

The SAPHIR humidity sounder

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1. Introduction – objectives of the instrument :

The SAPHIR (Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie) instrument is proposed by IPSL and Observatoire de Paris as part of the MEGHA/TROPIQUES payload, to study the vertical distribution of water vapour in the tropical troposphere, with two particular objectives:

- analysis of the diurnal cycle of the water vapour distribution, to evaluate the vertical transports associated with convective structures at the mesoscale and the large scale, and to understand the scale to scale interactions in the meridional flux;
- study of the role of the space-time distribution of humidity on the development of deep convection.

The measurements will help evaluating the vertical transports associated with convective structures at the mesoscale and the large scale, understanding the scale to scale interactions in the meridional flux, and studying the role of the space-time distribution of humidity on the development of deep convection. An additional aim is to improve parameterizations of humidity related processes in AGCM.

The need of such an instrument on the Megha / Tropiques platform was driven by the scarcity of local measurement in tropical latitudes :

- Existing and other future sounders are in polar orbit, leading to a complex combination of heterogeneous data
- The polar platform sensors will provide an insufficient sampling in the tropics for investigation of convective system life.

2. Scientific requirements for humidity sounding in the tropics:

2.1 Humidity sounding

The atmospheric opacity spectrum (Figure 1) shows a first water vapour absorption line centred at 22.235 GHz, and a second one at 183.31 GHz (pure rotation line). Between these two lines, the water vapour continuum slowly increase absorption by the atmosphere with frequency. Two oxygen lines appear also in this frequency range, which can be used for temperature profiling. The first water vapour line is too low to permit profiling, and its partial transparency is used to obtain the total

columnar content. The second line is high enough to enable sounding in the first 10 – 12 km of the atmosphere. The sounding principle consists of selecting channels at different frequencies inside the absorption line, in order to obtain a maximal sensitivity to humidity at different heights. Previous microwave sounders are SSMT2 and AMSUB, which are operational instruments, have 3 channels within the 183.31 GHz absorption line (at ± 1 , ± 3 and ± 7 GHz), and two window channels, at 150 and 89 GHz. These additional channels give information on the surface and near surface. The SAPHIR sounder is based on the same general principle.

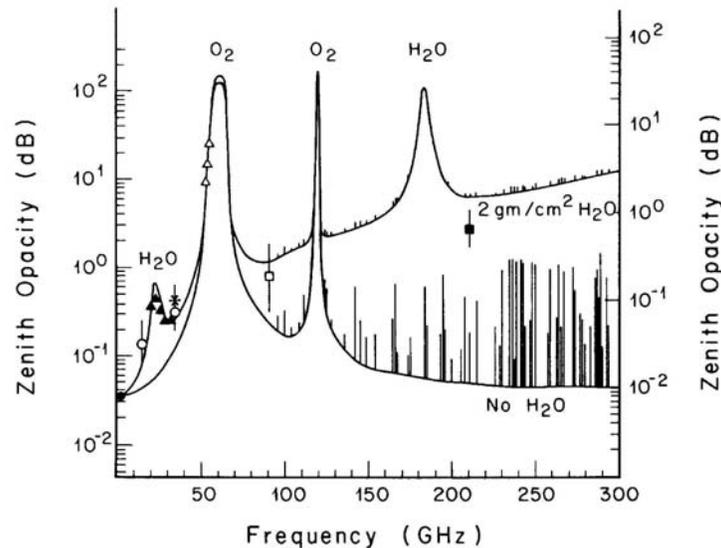


Figure 1 : Atmospheric opacity for a US standard atmosphere. The lower line is with no water vapour, and the upper line is for a 20 kgm^{-2} WV content (assuming an exponential decrease with height). From Waters, 1976.

