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# HEMERA

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## User's Manual for Sounding Balloons



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## 1 INTRODUCTION

HEMERA is a balloon infrastructure project, funded by the European Commission within its programme Horizon 2020. The project is coordinated by the French Space Agency (CNES) and involves a consortium of 13 partners from six European countries and Canada.

The HEMERA project will offer free of charge balloon flights to the user community. Twenty Sounding Balloon flights are foreseen from mid-2019 to late 2021. The flights of these Sounding Balloons, each carrying an experiment gondola with a 3,0 kg maximum mass of scientific or technologic payload, are planned from Aire sur l'Adour (South West of France). Launches will be operated by the French Space Agency.

Sounding balloons (SB) are small expandable balloons, usually made of latex. The volume of these balloons expands during its ascent until the pressure is too high and the balloon bursts which also means termination of the flight. The ascent speed, of around 5 m/s, allows to reach altitudes of 30 ÷ 35 km in 1.5 to 2 hours. After the balloon disintegration, the experiment gondola descends with a parachute, with a speed of 6 m/s at ground landing. The experiments are recovered and can be reused. During the balloon flight and the parachute descent, wind and atmospheric pressure, temperature and humidity are recorded and transmitted in real time via a weather radiosonde. Experimental data must be recorded on-board, to be collected after the payload recovery.

## 2 ALWAYS READ THIS

There is a lot of useful information in this manual. Make sure that you have found and understood the meaning of the following information.

### **Flight Support Application**

This is a document that the experimenter must complete by indicating their entries and their requests for the SB flight.

### **Experiment safety**

If there are hazardous items such as chemicals, lasers, radiation, pressure vessels etc. included in the experiment gondola, there may be a need for further investigation by the CNES Safety Authority. This may take some time and should be done early in the preparation of the flight.

### **Transceivers**

All experiment gondola that emits or receives RF must have permission by the CNES Campaign Manager.

### **Planning**

It is essential to have a build-up plan and checklists for your experiment. Without these, there is a significant risk of failures and delays during the campaign week.

### 2.1 Definitions

The SB system consists of the following components:

- Latex balloon (mass = 1200 grams, 2000 grams or 3000 grams according to the mass of experiment gondola.
- Separator: just when balloon naturally bursts, it ensures the separation between the balloon and the experiment gondola, to eliminate the risk of entanglement of the parachute by the flaps of balloon.
- A parachute to ensure a vertical speed of less than 7.0 m / s at the ground landing.
- CNES equipment for the flight tracking: a meteorological radiosonde (transmitter frequency in the range from 401 MHz to 404 MHz), a geolocation unit (GPRS/GSM or Iridium) ensuring a precise localization on the ground after landing, and a tri-axis accelerometer.
- The experiment gondola, with a maximum mass of 3,0 kg.
- The Control Center to track the vehicle during flight, with telemetry receiving equipment (no capability of remote control).

**Hierarchy:**

- | Flight Segment (aerostat)
  - | | Latex balloon
  - | | Separator
  - | | Parachute
  - | | Experiment gondola
  - | | CNES equipment (part or not of the experiment gondola)
  - | |
  - | |
- | Control Center

**2.2 References**

NOTE: The ECSS references link directly to the documents themselves, firstly though, in order to access the documents, registration is required (this is easy and free for the user).

- [1] ECSS, *Project planning and implementation*, ECSS-M-ST-10C (ESA Publications Division, 6 March 2009)  
<http://ecss.nl/standard/ecss-m-st-10c-rev-1-project-planning-and-implementation/>
- [2] ECSS, *Manual soldering of high-reliability electrical connections*, ECSS-Q-ST-70-08C (ESA Publications Division, 6 March 2009)  
<http://ecss.nl/standard/ecss-q-st-70-08c-manual-soldering-of-high-reliability-electrical-connections/>
- [3] ECSS, *Crimping of high-reliability electrical connections*, ECSS-Q-ST-70-26C Rev 1. (ESA Publications Division, 15 March 2015)  
<http://ecss.nl/standard/ecss-q-st-70-26c-crimping-of-high-reliability-electrical-connections/>
- [4] ECSS, *Data for selection of space materials and processes*, ECSS-Q-70-71C (ESA Publications Division, 15 October 2014)  
<http://ecss.nl/standard/ecss-q-st-70-71c-materials-processes-and-their-data-selection/>

## 2.3 Abbreviations

ANFR	Agence Nationale des FRéquences
ATC	Air Traffic Control
CNES	Centre National d'Etudes Spatiales
FSA	Flight Support Application
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
ICAO	International Civil Aviation Organization
PC	Personal Computer
PPE	Personal Protection Equipment
QA	Quality Assurance
RF	Radio Frequency
Rx	Reception
SB	Sounding Balloon
TBD	To Be Determined
Tx	Transmission



### 3 SB FLIGHT OVERVIEW AND MILESTONES

#### 3.1 Organization

The technical support in the integration and testing phase, as well as the campaign management and operations, is provided by CNES.

The evaluation of the experiment proposal and the financial support for the subsidence in the balloon launch site (Aire sur l'Adour / France), on the basis of 2 persons during 5 days, are the responsibility of the HEMERA consortium.

Each selected experiment gondola will get a dedicated SB flight.

#### 3.2 SB flight ticket

In the HEMERA SB "flight ticket", the following services are included:

- General management and planning of HEMERA flight.
- Provision of launch vehicle and subsystems necessary for a SB flight, with recovery.
- Provision of laboratory facilities at Aire sur l'Adour (CNES launch site).
- Daytime or night-time launch, tracking and recovery of the experiment gondola.
- Real-time acquisition of meteorological & position data, with provision to the experimenter after the flight.

#### 3.3 Experimenter's role

The primary responsibility of the experimenter is to ensure the timely delivery of their experiment gondola, in good order. This responsibility extends to defining the investigation, providing the instrumentation, timely processing of data, and publishing of results. The experimenters must also contribute to establishing and conducting the operational programme through correspondence and fulfilment of the documentation requirements.

Before flight, the experimenters must successfully demonstrate through testing, simulation and documentation that their experiment is fit and safe for flight.

The experimenter is responsible for developing and providing the experiment gondola and necessary support equipment. They are also responsible for ensuring that the experiment gondola payload meet safety requirements.

#### 3.4 Planning

T0 - 14 m	Call for experiment proposal.
T0 - 8 m	Selection of experiments & information for the applicants.
T0 - 6 m	Experiment documentation submitted.
T0 - 1 m	Experiment Acceptance Review.
T0	Earliest date of the SB flight at CNES Aire sur l'Adour (could be later in the year).
T0 + 1 m	Completion of the Operational Evaluation Form for the implementation of the flight.
T0 + 6 m	Provision of technical / scientific report by the experimenters.

#### 3.5 Experimenter documentation requirements

This documentation shall be provided by the experimenter to the CNES Manager of Sounding Balloon flights.

### **3.5.1 Experiment design documentation**

This documentation provides definition about the size, weight, and mechanical aspects of the experiment gondola, and details the mechanical interface with the flight train.

The primary purpose of this documentation is to allow verification that mechanical and electrical design requirements are met in the design of instrument modules (Cf. §5.3 & §5.4).

### **3.5.2 Flight Support Application**

This application form (see summary in appendix 1), which must be fulfilled by the experimenter, is a reference document, and care must be taken that information is correct and clear to avoid errors are made concerning the experiment gondola

This document gives a complete description of the specific SB flight, including payload information, a list of hazardous materials, experiment requirements on the launch operations, participants expected, etc. The compliance matrix for CNES requirements must be provided in this document. This is an important document used to prepare and operate the SB flight.

### **3.5.3 Recovery Sheet**

During the campaign, the recovery team requests a single A4 sheet containing dedicated experiment recovery instructions. This recovery sheet shall explain the handling after landing in limited text with colored pictures of the experiment (e.g. how to switch off power supply, disarm the experiment, etc. – see example in Appendix 3).

