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## THE LONG DURATION "MIR" BALLOON

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## ABSTRACT

In 1977, french searchers from the Service d'Aéronomie of CNRS had the idea to use the montgolfiere concept to perform long duration balloon flights.

Developped since by the CNES Toulouse, the MIR vehicle (Infrared Montgolfiere) is thus a hot air balloon of about 40 000 m<sup>3</sup>, with natural shape, only heated by radiative fluxes from the sun by day and by upwelling infrared fluxes during the night.

The envelope is made of two different hemispheres with materials that offer a good compromise between thermo-optical properties and weight budget.

During the day, the MIR balloon carrying a 60 kg payload will fly at an altitude of about 28 km and at night between 22 and 18 km, depending on the amount of infrared fluxes coming from below. Its trajectory follows the systemic circulation of winds.

After more than 40 flights, the MIR has demonstrated its capacity of long duration flights for scientific purposes. The average duration at tropical latitudes is 3 Weeks and the record was reached in 1989 by a MIR launched from Pretoria (RSA) that circled the globe 3 times in 69 days. The latest scientific campaign, AMETHYST, took place in Ecuador in 1994, for the benefit of LMD (Laboratoire de Météorologie Dynamique du CNRS) and IGP (Institut de Physique du Globe de Paris).

It was the occasion to perform one technological flight of a MIR capable of piloted vertical excursions, developed by CNES and using a top valve plus bottom shutter device automatically commanded onboard.

Until now gondolas were not recovered and scientists got their data through telemetry via Argos satellites or via CHACAL specific direct telemetry (50 to 100 kbits per day). For the first time, for SESAME Arctic campaign, where two SAOZ (SA, CNRS) flights were on schedule on MIR, CNES has elaborated a pre-programmed end of flight command for separation over a determined area, in view of a possible recovery of the payload. In the future, remote command via INMARSAT satellites will be implemented for an improved control of the flights.

## 1. THE VEHICLE AND ITS PRINCIPLE

## 1.1 Basic concept

In 1977, French searchers from the Service d'Aéronomie du CNRS had the idea to use the montgolfiere concept to perform long duration balloon flights in the stratosphere.

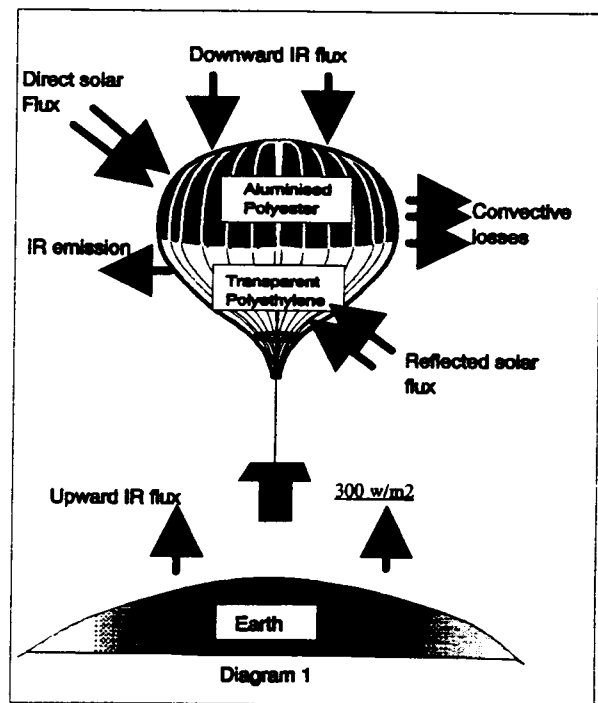
Developped since by the CNES Toulouse, the MIR vehicle (Montgolfiere Infra-Rouge) is a hot air balloon of 36000 to 45000 m<sup>3</sup>, with natural shape, only heated

by radiative fluxes from the sun by daytime and upwelling infrared fluxes during the night.

An over temperature inside the balloon of more than 15 degrees at night is needed to keep a balanced float level. That is the reason why the envelope is optimized for the captation of infrared fluxes rising from the earth (about 250 W/m<sup>2</sup> are available at flight level).