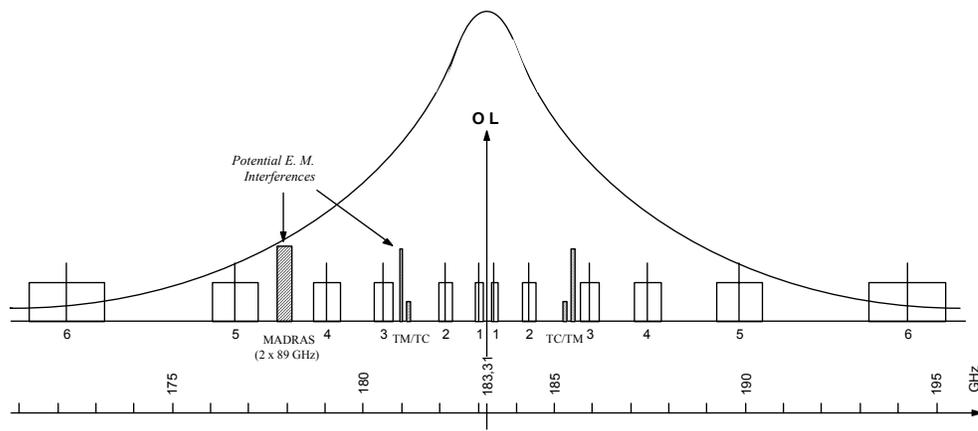
2.2 SAPHIR specifications :

The SAPHIR specifications are based on the following constraints :

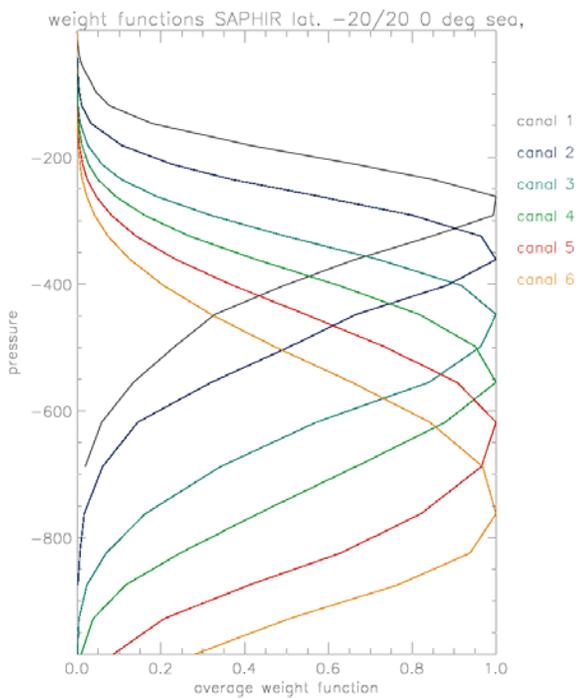
- as many layers as possible within the WV absorption line centered at 183.31 GHz
- horizontal resolution 10km (diameter at nadir)

Constraints on the mass and power, as well as existing experience with near similar sensors (AMSU-B) led to the SAPHIR specifications,. The mass and power constraints suggested us to propose to enlarge the whole bandwidth to 183.31 ± 12 GHz, in order to get information from the low atmosphere, without adding a specific receiver for a window channel (e.g. 150 GHz for AMSU-B).

Phase A scientific studies were performed to optimize the location of channels, accounting for polluted bands (telemetry antenna emission at about 2 GHz, as well as avoiding using the harmonic of the 89 GHz channel of Madras). Figure 2 shows the resulting channel locations and corresponding weight functions, for a mean tropical atmosphere, over sea, at nadir.



a



b

Figure 2 : *a* : 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. *b* : weight functions of the 6 channels for a mean tropical atmosphere, over sea, at nadir. Channels are numbered as shown on figure 1a.

Other preliminary studies allowed us to show that it is not necessary to have a temperature profiler on board the platform, thanks to the weak sensitivity of the SAPHIR channels to temperature in the tropical latitudes.

The final selection of channels was then performed by first building a learning data base, consisting of meteorological profiles (TIGR data base), and brightness temperatures simulated by running a radiative transfer model on the profiles ; then a neural network inversion scheme was applied to retrieve the humidity profile. The method is described in the paper by Franquet et al, *this issue*. The best retrieved profiles were obtained using the channels shown in table 1.

Channel N°.	Central frequencies (GHz)	Bandwidth (MHz)	radiometric sensitivity (estimated by calculation)	polarisation
S1	183,31 ± 0.20	200	1,82 K	H
S2	183,31 ± 1.10	350	1,01 K	H
S3	183,31 ± 2.70	500	0,93 K	H
S4	183,31 ± 4.00	700	0,88 K	H
S5	183,31 ± 6.60	1200	0,81 K	H
S6	183,31 ± 11.00	2000	0,73 K	H

Table 1 : Channel selection for SAPHIR on board Megha/Tropiques. The radiometric sensitivity estimate is detailed in section 3.3. H polarisation means that the polarisation vector at nadir is parallel to the scan direction.