### **3.5.4 Preliminary Flight Report Documentation**

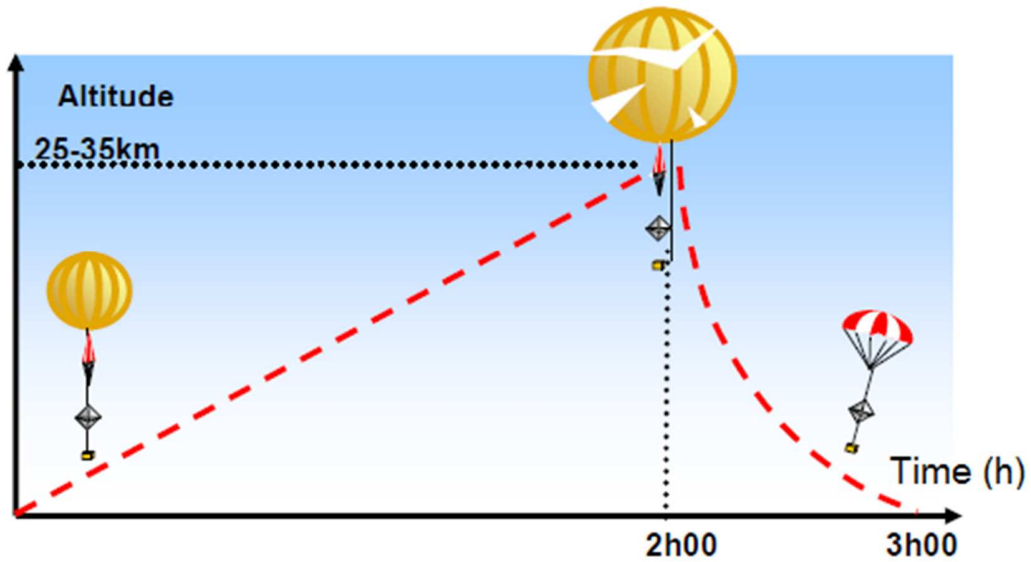
A post-flight report document for inclusion in the Flight Report must be produced following each launch. The experimenter must submit only one to two pages regarding performance of its experiment during the flight and preliminary results when possible. This must be submitted two weeks after the SB flight (the experiment team is expected to present a preliminary performance overview whilst at the campaign following the flight). The finalized version of this document will be delivered 4 months after the SB flight.

### **3.5.5 Failure Analysis Report**

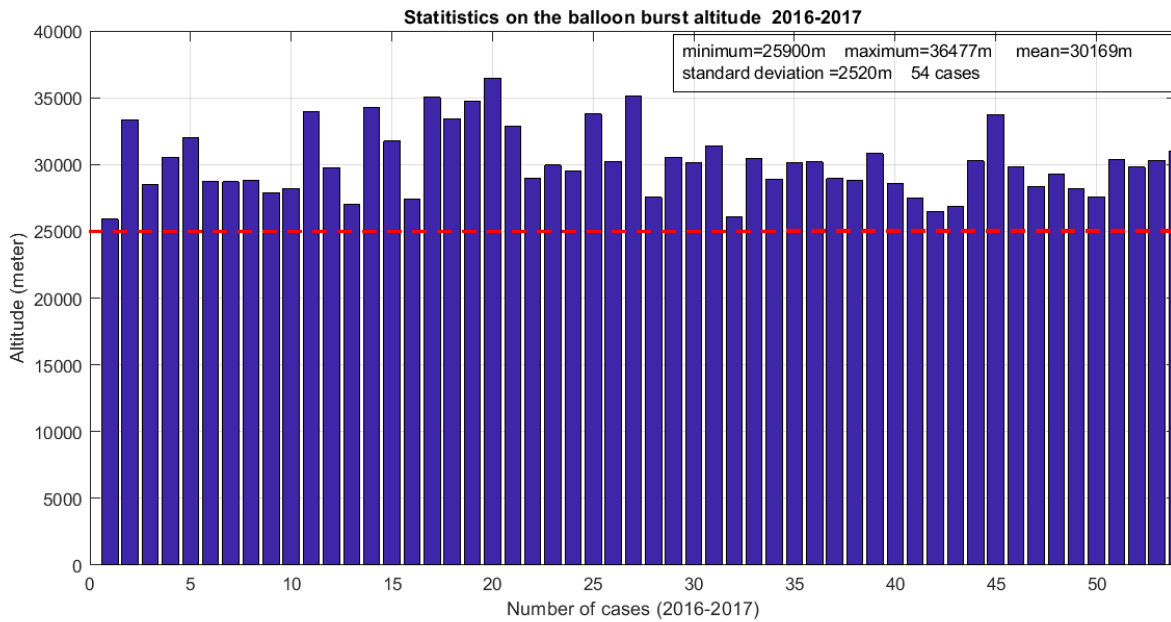
In case the experiment gondola does not perform as expected resulting in a limited scientific or technologic outcome, the experimenter is required to perform a failure analysis

## 4 SB SYSTEM

### 4.1 Altitude profile of a Sounding Balloon flight

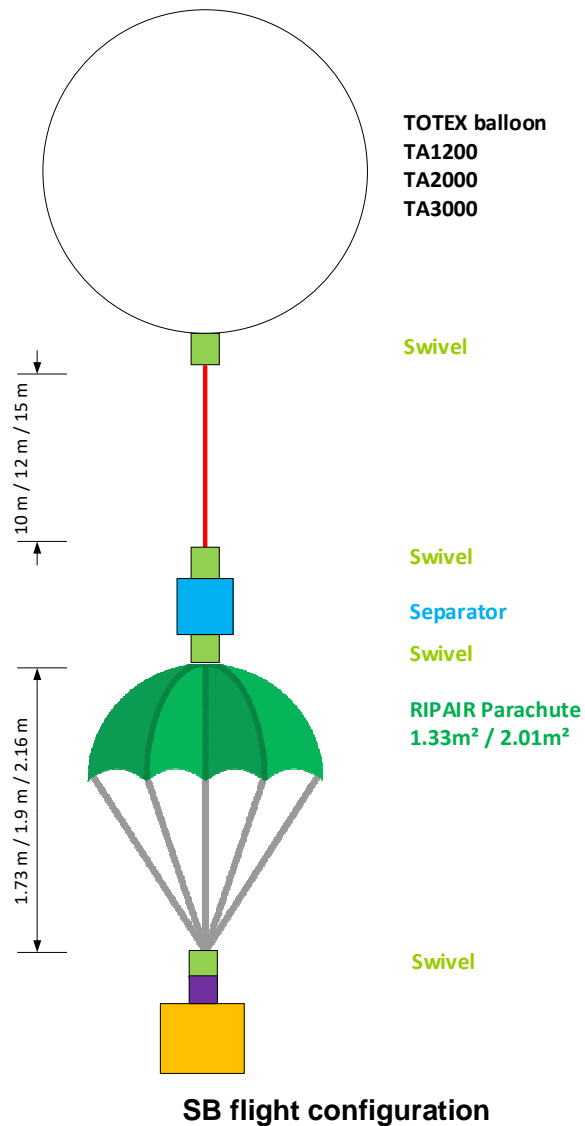


Sounding Balloon typical flight profile



Statistics on the balloon burst altitude

## 4.2 Flight configuration



## 4.3 Payload Gondola

The experiment gondola is provided by the experimenter.

## 4.4 CNES Flight Units

The CNES flight units are as follows:

- Meteorological radiosonde (MODEM M10) to measure the atmospheric parameters (pressure, temperature and humidity) and the GPS position, with a data transmission to the Control Centre in real time.
- A geotracer (TK-102 / GSM or SK50 / Iridium) to locate the gondola after landing for the recovery.
- A 3-axis accelerometer data logger (MSR 165) to measure the accelerations generated by the parachute opening and by the landing phase.



**Radiosonde MODEM**



**Geotracer SK50**



**Geotracer TK 102**



**3-axis accelerometer**









The CNES units (total mass less than 0.200 kg) will be either accommodated into the experiment gondola according to the available mass in regard to the maximum limit of 3.0 kg, or accommodated into a 2<sup>nd</sup> independent gondola.

#### 4.5 CNES Control Centre

The CNES Control Centre consists of the Modem SR10 TM receiving station with its associated antennas.

It ensures:

- The calibration of the radiosonde before launching.
- Receipt and decoding of data, allowing real-time flight tracking.
- Transfer and archiving on PC (Eoscan software) meteorological data from the radiosonde.

 <p><b>EOSCAN</b> Software for data acquisition</p>	 <p><b>SR10 Ground Receiver</b></p>	 <p><b>Groundcheck for Radiosonde calibration before launch</b></p>
 <p><b>Turnstile Antenna 400 MHz</b> (Optional / recommended for specific subtropical areas)</p>	 <p><b>Upper-Air sounding system</b> Desktop or Laptop</p>	 <p><b>Omnidirectional Antenna 400 MHz</b></p>
 <p><b>GNSS Antenna (GPS,...)</b></p>	 <p><b>User's manual</b> Installation &amp; Maintenance manual</p>	

## 5 EXPERIMENT DESIGN

### 5.1 Environmental factors

#### 5.1.1 Altitude

The maximum altitude will be between 30 km to 35 km (natural burst of balloon).

#### 5.1.2 Speeds, acceleration & shocks

##### Ascent

- Speed: average 5 m/s.
- Duration: as much as 2 hours.

##### Descent

- Free fall (after balloon burst) 4 to 6 seconds followed by the parachute opening, inducing accelerations deceleration (- 4.5 g vertical and  $\pm 1.1$  g lateral).
- Decrease of the vertical speed with the increasing of the atmospheric pressure, reaching at the most 7.0 m/s at ground level.
- Duration: approximately 35 minutes.

##### Landing

- Vertical speed: 7.0 m/s maximum.
- Wind speeds of 20 ÷ 40 km/h can be encountered at landing.
- Up to 35 g on impact.
- Landing nominally on land, with a low risk of water landing.

#### 5.1.3 Pressurization & depressurization

The experiment gondola shall be designed to be able to support depressurization during ascent and pressurization during descent. Then venting path shall be designed to avoid the contamination of sensors.