## 1.2 The vehicle

Assembled by ZODIAC INTERNATIONAL, the MIR is thus made of two different hemispheres with materials that offer a good compromise between thermo-optical properties and weight budget. The upper part is made of 12  $\mu$ m aluminised mylar forming a cavity for the absorption of upwelling infrared radiations, and avoiding reemission to the sky. The lower part is made of 15  $\mu$ m linear polyethylene, a material transparent to infrared fluxes and resistant to cold ambient conditions (less than -80°C) met by the balloon during its flight. Diagram 1 below shows the MIR radiative budget:



By day, the MIR will fly at an altitude of about 28 km and between 17 and 22 km at night depending both on the amount of infrared flux coming up from the overflow area, and on the air temperature profile at flight level. See diagram 2 for the vertical behaviour of the balloon:

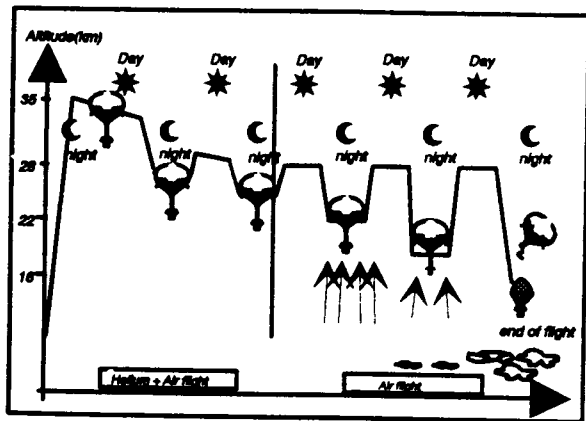


diagram 2

2. RESULTS OF LONG DURATION CAMPAIGNS

2.1 Statistics

After more than 40 flights the MIR has demonstrated its capacity of long duration flights for scientific purposes. The record flight of this kind of vehicle was reached in 1989 during a launching campaign from Pretoria, RSA, when a balloon circled the globe about 3 times during a 69 days trip (see sample of trajectory in diagram 3).

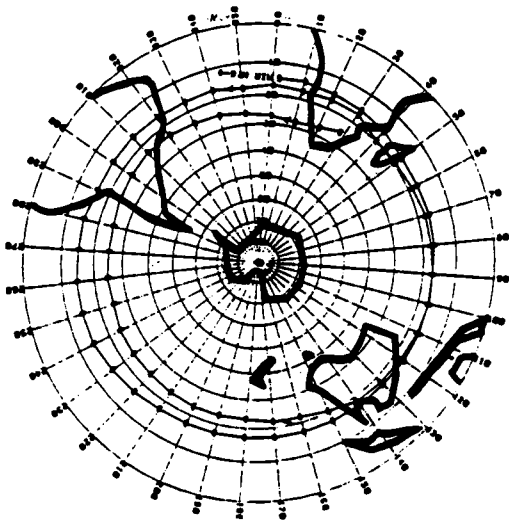
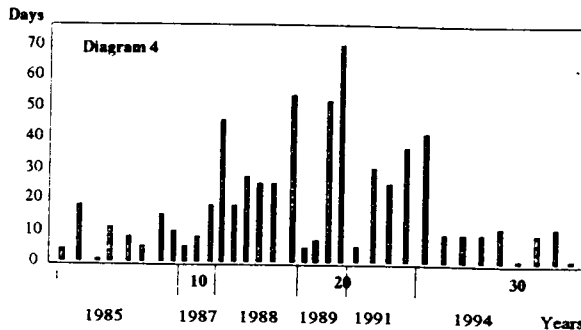


diagram 3

Diagram 4 gives a summary of the scientific flights durations for the last ten years, yielding an average of 21 days per flight:



2.2 Budget of the last ten years :

As already mentioned several scientific campaigns (3 to 9 flights each) have been organized in the last decade for the benefit of French searchers. They are listed below:

Campaign	Launch site	Laboratory	Experiment
1985	Pretoria, RSA	CNRS/ SA	Water vapour measurements
1986	Pretoria, RSA	CNRS/ LMD	Water vapour measurements
1989	Pretoria, RSA	CNRS/ LMD	Water vapour measurements
1991 PRE-AMETHYSTE	Latacunga EQUADOR	CNRS/ LMD	Water vapour measurements
idem	idem	IPGP	Magnetic field anomalies
1994 AMETHYSTE 1	Latacunga EQUADOR	CNRS/ LMD	Water vapour measurements
idem	idem	IPGP	Magnetic field anomalies