3. Instrument design

The instrument has been designed to respect the Megha/Tropiques general requirements concerning mass, power and data rate, in addition to the scientific requirements, described above. The SAPHIR instrument is a total power type microwave radiometer based on an heterodyne receiver. A general overview of the instrument is shown in figure 3, and we give in the next sections the mean features of the instrument :

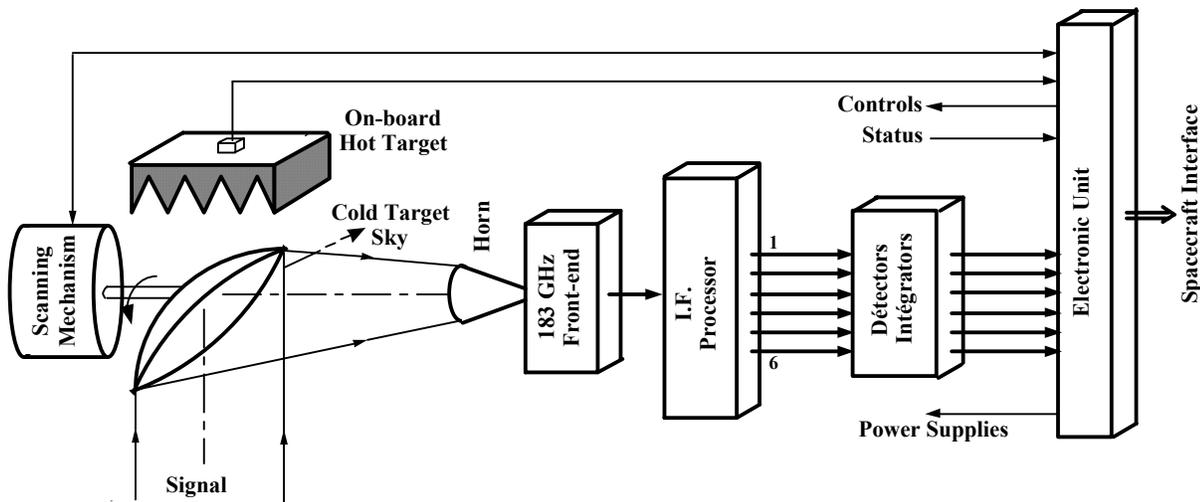


Figure 3 : SAPHIR block diagram, showing the main parts of the instrument, from the antenna (on left) to the satellite interface (to telemetry).

3.1 Antenna

The antenna unit includes the reflector, the shroud, the calibration target and the scanning mechanism. Every scan period, the antenna reflector will perform a entire rotation. A part of the period will be devoted to the collection of earth atmosphere temperature data. During the scan period, when the

reflector is properly oriented, acquisition of cold sky temperature measurements will be done. During an other part of the scan period, acquisition of hot target temperature measurements will also be performed.

The parabolic reflector, inclined at 45 degrees with respect to the rotation axis, corresponds to a projected aperture of diameter 200 mm.. An integral shroud turns with the main reflector to protect the internal target from environment thermal radiation. The received signal is reflected to the high frequency front end by a subreflector, as shown in figure 4.

