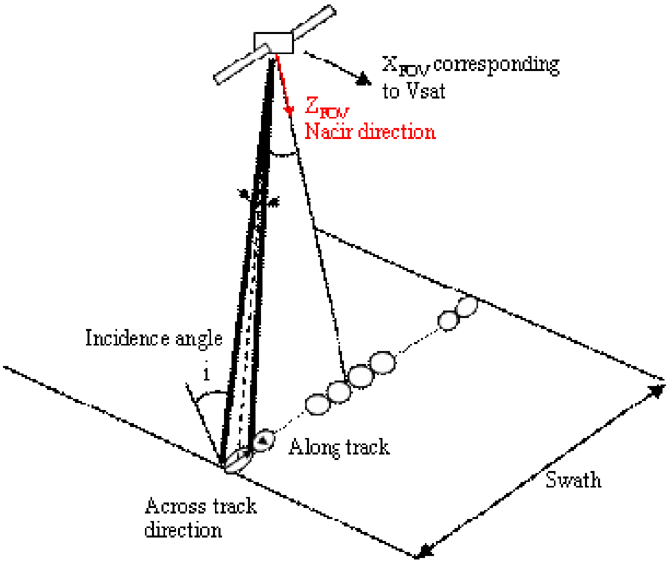


Figure 11 : SAPHIR acquisition geometry

The IFOV (footprint) is defined as the intersection of half power beam-width of the antenna main lobe and the earth surface. Due to the scanning of the antenna beam in the cross-track direction, the shape and the size of the instantaneous footprint change from a circle at Nadir to ellipses of different size over the swath. The basic resolution of 10 km is defined for the Nadir footprint. The rotation speed has been defined to ensure that at Nadir, pixels of two consecutive scan lines are adjacent.

The cold calibration is obtained by the observation of the cold sky. Around 183 GHz, the space temperature is estimated close to 4.75 K. The hot calibration is performed by the use of an internal hot load. The physical temperature of this load will be measured on-board by 7 PRTs (platinum resistance thermometers). During each continuous scan of the earth, the elementary measurements are integrated during regular sampling periods.

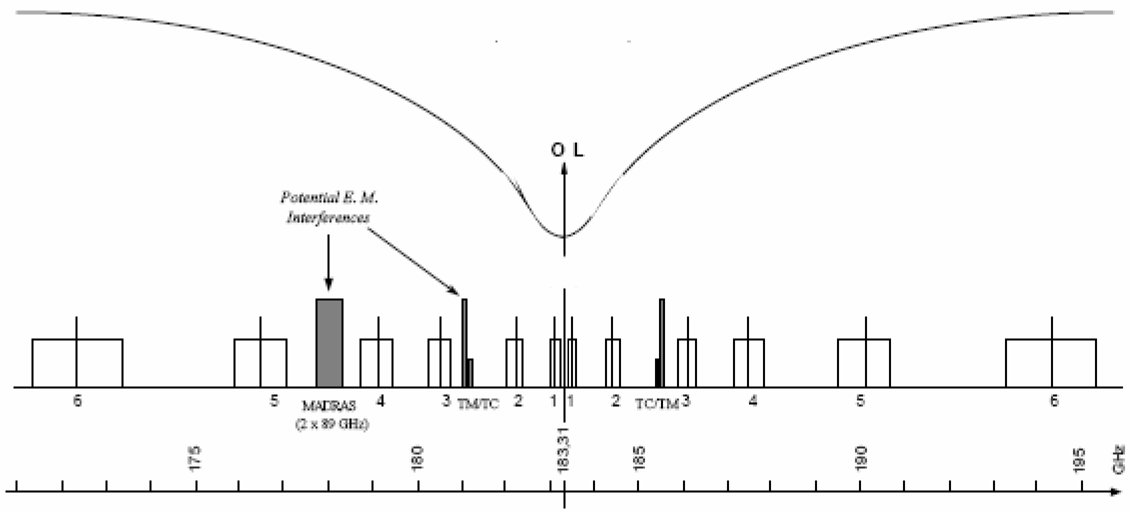


Figure 12 : Location of the 6 SAPHIR channels with respect to the centre of the absorption line. All channels are double band, to increase the radiometric sensitivity. The two polluted bands are indicated.

Table 2: SAPHIR characteristics

Altitude (Hs)	865.864 km
Scan view angle (ε) = θ	∈ [-42.96°, +42.96°]
Spatial resolution	10 km (at nadir)
-3dB bandwidth (α)	0.6616°
Azimuth angle (φ)	90°
Cycle duration	1.638 s [Earth + Cal] / 832.832 ms [Earth]
Duration/angular width for sample integration	4.576 ms / 0.472°
Sample number (level 1)	196 [Total] = 182 [Earth] / 7 [Hot load] / 7 [Cold target]
Pixels number (level 2)	130 [Earth]

The next images (
Figure **13** and
Figure **14**) show the different view angle dependencies of SAPHIR parameters – on these figures we only show half of swath data because of the symmetry of the viewing procedure.
Figure **13** shows the distance to the satellite path of each sample (the 0 index is for the farthest sample from along-track) and the viewing angle of each sample depending also of the along-track distance.
Figure **14** gives samples dimensions depending on FOV position, along-track (left image) and across-track (right image).

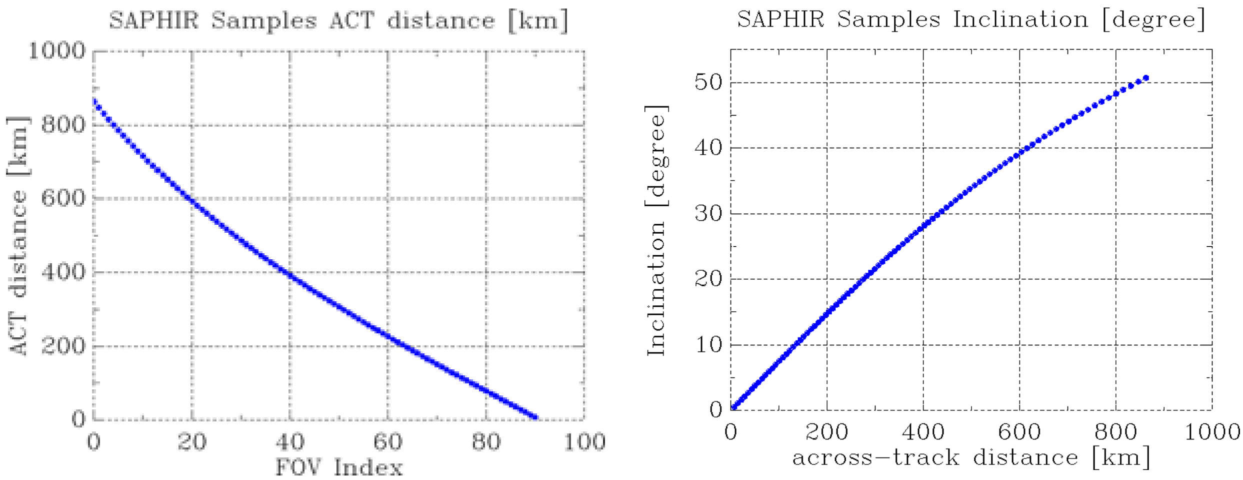


Figure 13: Left image = SAPHIR samples position (ACT, Across-Track Distance) Right image = Incidence of SAPHIR measurements for the center of each sample.

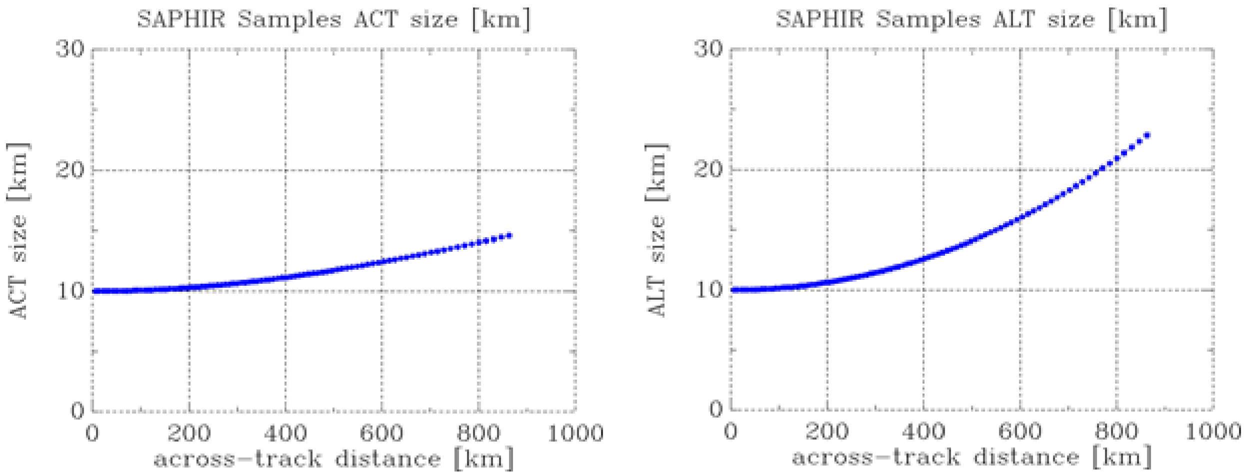


Figure 14: SAPHIR Samples dimension: across-track (left image) and along-track (right image)

4.1.2 Scan mechanism positions

During each scan period, the reflector of the antenna is performing one complete rotation in order to scan in sequence the earth atmosphere, the hot load and the cold sky. So there are several remarkable positions around the revolution circle:

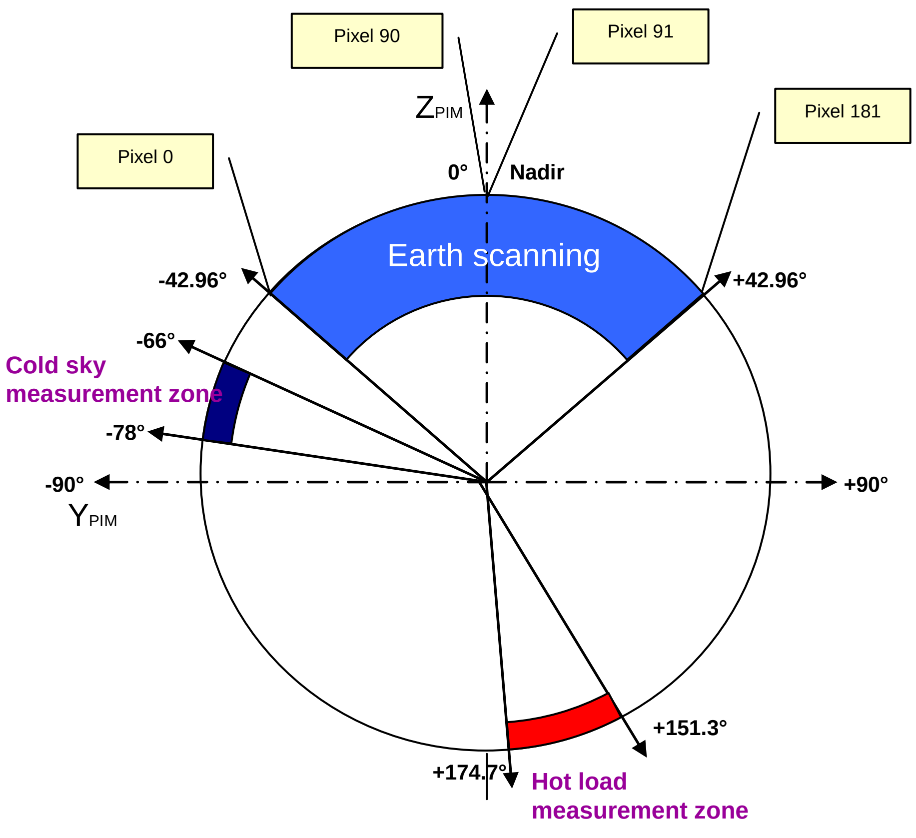


Figure 15: SCAN axis positions

The cold sky and hot load are positions that enables SAPHIR to perform its radiometric calibration. For each calibration, a sample will correspond to the calibration target radiation integrated over the integration time period. The different samples corresponding to the calibration periods of each scan rotation will be acquired and delivered to ground.

Around the position 0, corresponding to the nadir, a 182-pixel row (of the atmosphere) acquisition is performed.

NOTA : angle position for SAPHIR are always counted as positive number. For example, to command the position situated at -127.17°, you have to use -127,17+360 = 232,83°. It is not allowed to use negative number for angles.

4.1.3 SAPHIR pointing

Monitoring of maximal and minimal latitude values (resp Lat_Max and Lat_Min) for L1A SAPHIR data have shown a light dissymmetry between North and South data. The next 3 figures show the daily minimum and maximum latitude values for January 2015 (Fig 16), March 2014 (Fig 17) and more than two Year of Saphir data (Fig 18)

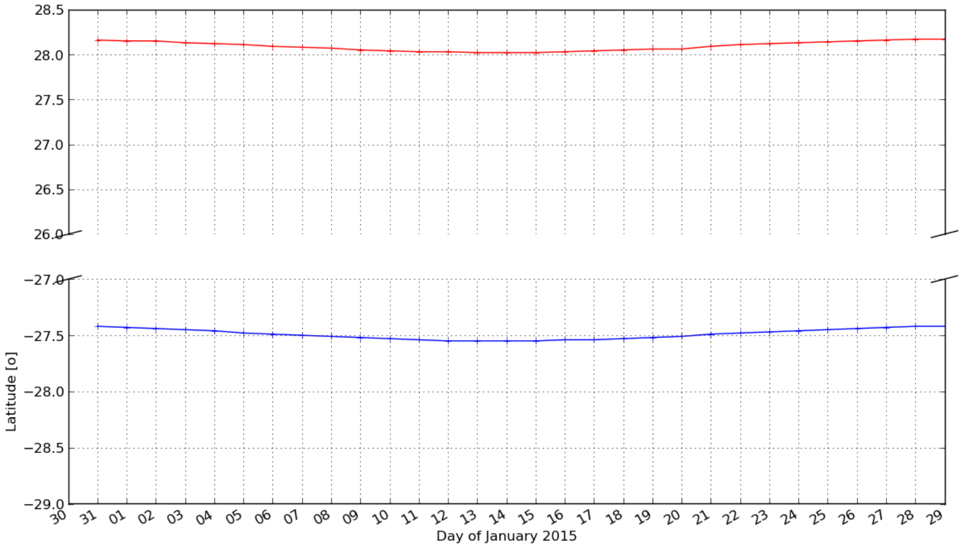


Figure 16: Daily Minimum (blue line) and maximum (red line) latitude values for SAPHIR sample data (L1A level) during January 2015.

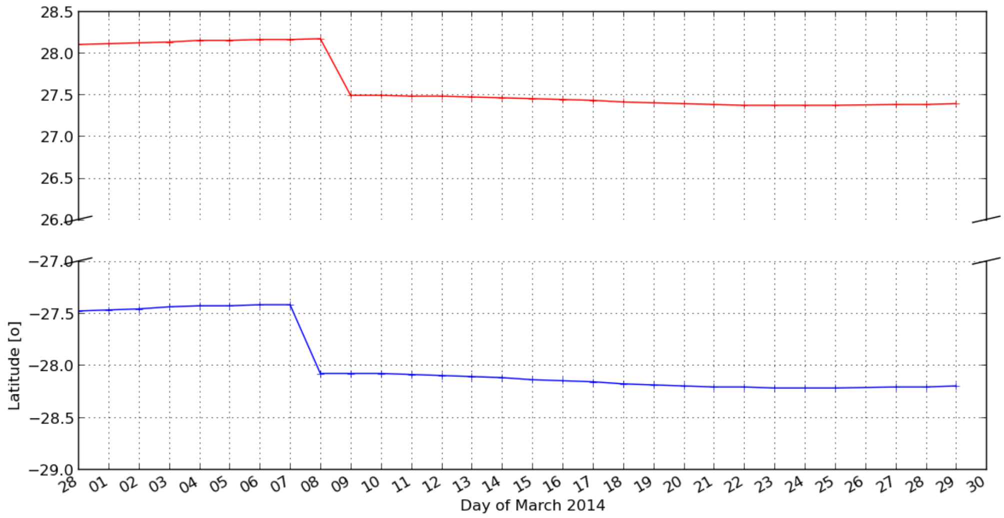


Figure 17 : Daily Minimum (blue line) and maximum (red line) latitude values for SAPHIR sample data (L1A level) during March 2015

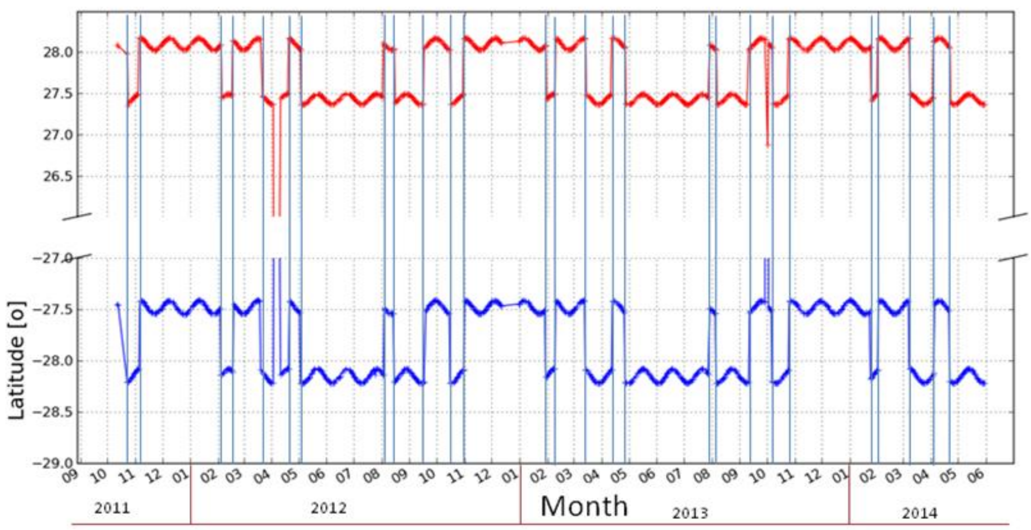


Figure 18: Daily Minimum (blue line) and maximum (red line) latitude values for SAPHIR sample data (L1A level) during 2 years of SAPHIR life. Vertical lines correspond to MGT flip events.

The dissymmetry ABS(Lat_Max) > ABS(Lat_Min) is around 0.7°, a monthly cycle is observed (amplitude around 0.1°) on 3 figures, the sinusoidal aspect appears clearly (figure 18). A large discontinuity is shown on Figure 18 which corresponds to a MGT flip event. At each flip maneuver of the platform the dissymmetry is inverted.

The dissymmetry is the result of the instrument accommodation on board Megha-Tropiques but fully compliant with the specifications. After the accommodation a precise measure was done and a transformation matrix take in account to insure a correct and precise location this point is monitored and explain hereafter.

When compare the position of the pixel at the center of the swath and we compare that position with the satellite nadir we found exactly 1° as it is expected. This coherent with the measurement in clean room and with matrix used by the ground segment. So the pixel are sifted but very well located regarding the location given inside the product.

This dissymmetry does not affect by any means the very good pointing of SAPHIR, as illustrated by the following figure. This latter shows a grid averaging of 5 days of SAPHIR S6 channel L1A TB (0.1° x 0.1°) and the coastal line provided by Hawaii University (http://www.soest.hawaii.edu/pwessel/gshhg/).

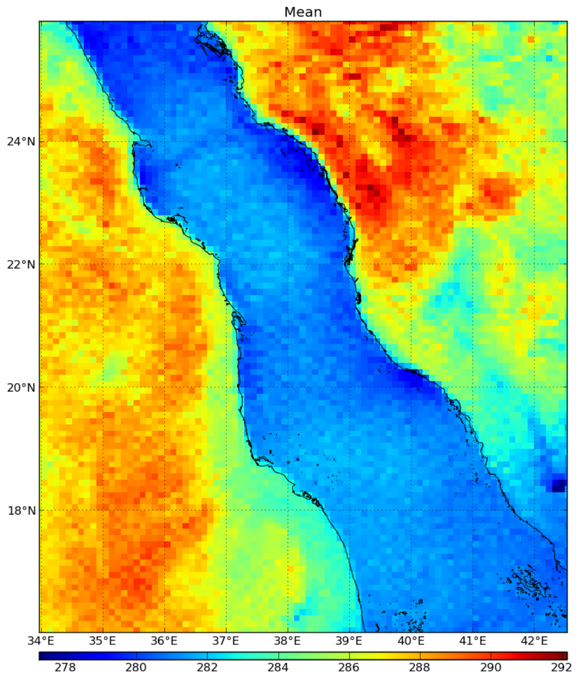


Figure 19: Superposition of SAPHIR (5 days gridded channel 6 data) data and coast lines (black line) above Red Sea.

4.1.4 SAPHIR Modes

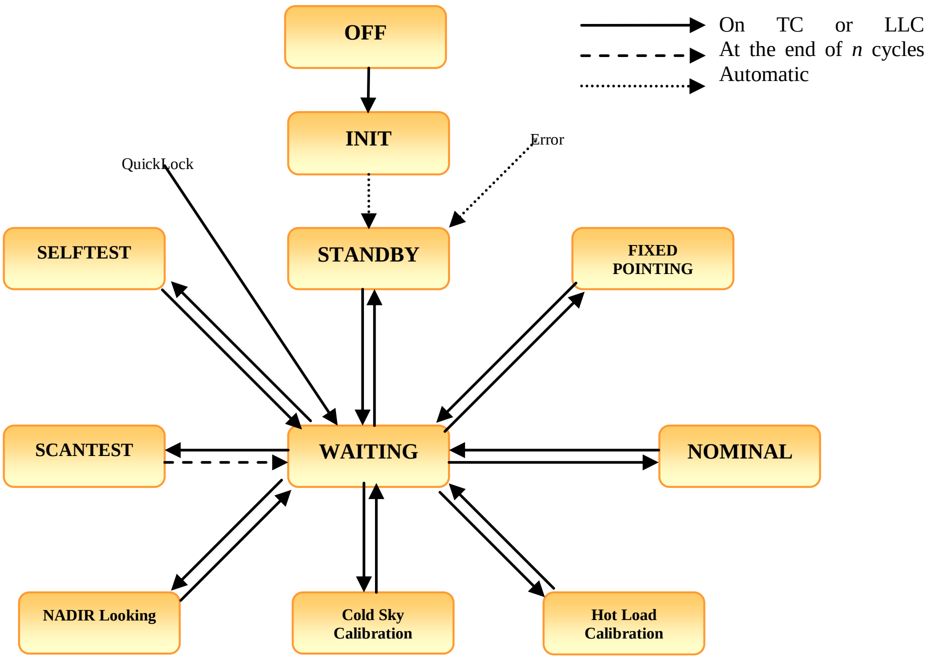


Figure 20: SAPHIR Modes transition graph

These modes are supplemented by support modes:

- DUMP mode (read memory)
- PATCH mode (write memory)

Mode	Scan mechanism status	Transition	Cycle	Number of cycles	Science TM
STANDBY	OFF	None	-	∞	NO
WAITING	Fixed security position	Moving to position	-	∞	NO
NOMINAL	Trajectory Cycle	Reaching speed	1.6s	∞	YES
Cold Space Calibration	Fixed position on cold space	Moving to position	1.6s	∞	YES
Hot Source Calibration	Fixed position on hot source	Moving to position	1.6s	∞	YES
NADIR pointing	Fixed position on nadir	Moving to position	1.6s	∞	YES
SELFTEST	Fixed security position	Moving to position	1.6s	∞	YES

Mode	Scan mechanism status	Transition	Cycle	Number of cycles	Science TM
SCANTEST	Trajectory Cycle	Reaching speed	1.6s	Supplied in the MODE CHANGE TC	YES
FIXED POINTING	Supplied in the MODE CHANGE TC	Moving to position	1.6s	∞	YES

Table 1: SAPHIR modes description

In all the modes, (excepted OFF) the RFU electronics are powered.