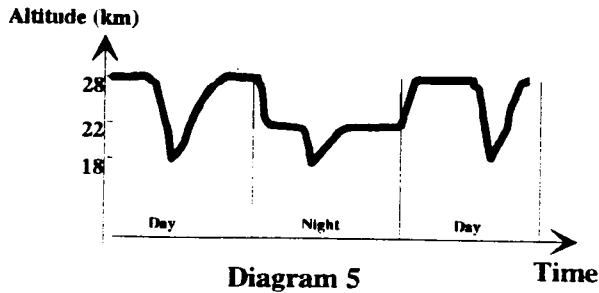
CNRS: Centre National de Recherche Scientifique  
 LMD: Laboratoire de Météorologie Dynamique  
 SA: Service d'Aéronomie  
 IPGP: Institut de physique du globe de Paris

2.3 Piloted vertical excursions

2.3.a) Scientific needs

To fulfil the requirements of the AMETHYSTE project, managed by LMD, of in situ water vapour measurements in the Equatorial stratosphere between 16 to 25 km, CNES started in 1989 the development of a 45000 m<sup>3</sup> MIR equipped for vertical excursions of several kilometres on command.

Based on results of numerical simulations the aim is to obtain one piloted vertical sounding by night and another one by day added to the natural behaviour of the balloon, as shown on diagram 5:



2.3.b) Mechanical devices

The equipment necessary to perform excursions with a MIR consists in a 90 cm diameter polar valve coupled with a south pole shutter, both actuated by an onboard automaton, using vertical speed  $v_z$  and flight level pressure  $P_a$  as piloting parameters.

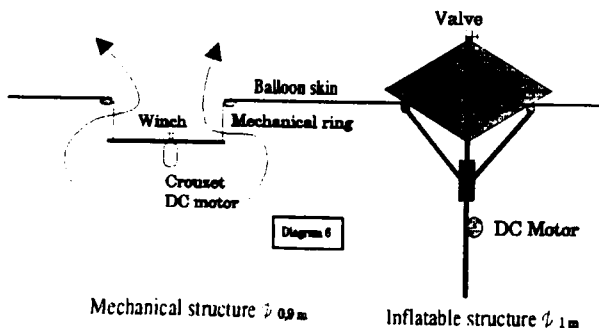
The results of flight simulations, confirmed by technological flights (Spitzberg, 1992, 7800 m<sup>3</sup> solar montgolfiere) showed that a venting valve of common size (less than 100 cm in diameter) at the top of this kind of hot air vehicle proved to be efficient only for balloons of small volume, until 10 000 m<sup>3</sup>. The warm air vented by the valve is replaced by fresh air absorbed by the bottom hole of the MIR, so the balloon will refill and reach a new balance only a few hundreds of metres lower as soon as it recovers its initial volume. Moreover the incoming air is quickly warmed by the radiative heating process of the MIR.

As a polar valve of several metres was not technically feasible, CNES Balloon Division designed a special device to close and open on command the bottom hole of the MIR to avoid fresh air to come in while venting at the top.

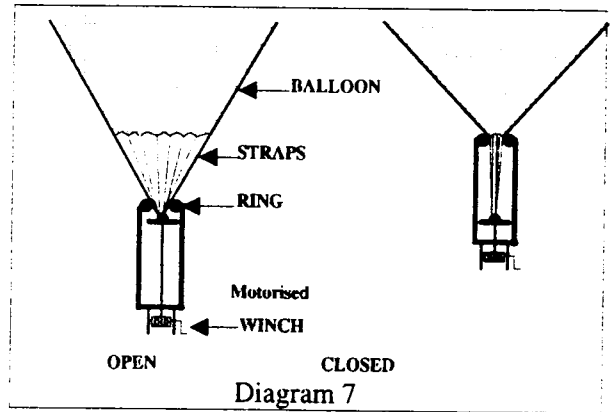
Two kinds of polar relief valves have been qualified on long duration flights (Spitzberg 1992 and Ecuador 1994):

\* Mechanical structure: a plate suspended to three straps, winded on a winch actuated by a DC motor will open or close the circular shaft at the top of the balloon. Total weight 12kg.