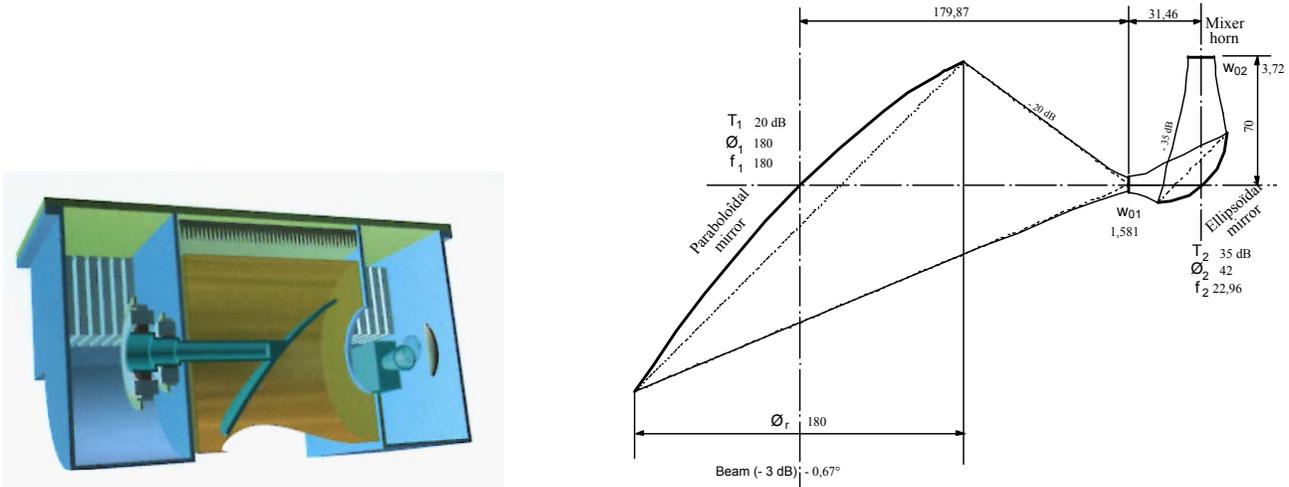


Figure 4 : left : artist's view of a cross section of the SAPHIR instrument, showing the scanning mechanism, and the antenna. Right : geometry of the antenna system (preliminary design for a 180 mm aperture).

3.2 Receiver

The millimeter Front End is composed of a horn, a mixer, a local oscillator, and a wide band low noise amplifier. The horn will focus the free space radiation collected by the antenna reflector. The mixer associated with the local oscillator will make the down conversion of the signal. The resulting signal will be amplified by the low noise amplifier.

The intermediate frequency processor will de-multiplex this wide band signal into 6 signals corresponding to the 6 channels of SAPHIR. Moreover, the IF processor will perform amplification and filtering for each channel. After amplification, analog power detection of the signal is performed for each channel.

The detailed block diagram of the front end and Intermediate frequency Processor is shown in figure 5.

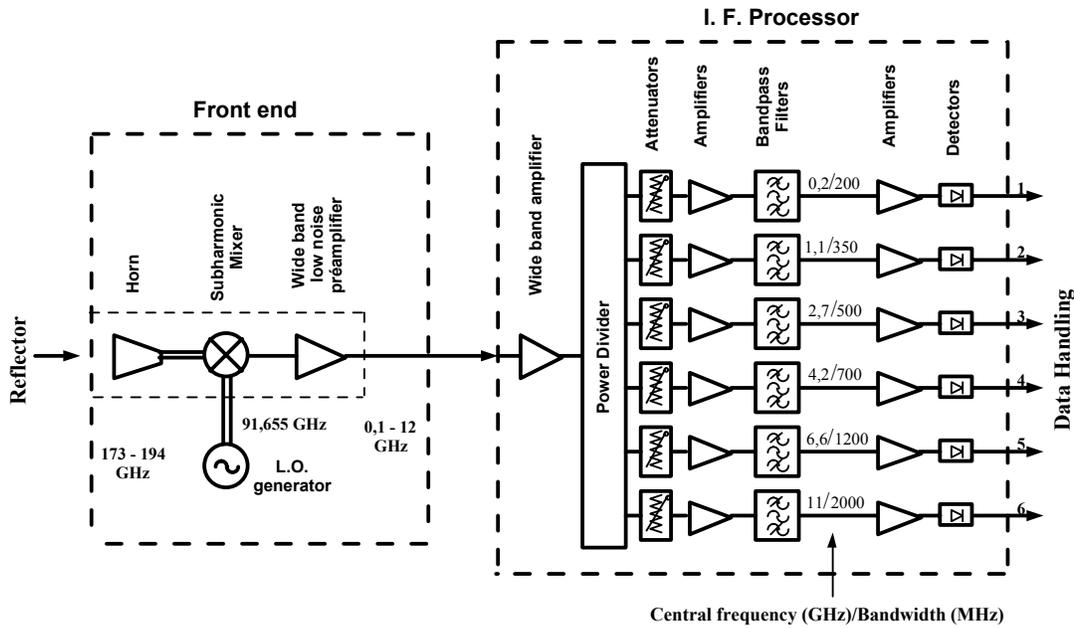


Figure 5 : Block diagram of the SAPHIR receiver

After down-conversion, IF demultiplexing, detection and integration, it is transmitted to the electronic unit, which also controls the scanning mechanism, and measures the calibration target temperature. Calibration is achieved by rotating the reflector at every scan to the hot load and to the sky. The gain variation between two calibration must be lower than 1.10^{-3} dB to get a 0.5K accuracy on the measurement. This requires that the temperature gradient within the IF module must remains lower than 2deg.C/minute.