4.1.5 Modes description

4.1.5.1 OFF mode

When the unit is switched OFF, the EM does not respond to received TC, either on the 1553 bus or via the spy link. The EM does not transmit any TM.

4.1.5.2 INIT mode (degraded mode)

This mode is entered automatically when the instrument is switched ON by “ON” LLC sent by the platform or after a reset.

The following functions will be operated during this mode:

- Initialisation of the SAPHIR Electronic Module (power lines, TM, 1553 interface, calculator…)
- Instrument units powering
- IFP gain configuration

In this mode, the scan mechanism is not operating.

At the end of the initialisation, there is an automatic transition to “Stand By Mode”.

4.1.5.3 STANDBY mode

The instrument reaches this mode :

- Automatically when the initialisation phase is completed
- When receiving the “Stand-By Mode” TC during the “Waiting mode”
- Automatically when an anomaly occurs in an operational mode

In this mode, the scan mechanism is not active.

The TM/TC interface function is operational: TC processing, generation of monitoring and housekeeping telemetry. The samples acquisition and the scientific telemetry are not active in this mode.

This mode is used in case of major anomaly of SAPHIR instrument.

The duration of this mode is not limited.

4.1.5.4 WAITING Mode

The instrument reaches this mode:

- Automatically when the Scan Test phase is completed
- When receiving the "Waiting mode" TC
- When receiving the "Quick Lock" Low Level Command

In this mode, the configuration of the instrument is the following: the necessary units are powered and the rotor is maintained in "hot load" configuration to protect the Front end system from possible sun illumination.

The TM/TC interface function is operational: TC processing, generation of housekeeping telemetry. The samples acquisition and the scientific telemetry are not active in this mode.

This mode is interrupted when receiving a TC to switch to another mode or when the instrument is switched OFF.

The duration of this mode is not limited.

4.1.5.5 NOMINAL Mode

In nominal mode, the antenna will scan the earth atmosphere according the specified nominal scanning law. The instrument will provide 182 samples of brightness temperature data in different channels as well as 2×7 samples of hot load and cold sky calibration measurements every scan period.

The instrument switches from the "Waiting mode" to this "Nominal mode" when it receives the "Nominal Mode" TC. The instrument leaves this mode when receiving the "Waiting mode" TC or a "Quick Lock" LLC.

The duration of this mode is not limited.

The following functions are fulfilled during this mode:

- Management of the instrument: scanning of the earth atmosphere with a constant speed to perform atmosphere measurements, calibration measurements over the cold sky and the internal hot load, using the specified scanning pattern.
- Acquisition and processing of science and calibration data.
- Processing of TC and generation of housekeeping and science telemetry.

In this mode, the system reach is maximum performance after the first cycle (after 1.638s). For this reason, the data received on the first cycle should not be taken into consideration.

4.1.5.6 NADIR looking mode

The instrument enters this mode from the "Waiting mode" when receiving the "Nadir looking mode" TC. The instrument leaves this mode when receiving the "Waiting mode" TC or a "Quick Lock" LLC.
In this mode, the rotor is maintained in a fixed position corresponding to the antenna beam pointing the Nadir direction. The instrument is not scanning the earth atmosphere in that configuration. This mode is designed for contingency situation, on ground and in orbit.
The following functions are fulfilled during this mode:

- Management of the instrument: the rotor is maintained in a fixed position which is the Nadir direction.
- Acquisition and processing of "Nadir looking" science data.
- Processing of TC and generation of housekeeping and science telemetry

4.1.5.7 Cold sky calibration mode

The instrument enters this mode from the "Waiting mode" when receiving the "Cold Calibration mode" TC. The instrument leaves this mode when receiving the "Waiting mode" TC or a "Quick Lock" LLC.
In this mode, the rotor is maintained in a fixed position corresponding to the antenna beam pointing the Cold sky. This mode will be mainly activated to increase calibration (cold sky) performances and for test during on ground integration phase.

The following functions are fulfilled during this mode:

- Management of the instrument: the rotor is maintained in the fixed position.
- Acquisition and processing of "Cold sky type" science data
- Processing of TC and generation of housekeeping and science telemetry

4.1.5.8 Hot calibration mode

The instrument enters this mode from the "Waiting mode" when receiving the "Hot Calibration mode" TC. The instrument leaves this mode when receiving the "Waiting mode" TC or a "Quick Lock" LLC.
In this mode, the rotor is maintained in a fixed position corresponding to the antenna beam pointing in a fixed direction which is the hot load direction. This mode will be mainly activated to increase (hot load) calibration performances.
The following functions are fulfilled during this mode:

- Management of the instrument: the rotor is maintained in the fixed position
- Acquisition and processing of "Hot load calibration" science data.
- Processing of TC and generation of housekeeping and science telemetry.

4.1.5.9 Selftest mode

The instrument enters this mode from the "Waiting mode" when receiving the "Selftest mode" TC. The instrument leaves this mode when receiving the "Waiting mode" TC or a "Quick Lock" LLC.

This mode is reserved for CNES investigation.

4.1.5.10 Fixed pointing mode

The instrument enters this mode from the "Waiting mode" when receiving the "Fixed Pointing mode" TC. The instrument leaves this mode when receiving the "Waiting mode" TC or a "Quick Lock" LLC.
In this mode, the rotor is maintained in a fixed position corresponding to the antenna beam pointing in a fixed direction. The requested rotor position is included in the TC as a parameter.
The content of science telemetry in this mode is defined in AD2.
The following functions are fulfilled during this mode:

- Management of the instrument: the rotor is maintained in the fixed position defined by the TC.
- Acquisition and processing of science data in "fixed pointing mode".
- Processing of TC and generation of housekeeping and science telemetry.

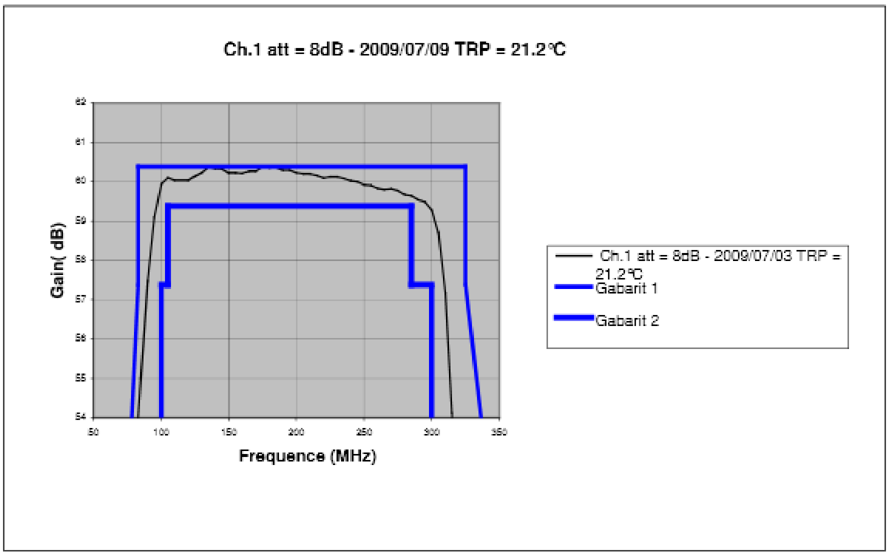
4.1.5.11 Scantest mode

The instrument enters this mode from the "Waiting mode" when receiving the "Scantest mode" TC. The instrument leaves this mode when receiving a "Quick Lock" LLC or automatically at the end of the Scantest phase.

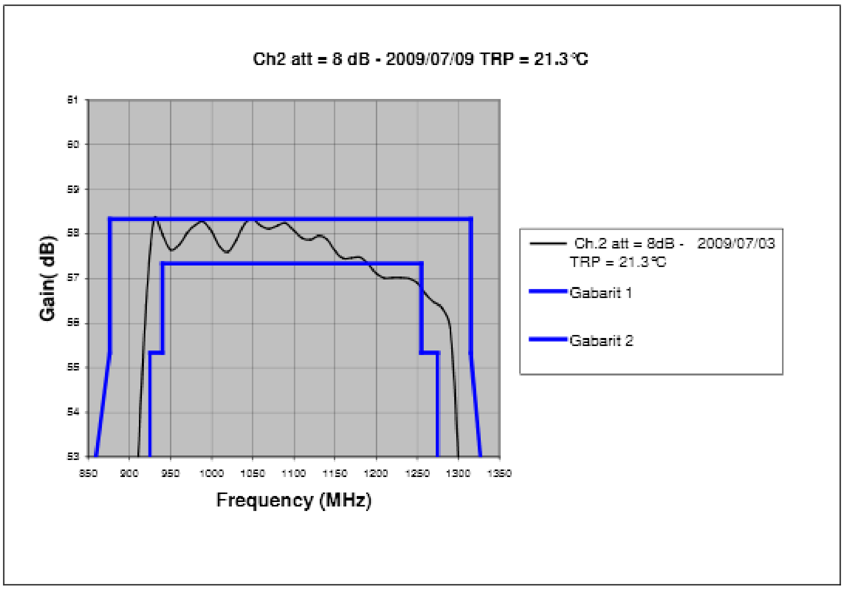
4.1.6 Transfer function for all SAPHIR channels:

In this paragraph all the data given are on ground measurement. Figures are in dB and MHz. The temperature of the filter during the measure is given in the chart. This temperature is very close to on board temperature less than a couple of Celsius degrees of differences.

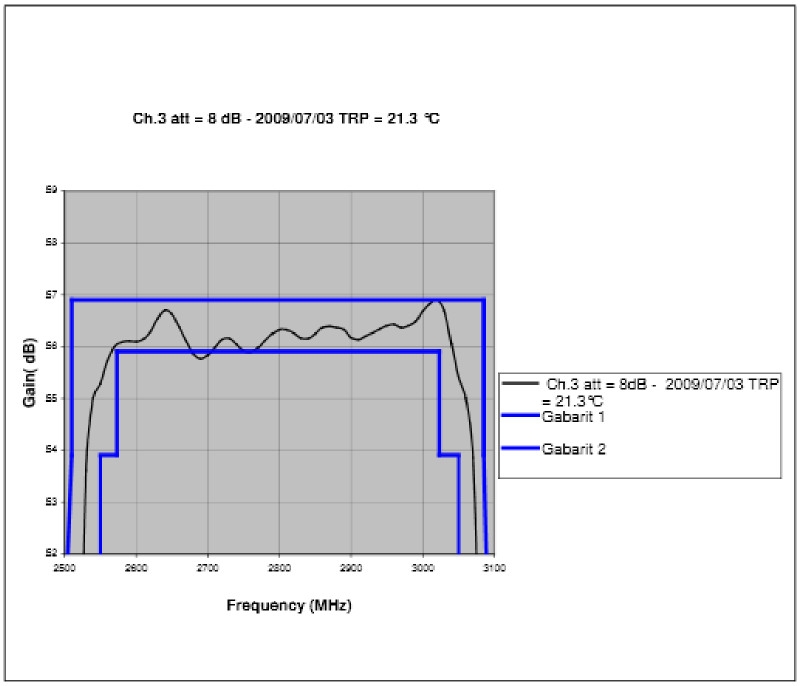
4.1.6.1 SAPHIR channels graphs:



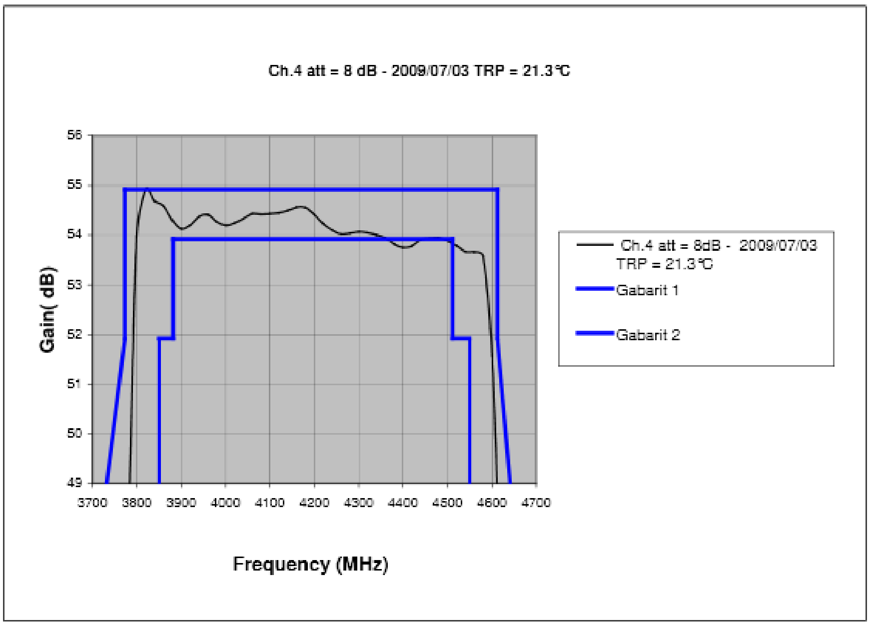
Channel 1 _ -1 dB & -3 dB bandwidth



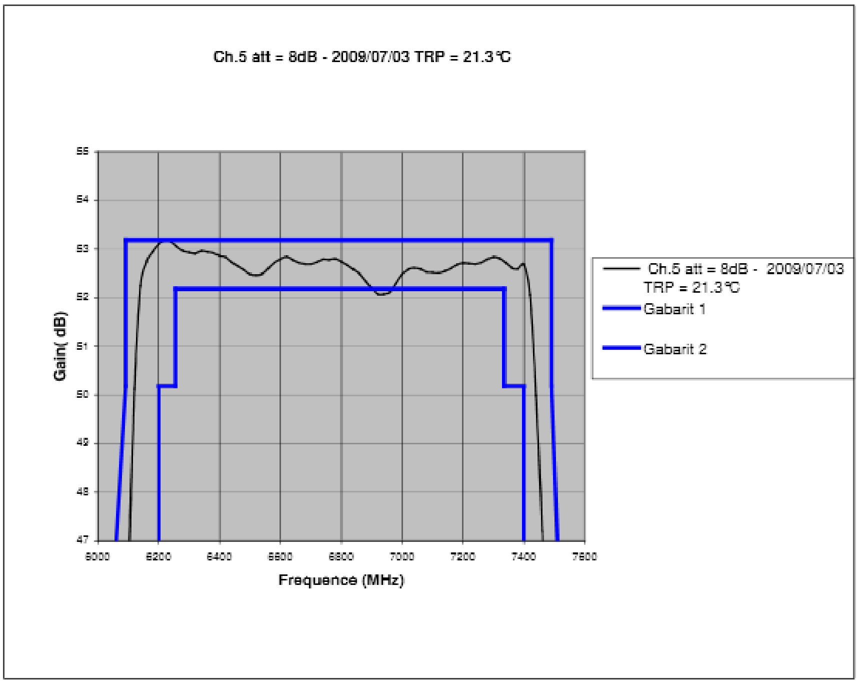
Channel 2 _ -1 dB & -3 dB bandwidth



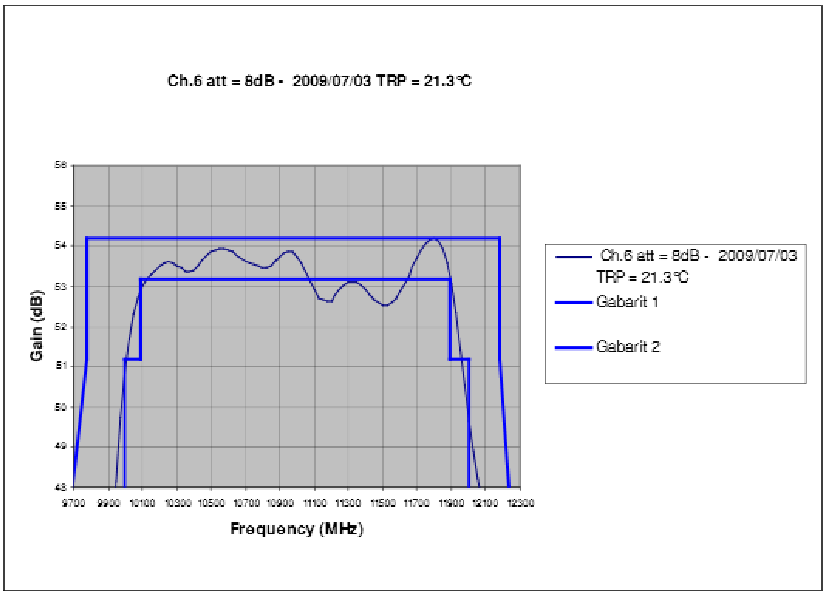
Channel 3 _ -1 dB & -3 dB bandwidth



Channel 4 _ -1 dB & -3 dB bandwidth



Channel 5 _ -1 dB & -3 dB bandwidth



Channel 6 _ -1 dB & -3 dB bandwidth

Figure 21 : SAPHIR Channel transfert function

4.1.6.2 Synthesis table Saphir filters :

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6
Max gain 1dB	60.38dB	58.33dB	56.91dB	54.92dB	53.18dB	54.18dB
Min gain 1dB	59.64dB	56.9dB	55.77dB	53.75dB	52.07dB	52.53dB
Ripple 1 dB Bw	0.74dB	1.43dB	1.14dB	1.17dB	1.11dB	1.65dB

This table give the extreme figures measured during on ground flight model test.

4.2 MADRAS

4.2.1 Characteristics

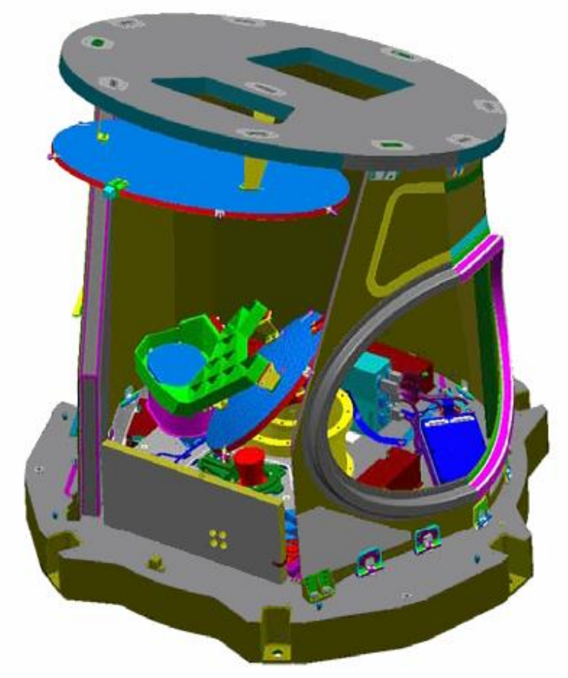


Figure 22 : MADRAS Instrument (MARFEQ for MAdras RF EQuipment)

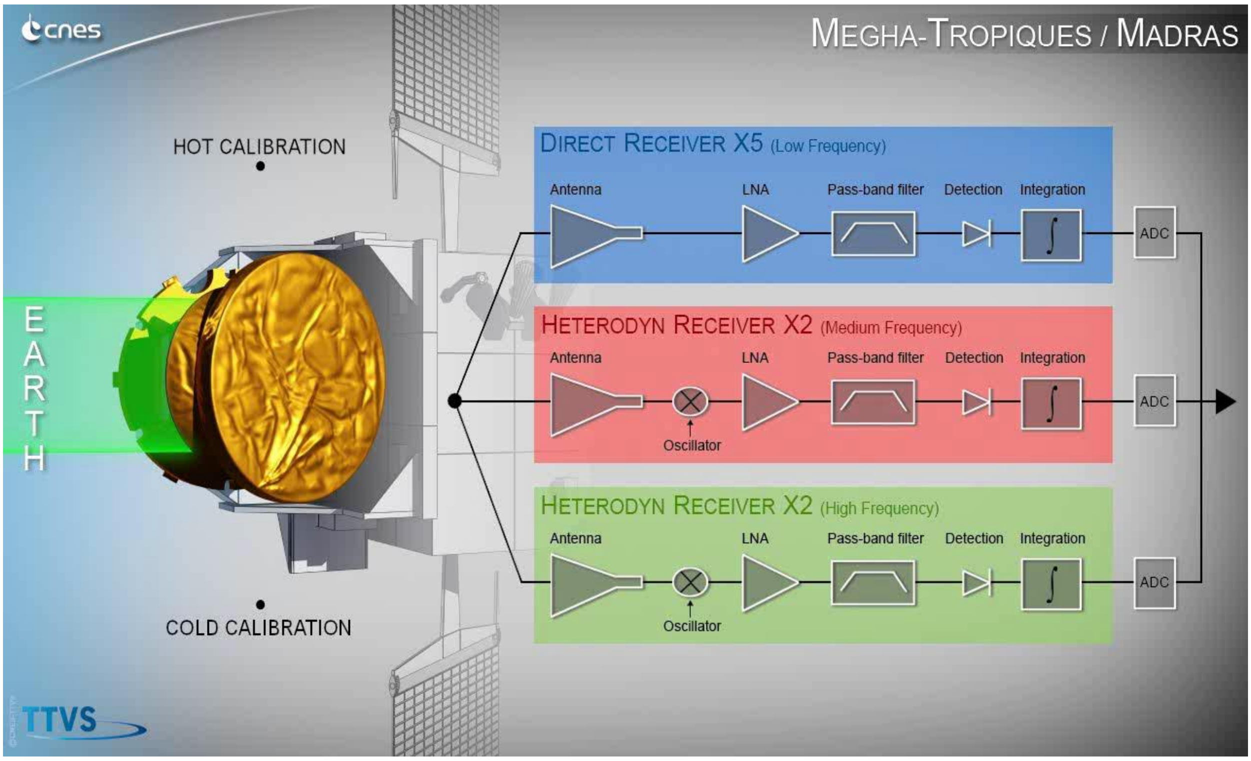


Figure 23: Schematic MADRAS instrument illustration.