\* Inflatable structure: the top of the balloon ends on a circular glass-fibre ring and a biconical inflated structure closes the hole. It is moved by a cable winded on a winch, actuated by a DC motor. Total weight: 4kg. Both concepts are presented below ( diagram 6):

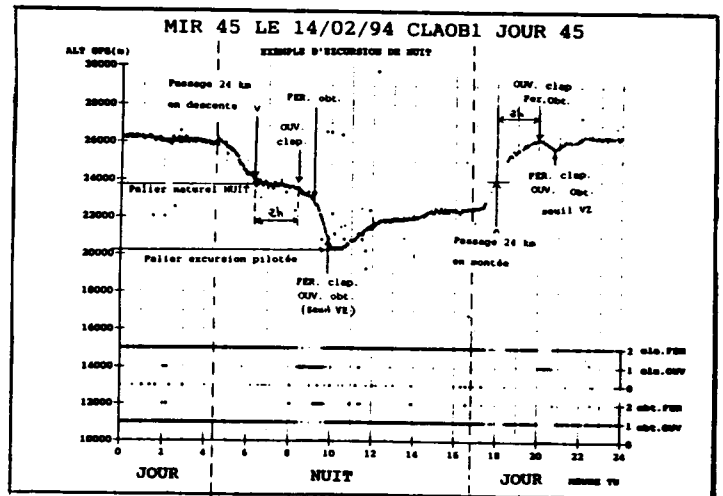


\* Shutter: the bottom hole on a MIR is 4 metres in diameter, and the concept to close it, qualified on long duration flight in Ecuador in 1994, is shown on diagram 7. A cylindrical cage, 3 metres high, moves upwards and downwards to close the south pole aperture. Total weight: 20 kg.



2.3.b) Technological flights

A technological 10 day's flight was performed from Ecuador in 1994 and yielded encouraging results, reaching piloted excursions of 3 to 4 km, as presented in diagram 8 :



Opening the polar valve initiates the descent of the MIR. By closing its bottom hole a decrease in volume is induced, and the descending speed grows until the balloon recovers a new balance after re-opening the obturator, shutting the polar valve and replenishment of the balloon.

Two or three extra techno-flights should allow CNES to ascertain the abilities of this new vehicle, by optimizing the automatic piloting laws.

### 3. MIR FLIGHTS SPECIFICITY

#### 3.1 Scientific payload and onboard electronics requirements

The payload devices onboard MIR long life balloons have to face the following problems:

\* Low weight systems: The normal flight train including scientific payload, batteries, housekeeping, telemetry and security devices is limited to 80 kg. So the scientific gondola with telemetry and batteries is allowed about 50 kg, for a flight in mean radiative conditions. That means to watch the consumption of energy.

\* Very low external temperature: in the middle and low stratosphere, temperatures of  $-70^{\circ}\text{C}$  are common, so onboard equipment will have to work at about  $-40^{\circ}\text{C}$  during the night after a few days of flight. Mainly three kinds of problems will have to be checked:

- Compensation of drift and bias on electronic components

- Thermal protection of quartz oscillators below  $-50^{\circ}\text{C}$

- Poor efficiency of batteries (loss of 50% of nominal capacity below  $-40^{\circ}\text{C}$ )

The common solution adopted both by the scientists and by CNES for thermal coating of the payload is the use of a 10 cm thick polystyrene box wrapped into layers of usual insulating aluminized material. If necessary, components like quartz can be heated alone, most of the components being chosen qualified at  $-55^{\circ}\text{C}$  when available.

#### 3.2 Telemetry (ARGOS, CHACAL)

Any telemetry or remote control system on long duration balloons has to be able to emit and receive data to and from all over the globe. Besides, onboard equipment has to be light and resistant to low temperature conditions. CNES Balloon department has acquired a know-how both in the use of via satellite systems like ARGOS and in the development of a home-made direct telemetry in the HF band, called CHACAL.

##### 3.2.a) ARGOS system

Developped by CNES in 1978, ARGOS system is dedicated to the localization of mobile platforms and to the collection of data emitted by their beacons. Two polar satellites at 800 km, Tiros and Telecom, when flying over the mobile, collect its signals, store them and re-emit them to ground stations (Toulouse and Landover) that give back processed data to the authorized users.