### 5.2 Thermal environment

#### 5.2.1 Thermal environment conditions

Compliance with the operating temperature range of electrical systems must be guaranteed. If necessary, temperature control systems will have to be installed. Detailed thermal environment characteristics is specified in appendix 2.

#### 5.2.2 Pre-launch phase

There is little thermal stress on the equipment while in the integration hall because work areas are heated or cooled as necessary. In normal conditions, the preparation of the experiment gondola is done at a room temperature of approximately  $20 \pm 5$  °C.

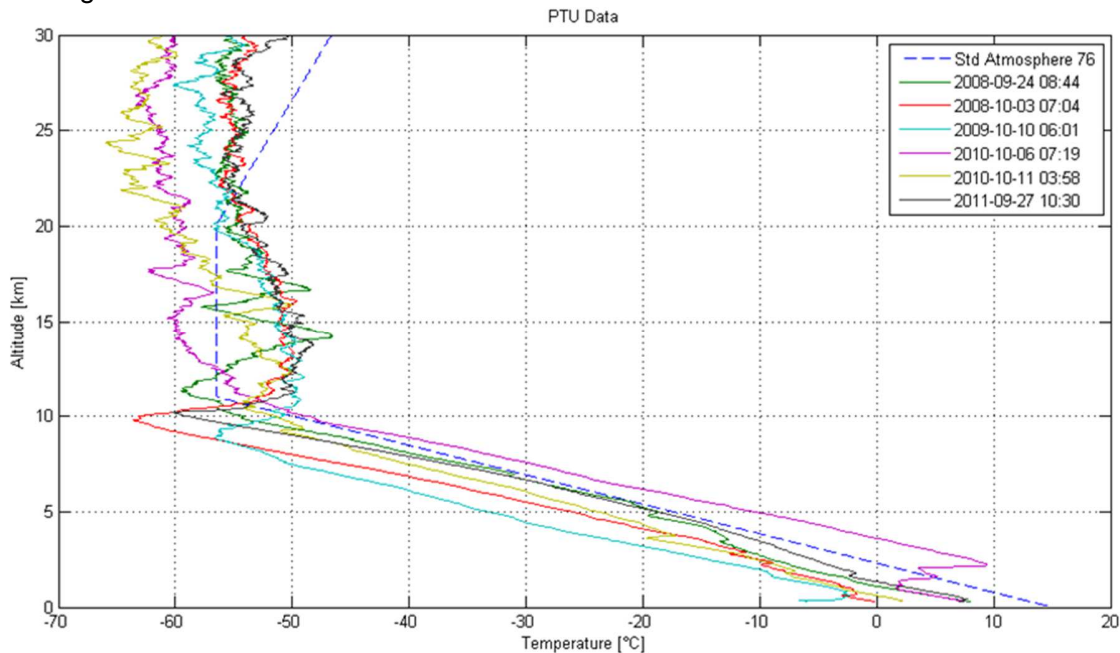
#### 5.2.3 Launch phase

After preparation, the experiment gondola is hooked to the balloon flight train in its preparation shelter. Just after the balloon in flight configuration is brought outdoors to the launch area and is released in the seconds that follow.

#### 5.2.4 Ascent phase

On ascent, the experiment gondola passes through the coldest layer (troposphere) from about 12 to 21 km. For as long as 60 minutes, the gondola is exposed to temperatures which could fall below  $-80^\circ$ . Frozen condensation

formed during ascent through the troposphere usually sublimates before the gondola reaches 21 km. Rate of ascent can average 4 to 6 m/s.



**Examples of atmospheric temperature profiles (meteorological radio sounding)**

### 5.2.5 Descent phase (after natural balloon burst)

On descent, the experiment gondola encounters the same thermal conditions as during ascent for typically about 35 minutes. As external components cool during descent, water may condense and freeze on the gondola. Moisture accumulation usually begins below 15 km on descent and may damage sensitive, unprotected components or may start corrosion if the equipment is not disassembled and cleaned soon after flight.

## 5.3 Mechanical design

The principles for the design, development and implementation applicable to experiment gondola must achieve control of the risks specific to their preparation, their flight and their recovery, including:

- Free fall of the experiment gondola, following the mechanical break of the hooking interface to the flight train.
- Free fall of a component by detaching or tearing away from the experiment gondola.

The experiment should be structured to withstand the loads mentioned below, as well as the loads that will be applied during the integration tests. It is the experimenters' responsibility to show that the structure and attachment of the experiment gondola is strong enough. This can be done by stress calculations or load tests. Under no circumstances will there be a flight with a component that has a risk of falling off the experiment gondola.

The most critical phases in terms of accelerations are the following events (Cf. §5.1.2).

- Transport prior campaign, rough handling by shipping company personnel. (shock/undefined vibrations).
- Flight termination (centrifugal forces of tumbling payload, shock).
- Landing (strong shock).
- Transport by car / truck back to balloon launch base (undefined vibrations).



To withstand those loads during transport and operation it is highly recommended to design the experiment hardware according to the specified loads. Those requirements shall be verified by analysis or/and tests.

The design load used for the payload are:

- Transient excitation (shock) of – 4.5 g vertically.
- Transient excitation of +/- 1.1 g horizontally.

As the mechanical design must be done by adding a safety coefficient of 1.5 with respect to the mechanical break, the combined acceleration is 7 g.

## 5.4 Electrical design

The requirements on the electrical design are the following:

- In order to avoid a fire that could spread to the rest of the SB system, the experiment gondola will be equipped with a system (such as a fuse) to prevent overloading of the circuits. Similarly, all cables shall be sized for a current equal or greater than that tolerated by the circuit breaker.
- The connectors of the electrical circuits at risk must be designed in such a way that there is no ambiguity in their connection (mechanical guides, fool proofing / keying device, etc.). They must also be protected against any deterioration, and be equipped with locking systems.
- All cables must be insulated, protected and secured.
- Any electrical hazard must be clearly indicated on the experiment gondola by labelling.

## 5.5 Radio-frequency constraints

For every transmitter or receiver that will be used at CNES Aire sur l'Adour for a SB flight, information must be given well in advance, in order to receive permission to transmit RF.

Thus, it is necessary to apply for frequency permission at ANFR. CNES can either apply on behalf of experimenters or give the information needed to perform such applications. The information required in advance includes parameters such as transmitting frequency, radiated power, bandwidth of signal, antenna, antenna pattern, and modulation type.

User	Frequency Band	Flight	Ground
Meteorological radiosonde	400 à 406 MHz	X	
Iridium (SK 50 beacon)	1616 à 1626,5 MHz	X	
GSM/GPRS frequencies	850/900/1800/1900 MHz	X	
Air Traffic Control (Rx)	1030 MHz	X	
Air Traffic Control (Tx)	1090 MHz	X	
GPS L2	1227,60 MHz	X	X
GPS L1	1575,42 MHz	X	X

**CNES frequencies that are not allowed for use by any experiment**

## 5.6 General design considerations

### 5.6.1 Experiment Accessibility

Bear in mind that designing for accessibility will make your task easier throughout the assembly and testing phases. This is an important point that is often overlooked by experimenters. It is in your interest that items such



as switches, battery packs and cable connections are easy to access. Considering access to fasteners is also worth the time.

### 5.6.2 Availability of parts

A major issue for many experimenters is late delivery and procurement delays. Rather than merely basing a design on parts from catalogues, ensure that they are available, this can save a lot of time and money for experimenters. Avoid designs based on hard to procure items or irreplaceable items where possible.

### 5.6.3 Experiment construction costs

Consider enforcing a three-quote minimum on components where possible (this is often not possible due to the specialized nature of items). When designing, remember that the cost for machining can differ greatly depending on early design decisions. Avoid close tolerances wherever possible, not only is it cheaper but it can save time with assembly.

### 5.6.4 Effectiveness of testing

When designing your experiment gondola, please take into consideration the testing in the future. This is an issue of accessibility, but also of design. Fast and simple methods of testing, calibrating, or adjusting important items will save experimenters' time. This will also make it simpler for testing.

### 5.6.5 Shipping

When designing your experiment gondola, please take into consideration the need for shipment, possible configurations and storage/transport requirements. Please remember that you will be responsible for packing your equipment after launch.

### 5.6.6 Safety

Safety is of the outmost importance to CNES. Any experiment that is deemed risky to the public, staff or experimenters, by the SB Flight Manager, will not fly. Take care to ensure that you perform any simulation, analysis, and testing that will help to convince CNES, that the experiment is safe to fly and handle.

### 5.6.7 Vacuum test

This test is applicable not only for experiments which will take place under vacuum conditions, but also helps to verify that systems, mainly electrical, have nominal performance in the flight thermal environment. Additionally, any experiments with sealed chambers should be vacuum tested to ensure survival. A margin of 1.5 times the working pressure is required. It is the responsibility of the experimenter to perform this test, if necessary.