MADRAS is a conical scanning radiometer with 9 channels, 5 frequencies in the range 18.7GHZ – 157GHz. The instrument are illustrated in Figure and Figure for mechanical and electronic overviews. The Table 3 gives the definition of the 9 channels with spatial resolution of each of them.

Table 3 : MADRAS channel definition

Channel nb.	Frequencies	Polarisation	Pixel Spatial resolution (km)
M1	18.7 GHz	H + V	40
M2	23.8 GHz	V	40
M3	36.5 GHz	H + V	40
M4	89 GHz	H + V	10
M5	157 GHz	H + V	6

The scene is scanned by rotation of the complete antenna (reflector and horns). The Figure presents the acquisition geometry of MADRAS.

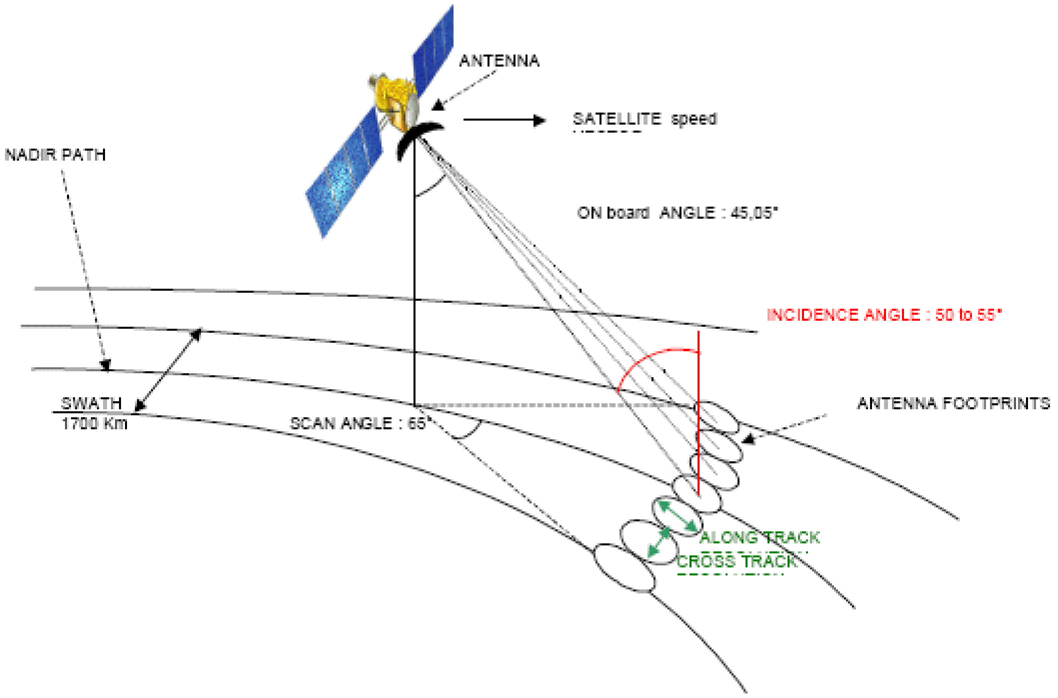


Figure 24 : MADRAS acquisition geometry

Figure clearly shows the high contribution of surface to the collected BT: from channel 18.7 H to 36.5 V the solid earth contrasts with ocean surface.

A projection of each channel above earth is presented in Figure . We focus here (small image at the bottom-right) on a hurricane between Honduras and Cuba.

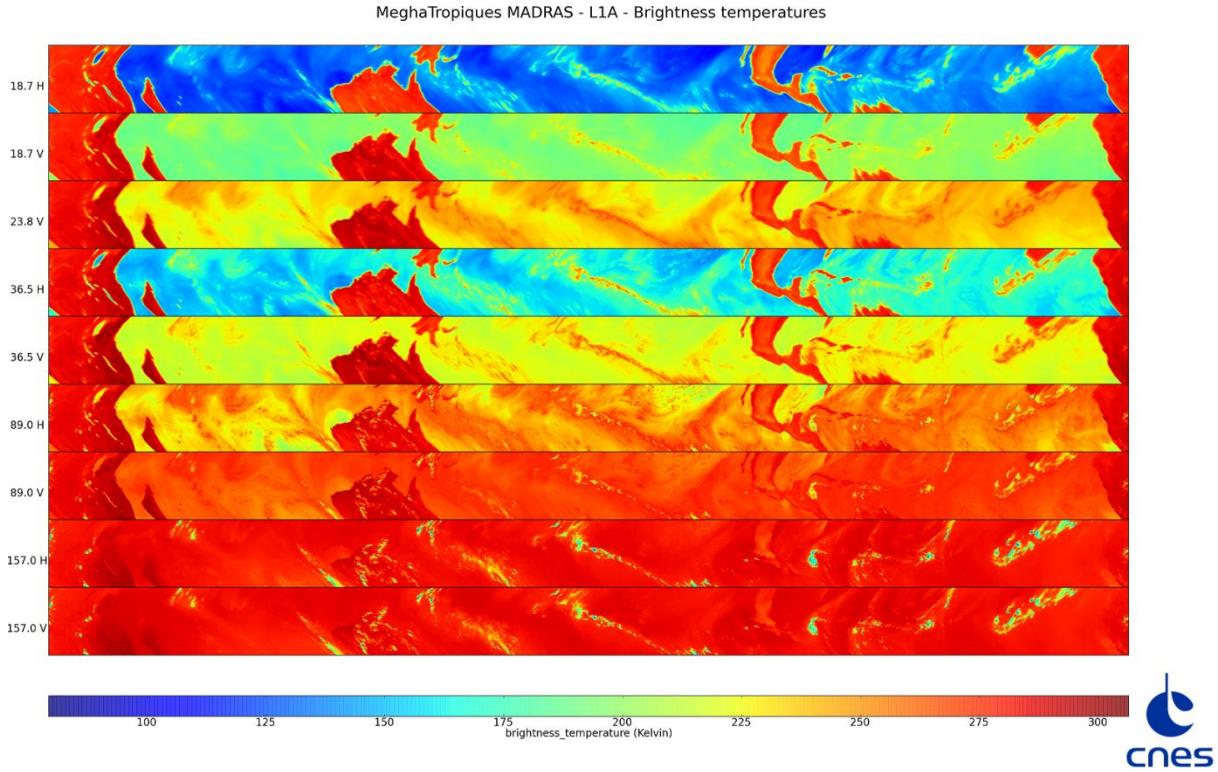
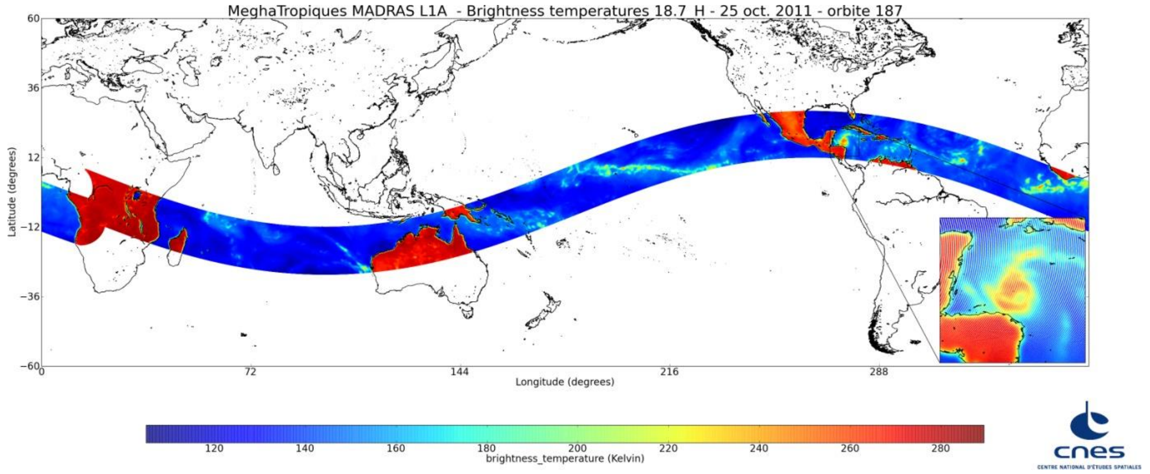
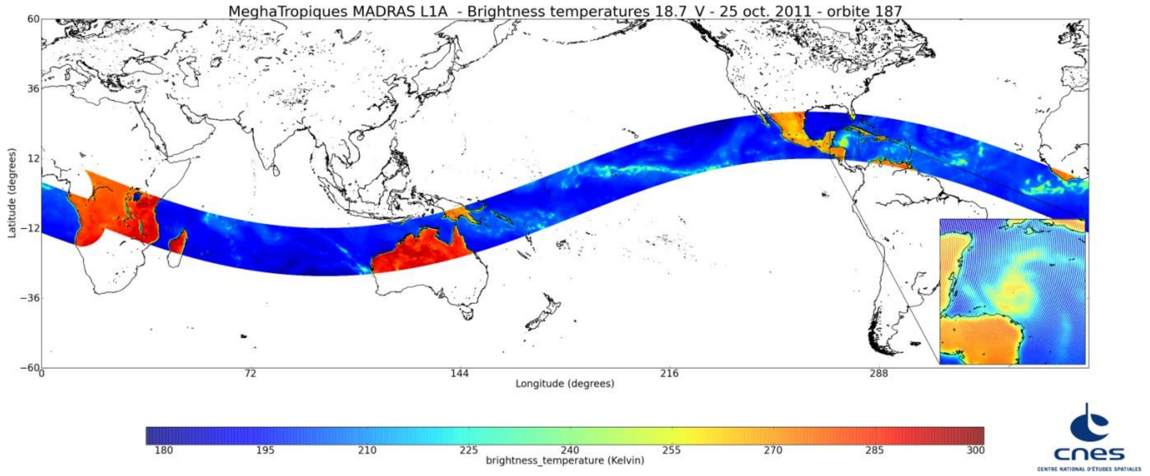


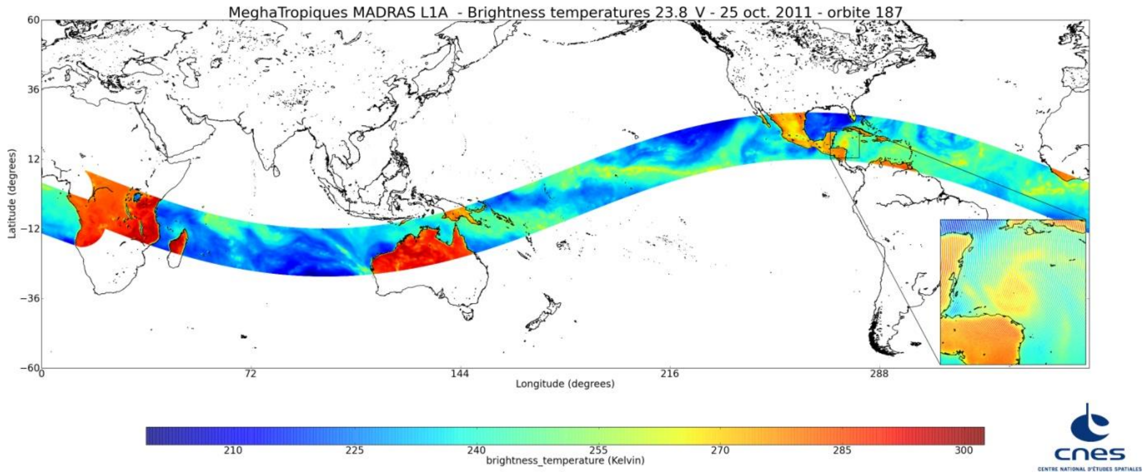
Figure 25 : Illustration of the MADRAS BT values for the orbit 187. All values for all 6 channels are plotted together, from channel 18.7 H (upper image) to 157.0 V (lower image)



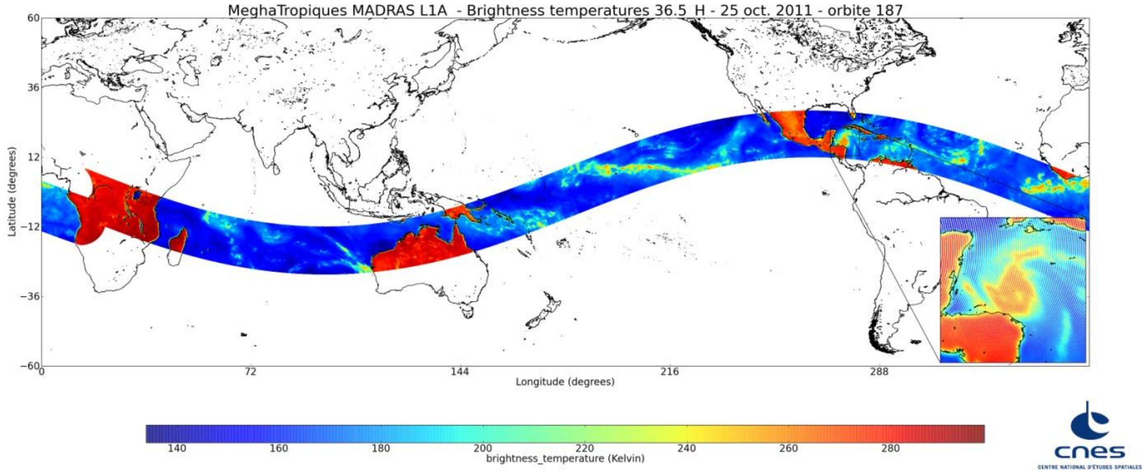
Channel 18.7 H



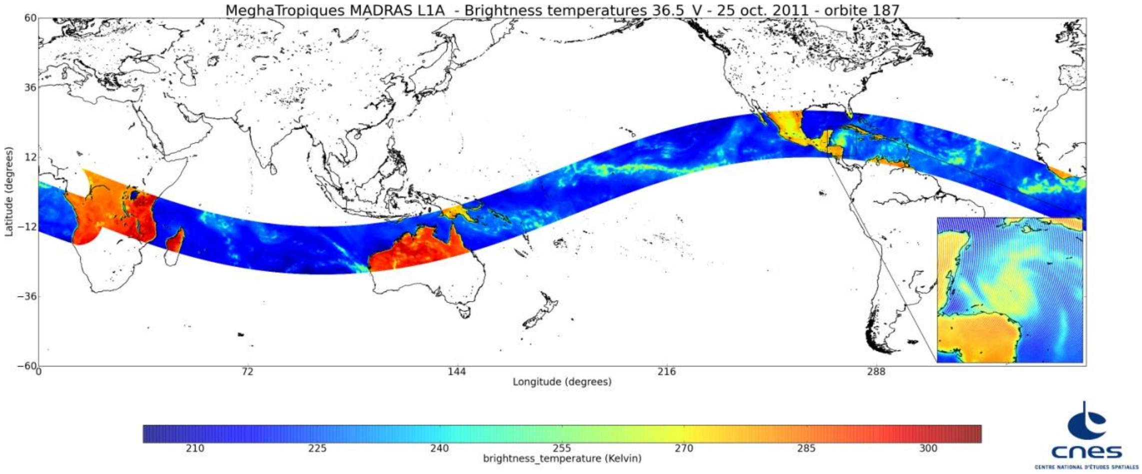
Channel 18.7 V



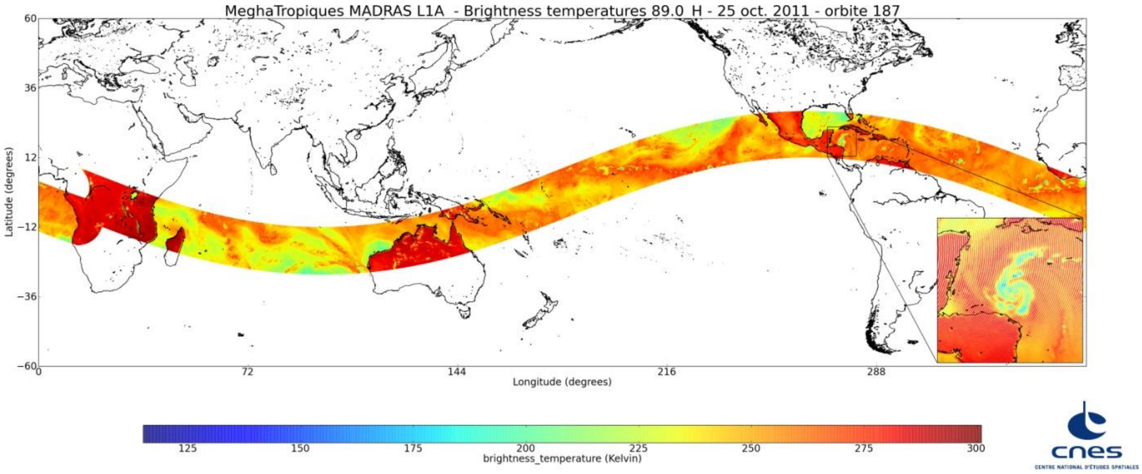
Channel 23.8 V



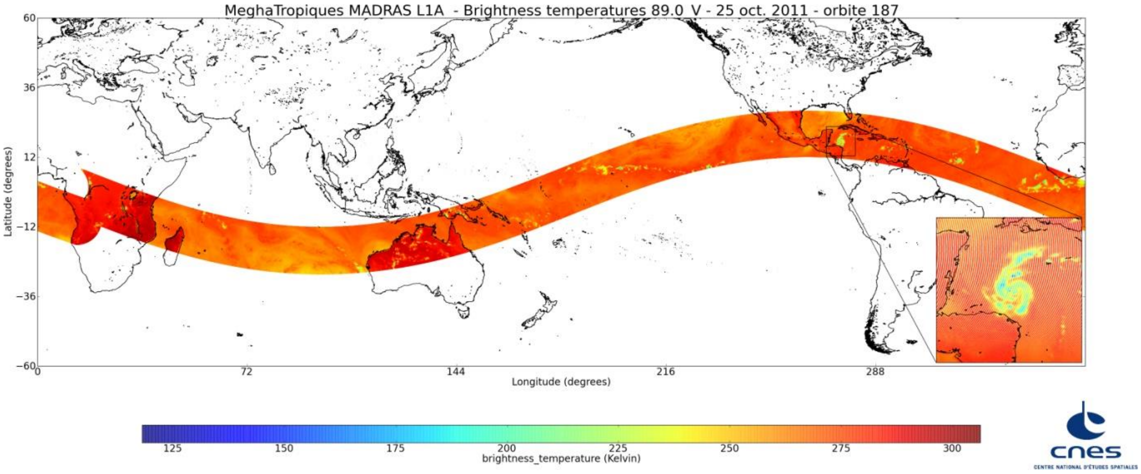
Channel 36.5 H



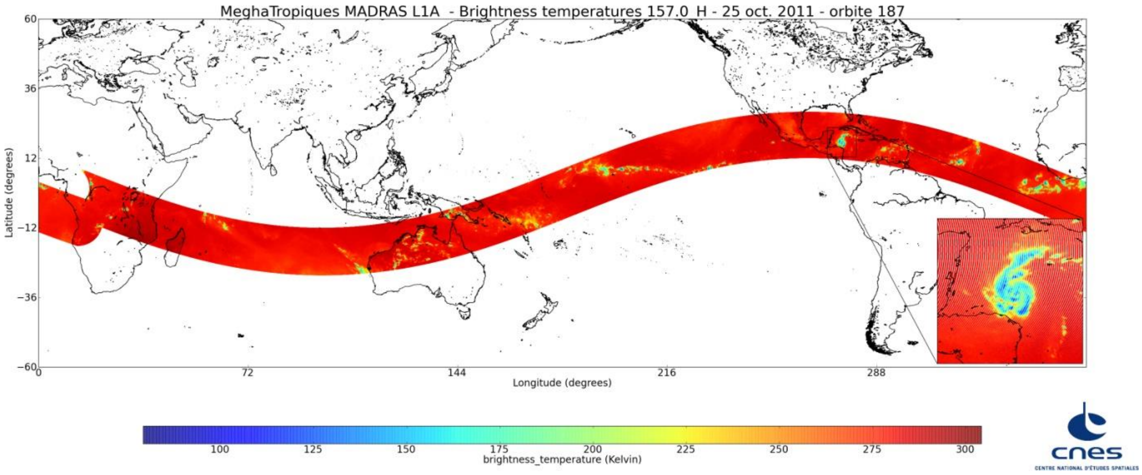
Channel 36.5 V



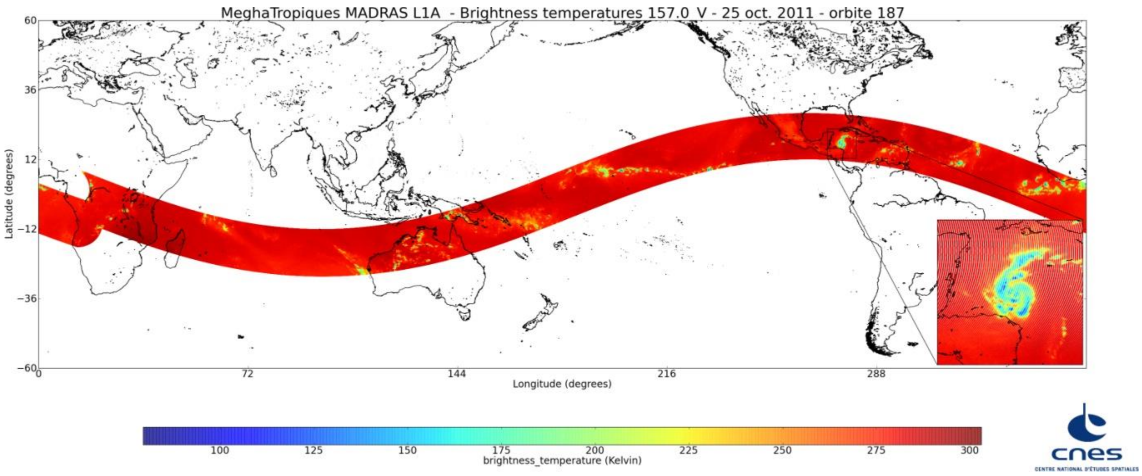
Channel 89.0 H



Channel 89.0 V



Channel 157.0 H



Channel 157.0 V

Figure 26 : BT projection on earth for MADRAS, orbit 187. All MADRAS channels are projected.

See the applicable document [AD4] for more details on the configuration of calibrations. During each continuous scan of the earth, the elementary measurements are integrated during regular sampling periods.

Table 4: Madras Characteristics

Altitude (Hs)			865.864 km
Angle to nadir (θ)			45.05°
Scan Angle (ε) = Azimuth (φ)			∈ [-65°, +65°]
Samples Number (L1A)	Earth		[Terre] : M1 à M4 : 448 (480 eff) M5 : 896 (960 eff)
	Hot load	M1 à M3	53
		M4	68
		M5	183
	Cold Calibration	M1 to M4	21
		M5	43
Nb pixels Number (L1A2)	Earth	M1 à M3	214
		M4	214
		M5	214

Following figures present graphics of sample characteristics depending on field of view (FOV) indexes (0 means the edge of FOV and high values means centre of FOV).