Thus, an ARGOS beacon onboard a balloon allows the recurrent transmission, every minute for instance, of 32 bytes messages corresponding to sensors data or scientific measurements. At each passage one satellite covers a belt of 5000 km circling the earth including the poles, as shown on diagram 9:

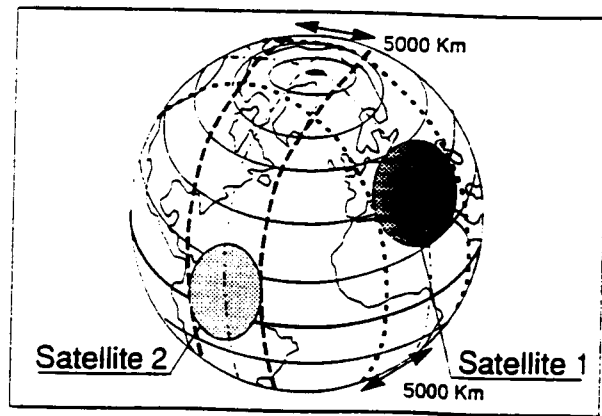


diagram9

Owing to the satellites trajectories, it is obvious that the amount of transmitted data is directly dependant on the location in latitude of the beacon:

Latitude of the beacon	Visibility per day	Average number of passages per day
0 degree	80 mn	7
+/- 15 degrees	88 mn	8
+/- 30 degrees	100 mn	9
+/- 45 degrees	128 mn	11
+/- 60 degrees	248 mn	22
+/- 75 degrees	322 mn	28
+/- 90 degrees	384 mn	28

As detailed in the board above satellite visibility is 384 minutes per day over the pole and only 80 minutes over the Equator line, that is why during Spitzberg campaign at  $79^{\circ}\text{N}$  we got **50 kbits/day/beacon** (data from 8 sensors every 3rd minute) and only **15 kbits/day/beacon** in Ecuador campaigns.

Except for the first 300 km where the balloon can be tracked directly from a groundbased ARGOS receiver, the collected data are available **within 6 hours** after reception by the satellite.

ARGOS beacon characteristics are:

- \* Transmission rate: 400 bits/s, 32 bytes in less than 1 s.
- \* Frequency: 401.650 Mhz
- \* Emission recurrence: about 45 s.
- \* Power radiated in emission: 1 A under 12 V.
- \* Average consumption: 240 mW
- \* Weight of transmitter: 1 kg
- \* Oscillator stability:  $10^{-8}$ / 20 min

##### 3.2.b) CHACAL system

This direct HF telemetry system was developed 15 years ago by CNES to improve the amount of data per day collected from MIR gondolas. CHACAL HF waves use ionospheric propagation to enhance the bearing of the onboard transmitter. Two frequencies are alternately emitted ( 18 Mhz and 6 Mhz ) in average every 90 th second each, that is the solution to get a good reception as far as 7 000 km from the MIR with 50 W emitted. Three ground stations are thus enough to track the balloon all over the world. For example during RSA campaigns, reception was made from Noumea, Brazil, and Pretoria, see below diagram 10:

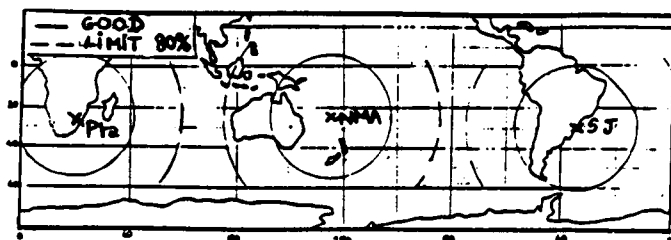


diagram 10

CHACAL system characteristics are:

- \* Transmission rate: 100 bits/s, 32 bytes in about 2 s.
- \* Frequency: 18 Mhz and 6 Mhz
- \* Emission recurrence: between 10 s and 1 hour on request
- \* Power radiated in emission: 50 W
- \* Average consumption (90 s recurrence): 200 mW
- \* Weight of transmitter: 2 kg
- \* "Day" aerial ( 18 Mhz): dipole, 8 m long
- \* "Night" aerial (6 Mhz): vertical "J", 30 m long

In each message, 23 bytes are available for the user, who can get until **75 kbits/day** of scientific data and know the location of the balloon **in real time**, if the signal of an onboard GPS receiver is transmitted.

Moreover a remote control of the MIR was studied at CNES, based on CHACAL concept, but is not in use: 200 W emitted from a ground station would allow a range of 5000 km.

#### 4. NEW CONCEPTS

##### 4.1 Telemetry and remote control via INMARSAT

INternational MARitime SATellite (INMARSAT) system was created in 1979 for via satellite telecommunications between mobile platforms, especially boats. Nowadays the system consists in 3 main elements:

- \* 4 geostationary satellites covering the whole globe:

- S1: Atlantic Ocean region East (15.5°W)
- S2: Atlantic Ocean region West (54°W)
- S3: Pacific Ocean region (178°E)
- S4: Indian Ocean Region (64.5°E)

- \* Land Earth Stations providing a relay between satellites and international telecommunication links.