#### Basic Procedure

- The experiment gondola shall be integrated and placed in a vacuum chamber (pressure below 5 mbar).
- Experiment data shall be supervised and recorded during the test.
- The experiment gondola shall be operating during the lowering of the pressure in the vacuum chamber. The experiment shall be in a similar mode as during the real SB flight.
- After this functional test / flight sequence has been performed, it is recommended that the module is kept operating for an additional 15 minutes, in order to detect any leakages or overheating problems.

### 5.6.8 Thermal test

A thermal test is mainly performed in order to verify the nominal function of the experiment gondola during the worst-case temperatures that can be experienced during the flight. It is the responsibility of the experimenter to perform this test.

## Basic Procedure

- The experiment gondola shall be integrated and placed in a thermal chamber.
- Experiment data shall be supervised and recorded during the test.
- The temperature shall preferably be measured in several places in the experiment.
- Low temperature test: regulate the temperature in the thermal chamber, preferably down to - 80 °C but at least to - 40 °C. When the measured temperatures in the thermal chamber have stabilised, perform a functional test/flight sequence during 2h 00. Be aware of condensation problems if the test is performed in normal humidity.

Note: to perform the most representative flight environment tests is to have a test chamber having the ability to regulate at the same time in pressure and in temperature. With such a chamber, it is then possible to best simulate the balloon ascent in 2h 00, adjusting the couple pressure / temperature corresponding to the altitude reached with an average speed of 5 m / s.

## 6 ACTIVITIES

### 6.1 Pre-campaign activities

Delivery of the experiment documentation and the Flight Support Application.

Once the FSA is issued, any changes that effect the document must be discussed with the SB Flight Manager before implementing the changes.

### 6.2 The Flight Readiness Review

The Flight Readiness Review (paper review) planned at least 1 month before the campaign, allows to give the green light for the flight. The following documentation is subject to review

- Report of functional test of the experiment gondola, certified by the experimenter.
- Synthesis of the experiment gondola certification (mechanics and electrical).

### 6.3 Summary of campaign activities

Here is the list of the main activities that will be carried out as soon as the team arrives at the balloon launch base:

- Kick-off Meeting: formal meeting organised by the SB Flight Manager after the arrival of the experimenter and its team at Aire sur l'Adour balloon launch base. It precedes the start of activities concerning the experiment gondola, with an associate schedule.
- Experiment gondola Incoming Inspection: all the mechanical and electrical interfaces of the experiment will be inspected at delivery at the balloon launch base, on the basis of documentation.
- If there is an RF transmitter in the experiment gondola, Flight Compatibility Test: a RF interference test is conducted. The experiment gondola is placed together with all other transmitting/electrical hardware at the same distances as in a real SB flight.
- Pre-Flight meeting: meeting planned, after verification of gondola conformity to certification documentation, and successful completion of the RF test if needed, to ensure the readiness of the experiment gondola for the flight.
- SB launch and experiment gondola recovery.
- Post-Flight Meeting: after the recovery, this meeting is held to debrief the flight and a short flight performance report is stated (quick-look of data). A short presentation of the performance of the experiment gondola is requested.

## 6.4 Countdown and launch

This phase begins with a set-up briefing consisting of a weather briefing on ground conditions for the launch and on the latest trajectory forecasts. The purpose is to confirm the mission and safety conditions before pronouncing the start of flight preparation operations. These results are presented in front of all the persons concerned by the SB flight in preparation.

At the end of this meeting, if the mission and the safety criteria are met, the SB Flight Manager authorises the flight. After this, the decision to fly falls to the experimenter, who assesses the state of readiness of its experiment gondola.

The schedule below indicates the standard count down actions relative to launch (T = 0). A final version of these actions is issued at the pre-flight meeting.

Time	Operations	Comments
T-1H30	Decision meeting	
T-1H00	Start of Count Down	
	Functional test of experiment payload in in the integration hall	
T-0H30	Experiment Gondola ready to fly	
T-0H20	Start of balloon inflation Information to ATC	
T-0H10	Attachment of the experiment gondola to the flight train	
0H00	Balloon release	Launch
T+~ 2H00	Burst of the sounding balloon	

## 7 EXPERIMENT QUALITY INSURANCE

### 7.1 Materials

In addition to normal concerns when choosing materials, special attention shall be paid to out gassing phenomena due to vacuum environment during flight.

As an aid the ECSS-Q-70-71 [4] (Data for selection of space materials and processes) may be used.

### 7.2 Components

All electrical and mechanical components must have a reliability that is consistent with the overall reliability of the payload. For electronic components, MIL-std specified types are recommended.

### 7.3 Additional quality topics

In addition to the QA-topics above, the following topics should be treated.

Procured products and audits:

- Careful planning of the procurement and manufacturing must be made for identification of long lead items. Preferably, a flow chart shall be made which shows the sequence of operations.

**Manufacturing control and inspection:**

- For the manufacturing and inspection of critical processes, the personnel should be aware of standards in applicable areas, such as:
  - o Manual soldering according to ECSS-Q-ST-70-08C [2].
  - o Crimping of connections according to ECSS-Q-ST-70-26C [3].
- Specific requirements of the project or product concerning cleanliness, contamination and environment shall be stated in the input to the Flight Requirements Plan.
- When positioning the parts or components, the sensitivity to, heating, ESD and electrical disturbances shall be considered.
- Connectors shall be well marked and preferably keyed.

**Re-used item:**

- It is important to consider the complete history of the re-used item, by consulting the hardware logbook or former project logbook; to be sure that it does not include any hidden failures.

**Availability and maintainability:**

- Spare parts for components susceptible of failure, shall be available during the test of experiment payload before the launch. The design shall allow for easy and fast replacements of such components.

**Handling, storage, and packing:**

- ESD susceptible components shall be handled in an ESD protected environment.
- Before transport, the product shall be thoroughly packed to withstand the expected loads. The use of a bump recorder is recommended.

## **8 SAFETY AT AIRE SUR L'ADOUR BALLOON BASE**

The scientific teams are responsible for the supply of the PPE for their staff. These equipments are obligatory.

For each person and according on the type of operations to be performed, procure (non-exhaustive list):

- A helmet or safety cap.
- Safety shoes.
- Protective gloves.
- Safety glasses.
- High visibility clothes.

-.

## APPENDIX 1: SUMMARY OF SB FLIGHT APPLICATION

### **General Information**

Experiment / Principal Investigator contact information.

Experiment team.

Scientific or technologic experiment objective.

Brief description of the experiment gondola

General characteristics of the experiment gondola: dimensions, weight and power.

### **Flight information**

Experiment gondola: previous operations of the payload (ground, aircraft, balloon, etc.).

Flight profile: preferred launch time.

Specific weather conditions.

Recovery: constraints on recovery time.

### **Support requirement**

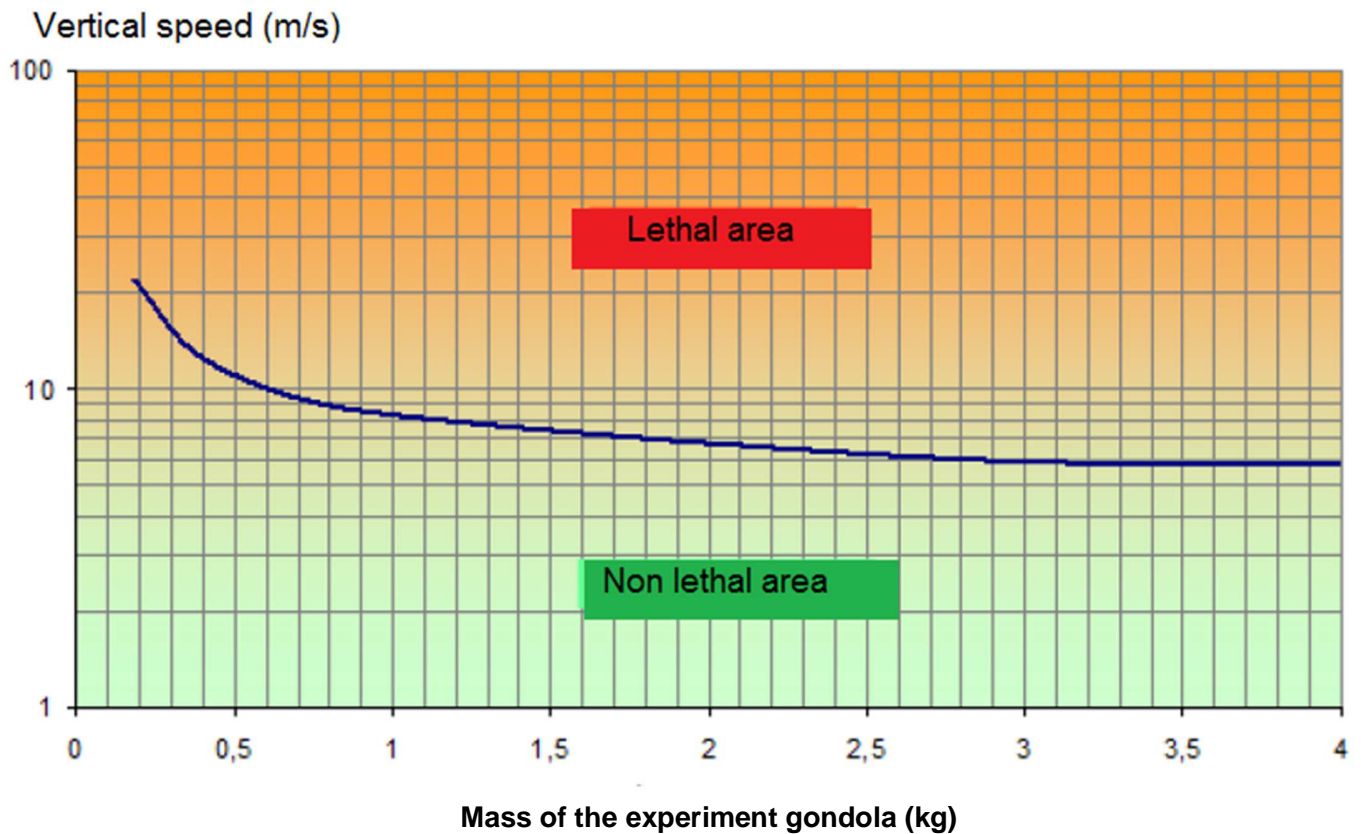
Assembly, integration and testing phase.