Figure 7 presents across track distance of each sample (left image) and along-track distance of each V channel sample.

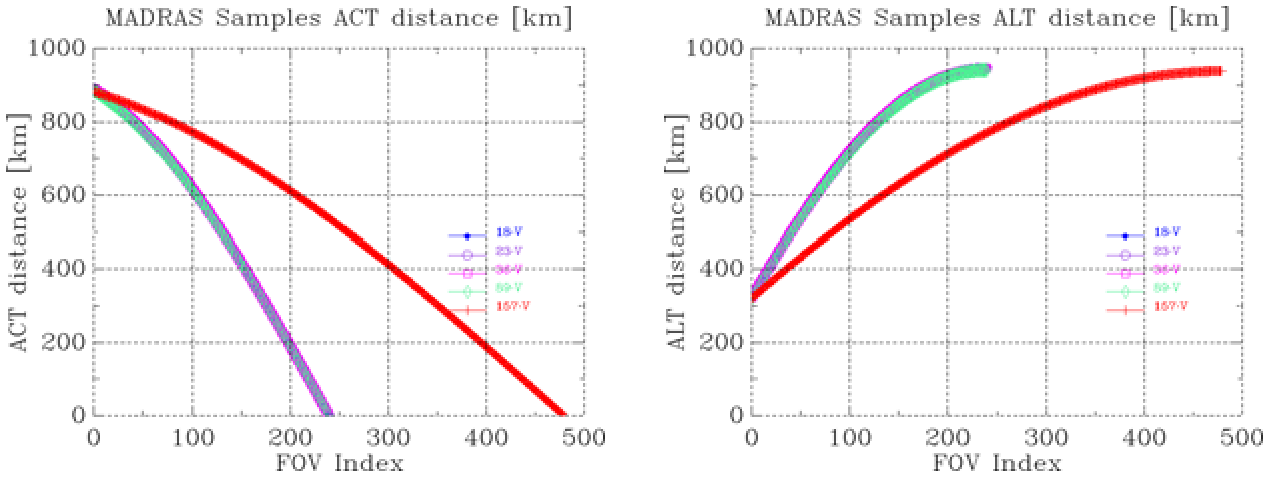


Figure 27: MADRAS samples position: distance across-track (left) and along-track (right) for the 5 V polarized channels.

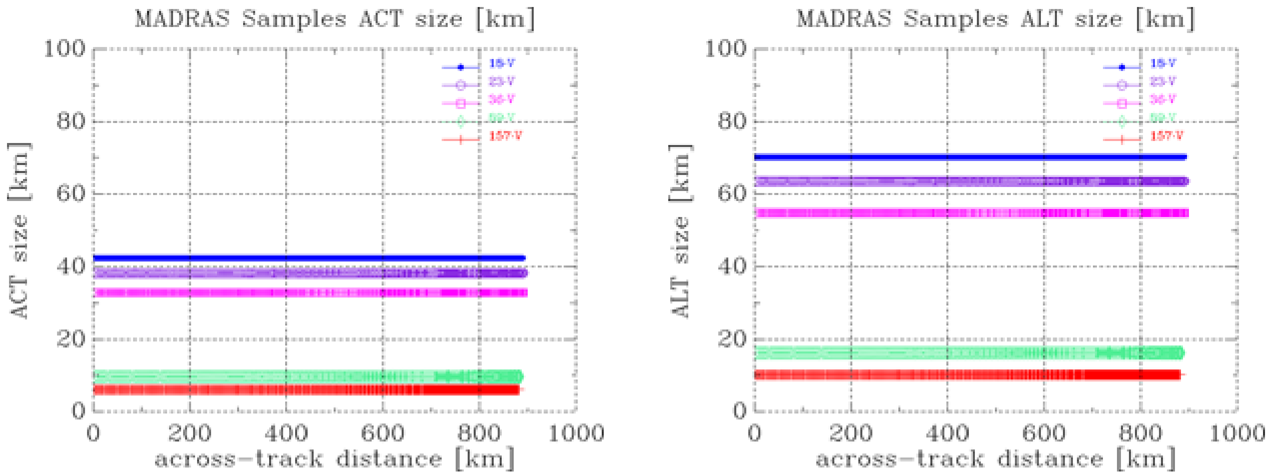
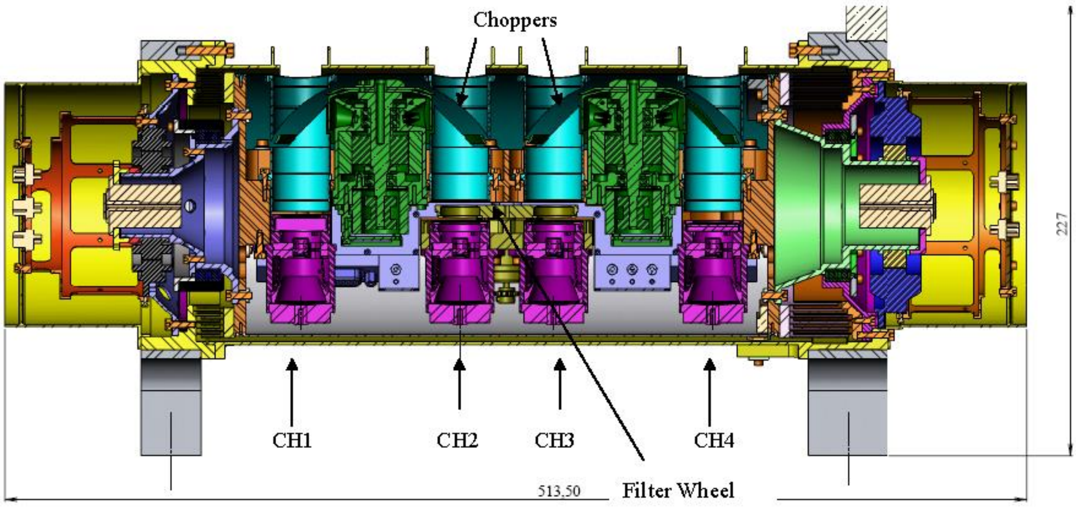


Figure 28: MADRAS Sample size: along-track (left image) and across-track (right image)

4.3 SCARAB INSTRUMENT

4.3.1 Characteristics



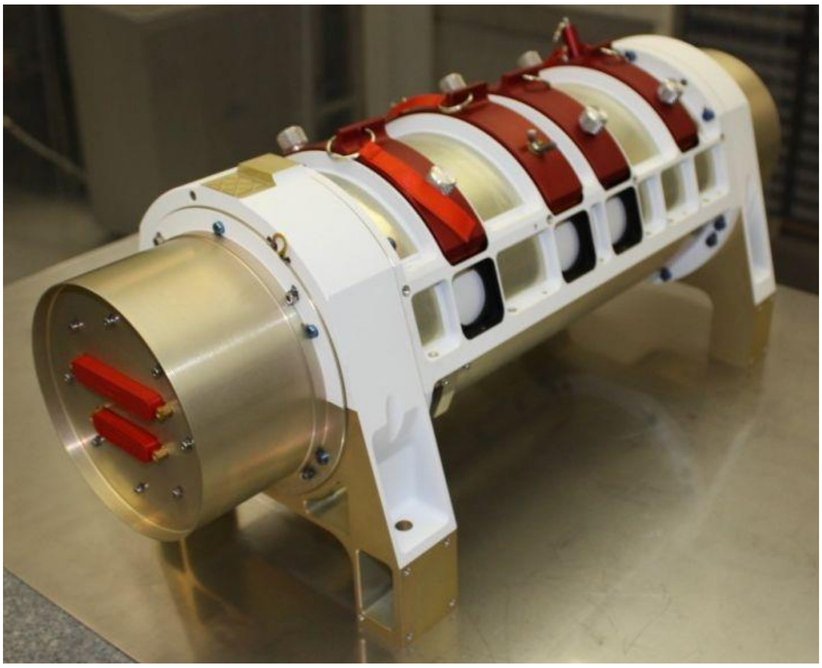


Figure 219 : Picture of ScaRaB instrument

SCARAB is an optical scanning radiometer devoted to the measurements of radiative fluxes at the top of the atmosphere. The optical radiometer is composed of 4 parallel and independent telescopes focusing the reflected solar and emitted thermal radiation of the earth atmosphere on 4 detection channels. Channel 2 and channel 3 are considered as the main channels, channel 2 providing directly the solar energy reflected

by the earth- atmosphere, channel 3 measuring the total energy (solar and thermal). Channel 1 and channel 4 are narrow band channels used for scene identification in the visible (channel 1) and in the Infrared (channel 4) domains.
The main channels characteristics are listed in the table hereafter:

Channel	Wavelength
SC1 - Visible	0,5 to 0,7 µm
SC2 - Solar	0,2 to 4 µm
SC3 - Total	0,2 to 50 µm
SC4 - IR Window	10,5 to 12,5 µm

Table 4.3-1: SCARAB channels

To ensure a swath of about 2200km, a cross track scanning of the instrument is performed. The cross track scanning is obtained by the rotation of the telescopes and associated detectors in the Nadir plane, which is perpendicular to the satellite speed vector.

The footprint size of a radiometer sample is defined by detector channel characteristics and is varying from 40km at Nadir to 200Km on the edge.

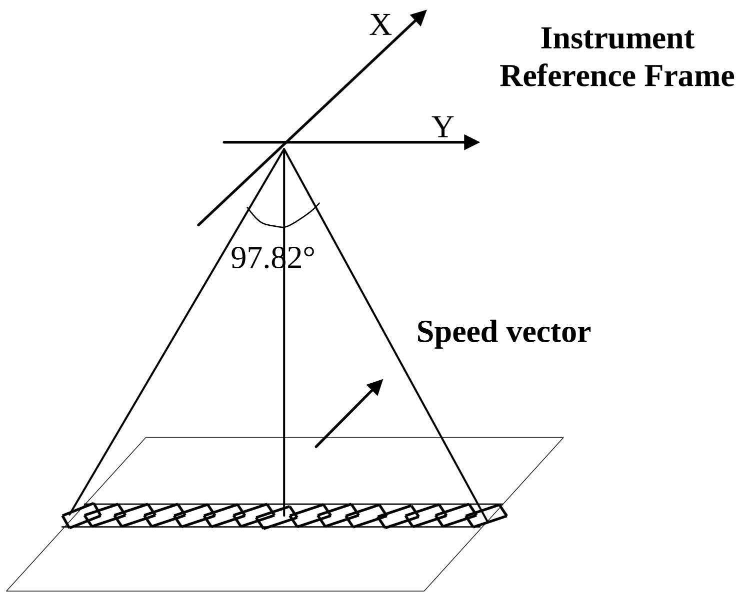


Figure 30: ScaRaB imaging geometry.

51 measurements per scan line and per channel are collected when the radiometer is scanning the earth surface over + 48.91°.
These measurements correspond to overlapped pixels on ground by definition.
The raw science data acquired on board corresponds to overlapped pixels as defined by the science community.

The characteristics of the scan are the following:

Scan type	Cross track scanning at constant speed over the earth/atmosphere observation
Scan period	6 seconds
Acquisition angle	± 48,91° around Nadir
Angular sampling	34,15mrad corresponding to 62,5ms

Table 4.3-2: scan characteristics of SCARAB

The sample size is varying along the swath with the following characteristics:

	At Nadir	Pixel 0 and N°50
Sample size diagonal across track	58,72 Km	192,04 Km
Sample size diagonal along track	58,72 Km	99, 27Km

Table 4.3-3: Samples size of SCARAB

Every scan period, a space view measurement is performed for calibration, three samples are measured per channel per scan.

4.3.2 Filter wheel positions

A filter wheel is implemented between channel 2 and 3 and is commanded by a stepping motor. The following figure describes the various positions reachable by the filter wheel:

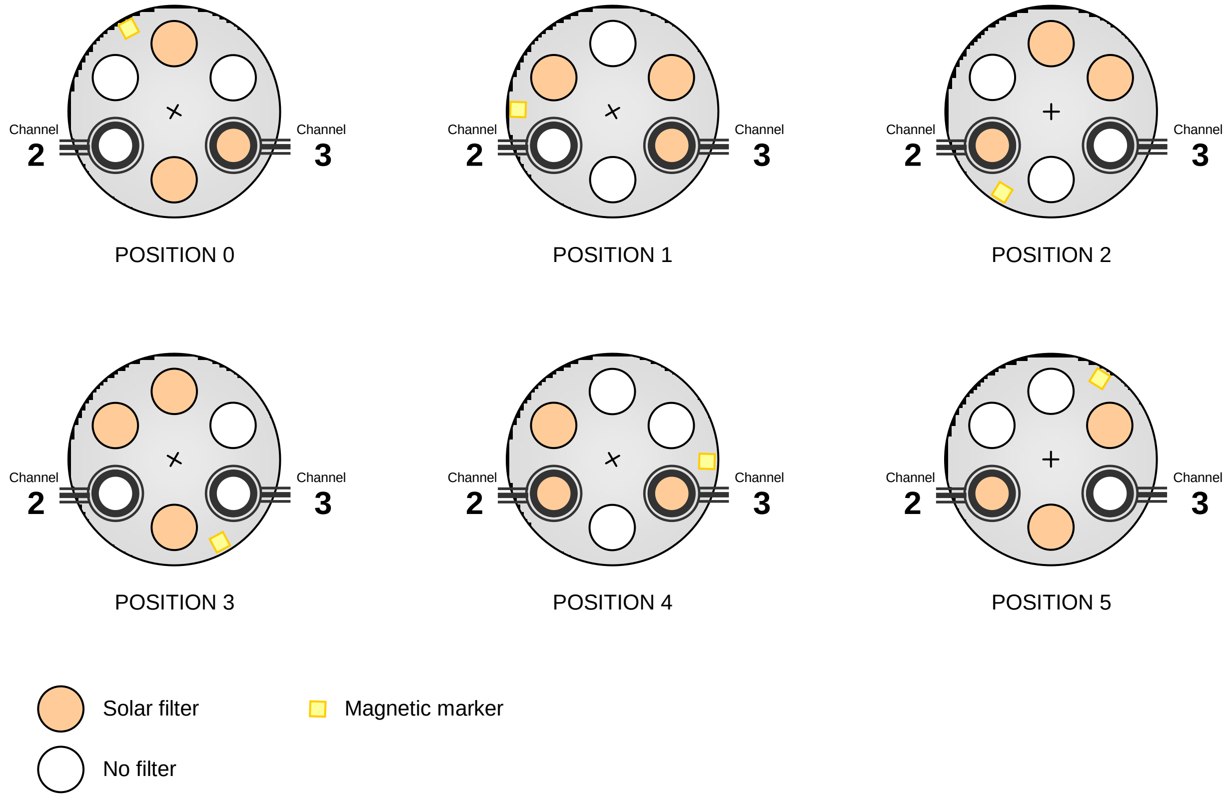


Figure 31: Filter wheel positions

4.3.3 Scan mechanism positions

The four optical heads are rotating together around the scan axis. There are several remarkable positions around the revolution circle:

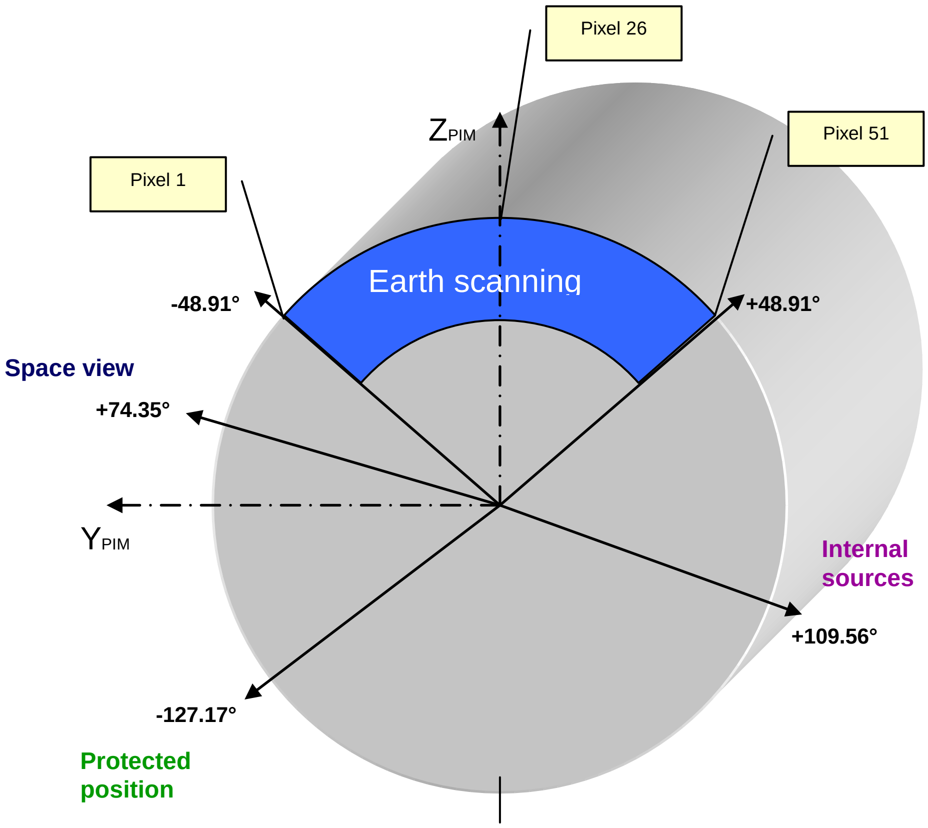


Figure 32: SCAN axis positions

The space view is an opening on the housing that enables SCARAB to perform the offset calibration of the optical heads, aiming towards deep space.
The Internal sources are one lamp (for channel 1) and 3 blackbodies used to perform the gain calibration.
Around the position 0, corresponding to the nadir, a 51-pixel row (of the earth surface) acquisition is performed.
The protected position protects the optical parts. It shall be set on ground as soon as SCARAB is not used. In flight, this position is set during nominal switch off, or in case of a safe emergency.
NOTA : angle position for Scarab are always counted as positive number. For example, to command the protective position, you have to use -127,17+360 = 232,83°. It is not allowed to use negative number for angles.

4.3.4 SCARAB Modes

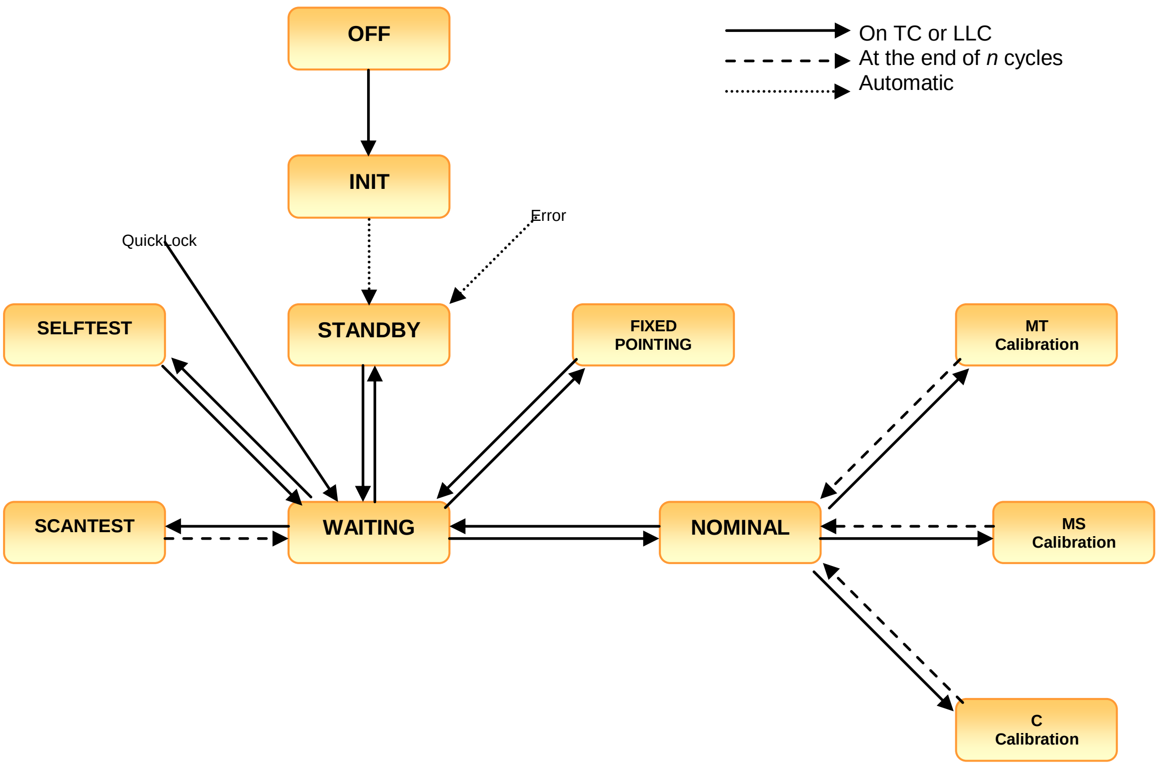


Figure 33: SCARAB Modes transition graph

These modes are supplemented by support modes:

- DUMP mode (read memory)
- PATCH mode (write memory)

Mode	Scan mechanism status	Filter Wheel (index-steps)	Lamp	Cycle	Number of cycles	Science TM
STANDBY	OFF	Previous	OFF	-	∞	NO
WAITING	Fixed security position	Nominal (2-64)	OFF	-	∞	NO
NOMINAL	Nominal Cycle	Nominal (2-64)	OFF	6s	∞	YES
MT Calibration	Nominal Cycle	(3-96)	OFF	6s	Software Parameter	YES

Mode	Scan mechanism status	Filter Wheel (index-steps)	Lamp	Cycle	Number of cycles	Science TM
MS Calibration	Nominal Cycle	(4-128)	OFF	6s	Software Parameter	YES
C Calibration	Calibration Cycle	(3-96)	ON during part of the mode*	6s	Software Parameter	YES
SELFTEST	Fixed security position	Previous	OFF	6s	∞	YES
SCANTEST	Nominal Cycle	Previous	OFF	6s	Supplied in the MODE CHANGE TC	YES
FIXED POINTING	Supplied in the MODE CHANGE TC	Supplied in the MODE CHANGE TC	Supplied in the MODE CHANGE TC	6s	∞	YES

Table 4: SCARAB modes description

*: In C Calibration, the lamp is ON during 50 cycles on 80
In all the modes, (excepted OFF) the OSM electronics are powered.

4.3.5 Modes description

4.3.5.1 OFF mode

When the unit is switched off, the EM does not respond to received TC, either on the 1553 bus or via the spy link. The EM does not transmit any TM.