The data handling and data processing functions will include the following :

- Management of the instrument TM/TC
- Clock generation and synchronisation of the instrument
- Sampling and formatting of radiometer data : The 6 video data flows will be sampled using Analog to digital converters and integrated before being processed for format generation. Radiometer Data will be time tagged. Ancillary data will be added to the data stream.
- Transfer of radiometer data to the platform The data streams will be transferred to the mass memory located in the platform through the 1553 bus interface.

3.3 Radiometric sensitivity

The radiometric resolution or the brightness temperature sensitivity ΔT is defined as the smallest change in brightness temperature at the instrument collecting aperture that can be detected by the radiometer. This parameter is also named “noise equivalent brightness temperature difference NEDT”. The radiometric sensitivity can be expressed by the following formula :

$$\Delta T = T_{sys} \chi \sqrt{\frac{1}{B\tau} + \left(\frac{\Delta G}{G}\right)^2 + X^2}$$

with B = channel pre - detection bandwidth, τ = integration time, G = receiver gain, $\Delta G/G$ gain stability between calibration, $T_{sys} = T_{antenna} + T$ receiver equivalent temperature collected at the

receiver input. X^2 corresponds to the quantization effects and noise contributions on analog signals before digital encoding.

An important requirement is that the sensitivity to humidity be sufficient. Preliminary simulations showed that a 1K error corresponds to an uncertainty of 10% in humidity. Unfortunately, the width of the first channel (close to the line centre) cannot be enlarged, making impossible to reach this value. Table 1 gives the radiometric requirements for a T_{ant} brightness temperature of 300 K. It drives the integration time in order to keep the radiometric sensitivity within the scientific requirement (assuming that the absolute calibration will not add any significant varying error), to a nominal integration time for all the channels is 7,34 ms.

3.4 Field of view : antenna rotation and footprint geometry

To obtain a large swath coverage when observing the scene of interest, the sampling strategy combines the satellite motion (along track) and the across track scanning of the narrow beam of the instrument antenna.

The antenna main beam shall perform a Nadir scanning over the swath in the cross-track direction at a constant periodicity of 1,639 s (about 36.6 revolutions per minute). This value is derived from satellite ground track speed, footprint size requirement with 0 to 10% overlapping. The surface will be observed over the swath with an incidence angle less than 55° , to keep it smaller than the Brewster angle. It leads to a swath of about 1700 km. Figures 6 and 7 shows the scanning geometry and resulting footprints.

In order to comply both with the integration time required to keep the radiometric sensitivity small enough, and with the scan to scan period, it is necessary to slow the motor rotation during the earth view, and accelerating it while observing the calibration targets. Due to technical restrictions (the acceleration of the motor rotation is limited), we have chosen to scan the Earth between Nadir - 42° and Nadir + 42° .