Launch pad operations before launch: electrical power, etc.

### **Compliance matrix for CNES SB regulation**

<b>Are forbidden</b>	<b>Compliance</b>
The dangerous experiments to the environment and people.	
The experiments to drop objects that do not have an aerodynamic speed reducer insuring the not dangerousness of the object at landing (see curve below).	
The electrical systems generating voltages greater than 24 V and / or optical systems with power exceeding 5 mW unprotected. Where necessary, they must be accommodated into an insulating case with a label, in French, informing of the nature of the hazard.	
The sources of ionizing radiation.	
The boarding of animals or genetically modified organisms.	
Any items likely to injure so inside that outside of the gondola.	
Any on-board radio system not in compliance with the legalization related to the use of radio frequencies in France (see § 5.5).	
All pyrotechnic systems, including fumigants.	
All pneumatic systems with a pressure service greater than 2 bars.	

Mechanical requirements	Compliance
The mass of the gondola must be less than 3 kg.	
If the mass of the gondola is greater than 2 kg, the surface density must necessarily be less than 13 g / cm <sup>2</sup> .	
The components of the gondola must be accessible until the moment of balloon launch.	
The gondola must tolerate accelerations of 4.5 g in the vertical direction and 1.1 g in the lateral direction with a safety factor of 1.5 (i.e. 7.0 g combined) without any mechanical failures. This must be justified by tests or modeling.	

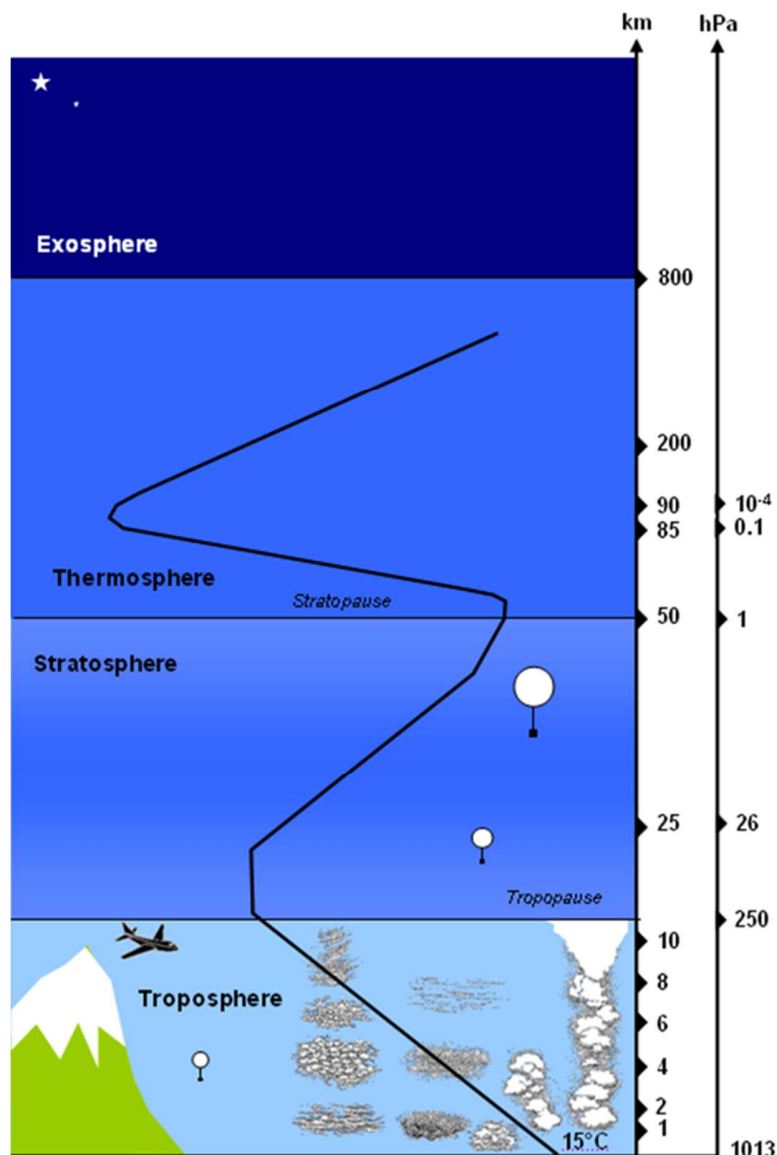


## APPENDIX 2: ATMOSPHERIC THERMAL ENVIRONMENT

### Air Pressure and Temperature Profiles

Air pressure and temperature profiles along the different phases of the flight are important parameters for determining convection heat transfer affecting the payload gondola. Convection heat flux ( $Q_h$ ) is directly proportional to the temperature difference between the air and the gondola.

Atmospheric pressure diminishes with altitude by a factor of 10 every 16 km approximately as per the Standard Atmosphere reference. Atmospheric pressure is 100 hPa at an altitude of 16 km, 25 hPa at 25 km, 10 hPa at 31 km and 2 hPa at 42 km. Pressure is usually used by balloonists as a vertical coordinate. In the troposphere (the layer of the atmosphere from the ground to the tropopause), there are horizontal pressure variations and the altitude of isobars varies with the occurrence of high- and low-pressure systems.



**Standard Atmospheric Profile along the Pressure and Altitude Scales**

The air temperature in the troposphere decreases on average by 6.5°C every 1 km. The rate of decrease can be altered, however, when a wintertime temperature inversion occurs in the interior of a continent, where the

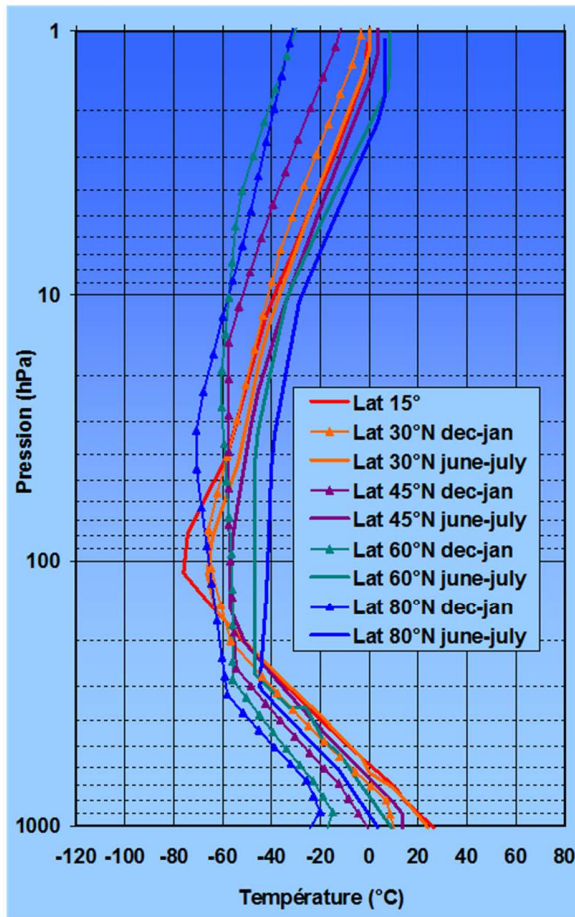


ground surface cools because it receives very little solar energy. In the stratosphere (from the tropopause to about 50 km), the temperature of the air increases with altitude due to absorption of solar radiation by ozone. The tropopause is defined as the upper limit of the troposphere. Its altitude varies according to the season and geographical area (from 8 km at the poles to 18 km at the equator, approximately). It is also affected by atmospheric phenomena in the troposphere.