4.3.5.2 INIT mode (degraded mode)

When the unit is switched ON or following a reset, the EM activates an initialization phase (lasting less than 2 seconds). In the nominal case, the first available HOUSEKEEPING TM indicates that the EM is in STANDBY mode. When the initialization phase has been successfully completed, the HOUSEKEEPING TM is available every 6 seconds and the EM is ready to receive TC.
If this is not the case, an error has occurred during the initialization phase. The HOUSEKEEPING TM indicates that the EM is in INIT mode and that the Level 3 error indicator has been activated (DIAGNOSTIC TM to be provided to CNES).
In the event of a degraded mode (INIT mode), it will be necessary for CNES to investigate the problem. Activities shall be stopped and CNES contacted.

4.3.5.3 STANDBY mode

This mode is reached starting from initialization following a powering ON or after a hot reset (Reset TC), either by specific request (MODE CHANGE TC) or as the result of errors. In this mode, none of the mechanism is under control. The HOUSEKEEPING TM is updated cyclically every 6 seconds.

4.3.5.4 Hot reset

A hot reset is initiated by two events:

- A Reset TC
- A serious Level 3 error with hot reset processing (autonomous reset).

When the unit restarts after a reset, the software starts on the redundant EEPROM and indicates in the HOUSEKEEPING TM the identifier of the EEPROM used ('Boot' field: 0 : Primary, 1 : Secondary).
Certain types of data are saved during the reset:

- The functional parameters
- Data which are specified 'Not soft reset'
- The error structure enabling an update of the DIAGNOSTIC TM.

If there are no errors during initialisation following a reset, the EM enters the STANDBY mode.

4.3.6 SCARAB monthly calibration

Each month the instrument receive a TC from Satellite mission control centre in Bangalore to do a calibration cycle.

For example the calibration performed on 05th March, 2015

S.No.	Command Code	Command Description	CAL start time	Orbit Number
1.	0184CF56000000	SRB C CAL	03:58:09	17518
2.	0184CF55000000	SRB MT CAL	05:28:43	17519
3.	0184CF54000000	SRB MS CAL	07:10:46	17520
4.	0184CF54000000	SRB MS CAL	08:16:47	17521
5.	0184CF51000000	SRB WAITING	09:23:51	17522
6.	0184CF53000050	SCARB SCANTEST DATA COMMAND	09:24:51	17522
7.	0184CF52000000	SRB NOMINAL	09:33:51	17522

This calibration is used to determine the radiometric parameter as gain A-prime etc.

For example for march 2015

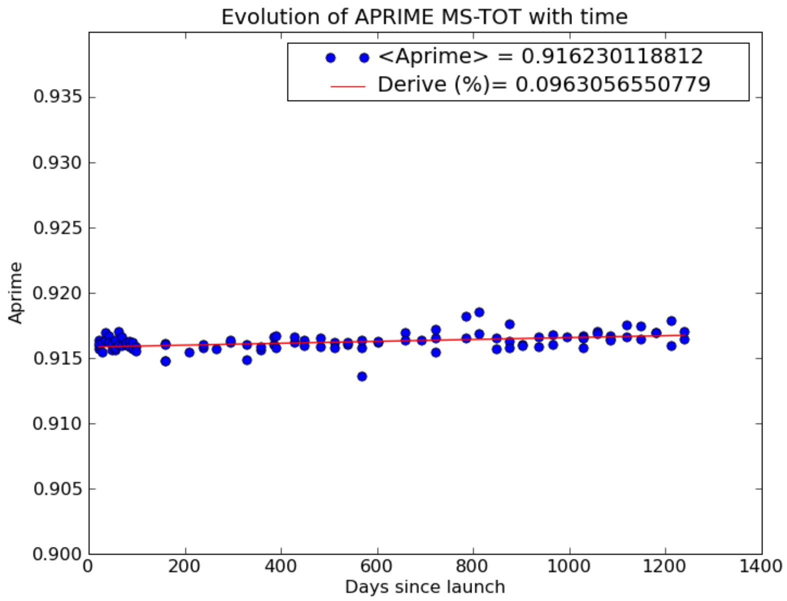


Figure 34 : Aprime évolution

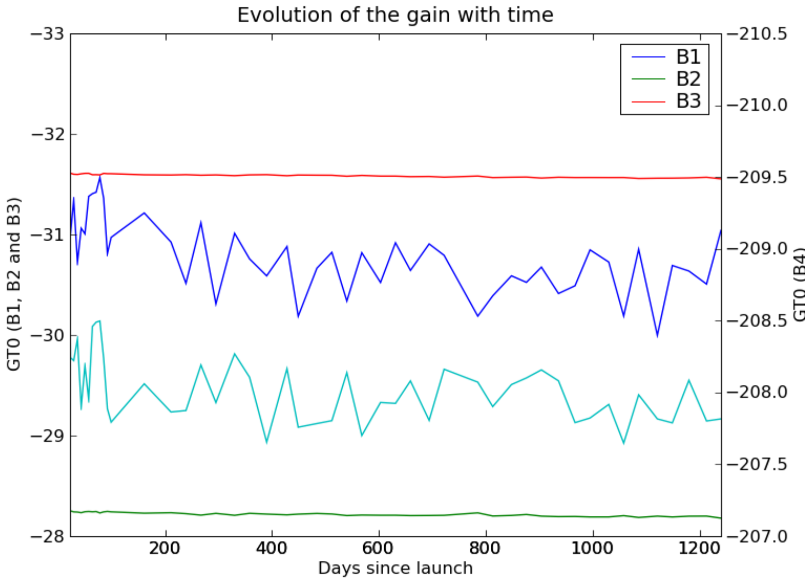


Figure 35 : Gain evolution

Each month, 22 controls are made with tendency curves. the objective is to prevent eventual drifts or anomalies.

5 GEOMETRICAL CONSIDERATION

5.1 VIEWING ZENITH ANGLE (SCARAB) OR INCIDENCE ANGLE (MADRAS, SAPHIR)

The satellite viewing zenith angle at pixel centre (θv) is the angle in degrees between Ze (zenith) and VD (viewing direction). Assuming that (N, W, Ze) is the local referential, earth tangent in P. P is the pixel centre on earth surface.

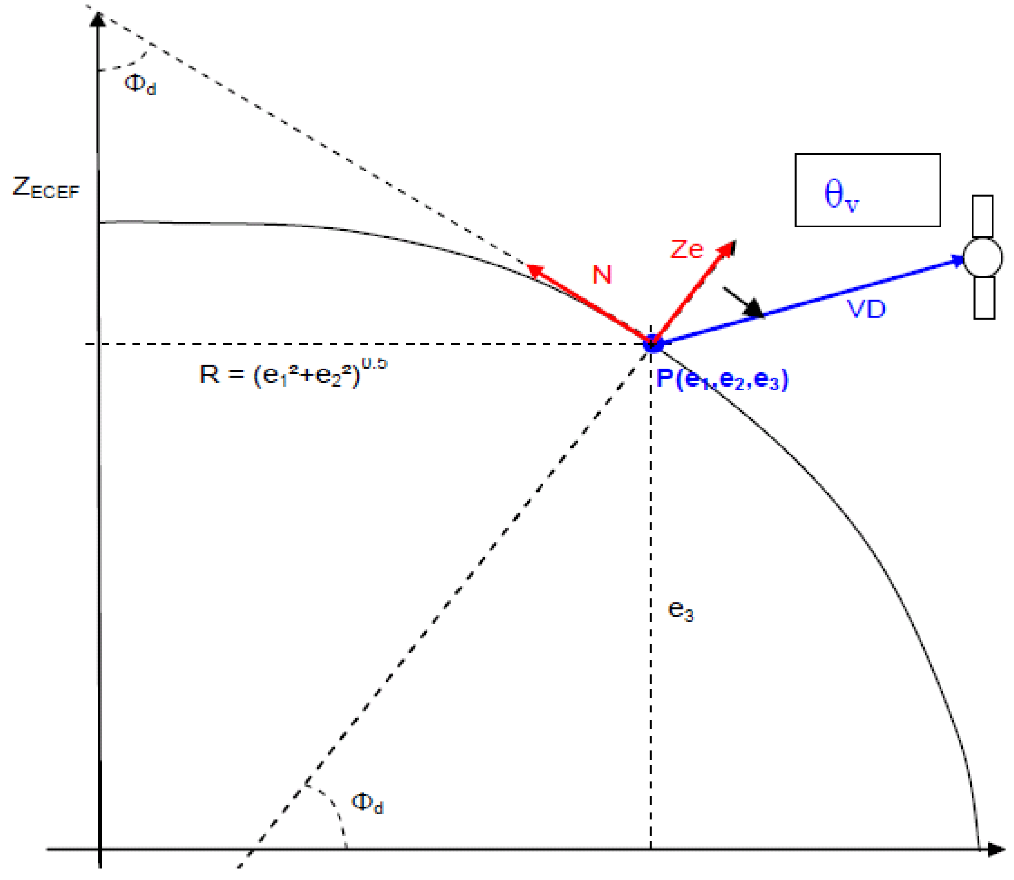


Figure 36 : Viewing zenith angle or incidence angle

(ΦD) is the geodetic latitude. The viewing zenith angle (θ_v) is the angle in degrees between Z_e and VD.

5.2 DEFINITION OF SATELLITE AZIMUTH VIEWING ANGLE AT PIXEL CENTRE

Let VDt be the projection of VD in the plane (N, W). The satellite azimuth viewing angle (φv) is the angle in degrees between the local North N R and VDt. φv is computed from North and is positive (between 0 to 180°) if VDt is located on the East side of the reference frame and negative (between 0 and -180°) if VDt is located on west side.

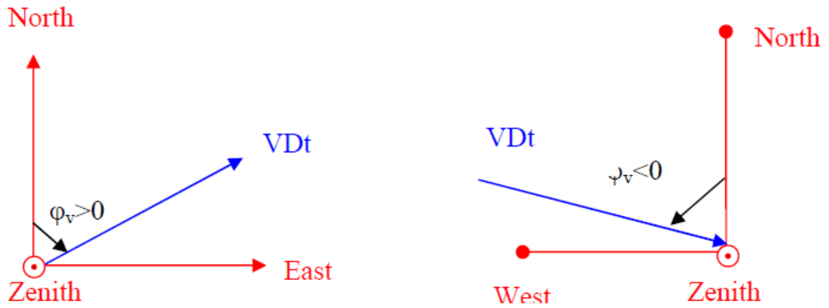


Figure 37 Viewing azimuth angle at pixel center

Finally, 0° corresponds to North , +180 and -180° azimuth correspond to south, +90° azimuth correspond to East and -90° to West.

5.3 SOLAR ZENITH ANGLE

The same conventions are used to define the solar zenith and azimuth angles at pixel centre, replacing the viewing direction by the sun direction SD (vector from P to the sun):
The solar zenith angle (θs) is the angle in degrees between Ze and SD.

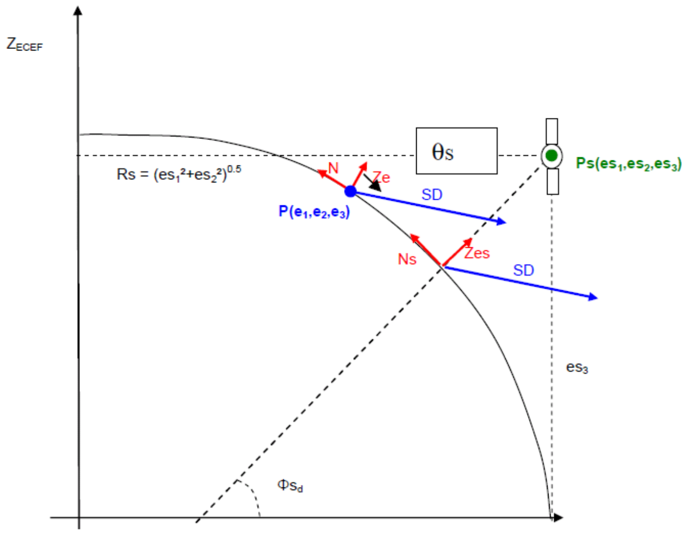


Figure 38 : Definition of solar viewing angle θ_s

The solar zenith angle is varying from 0 to 180° , if the angle is between 0 and 90°, it corresponds to day time and if the angle is varying from 90 to 180°, it corresponds to night.
Let SDt be the projection of SD in the plane (N, W). The solar azimuth angle (φs) is the angle in degrees between N and SDt. φs is from the North axis.

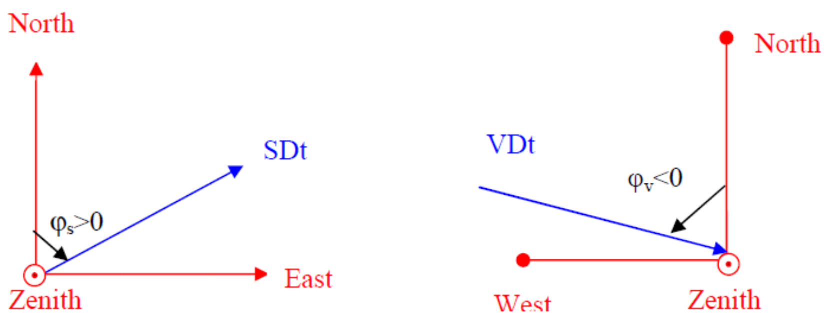


Figure 39 : Solar azimuth angle at pixel center φ_s

Finally, 0° azimuth corresponds to North , +180 and -180° azimuth correspond to south, +90° azimuth correspond to East and -90° to West.

5.4 RELATIVE AZIMUTH ANGLE

Relative azimuth angle = Solar azimuth angle – Viewing azimuth angle.
The relative azimuth angle can vary between 0 and 360°.

6 BASICS OF L1 PROCESSING

L1 processing a radiometer mainly consists on computing antenna temperature (Ta) from raw measurements, the antenna counts (Vouts).
SAPHIR and MADRAS are full power radiometers. The receivers (see instruments description) ensure the low-noise amplification of the signal, band pass filtering and integration. The outputs are voltages which are digitalized to give the so-called “counts”.

Basically the receivers transform a brightness temperature in counts through a linear calibration law.

$$V_{out} = G_{rec}(TA + T_{rec}) + V_{offset}$$

Where G_{rec} (mV/K) is the slope of the linear function.
In flight, the internal calibration should be performed regularly to adjust the calibration function. For SAPHIR and MADRAS, the internal calibration of the radiometer is performed every scans by observing alternatively the deep space (“cold sky”) and internal hot loads.
The cold calibration and hot calibration counts are used to estimate the gain of the receiver, required to retrieve the antenna temperature:

$$\tilde{G}_{rec} = \frac{V_{hot} - V_{cold}}{TA_{hot} - TA_{cold}}$$

$$TA = \frac{V_{out}}{\tilde{G}_{rec}} - TE$$

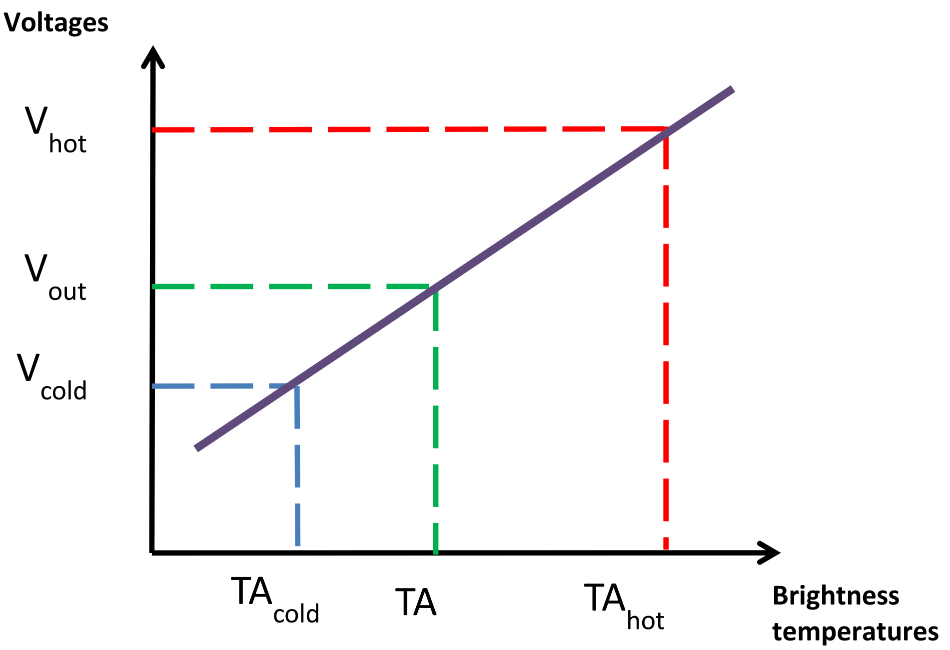


Figure 40 : Conceptual diagram of a total power radiometer

The process is made by step itch step correspond to one algorithm for SAPHIR and SCARAB.

A delivered OAT file contains orbit and attitude information given in terms of records. Each record contains orbit and attitude parameters for the time specified. These records will be at the interval of Δt=128ms. The time interval may be longer if data blocks are subsequently missing. Missing value can be extrapolated interpolated etc. respecting processing specification that guaranty the validity of the product.

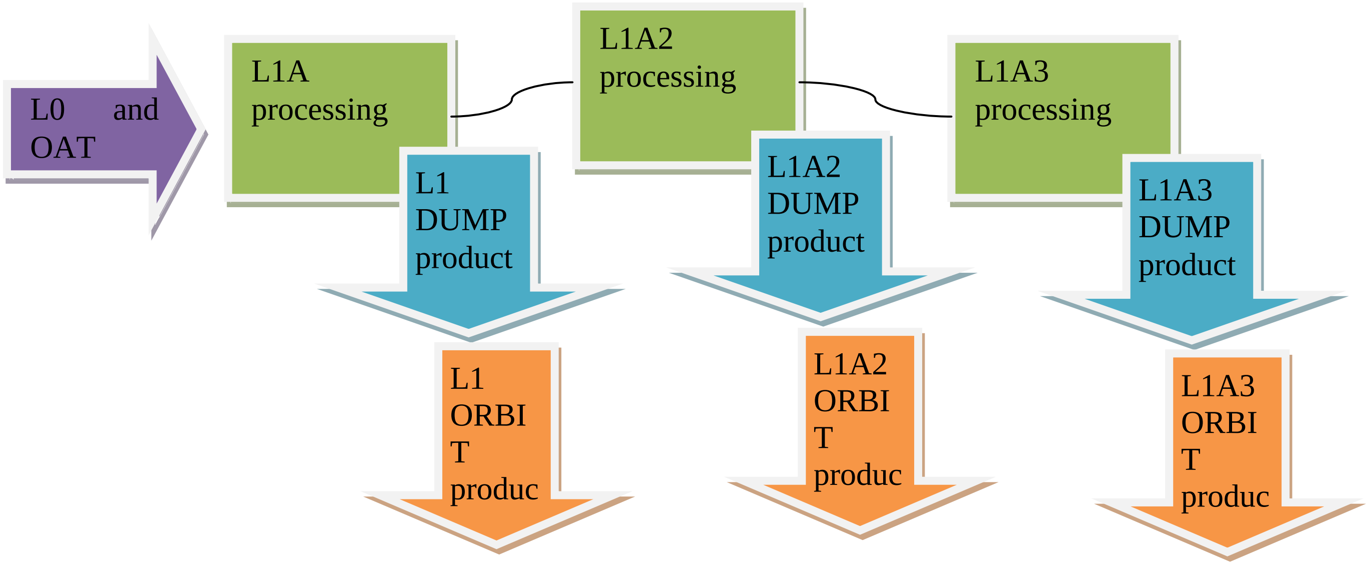


Figure 41 SAPHIR and SCARAB process chain

The process is made by step itch step correspond to one algorithm for MADRAS

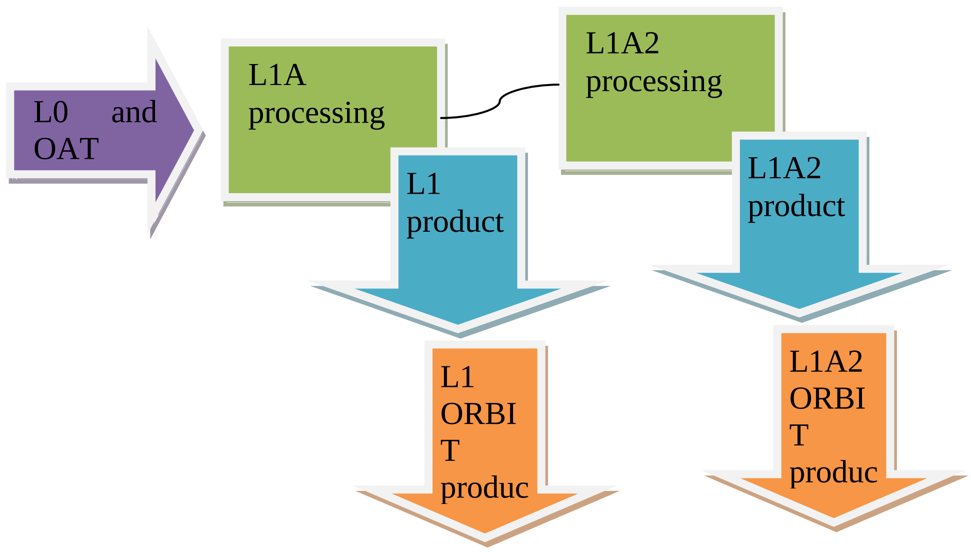


Figure 42 MADRAS process chain

The orbit products are made from dump product. The algorithm wait 24 hours maximum all the dump needed to make an orbit. When all expected dump are ready the orbit is generated.

7 OVERVIEW OF THE MEGHATROPIQUES PRODUCT FAMILY

7.1 DEFINITION OF DATA LEVELS

SAPHIR and MADRAS L1A products consists on 3 and 2 sub-levels respectively. As a reminder, we also define the L0.

For each of processing level, number of samples and pixels per scan is varying. The next table (Table 5) presents the values for each level.

Table 5 : number of pixels and samples for each scan for L1 levels (LF is for Low Frequency, MF Middle Frequency and HF High Frequency)

	SAPHIR	MADRAS		
		LF	MF	HF
Level 1A	182	480	480	960
Level 1A2	130	214	214	214
Level 1A3	214	*	*	*

Physical Level	MADRAS	SAPHIR	SCARAB
Level 1A	TB sample (with overlap)	TB sample (with overlap)	Radiance sample (with overlap)
Level 1A2	TB pixels (non-overlapping)	TB pixels (non-overlapping)	Idem 1A with better registration
Level 1A3	NA	TB projection in MADRAS 89Ghz grid	Radiance projection in MADRAS 89Ghz grid

7.1.1 Level 0 data

The production of level 0 data is not a mission requirement but a consequence of technological constraints. The level 0 data consists on payload and raw telemetry data on one hand and Orbit and Attitude Tracking (OAT) on the other hand.