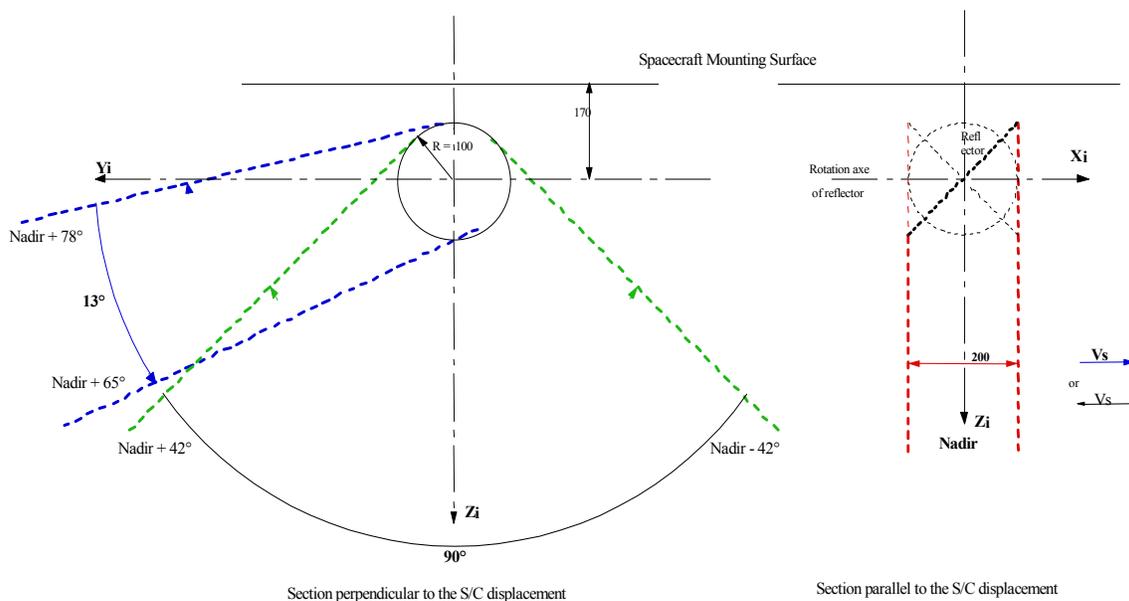


Figure 6 : scanning geometry within the reflector rotation, showing the earth field of view and the cold sky view. The X axis is parallel to the satellite track, and Z in downward to the earth. The view of the cold sky is above the earth limb and below the solar panel.

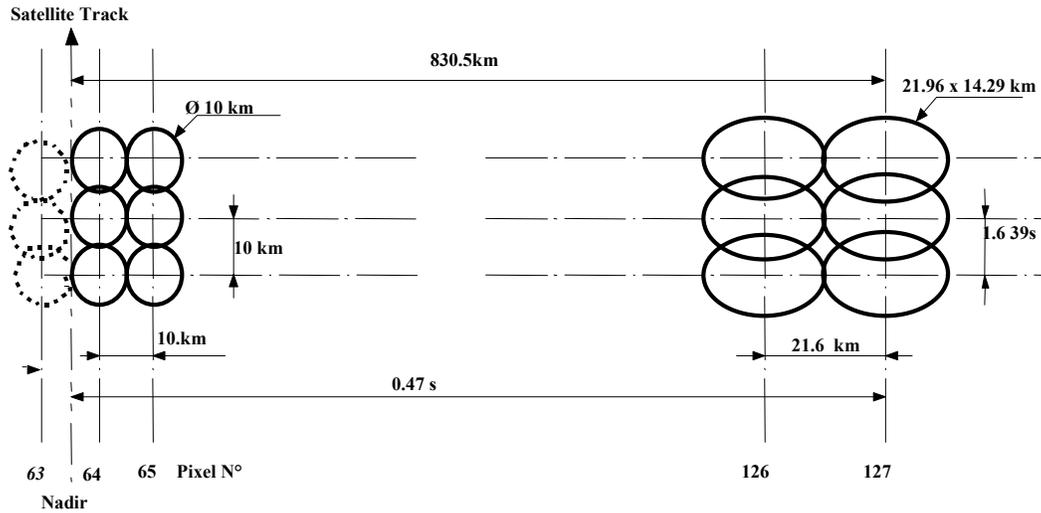


Figure 7 : footprints from nadir to swath limit (half swath). The footprint shape becomes elliptic due to the increased incidence angle. 3 successive scans are shown here.

The footprint requirements are summarized in table 3.

Pixel interval /y (nadir)	10 km
Earth pixel Number of pixels (Earth)	128
Incidence angle (ground)	≤ 50 deg.
Swath	1661 km
Extreme pixel size /x	21.96 km
Extreme pixel size /y	14.29 km
Average pixel size /x	13.3 km
Average pixel size /y	11.3 km
Average pixel size	12.3 km
Scan interval (/x)	10 km
Rotation period	1.639 s
Rotation frequency	0.61 Hz

Earth observation duration	0.94 s
Integration time	7.34 ms

Table 3 :swath and earth field of view requirements for SAPHIR. /y is the scan direction (across track) ; /x is the track direction

4 Data processing and scientific use :

The geophysical data processing will consist of retrieving the humidity profiles in 6 layers between the surface and 100 – 200 hPa. Due to the instrument specifications, the data processing will be based on SAPHIR measurements and auxiliary data :