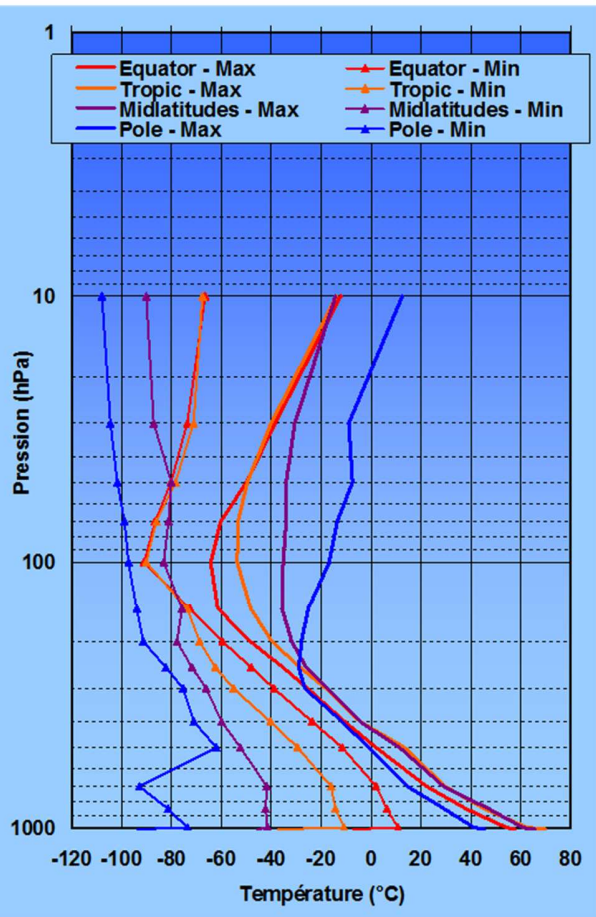
The most “stable” temperature in the troposphere and stratosphere over the course of the year is seen in the equatorial zone, where insolation varies little. The air temperature profile in the tropical zones is similar to that found in the equatorial zone. In the temperate zones, temperatures vary widely with the seasons and with the movement of atmospheric air masses which modify the temperature profile according to where they originate. And last, the polar regions experience the greatest variations in solar radiation, and therefore in temperature.

Figures below shows the extremes of air temperature that could be encountered by flights launched from various latitudes and time of the year. You may find that there are significant differences of the minimum and maximum temperature profiles between ISO model and GGUAS model (NOAA) for the Equator, the Tropic, the Mid or Tempered and the Pole latitudes

ISO 5878 average temperatures



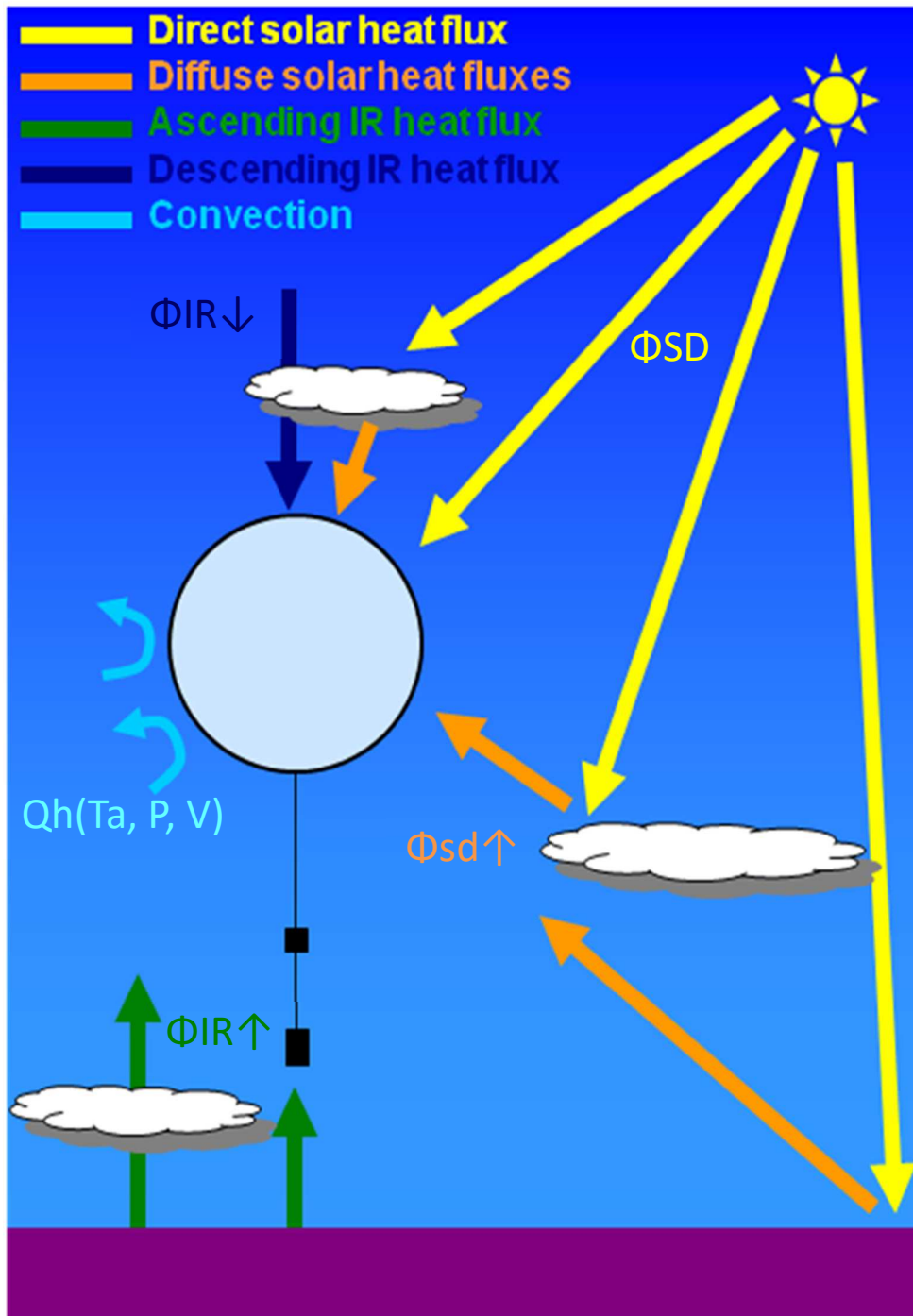
Results of the GGUAS model (NOAA)



Atmospheric Temperature Profiles for Various Latitude and Period of the Year



## Heat Transfer Modes



### Heat Transfer Modes and Thermal Environment Parameters for Payload Gondolas

As illustrated, the payload gondola, with its experiments, is exposed to direct solar flux, diffused solar flux reflected from the ground and the clouds (according to their respective albedo,  $A_G$  and  $A_C$ ), upward infrared (IR) flux from the ground and the clouds at low altitude, downward IR flux from the sky and clouds at high altitude, and convection heat flux from surrounding air which is a function of air temperature, pressure and relative velocity.

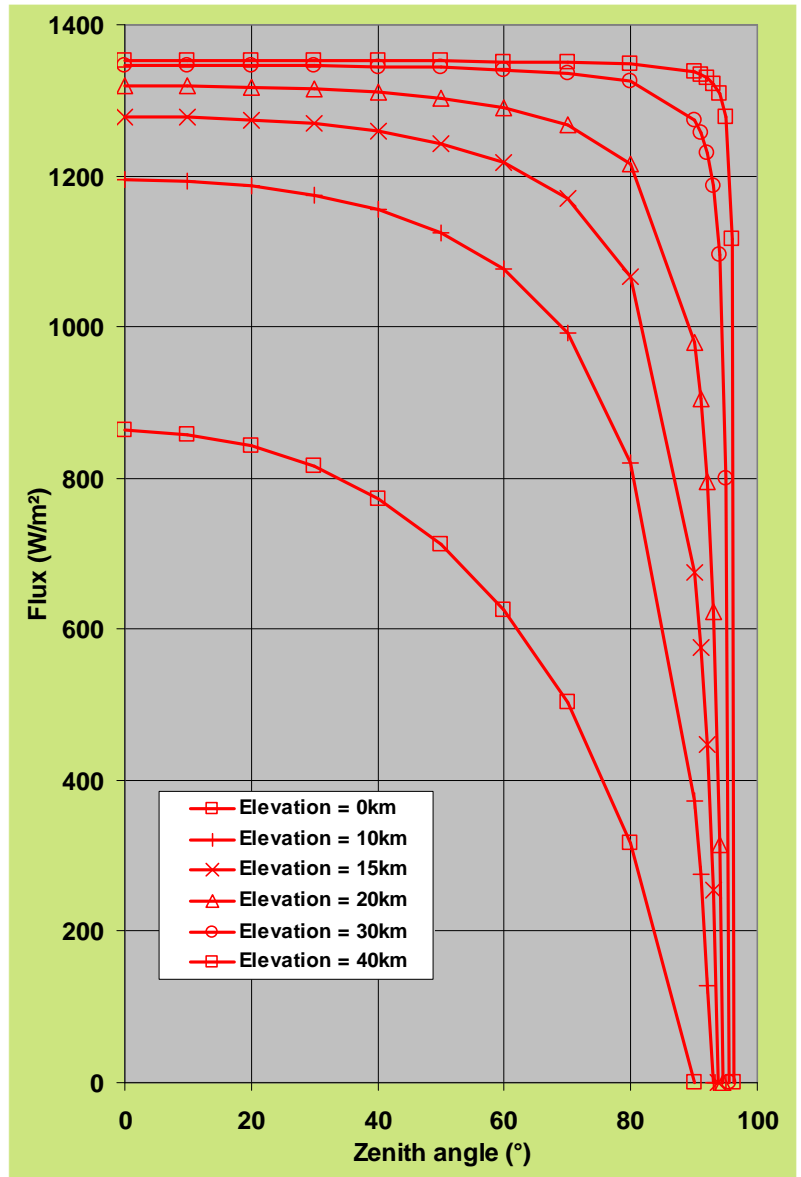
### Direct Solar Flux

Beyond the atmosphere, direct solar flux ( $\Phi_{SD}$ ) is equivalent to the solar constant. Within the atmosphere, the direct solar flux is attenuated by diffusion and absorption by components of the atmosphere. It depends in this case on altitude and on the position of the sun relative to the zenith (given by the zenith angle of the sun). Due to the rarified air in the upper layers of the atmosphere, during the course of the day, a payload gondola at float altitude will see a density of direct solar flux close to the solar constant over a wide range of solar zenith angles.