7.1.2 Level 1A data

There should be no loss of information in processing level 0 data into level 1A data. For Each instrument of the MEGHA-TROPIQUES payload, the level 1A data (radiances) are obtained in the nominal MEGHA-TROPIQUES operating mode and corrected for all geometrical and instrumental effects based on an internal calibration procedure, merged with time and location information derived from the instrument housekeeping and on-board calibration data, satellite housekeeping, orbit and attitude data, and with quality flags. Level 1A data include, for each instrument of the MEGHA-TROPIQUES payload, all the information and supporting data needed to further process the instrument data, including, for each instrument of the MEGHA-TROPIQUES payload, flags, pertinent instrument and satellite housekeeping, and instrument status data.

7.1.3 Level 1A2 data

In order to respect the Nyquist sampling rate, the L1A brightness temperature “samples” combined to produced de-correlated (non-overlapping) L1A2 “pixels”.

7.1.4 Level 1A3 data

In a third time and in order to facilitate the inter comparison of the whole set of products delivered by the Megha-Tropiques mission, the brightness temperatures from Level 1A2 are interpolated inside a grid defined by the position of the pixels of MADRAS at 89 GHz. The brightness temperatures inside the Level 1A3 products are given onto this grid. It is a scan mode product

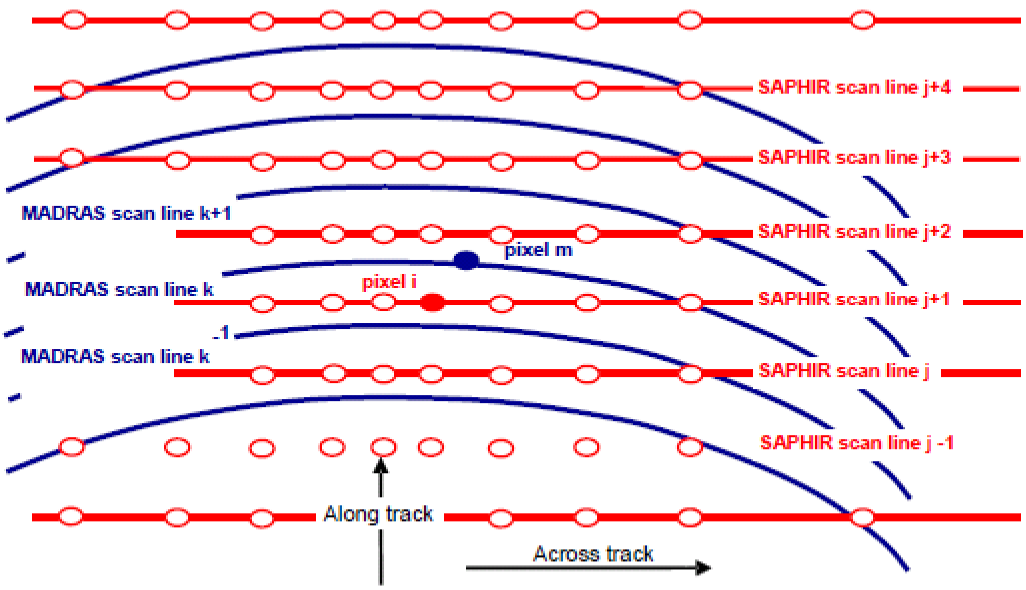


Figure 43 : Projection on earth of MADRAS (blue lines) and SAPHIR (red lines) scan lines and relative position of L1A3 Pixels (blue point) with SAPHIR pixels (red point)

7.2 PRODUCTS TYPES

- **DUMPWISE Product** : this product is as it is download from the station but upgraded at L1 level. This product have variable size.
- **ORBITWISE Product** : it's a sum of N (= 1,2,3,...) DUMPWISE product. All the product cover 1 orbit.

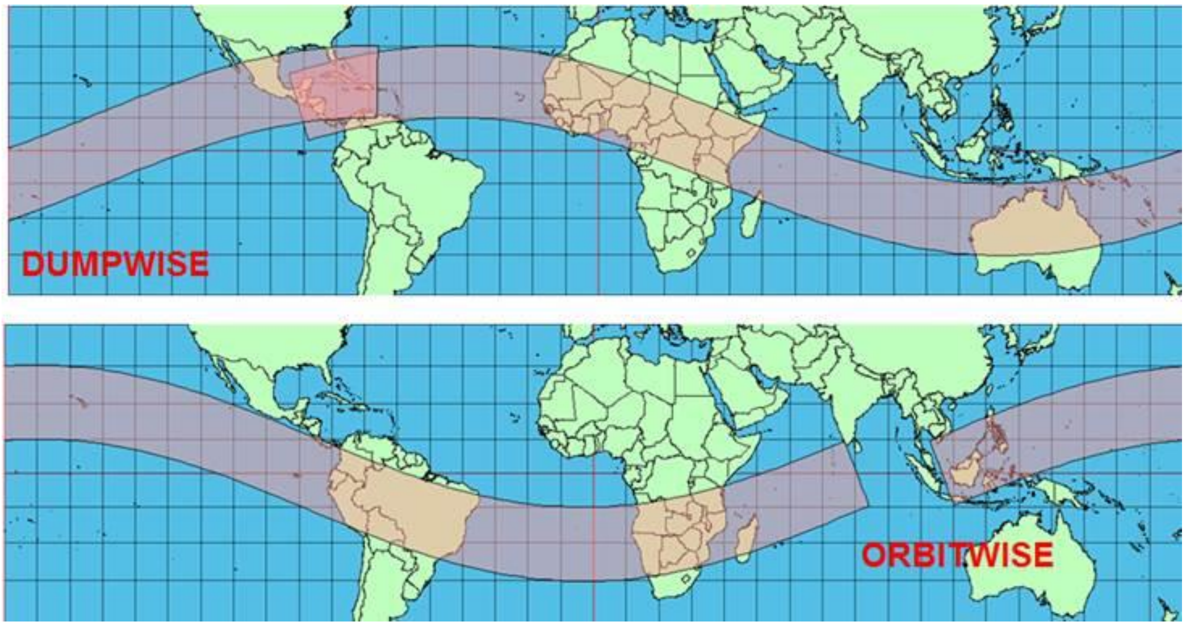


Figure 44 : products types

7.3 FRENCH SCIENCE GROUND SEGMENT AND DATA DISSEMINATION

The ICARE Data and Services Centre is the scientific ground segment for the Megha-Tropiques mission. As such, it is responsible for the routine processing of the science products, using science codes provided by the French science team at IPSL. The ICARE Data and Services Centre is in charge of Megha-Tropiques data dissemination for French CNES agency. More information on the ICARE website http://www.icare.univ-lille1.fr/drupal/.

7.4 NRT DATA BY EUMETCAST

The operational users who require a near real time access should use EUMETCAST services.

EUMETCAST broadcast SAPHIR NRT for all users of this services.

This product is less than 3 hours. To be compliant with this specification we use 3 stations spread on the globe Bangalore, Hartbeesthoek and Kourou.

The volume of level 1 standard products is as described in Table 6:

Table 6 : Volume of standard level 1 data

Sensor Name	Volume of Orbit-wise product in Mega Bytes(MB)				
	L1A	L1A2	L1A3	L1B	
MADRAS	67.96	20.34	20.34	10x10Grid	
				5x5grid	
				Total(MADRAS)	76.78
SAPHIR	19.66	14.11	17.14	27.84	
SCARAB	2.11	2.11	18.15	2.35	
Total by orbit	89.73	36.56	55.63	106.97	
Total by day (14 orbits)	1256.2	511.84	778.82	1497.58	

7.5 FILE NAMING CONVENTION

The proposed filename conventions for various levels of data products orbit wise/ segment wise are as follows:

Table 7 : Filename convention

Level Product type	Product File	Name
1A	NRT (Segment wise)	MT1SSSSL1A__X.XX_VVV_I_II_L_YYYY_MM_DD_HH_mm_ss_YYYY_MM_DD_HH_mm_ss_NNNNN_MMMMM_CCC_TT_UU_STN_SG.h5
	Standard (Orbit wise)	MT1SSSOL1A__X.XX__I_I I _L_YYYY_MM_DD_ CCC_ TT_OOOOO.h5
1A2	NRT (Segment wise)	MT1SSSSL1A2_X.XX_VVV_I_II_L_YYYY_MM_DD_HH_mm_ss_YYYY_MM_DD_HH_mm_ss_NNNNN_MMMMM_CCC_TT_UU_STN_SG.h5
	Standard (Orbit wise)	MT1SSSOL1A2_X.XX_VVV_I_I I _L_YYYY_MM_DD_ CCC_ TT_OOOOO.h5
1A3	NRT (Segment wise)	MT1SSSSL1A3_X.XX_VVV_I_II_L_YYYY_MM_DD_HH_mm_ss_YYYY_MM_DD_HH_mm_ss_NNNNN_MMMMM_CCC_TT_UU_STN_SG.h5
	Standard (Orbit wise)	MT1SSSOL1A3_X.XX_VVV_I_II_L_YYYY_MM_DD_CCC_TT_OOOOO.h5
1B	NRT (Segment wise)	MT1SSSSL1B__X.XX_VVV_I_II_L_YYYY_MM_DD_HH_mm_ss_YYYY_MM_DD_HH_mm_ss_NNNNN_MMMMM_CCC_TT_UU_STN_SG.h5
	Standard (Orbit wise)	MT1SSSOL1B__X.XX_VVV_I_II_L_YYYY_MM_DD_CCC_TT_OOOOO.h5

Where:
(a) MT1: Megha –Tropiques
(b) SSS: Indicates the Sensor Name "MAD"/"SAP"/"SCA" for MADRAS, SAPHIR & SCARAB respectively
(c) O/S: Indicates the data is standard (Orbit –wise)/ NRT(Segment-wise) product type
(d) Product type: L1A,L1A2, L1A3 or L1B
Remark: As MADRAS L1A2 and L1A3 are identical, for that case, the "L1A2" label will be indicated in the file name
(e) X.XX indicates the software version.
(f) VVV: is an extension for software which will be frozen to 000 for operational software but will be significant for validation Software
(g) I_I I indicates the IODD version. The version will change if version of any IODD file will change example 9_07
(h) L indicates the origin of processing I/C for ISRO or CNES
(i) YYYY: The calendar year when first sample of Ist Record of data was acquired
(j) MM: The month of the year when first sample of the Ist Record of data was acquired
(k) DD: The date of the year when first sample of the Ist Record of data was acquired C.N.E.S./ I.S.R.O. MeghaTropiques
(l) HH_mm_ss: Hour, minutes, second of first sample /pixel of first record of data
(m) YYYY: The calendar year when first sample of last record of data was acquired
(n) MM: The month of the year when first sample of the last record of data was acquired
(o) DD: The date of the year when first sample of the last record of data was acquired
(p) HH_mm_ss: Hour, minutes, second of first sample /pixel of last record of data
(q) NNNNN: Orbit start number no. of the first sample of the first Record
(r) MMMMM: Orbit end number: no. of the last sample of the last Record acquired
(s) CCC: Index of the orbit cycle (a cycle is 7 days)and corresponds to orbit of first scan
(t) TT: First scan Cycle number: Relative orbit in the cycle for the first record (1 to 97)
(u) UU: last scan Cycle number: Relative orbit in the cycle for the last record (1 to 97)
(v) STN: Ground station name : KRU, HBK, BL1 or BL2
(w) SG: segment number copied from L0 file name , only for NRT products
(x) OOOOO: Satellite orbit no. of archived orbit wise product

Remark:
For MADRAS, date for first and last samples of 18,7Ghz polarization H channel will be considered. For SCARAB, date of first and last sample of Solar channel will be considered.

Using this convention, sample product names for 25th December 2009 and orbit no. 12345 is shown in Table 8 as follows with time of first record sample of the dump equal to 02H50mn01sec and time of last record equal to 03H40mn20sec. Cycle number is: 91 and first and last cycle number are 85 and 86. Ground station is Bangalore N°1: BL1 and Segment number is SG=01.

Table 8 : Example of a filename

Product Level	**Product File Name**
Level1A (segment wise)	MT1MADSL1A__1.00_000_9_07_I_2009_12_25_02_50_01_2009_12_25_03_40_20_12345_12346_091_85_86_BL1_01.h5
Level1A2 (segment wise)	MT1MADSL1A2_1.00_000_9_07_I_2009_12_25_02_50_01_2009_12_25_03_40_20_12345_12346_091_85_86_BL1_01.h5
Level1A3(segment wise)	MT1MADSL1A3_1.00_000_9_07_I_2009_12_25_02_50_01_2009_12_25_03_40_20_12345_12346_091_85_86_BL1_01.h5
Level1B(segment wise)	MT1MADSL1B__1.00_000_9_07_I_2009_12_25_02_50_01_2009_12_25_03_40_20_12345_12346_091_85_86_BL1_01.h5
Level 1A (orbit wise)	MT1SAPOL1A__1.00_000_9_07_I_2009_12_25_85_091_12345.h5
Level 1A2 (orbit wise)	MT1SAPOL1A2_1.00_000_9_07_I_2009_12_25_85_091_12345.h5
Level 1A3 (orbit wise)	MT1SAPOL1A3_1.00_000_9_07_I_2009_12_25_85_091_12345.h5
Level 1B (orbit wise)	MT1SCAOL1B__1.00_000_9_07_I_2009_12_25_85_091_12345.h5

7.6 DATA FORMAT

7.6.1 Formatting conventions

The MT Level-1 orbit-wise or segment-wise products will be archived in HDF5 format version 5-1.6.4. The HDF is a common data format that has been developed to aid scientists and programmers in storing, transfer and distribution of datasets (products) which are created on various machines and with different software. It also refers to a collection of software, application interfaces, and utilities that comprise the HDF library and allows users to work with HDF files.
HDF is designed by the US National Centre for Supercomputing Application (NCSA) in 1988 and freely available function library by the same name with a set of command line utilities. HDF having the properties like self-describe-ability, extensibility, versatility, flexibility, portability, standardization and most important is that it is available in public domain.

Data dissemination in HDF format:
HDF is a multi-object file format for sharing scientific data in a distributed environment. HDF was designed to address many requirements for storing scientific data, including:

(a) Support for the types of data and metadata commonly used by scientists
(b) Efficient storage of and access to large data sets
(c) Platform independence
(d) Extensibility for future enhancements and compatibility with other standard formats

HDF files are self-describing. The term “self-description” means that, for each HDF data structure in a file, there is comprehensive information about the data and its location in the file. This information is often referred to as metadata. Also, many types of data can be included within an HDF file. For example, it is possible to store symbolic, numerical and graphical data within an HDF file by using appropriate HDF data structures.

7.6.2 MeghaTropiques Data products Distribution requirements

Data Products of MEGHA-TROPIQUES mission are global in nature and is likely to be provided to registered users on internet. A data storage and retrieval system should bear the following features:
1. Support for a Scientific Data and Meta data: Storage of MT data requires support for extremely large and complex datasets and various datatypes. Metadata, supplementary data that describes the basic data, includes information such as the dimensions of an array, the datatype of the elements of the record etc
2. Support for a range of hardware platform: The Hyper Spectral Imager data can be originated from any one machine only to be used later on many different machines. So the aim is to help user’s to access data and meta data on as many hardware platforms as possible
3. Support for range of software tools: Variety of tools, utilities and range of library for reading, writing, searching, analyzing, archiving and transporting the data and metadata are required The all above features are supported by the HDF freeware library. HDF-5.1.6.3 released in 2004, has been used as a reference for reading and writing of formats of MT data products.

7.6.3 Basic Elements of HDF5

HDF5 file appears to the user as a directed graph. The hierarchical structure is represented through nodes of this graph as the higher-level HDF5 objects which are two primary structures: groups and datasets. Beside that each can have associated attributes which are a user-defined HDF5 structure to provide extra information about an HDF5 object..

• HDF5 Group: A mechanism of describing collection of related object designated as grouping structure, containing zero or more groups or datasets, together with supporting metadata. It has two parts, namely, group header (contains a group name and list of group attributes.) and group symbol table (list of the HDF5 objects belong to the group).

• HDF5 Datasets: A dataset is a multidimensional array of data elements, together with supporting metadata. It contains a header and a data array. There are four essential classes of information in any header viz. name, datatype, dataspace and storage layout.

• HDF5 Data types: HDF5 allows following datatypes viz.,

a. Automatic data type: it includes integer, float, floating point numbers, date, time, string, bit field and opaque. Each automatic data type belongs to a particular class and has several properties: size, order, precision and offset.
b. Native data type: these are C-like datatypes that are generally supported by the hardware of the machine on which the library was complied.
c. Compound data type: it represents the collection of several datatypes in a single unit, similar to a struct used in C. The parts of compound data types are called members.
d. Named data type: It is used to share the datatype of a dataset with different datasets which are not defined in HDF library.

• HDF5 Dataspace: The dataset dataspace describes the dimensionality of the dataset. The dimensions of a dataset can be fixed or unlimited or extendible. The properties of dataspace represents the rank (number of dimensions) of the data array, the actual sizes of the dimensions of the array and the maximum sizes of the dimensions of the array.

• HDF5 storage layout: The HDF5 format makes it possible to store data in three ways, (i) contiguous (ii) compact storage & (iii) chunked storage.

• HDF5 Attribute: Attributes are the small data objects describing the nature and/or intended usage of a primary data object, which may be a dataset, group, or named datatype. It has two parts (i) name and (ii) value. The value part contains one or more data entries of the same datatype.

A typical structure of HDF5 objects in HDF5 formatted file is pictorially depicted in Figure : HDF5 objects in HDF5 file

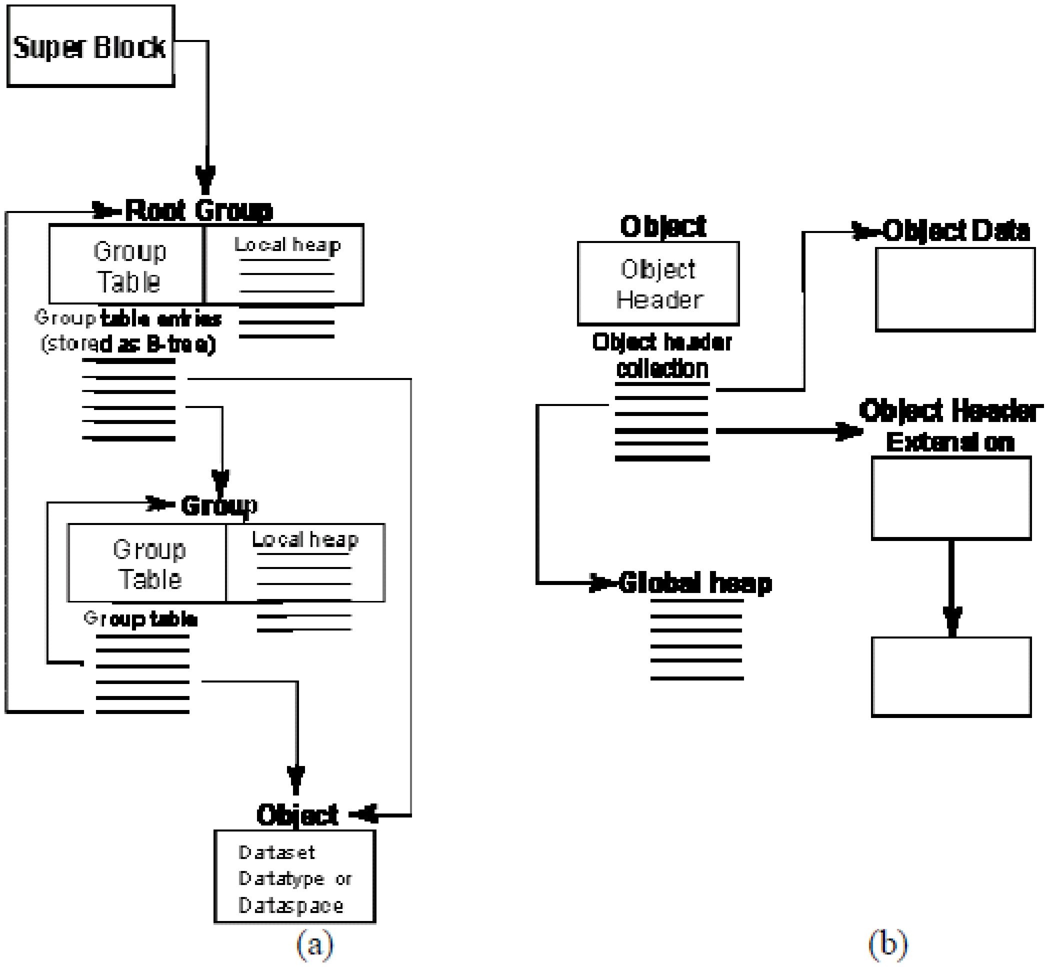


Figure 45 : HDF5 objects in HDF5 file (a) Relationship between root group, other group and objects. (b) HDF5 objects- datasets, datatypes or dataspaces

7.6.4 MT Level-1 file structure

The structure of archived MT Level-1 product file will have a "Science Data Group" within file root group. The Science Data Group will contain all the datasets related to Level-1 product parameters.

The datasets are two dimensional or one dimensional array. The Science Data Group will have few attributes, which are to provide information about the product, they can have different data types namely string type, short integer type etc. Each dataset also can

have few attribute which provides additional information about the physical parameter associated with the dataset e.g. valid range of parameter, units of parameter, fill value of dataset, numeric range of dataset, scale factor to convert dataset numeric values to the physical parameter values etc. The layout of Level-1 product file is shown in Figure as an example of MADRAS Level-1A structure.