- a temperature profile will be used (from a global meteorological model, as ECMWF), as an input data. A preliminary sensitivity study has shown that a rather weak accuracy on this profile is sufficient ;
- the precipitable water (water vapour total content), derived from SAPHIR itself and from MADRAS (over ocean at least), will be used to optimize the distribution of retrieval layers in the vertical (the weight functions shift vertically up or down depending on the humidity content of the atmosphere).
- The major problem lies in the cloud detection and identification. A first method to get this information is to perform cloud classifications on the geostationary satellite imagers. Such classification (see Sèze and Desbois, 1987) would provide the cloud type and top altitude. In case of low clouds (boundary layer), upper layer channels will be processed to get the humidity profile above clouds. In case of high ice clouds (cirrus), it is expected that the SAPHIR data can be processed, assuming that the cirrus effect can be accounted for. In case geostationary satellite cannot be processed, an alternative method should be to use MADRAS cloud liquid water content as an cloud detector (but with no clear indication of the cloud type). Note however that the MADRAS low frequency channels have a 40 km resolution, compared with the 10km nadir SAPHIR footprint.

Combined use of SAPHIR data with MADRAS and Scarab will then be stronger in science analyses, as well as with MSG (as suggested in figure 2) : mesoscale water vapour around clouds, possibly information about ice scattering at the cloud top, contribution of the scene analysis for Scarab. Direct coupled retrievals of MADRAS and SAPHIR are also envisaged.

An alternative procedure for retrieving water vapor information from the SAPHIR sounder is also envisioned. It consists in the retrieval of weighting function weighted mean relative humidity from the individual channels. Such an approach is emphasized in Roca et al. (2001b, this issue). While such a layer products will not meet the profile inversion requirements in terms of vertical localisation, it offers a complementary exploitation of the sounder for process oriented analysis. Furthermore, it will be less influenced by the presence of low level clouds, as the upper tropospheric humidity can be retrieved independently of what is below.

In addition to humidity profile retrieval, SAPHIR will be used tentatively to complement MADRAS for cloud characterization, following some recent works which have evidenced the interest of high frequencies for ice clouds (Bennartz and Bauer, 2001, Bennartz et al, 2001).