Due to the eccentricity of the earth's orbit, insolation varies over the year.

	Solar constant
Winter solstice	1415 $\pm$ W/m <sup>2</sup>
Spring equinox	1382 $\pm$ W/m <sup>2</sup>
Summer solstice	1326 $\pm$ W/m <sup>2</sup>
Autumn equinox	1362 $\pm$ W/m <sup>2</sup>

The solar constant averages 1371 W/m<sup>2</sup> over the year.



Solar constant and example of direct solar flux density in atmosphere.

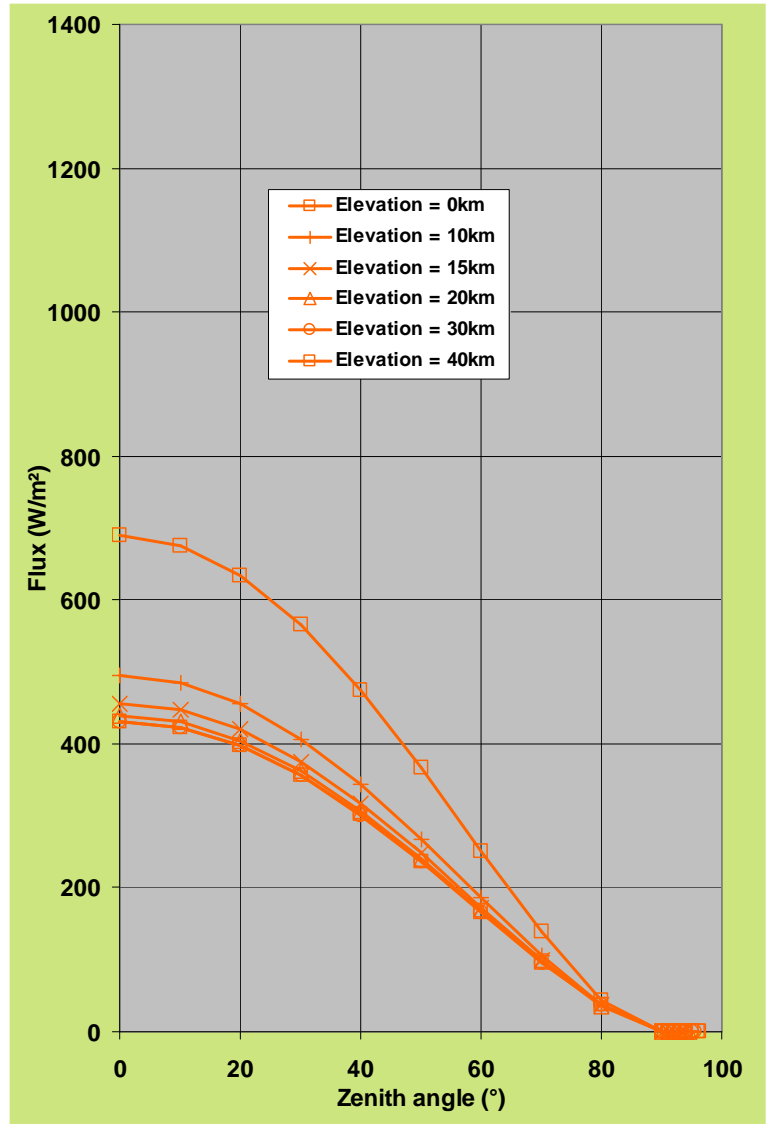
### Upward Diffuse Solar Flux ( $\Phi_{sd\uparrow}$ ) or Albedo

Upward Diffuse Solar Flux ( $\Phi_{sd\uparrow}$ ) or Albedo results from diffuse reflection of direct solar flux from the ground and from diffuse reflection and transmission of solar flux by clouds. It depends on the albedo coefficient (or coefficient of reflection,  $A$ ) of the area overflow (Earth surface or clouds) as per ( $\Phi_{sd\uparrow} = A \cdot \Phi_{SD}$ ).

Like direct solar flux, this reflected solar flux is subject to attenuation caused by diffusion and absorption by components of the atmosphere. In the stratosphere, the density of albedo flux can be high (of the order of 400  $W/m^2$ ) when flying over ground covered with new snow, for example.

Type of cloud	Albedo coefficient ( $A_n$ )
Cumulonimbus	~1
Cumulus	0.56 to 0.81
Altostratus	0.39 to 0.59
Stratus 200 m thick	0.1 to 0.5
<b>Average <math>A_n</math></b>	<b>0.5</b>

Earth surface	Albedo coefficient ( $A_T$ )
New snow	0.8 to 0.9
Old snow	0.45 to 0.7
Desert	0.24 to 0.28
Grass	0.15 to 0.3
Dry soil	0.08 to 0.14
Wetland	0.08 to 0.09
Woodland	0.04 to 0.1
Ocean	0.03
<b>Average <math>A_T</math></b>	<b>0.29</b>



Examples of albedo coefficients and albedo flux densities with clear sky when ground albedo coefficient is 0.8 (new snow).

**Infrared Radiation**

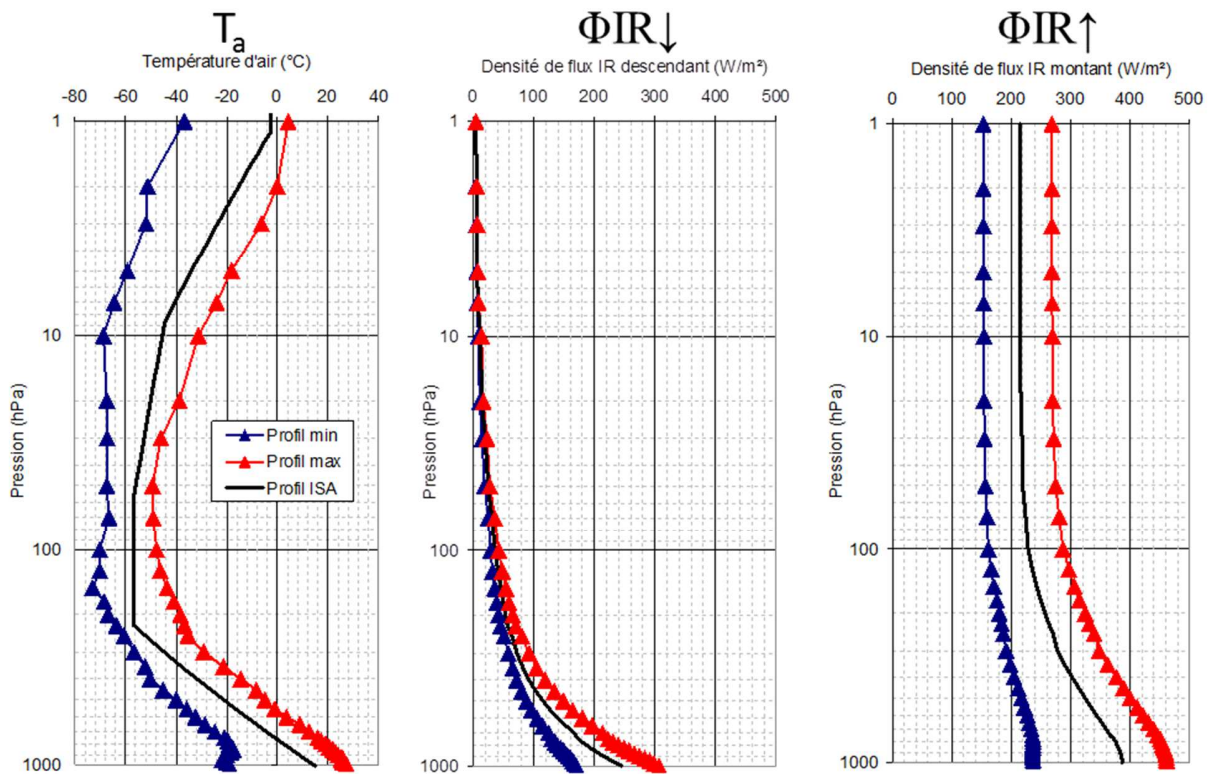
The aerostat is exposed to upward infrared flux and downward infrared flux.