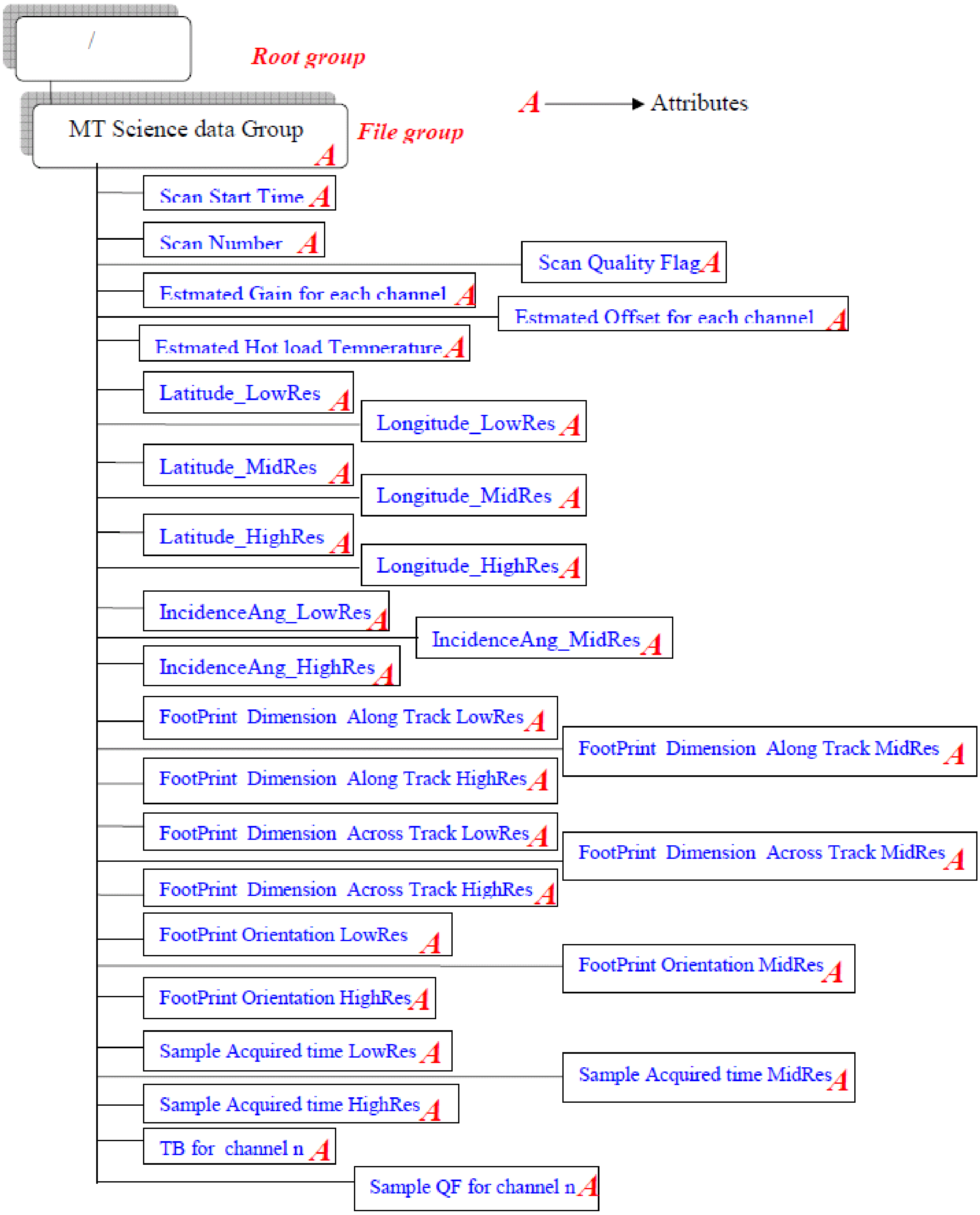


Figure 46 : MT HDF5 file

7.6.5 Data type conventions

The following conventions are used in the format description.

Table 9 : Data type conventions

HDF5 data type	C data type	Description	Valid range
H5T_STD_I8LE	Char	8-bits (1-byte) signed char	-128 to +127
H5T_STD_I16LE	Short Integer	16-bits(2-bytes) signed integer	-32768 to +32767
H5T_STD_I32LE	Integer	Integer 32-bits (4-bytes) signed integer	-2147483648 to +2147483647
H5T_STD_U8LE	Unsigned Char	8-bits (1-byte) unsigned char	0 to 257
H5T_STD_U16LE	Unsigned short integer	16-bits (2-bytes) unsigned	0 to 65535
H5T_STD_U32LE	Unsigned integer	32 Bits (4 bytes) signed integer	0 to 4294967296
H5T_IEEE_F32LE	Float	32-bits (4-bytes) floating-point integer	-1,4 *10-45 to 3,4*10+38
H5T_IEEE_F64LE	Double	64-bits (8-bytes) floating-point integer	-4,9 *10-324 to 1,7 *10+308
H5T_C_S1	Char[]	Array of 8-bit character (string)	

8 USING THE DATA

8.1 OPEN, BROWSE, VISUALIZE DATA

There exists many tools to manipulate HDF5 data. We propose here some tips using HDFView.

The HDFView is a tool for browsing and editing HDF4 and HDF5 files. HDFView allows users to browse through any HDF4 and HDF5 file, starting with a tree view of all top-level objects in an HDF file's hierarchy. HDFView allows a user to descend through the hierarchy and navigate among the file's data objects. The content of a data object is loaded only when the object is selected, providing interactive and efficient access to HDF4 and HDF5 files. HDFView editing features allow a user to create, delete, and modify the value of HDF objects and attributes.
HDFview is available here:
http://www.hdfgroup.org/downloads/index.html
This site gives links to different versions of HDFview, to open HDF4 or HDF5 and also to use the software on either Windows or Linux IO.

The HDFView graphical user interface (GUI) is simple and easy-to-use. First, HDFView was implemented by using the Java 2 Platform, which is machine-independent. The GUI components have the same look-and-feel for all machines. Second, HDFView uses conventional folders and icons to display groups and datasets in a tree structure. Users can easily expand or collapse folders to navigate the hierarchical structure of an HDF file. Third, HDFView shows data content as text (table or plain text) or as image.

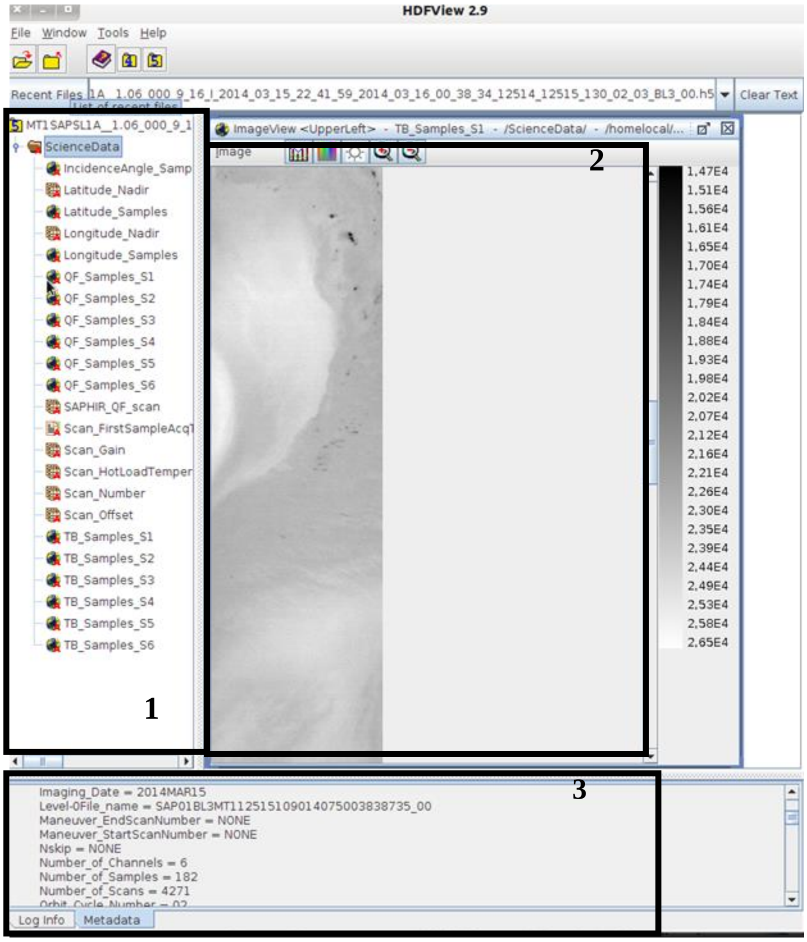


Figure 46 : Example of HDF 5 file as displayed using HDFview software.

There are 2 ways to display data: user may want to have an image (when it is possible) or to have parameter values. Parameters that could be displayed as image have icon like an earth, others are like tables. To select tables, user should right click in the icon and select “open as” and then select “Spreadsheet”.

Quality flags are recorded in binary format. If user wants to display these values in this format, “Table” should be selected on the upper left side of the 2nd window on Figure and then “show binary”.

8.2 GLOBAL ATTRIBUTES

Different information is available in the attribute fields. These information concern versions number, some parameters values... and are usually explicit. We list here global attributes that are given with an SAPHIR HDF5 file.

- Channel_Bandwidth = 200 MHz 350 MHz 500 MHz 700 MHz 1200 MHz 2000 MH
- Channel_CentralFrequency = 183+/-0.2 GHz 183+/-1.1 GHz 183+/-2.8 GHz 183+/-4.2 GHz 183+/-6.8 GHz 183+/-11.0 GHz
- Date_Format = YYYYMMMDD
- FirstScanNumber = 037055490
- Flip_EndScanNumber = NONE
- Flip_StartScanNumber = NONE
- GEO_AuxFile_Version = 9_16
- GRB_AuxFile_Version = 9_16
- INS_AuxFile_Version = 9_16
- Imaging_Date = 2014MAR15
- Level-0File_name = SAP01BL3MT112515109014075003838735_00
- Maneuver_EndScanNumber = NONE
- Maneuver_StartScanNumber = NONE
- Nskip = NONE
- Number_of_Channels = 6
- Number_of_Samples = 182
- Number_of_Scans = 4271
- Orbit_Cycle_Number = 02
- Orbit_EndNumber = 12515
- Orbit_StartNumber = 12514
- Organization_Name = ISRO
- PCS_AuxFile_Version = 9_16
- PRO_AuxFile_Version = 9_16
- Payload_Name = SAPHIR
- ProcessorVersion = ISRO_SAC_DP-MT1-SAPL1A_SW-VER-1.06F000(ISRO_SAC_DP-MT1-SW_PROD_ID-100_01_L1A2_011_01_L1A3-0007000)
- Product_Format = NCSA-HDF
- Product_Format_Version
- Product_Generation_Date = Date corresponding to the orbite begining
- Product_Identification = Name of the file without extention
- Product_Name = Level-1-A-segment-wise
- Property_of_data = ISRO_and_CNES
- QF_Product_%Processed_Scans
- RAD_AuxFile_Version
- SAPHIR_QF_Sample_Definition = 16-bits_array(=0:good/=1:bad): #15:TB_validity #14:sun_glint #13:land/sea_contamination #12:surface_type #11:On/Off_Channel #10:Level-0_Count_Saturated #9:Level-0_Count_poor_value #8:geolocation_estimation #7-6:calibration_flag #5:hot_count_error #4:cold_sky_count_error #3:interpolation_quality #2:Blank #1-0:Ice_flag
- SAPHIR_QF_Scan_Definition = 16-bits_array(=0:good/=1:bad):#15:scan/row_quality_flag_validity #14:pass_type_#13:Scanning_type #12:Scan/Row_error #11:datation_error #10:PRT_Error #9-8:Blank #7:CRC_Status #6:Blank #5-3:Payload_Mode #2-0:Satellite_Mode
- SLC_AuxFile_Version
- SLConf
- Sample_IncidenceAngles
- Sample_Size_AcrossTrack
- Sample_Size_AlongTrack
- Satellite_Name = MEGHATROPIQUES
- Skip_EndScanNumber = NONE
- Skip_StartScanNumber = NONE
- SunGlint_Limits = [0, 30] degree
- Time_Sample_Interval = 0.004576
- UCS_AuxFile_Version = IODD file number

The access to the whole list (and other attributes) can be done easily by selecting, in the window 1 of Figure , on one or other parameter. Attributes are then presented in window 3.

8.3 DATATION

UTC time: it is a time standard based on International Atomic Time (TAI) with leap seconds added at irregular intervals to compensate for the Earth's slowing rotation. Leap seconds are used to allow UTC to closely track UT1, which is mean solar time at the Royal Observatory, Greenwich. The difference between UTC and UT1 is not allowed to exceed 0.9 seconds. The leap second will be handled at level 0 processing.

- Datation of MADRAS L1A samples

As samples are acquired at regular period within a scan line, for each sample, the date is obtained by the date of the first sample given in the header plus the number of instrument sample acquisition period depending on sample position.
For each scan,
Date of MF Sample (n) = Scan_FirstSampleAcqTime + n * (LF_Sample_AcquisitionPeriod))
Date of LF Sample (n) = Scan_FirstSampleAcqTime + n * (MF_Sample_AcquisitionPeriod)
Date of HF Sample (n) = Scan_FirstSampleAcqTime + n * (HF_Sample_AcquisitionPeriod)

- Datation and L1A3/L1A2 MADRAS pixels

For the same reasons as above, date of pixels in the scan is as follows
For each scan,
Date of MF pixels (n) = MF_Scan_FirstPixelAcqTime + n * (Pixel _AcquisitionPeriod))
Date of LF pixels (n) = LF_Scan_FirstPixelAcqTime + n * (Pixel_AcquisitionPeriod)
Date of HF pixels (n) = HF_Scan_FirstPixel AcqTime + n * (Pixel _ AcquisitionPeriod)
The pixel acquisition period corresponds to the time interval between 2 consecutive 10km 89GHz pixels

- Datation of SAPHIR L1A Samples

As samples are acquired at regular period, for each sample the date is derived for the date of the first sample given in the header plus the number of instrument sample acquisition period from first sample to the current sample
Date of SAPHIR sample (n) = Scan_FirstSampleAcqTime + n * (Sample Acquisition Period)

- Datation of SAPHIR L1A2 pixels

For the same reasons as above, date of pixels in the scan is as follows
For each scan,
Date of SAPHIR pixel (n) = Scan_FirstPixelAcqTime+ n * (Pixel Acquisition Period)

- Datation of Scarab L1A/L1A2 samples

As samples are acquired at regular period, for each sample the date is derived for the date of the first sample given in the header plus the number of instrument sample acquisition period from first sample to the current sample
Date of SCARAB sample (n) = Scan_FirstSampleAcqTime + n * (Sample Acquisition Period)

- Datation of SAPHIR/SCARAB L1A3

Date of SCARAB (SAPHIR) (n) = Scan_FirstpixelAcqTime + Pixel Acquistion time(n)
The “pixel acquisition time” corresponds to time interval elapsed from “Scan first pixel Acquisition time”

8.4 LOCATION

8.4.1 Geodetic Latitude

The geodetic Latitude (angular distance between Zenith of each place and equator) will be provided for SAPHIR and MADRAS, and also for the products L1A3 et L1B of SCARAB (combined products).
Convention: -90/ +90° (0° corresponds to equator, +90° is north and -90° is south).

8.4.2 Geodetic Co-Latitude

Geodetic Co-latitude (angular distance between the north pole and the zenith of each place) will be provided for the products L1A and L1A2 of SCARAB.
Convention : 0/180° (0° corresponds to north, 90° is equator and 180° is south).

8.4.3 Longitude

Convention : 0 to 360°, starting from Greenwich (0)) and rotating towards the East.

8.4.4 Longitude and latitude at Nadir

Longitude and latitude at Nadir are computed at the time of the first pixel /sample for L1A and L1A2 products.

8.5 SAMPLE VIEW ANGLE

For instance, we give here SAPHIR view angle attributes:

CLASS = IMAGE
IMAGE_MINMAXRANGE = -4296,4296
IMAGE_SUBCLASS = IMAGE_GRAYSCALE
FillValue = 32767
comment = angle between zenith and line of sight
dimension_label = Number_of_Scans, Number_of_Samples
geolocation_label = Latitude, Longitude
long_name = Incidence angle at the center of samples
scale_factor = 0.01
standard_name = incidence_angle
units = degrees
valid_range = [0.0,51.0]

Values are recorded in an integer format and therefore to compute float values in degree user should multiply read values by 0.01.

8.6 RADIOMETRY

8.6.1 Calibration

8.6.1.1 Scan Hot Load Temperature

Scan Hot Load temperature parameter is the mean value of the hot load that is used to compute the Gain and the Offset. Hot load temperature delivers valuable information on the temperature stability of the radiometers.

FillValue = 65535
add_offset = 0.0
comment = Estimated average hotload temperature of the hot load used for TB calculation
dimension_label = Number_of_Scans
geolocation_label = Scan_FirstSampleAcqTime
long_name = Hot load estimated average physical temperature
min_max = 29097,65535
scale_factor = 0.01
standard_name = Hot Load Temperature
units = Kelvin
valid_range = [0.0, 400.0]

8.6.1.2 Scan Gain

The gain is channel dependant, therefore 9 gain values for MADRAS and 6 values for SAPHIR are recorded for each scan.

Scan Gain attributes for MADRAS are:

FillValue = 3.4E38
add_offset = 0
comment = Estimated gain value applied to TB calculation for each channel in the sequence 18.7H, 18.7V, 23.8V, 36.5H, 36.5V 89.0H, 89.0V, 157.0H, 157.0V
dimension_label = Number_of_Scans, Number_of_Channel
geolocation_label = Scan_FirstSampleAcqTime
long_name = Estimated Gain
min_max = 9.01952, 3.4E38
scale_factor = 1.0
standard_name = Gain
units = instrument counts/Kelvin
valid_range = [5.0, 13.0]

8.6.1.3 Scan Offset

The offset calculated to compute BT values is recorded such as gain values. Attributes are similar.

8.6.2 Brightness temperatures (BT Samples)

For each channel of both instruments SAPHIR and MADRAS, all BT are recorded in an integer format. Values should be multiplied by 0.01 to have values in Kelvins.
For MADRAS, an example of given attributes is as follow:

CLASS = IMAGE
IMAGE_MINMAXRANGE = 9060,65535
IMAGE_SUBCLASS = IMAGE_GRAYSCALE
FillValue = 65535
add_offset = 0.0
comment = TB estimated from raw instrumental measurements (see additional geometrical information in attributes of MADRAS)
dimension_label = Number_of_Scans, Number_of_Samples_HF
geolocation_label = Latitude_HF, Longitude_HF
long_name = Sample brightness temperature of 157.0_H channel
quality_flag = QF_Sample_157.0_H
scale_factor = 0.01
standard_name = brightness_temperature
units = Kelvin
valid_range = [0.0, 400.0]

Note that the valid range is not straight and do not corresponds to values that define quality flags that we describe hereafter.

8.7 QUALITY FLAGS

8.7.1 Quick look

The product level attribute is defined to indicate the percentage of valid scans in the product (see **QF_product_%Processed_Scans** attribute).
It's worth noting that, apart from instrumental or processing issues, the invalid scans may be caused by potential skips existing in data stream with reference to flip transition period, attitude maneuvers for orbit maintenance, attitude maneuvers for payload calibration purpose, attitude bias for payload operation, Gyro calibration.
During Flip, L1data product will not be generated or scans will be declared "invalid". During calibration modes such as MADRAS fixed mode, SAPHIR and SCARAB calibrations modes, the L1 data product will not be generated.

One of the parameters stored in HDF files is the quality flag (QF) that gives information about the quality of each scan separately and, for any scan, on each sample (or pixel). Detailed description of all QF is given in section 8.7.2.
We summarise here the most useful information concerning QF and we suggest a way to use them.

First of all, the different numbers that can be read should be in the binary format. Each of the binary elements is a QF that can be 0 (OK) or 1 (not OK).
Different level of elaboration could be used to select data with the help of QF, this proposition is correct for MADRAS and SAPHIR data and for both L1 and L1A2 products:

- **The use of QF scan only**. The scan/row validity flag is the most important and should be set to 0. If it is set to 1, either BT or Localisation of one or more of the samples are corrupted. Other QF are annexe and could be checked a posteriori.

- **Use of QF sample**. If the user needs to process a maximum of data, QF samples should be processed; this requires more CPU time but it is necessary to avoid bad BT values. Two QF are most important: the BT validity (number 15) and the geolocalisation estimation flag (number 8). Both should be set to 0. Other QF samples should be checked a posteriori to understand more deeply if errors were noticed in the calibration process.

For instance, a typical valid QF value in binary is

```
00110000 00000011
|        |
```

In this case, flag number 15 and flag number 8, that are marked by vertical lines, are set to 0: the BT values are correct and t location is correct as well.

8.7.2 Level-1 Product Quality flags

Two levels of Quality flag are available:

- Scan level or row level Quality flag
- Sample/Pixel /cell level Quality flag

8.7.2.1 Definition of Scan/row level Quality flag

Scan/row level Quality flag will be provided in short integer (16 bit) data type. The bitwise component definitions are provided in sub sections, for MADRAS SAPHIR and SCARAB payloads respectively.
The definition of few scan level quality flags component is as follow:

- Scan Validity / Flag:

This flag is set to value "1" to indicate users to skip these records. The flag is set to 1 in case of missing MADRAS, (SAPHIR or SCARAB) data records, or in case of maneuvers or flip

- Pass Type:

This flag is set to value "1" if pass for the current scan is Descending.

- Scanning type:

This flag is set to "1" if scanning is carried out through backward scanning mode
Remark:
SAPHIR and SCARAB are switched to waiting mode during flip, then no data are downloaded for both instruments.
During Flip, MADRAS is maintained in nominal mode, then flip can be observed in the data flow, but satellite mode flag should be indicating "Flip transition"

- Scan Error:

It is set to value "1" during satellite mode change operation or payload mode change of operation and also in fixed mode

- Row error:

Same as scan error

- Datation error:

It is set to value "1" if time stamping for the record in Level-0 Sensor file is not identified correctly or consistent with date of previous scans

- PRT error:

It is set to value "1" if at minimum one of the Platinum Resistance Thermometer (PRT) is invalid or if dispersion on the data is not as expected

- Encoder error

It is set to value "1" if Encoder error is found; It is applicable to MADRAS Level 0 CRC status. It is applicable to SAPHIR and SCARAB L1A, L1A2 products and will identify bit error in the L0 input data flow.

- Madras correction flag:

Due to a suspected electrical interference, the MADRAS instrument, two types of observations were made:

- Data are affected by random channel mixing. It is found that intrinsic data of the 9 channels are generally not affected but located at different positions in the transmitted data stream. A methodology has been worked out by the CNES and ISRO Project teams for realignment of the data. With this additional processing, a significant amount of data is recoverable. All scans affected and processed for corrections are tagged (refer to bit 8 “Madras correction flag”). This flag is set to value “1” if the data (initial L0 count value) of the scan line have been corrected. This is applicable to MADRAS L1A and L1A2, L1A3
- Another observation leads to invalid data in all the scans, these scans are not corrected but flagged invalid

Each scan is processed independently to avoid any error propagation

- Global consistency of corrections flag (refer to bit 7)

Some final checks are performed on L0 data after final realignment, on each processed scan, to identify some possibly bad corrected scans. This flag is just a warning raised for users.