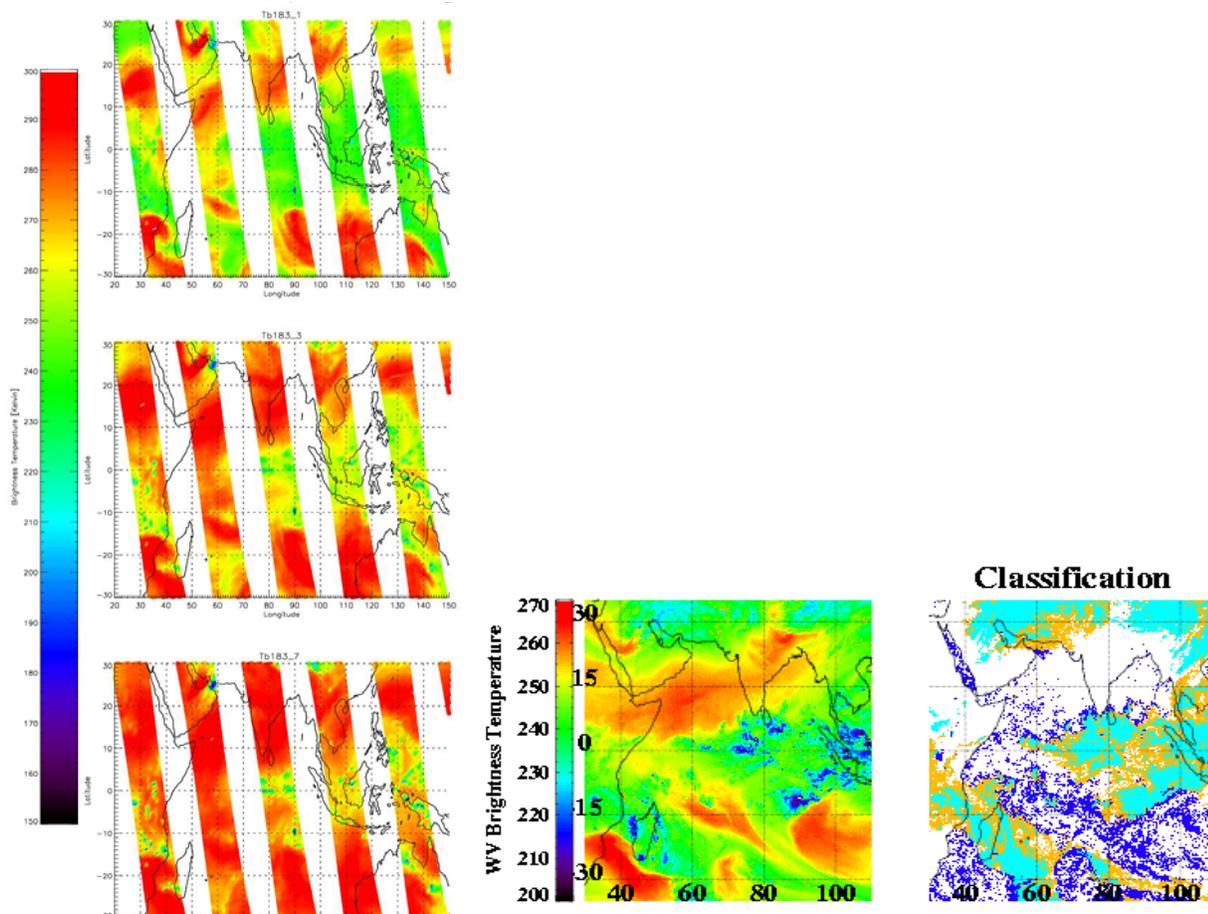


Figure 2 : SSMT2 profiling channels (left) and Meteosat water vapour channel and cloud classification (right). Example of data obtained during the Indoex field experiment in 1999, to evidence the interest of a combined use of sounder and geostationaries to map and monitor the 3D water vapour field from the small scale (convective systems) to large scale (intertropical variations). (from Roca et al., 2001)

4 Conclusions

The SAPHIR humidity sounder is designed to provide the humidity profile in the tropical latitudes, in complement of MADRAS and SCARAB measurements. Its specifications have been chosen in order to get the humidity profiles with acceptable accuracy and horizontal / vertical resolution, providing instrumental constraints due to accommodation on the platform, and technical feasibility. The specifications described in section 3 and summarized in tables 2 and 3 are to be refined during phase B. In particular, some critical issue have to be better examined :

- front end performances and low noise amplifier total bandwidth
- electronic unit design, including data compression to keep the data rate within the Megha/Tropiques requirements
- ground segment definition and preliminary design

Some breadboards will be made to check if the technical performances are compliant with the requirements (antenna reflector, hot load, mixer and low noise amplifier, IF processor limited to 3 channels, electronic unit).

The other major field of activity in the next years will be the geophysical data processing to derive humidity profiles in clear and partially cloudy situations. AMSUB will serve as “simulator” to prepare the SAPHIR data processing. First radiative transfer simulations will be performed to study the sensitivity of AMSUB/SAPHIR channels to land surface emissivity variations and to clouds. Then the data processing strategy will be established in the framework of the Megha/Tropiques global scientific objectives.

Central frequency	183.31 GHz
I.F. bandwidth	± 10 GHz (goal: ± 12 GHz)
Frequency resolution	6 channels from 200 MHz to 2 GHz
Total frequency stability	± 20 MHz
Sensitivity	From ≤ 2 K (200 MHz) to ≤ 1 K (2 GHz)
Linearity (over the dynamic range)	10^{-4}
Calibration accuracy	≤ 2 K (2 different radiation targets)
Swath	> 1500 km (incidence angle 0 to 50 °)
Spatial resolution (nadir, - 3 dB)	≤ 10 km
Beam efficiency	95% in 2.5 lobe at -3 dB
Side lobes	≤ -30 dB : mainlobe center
Data rate	≤ 8 kb/s
Total pointing accuracy	$< 0.07^\circ$ over 1 second, $< 0.5^\circ$ over 10 minutes

Table 2 : SAPHIR main requirements

PARTS	Mass (kg)	Power (W)
Rotating part	0.7	
Scanning, calibration target	2.2	2.9
Front end	0.8	4.7
I F electronics	1.9	10.3
Electronic unit	2.1	3
Supplies, harness	3.8	4.1
Mechanical structures	3.2	
Margin (20 %)	3.0	5
TOTAL	17.7 kg	30 W

Table 3 : Mass and power budgets

Références :

Sèze and Desbois, 1987, cloud cover analysis from satellite imagery using spatial and temporal characteristics of the data journal of climate and applied meteorology 26 (2): 287-303

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