The upward infrared flux ( $\Phi_{IR\uparrow}$ ) is often referred to as terrestrial infrared flux because it comes primarily from the ground. The diffuse infrared radiation emitted by the earth's surface is partly transmitted by the air and the clouds, which also emit in the infrared.

CNES models indicate that in ISA it amounts to about 390 W/m<sup>2</sup> at 1000 hPa and about 220 W/m<sup>2</sup> at 2 hPa with clear skies.

Downward infrared flux ( $\Phi_{IR\downarrow}$ ) is the diffuse infrared radiation emitted and transmitted by the air and the clouds (when the aerostat is in the troposphere).

CNES models indicate that in ISA it is about 250 W/m<sup>2</sup> at 1000 hPa. In clear sky conditions, it then diminishes steadily to a few W/m<sup>2</sup> in the stratosphere due to the rarified air in the higher layers of the atmosphere.



**Densities of upward ( $\Phi_{IR\uparrow}$ ) and downward ( $\Phi_{IR\downarrow}$ ) infrared flux in clear sky conditions from CNES model based on temperature ( $T_a$ ) profiles**

**Symbols and units**

- ΦSD: direct solar flux (W/m<sup>2</sup>)
- Φsd↑: upward diffuse solar flux or albedo (W/m<sup>2</sup>)
- A<sub>T</sub>: Albedo coefficient from Earth
- A<sub>n</sub>: Albedo coefficient from clouds
- ΦIR↑: upward IR flux (W/m<sup>2</sup>)
- ΦIR↓: downward IR flux (W/m<sup>2</sup>)
- Q<sub>h</sub>: convection heat flux (W/m<sup>2</sup>)
- P: pressure (hPa)

- P<sub>0</sub>: pressure at ground level (= 1013hPa)
- T<sub>a</sub> or T: air temperature (°C)
- V: velocity (m/s)

## Radiation

Concerning radiation, the protection of the aerostatic system's flight control equipment has been dimensioned on the basis of the following results from balloon flights made during previous campaigns. These data can serve as a reference for assessing the protections to be provided for the most sensitive instruments, and depending on the time they will remain exposed.

Extract from the report of the ONERA study "*Impact de l'Environnement Radiatif Naturel Atmosphérique sur les nacelles électriques embarquées sur ballons*" (Impact of the Natural Atmospheric Radiation Environment on the electrical gondolas carried by balloons) written by G. Hubert and referenced RF 1/20635 DESP – November 2012.

"The flux of neutrons in the atmosphere varies with altitude and latitude. In Figure 3-a, showing the variation of the neutron flux as a function of altitude for a latitude of 43°N, we note that the flow increases with the altitude, reaching a maximum at 18 km ( $\sim 1.25 \text{ n.cm}^{-2}.\text{s}^{-1}$ ), known as the Pfozter maximum, and declining thereafter. This evolution is the result of the interaction between the cosmic particles, whose flow increases with altitude, and the atmosphere, whose density decreases with altitude (given by the US Standard Atmosphere, 1962).

Figure 3-b shows the flow of neutrons in the atmosphere for a range of energies from 1 to 10 MeV as a function of latitude and for an altitude of 10.7 km. We note that this flow is very low at the equator ( $\sim 0.2 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) and reaches a maximum value ( $\sim 1.4 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) at the Poles. We find the same behaviour regarding latitude as that of cosmic rays arriving in the atmosphere (minimum flows in equatorial regions and maximum in polar regions). Since the production of neutrons in the atmosphere is directly linked to incident cosmic particles, neutron flux is also dependent on latitude.

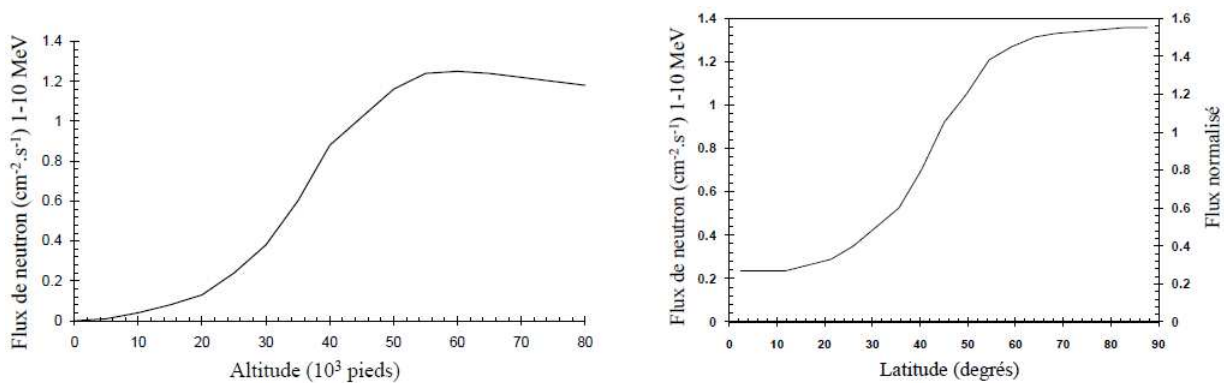


Figure 3-a Flux de neutrons dans l'atmosphère ( $1 < E < 10 \text{ MeV}$ ) en fonction de l'altitude. On remarque un flux maximum de  $\approx 1,25 \text{ n/cm}^2.\text{s}$  pour une altitude de  $\approx 60000$  pieds ( $\approx 18 \text{ km}$ ). Figure 3-b. Flux de neutrons dans l'atmosphère ( $1 < E < 10 \text{ MeV}$ ) en fonction de la latitude pour une altitude  $\approx 10,7 \text{ km}$ . On remarque un flux quasiment nul ( $\approx 0,2 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) au niveau de l'équateur (champ magnétique terrestre fort) et un flux maximum ( $1,4 \text{ n.cm}^{-2}.\text{s}^{-1}$ ) au niveau des pôles (champ magnétique terrestre faible).

It is quite common practice to consider only neutrons and to ignore other types of particles. However, we must not neglect the proton component, which can also be at the origin of Single Event Effect. This is particularly true for balloon applications. Up to altitudes of about 18-20 km, it is justifiable to consider only neutrons; however, for high altitudes (typically higher than 25 km), protons can become the majority component (this depends on the latitude considered). For example, at an altitude of 40 km, neutrons can be ignored, while the protons are in the majority. Moreover, when studying high energies ( $>$  about 100 MeV), the proton component is the most important.

In other words, in the framework of balloon applications, characterisation of atmosphere's natural radiative environment requires that we consider both neutrons and protons. Regarding the effects, it is admitted that the induced effects are equivalent for energies of about 50 MeV and above."

Here is another reference concerning the assessment of levels of radiation in the stratosphere:

### RADIATION MEASUREMENTS IN THE STRATOSPHERE

Denis Pantel, Yago Gonzalez, Mickael Gedion, Frédéric Wrobel, Jean-Roch Vaillé, Frédéric Saigné

Université Montpellier 2, UMR-5214, CC083, Place Eugène Bataillon, 34095 Montpellier CEDEX 5

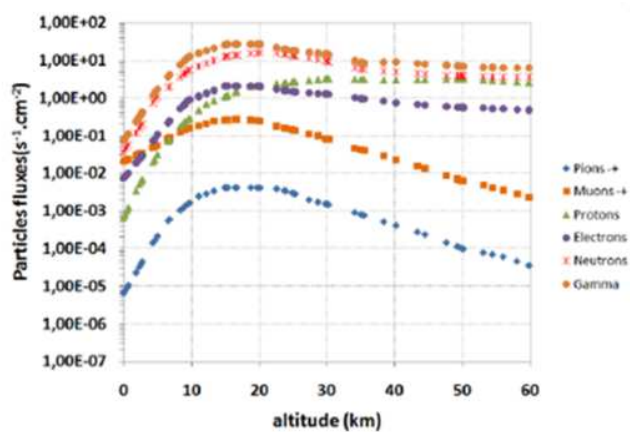


Figure 1 : Particles fluxes as a function of altitude [7].

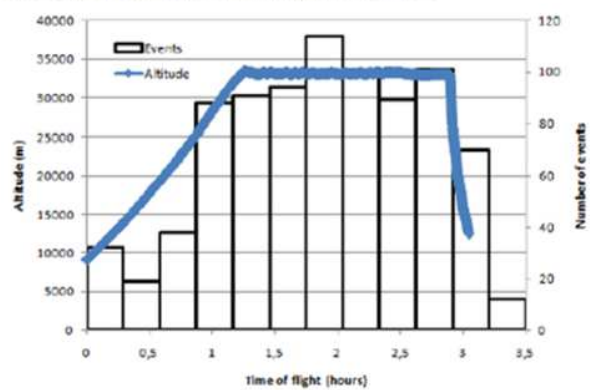


Figure 9 : Comparison between the evolution of the number of detected events as a function of time of flight and altitude profile.