8.7.2.2 Scan /row quality Flag for MADRAS L1A to L1B

The Scan/row quality flag is 16 bit unsigned integer parameter. Each bit of this parameter is assigned to different Quality flags which are listed in following table:

Table 10 : Scan quality flag for MADRAS

Bit no.	Quality Flag Name	Definition of bit values			
		Bit Value	**Definition**		
15	Scan/row validity flag	Bit = 0	Scan/row valid		
		Bit = 1	Scan/row invalid		
14	Pass type	Bit = 0	Ascending Pass		
		Bit = 1	Descending Pass		
13	Scanning Type	Bit = 0	Forward Scanning		
		Bit = 1	Backward Scanning		
12	Scan/row error	Bit = 0	Ok		
		Bit = 1	Error		
11	Datation error	Bit = 0	OK		
		Bit = 1	Error		
10	PRT error	Bit = 0	OK		
		Bit = 1	Error		
09	Encoder error	Bit = 0	OK		
		Bit = 1	Error		
08	Madras correction flag	Bit = 0	No correction in the scan		
		Bit = 1	Correction applied in the scan		
07	Madras consistency of corrections	Bit = 0	Ok		
		Bit = 1	Error		
06	Blank	Bit = 0			
5-3	Payload mode	Bit 5	Bit4	Bit3	
		0	0	0	Nominal

		0	0	1	Calibration
		0	1	0	Fixed
		0	1	1	Invalid
2-0 (LSB)	Satellite mode	Bit 2	Bit 1	Bit0	
		0	0	0	Valid: No Flip condition equivalent forward configuration
		0	0	1	Invalid: Attitude maneuvers for orbit maintenance
		0	1	0	Invalid: Attitude maneuvers for payload calibration purpose
		0	1	1	Invalid: Attitude bias for payload operation
		1	0	0	Invalid: Attitude maneuvers for payload calibration purpose
		1	0	1	Invalid: Attitude bias for payload operation
		1	1	0	Invalid data: Gyro calibration
		1	1	1	Valid: MADRAS in fixedMode (ground investigation only)

8.7.2.3 Scan/row Quality Flag for SAPHIR in levels L1A to L1B

Table 11 : Scan quality flag for SAPHIR L1A to L1B

<table>
<tr><th rowspan="2">Bit no.</th><th rowspan="2">Quality Flag Name</th><th colspan="4">Definition of bit values</th></tr>
<tr><th colspan="3">Bit Value</th><th>Definition</th></tr>
<tr><td rowspan="2">15</td><td rowspan="2">Scan/Row validity Flag</td><td colspan="3">Bit = 0</td><td>Scan/Row is valid</td></tr>
<tr><td colspan="3">Bit = 1</td><td>Scan/Row is valid</td></tr>
<tr><td rowspan="2">14</td><td rowspan="2">Pass Type</td><td colspan="3">Bit = 0</td><td>Ascending Pass</td></tr>
<tr><td colspan="3">Bit = 1</td><td>Descending pass</td></tr>
<tr><td rowspan="2">13</td><td rowspan="2">Scanning type</td><td colspan="3">Bit = 0</td><td>Forward scanning</td></tr>
<tr><td colspan="3">Bit = 1</td><td>Backward scanning</td></tr>
<tr><td rowspan="2">12</td><td rowspan="2">Scan/row error</td><td colspan="3">Bit = 0</td><td>OK (not applicable to L1A3)</td></tr>
<tr><td colspan="3">Bit = 1</td><td>Error (not applicable to L1A3)</td></tr>
<tr><td rowspan="2">11</td><td rowspan="2">Datation error</td><td colspan="3">Bit = 0</td><td>OK</td></tr>
<tr><td colspan="3">Bit = 1</td><td>Error</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">PRT error</td><td colspan="3">Bit = 0</td><td>OK (not applicable to L1A3)</td></tr>
<tr><td colspan="3">Bit = 1</td><td>Error (not applicable to L1A3)</td></tr>
<tr><td>09</td><td>Blank</td><td colspan="3">Bit = 0</td><td></td></tr>
<tr><td rowspan="2">07</td><td rowspan="2">CRC Status</td><td colspan="3">Bit = 0</td><td>OK</td></tr>
<tr><td colspan="3">Bit = 1</td><td>Error</td></tr>
<tr><td>06</td><td>Blank</td><td colspan="3">Bit = 0</td><td></td></tr>
<tr><td rowspan="6">5-3</td><td rowspan="6">Payload mode</td><td>Bit 5</td><td>Bit 4</td><td>Bit 3</td><td></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>Nominal mode</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>Fixed mode (investigation only)</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>Hot calibration (investigation only)</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>Cold calibration (investigation only)</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>Nadir looking (investigation only)</td></tr>
<tr><td rowspan="2">2-0 (LSB)</td><td rowspan="2">Satellite mode</td><td>Bit 2</td><td>Bit 1</td><td>Bit0</td><td></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>Valid data : No Flip condition equivalent forward</td></tr>
</table>

					configuration
		0	0	1	Invalid data: Attitude maneuvers for orbit maintenance
		0	1	0	Invalid data: Attitude maneuvers for payload calibration purpose
		0	1	1	Invalid data: Attitude bias for payload operation
		1	0	0	Invalid data: Attitude maneuvers for payload calibration purpose
		1	0	1	Invalid data: Attitude bias for payload operation
		1	1	0	Invalid data: Gyro calibration
		1	1	1	Valid data : MADRAS in fixed Mode (ground investigation only)

8.7.2.4 Definition of Sample/Pixel/cell level Quality flag

The sample level quality flag is defined for level-1A, pixel level quality flag for Level-1A2 products, level-1A3 product, and cell level quality flag for level-1B product. These 16bit (short integer data type) flags are implemented to indicate information about the particular sample/pixel/cell.

- *ON/OFF Flag:*

This flag is set to bit value "1" when particular channel is "ON" and working nominally. The parametric value of TB/Radiance value will also be assigned to a fill value if channel is OFF or declared unable for nominal use. This is fully applicable to MADRAS. In SAPHIR/SCARAB, channels can't be switched ON/OFF separately but this could be used for invalid data in case on channel is not working properly.

- Sun Glint:

This flag is set to value "1" if and only if sun glint is present. The flag is not applicable to Scarab. More information are available the appendix page 108.

- Surface type

With reference to a map, the flag identifies if the centre of the sample or pixel is located over Land or over the sea.

- Land/sea contamination

With reference to a map, only if the pixel/sample centre is located over sea (refer to surface type flag) the flag identifies possible land contamination in an area surrounding the pixel centre and having dimensions close to pixels/sample surface. In case the surface type flag is indicating land, the flag land/sea contamination has no significance.

- *TB/Radiance Validity:*

This flag is the representative of TB/Radiance dynamic range specification; it is set to value "1" if corresponding sample TB/Radiance value is out of dynamic range as per specification or in case of any error that might affect the proper use of data (geolocation error, scan invalid, channel OFF, calibration failure …)

- Level-0 Count error

This flag is set to value "1" if the sensor count overpass a threshold (L0 count is saturated) or if sensor count is less than a threshold (L0 count has a poor value)

- TB correction flag :

This is applicable to MADRAS only. Due to a suspected electrical interference, the MADRAS instrument data are affected by random channel mixing. It is found that intrinsic data of the 9 channels are generally not affected but located at different positions in the transmitted data stream.

A methodology has been worked out by the CNES and ISRO Project teams for realignment of the data. With this additional processing, a significant amount of data is recoverable. Not recoverable data will be tagged as filled values. This flag is set to value "00" if no correction is applied to samples, and 11 or 01 or 10 information is given on "complexity of corrections". IF complexity is higher, probability to have incorrect data is getting higher. This flag is a warning to user.

- Geolocation poor estimation

The flag is set to value "1" in case there are some errors in geolocation computations due to lack of OAT for example or during maneuvers etc…

- Calibration flag

The flag may correspond to various situation

  - Calibration Failure: This flag is set to value "11" if calibration process is failed for a scan due to unavailability of valid Hot count data/cold count/PRT counts data. For MADRAS, this may indicate that the channel is saturated and data are not valid
  - Partial calibration: This flag is set to value "10" if some PRT or earth count or cold count error has been encountered In Madras the flag could be set to partial calibration if the calibration data gain, offset have been derivate from previous valid calibration data
  - Degraded gain averaging The flag is set to "01", if calibration data can't be computed averaging over a nominal number of scans
  - Nominal Calibration The flag is set to "00"

- Hot count error:

This flag is set to value "1" if valid hot count data is not available or erroneous. It is valid in case of MADRAS & SAPHIR sensors.

- Cold Sky count error:

This flag is set to value "1" if valid Cold Sky count data is not available or erroneous.

- AGC/AOC loop

The flag indicates if the loop is active or inactive. It is applicable to MADRAS only. Space count error: the flag is set to "1" if the computation of space pixels mean is not erroneous

- Ice flag

With reference to a map, the flag identifies if ice or no ice is possible and when map information is not available

8.7.2.5 Sample/pixel /cell Quality Flag for MADRAS for levels L1A, L1A2, L1A3 & L1B product

Table 12 : Sample/Pixel quality flag for MADRAS

Bit no.	Quality Flag Name	Definition of bit values		
		Bit Value		Definition
15 (MSB)	TB validity	0		Valid
		1		Invalid
14	Sun glint	0		Sun Glint not present
		1		Sun Glint present
13	Land/Sea contamination	0		Land/Sea contamination not exist
		1		Land/Sea contamination exist
12	Surface type	0		Sea
		1		Land
11	ON/OFF channel Flag	0		Channel is ON
		1		Channel is OFF
10	Level-0 Count error	0		No error
		1		L0 count saturated or L0 count poor value
09	Level-0 hot or cold count error	0		No error
		1		Error in cold or hot count
08	Geo-Location estimation	0		Good
		1		Poor/Bad
07 and 6	Calibration Flag	Bit 7	Bit 6	
		0	0	Calibration is ok
		1	1	Calibration Failure
		0	1	Degraded gain averaging
		1	0	Partial calibration
5-4	Complexity of TB correction	Bit 5	Bit 4	
		0	0	No correction
		0	1	Low

		1	0	Medium
		1	1	High
3	Interpolation quality	0		Good
		1		Bad
2	AGC/AOC loop	0		Active
		1		Inactive
1-0 (LSB)	ICE flag	Bit 1	Bit 0	
		0	0	Ice
		1	0	No Ice
		0	1	Spare
		1	1	Ice Map information not available

8.7.2.6 Sample/pixel/cell Quality Flag for SAPHIR in the levels L1A and L1A2, L1A3 & L1B product

Table 13 : Sample/Pixel quality flag for SAPHIR L1A and L1A2, L1A3 & L1B

Bit no.	Quality Flag Name	Definition of bit values		
		Bit Value		Definition
15	Tb Validity	0		Valid
		1		Invalid
14	Sun Glint	0		Sun Glint not present
		1		Sun Glint present
13	Land/Sea contamination	0		Land/Sea contamination not exist
		1		Land/Sea contamination exist
12	Surface type	0		Sea
		1		Land
11	On/Off channel Flag	0		Channel is valid
		1		Channel is unvalid
10	Level-0 Count Saturated	0		Not saturated
		1		Saturated
09	Level-0 count poor value	0		Count is ok – Able to generate TB
		1		Count is poor – Unable to generate TB
08	Geo-Location estimation	0		Good
		1		Poor/Bad
7-6	Calibration flag	Bit 7	Bit 6	
		0	0	Calibration Ok
		1	1	Calibration failure
		0	1	Degraded gain averaging
		1	0	Partial calibration
5	Hot count error	0		OK

		1		Error
4	Cold sky count error	0		OK
		1		Error
3	Interpolation quality	0		Good
		1		Bad
2	Blank	0		
1-0	ICE flag	Bit 1	Bit 0	
		0	0	Ice
		1	0	No ice
		0	1	Spare
		1	1	Ice Map information not available

9 PRODUCT EVOLUTION HISTORY

September 7th 2012 Software Product version V2000

Products	General L1 chain version	SW version	IODD version	Changes
SAPHIR L1_A	V2000	1.03	9_10	Version used for First Reprocessing First reprocessing : Data from October 2011 to August 2012 have been reprocessed in November/December 2012
SAPHIR L1_A2	V2000	1.03	9_10	Version used for First Reprocessing First reprocessing : Data from October 2011 to August 2012 have been reprocessed in November/December 2012
SAPHIR L1_A3	Not yet open to users			
SCARAB L1_A	V2000	1.03	9_10	Version used for First Reprocessing First reprocessing : Data from October 2011 to August 2012 have been reprocessed in November/December 2012
SCARAB L1_A2	V2000	1.03	9_10	Version used for First Reprocessing of data. First reprocessing : Data from October 2011 to August 2012 have been reprocessed in November/December 2012
SCARAB L1_A3	Not yet open to users			

January 2nd 2013: Software product version V3000

Products	General L1chain version	SW version	IODD version	Changes
SAPHIR L1_A	V3000	1.04	9_10	Corrections of generalattributes Correction of flags Corrections of geolocation degraded cases : erroneous latitudes Validation of orbit wise products
SAPHIR L1_A2	V3000	1.04	9_10	Corrections of general attributes Correction of flags Corrections of geolocation degraded cases : erroneous latitudes Validation of orbit wise products
SAPHIR L1_A3	Not yet open to users			
SCARAB L1_A	V3000	1.04	9_10	Corrections of general attributes Correction of flags Corrections of geolocation degraded cases : erroneous latitudes Validation of orbit wise products
SCARAB L1_A2	V3000	1.04	9_10	Corrections of generalattributes Correction of flags Corrections of geolocation degraded cases : erroneous latitudes Validation of orbit wise products
SCARAB L1_A3	Not yet open to users			

January 25th 2013: Software product version V4000 from orbit 6646

Products	General L1chain version	SW version	IODD version	Changes
SAPHIR L1_A	V4000	1.05	9_14	Based on calibration results, correction of Sample location Change on some thresholds for count validity File naming convention + in General attribute name of L0 file added
SAPHIR L1_A2	V4000	1.05	9_14	Based on calibration results, correction of Pixel location Change on some thresholds for count validity File naming convention + in General attribute “nameof L0 file” added
SAPHIR L1_A3	Not yet open to users			
SCARAB L1_A	V4000	1.05	9_14	File naming convention + in General attribute “name of L0 file “added
SCARAB L1_A2	V4000	1.05	9_14	Corrections of relative azimuth coding File naming convention + in General attribute “nameof L0 file” adde
SCARAB L1_A3	Not yet open to users			

February 12th 2013: Software product version V5000 from orbit 6910

Products	General L1chain version	SW version	IODD version	Changes
MADRAS 1A	V5000	1.05	9_14	Initial version
MADRAS 1A2	V5000	1.05	9_14	Initial version
SAPHIR L1_A	V5000	1.05	9_14	No change
SAPHIR L1_A2	V5000	1.05	9_14	No change
SAPHIR L1_A3	Not yet open to users			
SCARAB L1_A	V5000	1.05	9_14	No change
SCARAB L1_A2	V5000	1.05	9_14	No change
SCARAB L1_A3	Not yet open to users			
Orbit Wise Products	V5000	NA	NA	Correction of “first scan validity

AUGUST 10th 2013: Software product version V6000 from orbit 9445

Products	General L1chain version	SW version	IODD version	Changes
MADRAS 1A	V6000	1.06	9_16	Updated Calibration : • Corrections for reflector losses added • Corrections for Scan mechanism speed variations added • Corrections on attributes names and content
MADRAS 1A2	V6000	1.06	9_16	Update Calibration : • Corrections for reflector losses added • Correction on Flag for interpolation degraded case • Corrections on attributes names and content
SAPHIR L1_A	V6000	1.06	9_16	Corrections on attributes names and content
SAPHIR L1_A2	V6000	1.06	9_16	Corrections on attributes names and content
SAPHIR L1_A3	V6000	1.01	9_16	Initial version
SCARAB L1_A	V6000	1.06	9_16	Corrections on attributes names and content • Gain; Aprime change from orbit 7500
SCARAB L1_A2	V6000	1.06	9_16	Corrections on attributes names and co Quality flags correction Gain; Aprime change from orbit 7500
SCARAB L1_A3	V6000	1.01	9_16	Initial version
Orbit Wise Products	V6000	NA	NA	Correction of "first scan validity

DECEMBER 27th 2013: Software product version V7000 from orbit 11403

After a validation period December 12, 2013 to February 28, 2014 and minor bug correction to improve the completeness, ISRO and CNES decide jointly to reprocess all the archive from the first orbit.

So all the data are in V7000.

Products	General L1chain version	SW version	IODD version	Changes
MADRAS 1A	V7000	1.06	9_17	Varying MSM speed correction in rotor angle
MADRAS 1A2	V7000	1.06	9_17	Idem 1A
SAPHIR L1_A	V7000	1.06	9_16	No change in the products (minor bug correction for better completeness)
SAPHIR L1_A2	V7000	1.06	9_16	No change in the products (minor bug correction for better completeness)
SAPHIR L1_A3	V7000	1.02	9_16	Implementation of multiple segment synchronization in a dump for MADRAS wrt SAPHIR/SCARAB. Integration of L1A3 multiple segment in a single dump for SAPHIR/SCARAB
SCARAB L1_A	V7000	1.06	9_16	No change in the products (minor bug correction for better completeness)
SCARAB L1_A2	V7000	1.06	9_16	No change in the products (minor bug correction for better completeness)
SCARAB L1_A3	V7000	1.02	9_16	No change in the products (minor bug correction for better completeness)
Orbit Wise Products	V7000	NA	NA	Implementation of new assimilation scheme for orbit products corresponding to all payloads independently.

Appendix A - Sun glint detection

Sun glint is a phenomena that occurs when the sun reflects off the surface of the ocean at the same angle that the satellite sensor is viewing the surface. To detect this phenomena, a flag will be raised when pixels/samples are likely affected by Sun glint (specular reflectance of Sun light over the observed surface). For a perfectly flat surface and a given viewing geometry, the geometry is described in the 2 figures bellow (Figure and Figure):

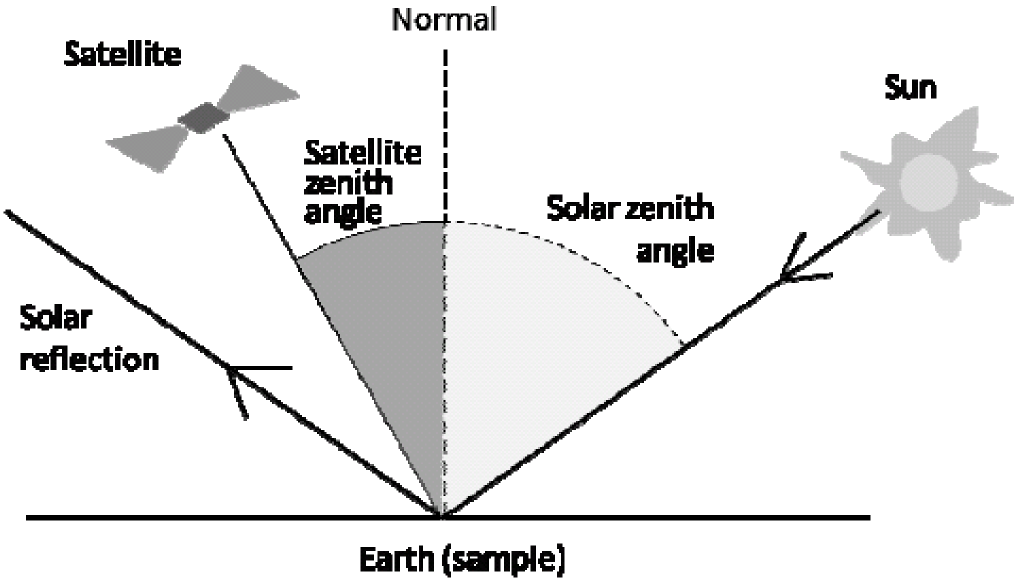


Figure 47 : Sun glint geometry, illustration of solar reflexion vector

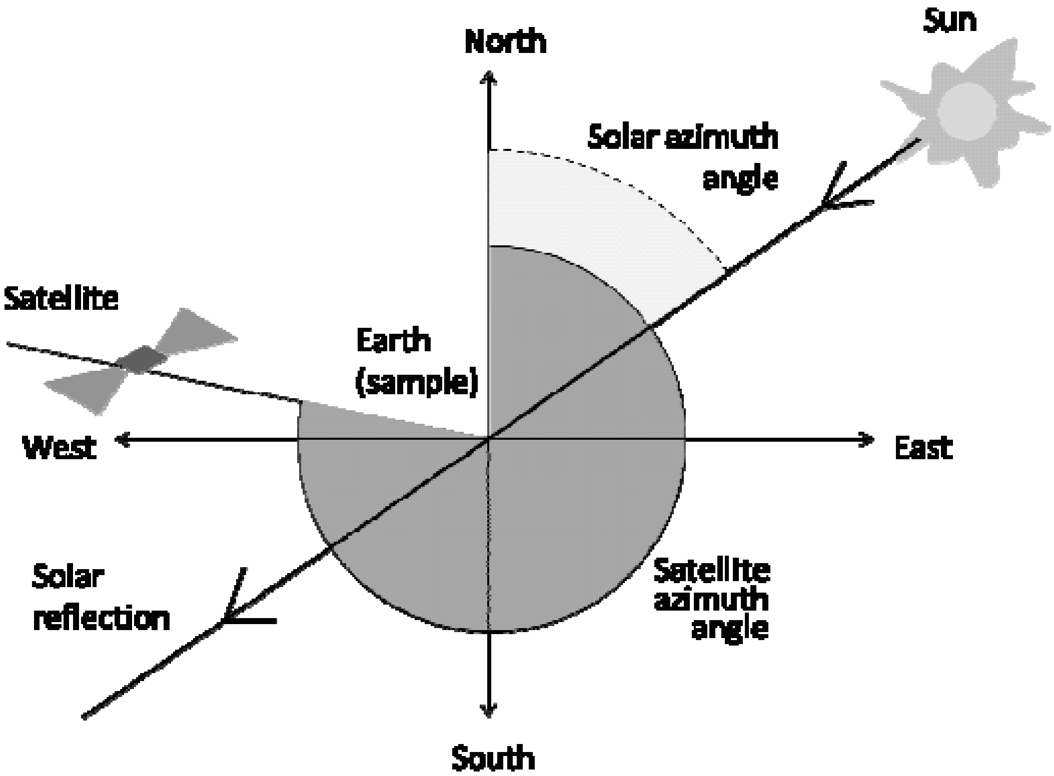


Figure 48 : Sun glint geometry in azimuth plane where sun and satellite angles vectors projected on the plane tangent to the Earth's surface.

Then, for a flat surface, and sun and instrument being considered as points, a sun glint event happens when the following solar and viewing angles are fulfilling the formula below :
Solar_Angle_zenith = Viewing_Angle_zenith
Solar_Angle_azimuth = Viewing_Angle_azimuth – 180°
In fact, as the sun has an angular diameter of 0.53°, there will be a range of specular reflection angle that can reflect light from some part of the sun disc's into the radiometer. In addition, surfaces observed by the instrument are not perfectly flat; they exhibit roughness at very different scales. These many tiny facets of varying slope and orientation will reflect incident sun light in a wide-ranging direction.
Then, to take into account these items, a flag will be raised when computed solar angles are within a cone angle closed to the value of the above formula. The limits will be identified as parameters and could be modified if required after launch.

------------------ End of the document ---------------------