- \* Mobile Earth Stations, transmitting directly to the satellites, composed of one transmission/ reception antenna and one communication interface managing the dialogue with the satellite. Four kinds of communication

systems are available, and CNES is adapting a balloon-borne Standard-C terminal as a new telemetry and remote control system, able to give location data as it is GPS-aided.

Each terminal has its specific phone number and in each way transmission is made on the base of store and forward, data are memorised before sending. Standard-C is able to send about 32 000 bytes at a time to one satellite that forwards them to a land station, from which the users can get their data back. The different telecommunication links are shown on diagram 11:

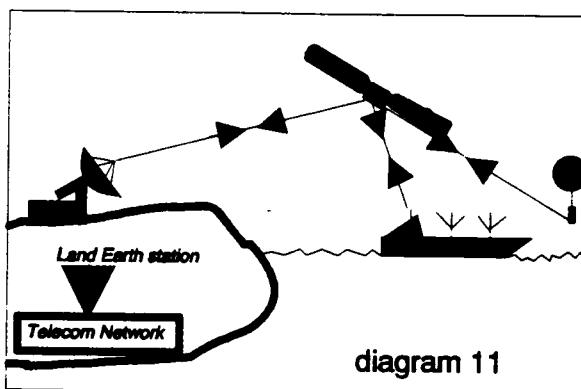


diagram 11

INMARSAT Standard-C system characteristics are:

- \* Transmission rate: 600 bits/s, 31600 bytes in 15 mn
- \* Frequency: - Transmission: 1626.5 to 1646.5 Mhz  
- Reception: 1530.0 to 1545.0 Mhz
- \* Emission recurrence: once a day to limit consumption
- \* Average power consumption (31600 bytes/ day): 500mW
- \* Weight of transmitter: 5 kg
- \* Omnidirectional aerial

One technological flight of an INMARSAT terminal is on schedule for 1996.

##### 4.2 Payload recovery

Until now gondolas were not recovered and scientists got their data through telemetry and lost their equipment. For the first time, for SESAME Arctic campaign, where two SAOZ (SA,CNRS) flights were on schedule on MIR, CNES has elaborated a pre-programmed end of flight command for separation over a determined area, in view of a possible recovery of the payload. The onboard automaton, aware of the location of the balloon thanks to the help of a GPS receiver, was programmed to stop the flight above a known area after a certain date.

This possibility could allow recoveries after overseas long duration flights and is already a great help for safety aspects (end of flight in case of drift to latitudes lower than 60°N for instance).

#### 4.3 High latitude winter flights

As a hot air balloon, MIR shows its best efficiency at tropical latitudes (Pretoria, 25°S), where upwelling infrared fluxes are high (> 190 W/m<sup>2</sup> at 99%) and clear nights are a rule. Flights are a bit more risky in Equatorial regions where the tropopause is very high and the occurrence of cold clouds important: most of the balloons of Ecuador 1994 campaign died above the cloudy areas of Micronesia after 10 days of easy flight over the Pacific ocean.

On the other hand, summer flights in high latitude regions are very easy for the MIR, due to the presence of a quasi-ever shining sun (30 days' flight in July from Spitzberg, 79°N, in 1992).

Things are more difficult when it is planned to perform MIR flights above 60°N (or below 60°S) in winter or early spring because of night duration and poor infrared fluxes coming from iced lands like Greenland and North Siberia. The fact remains that such flights would be of great interest for chemistry measurements (ozone and aerosols) inside the polar vortex, and that they can be performed in certain conditions that we mention below:

\* Light payload: 25 kg maximum

\* Sufficient Infrared Fluxes ( Inside temperature warm enough) combined with low stratospheric temperature profile (cold temperature outside, <-70°C at 70 Hpa): these conditions can be met in general between February 10th and March 15th (reference R7).

#### 5. CONCLUSION

After having developed the MIR for long duration scientific flights, CNES goes on improving the abilities of this vehicle. The complete qualification of the vertical excursion system is on schedule for 1996 in Ecuador and should contribute to the full success of 1998 AMETHYST 2 campaign. Moreover, MIR could be used (at the right period) for chemistry measurements in the Arctic and the Antarctic. At last, CNES Balloon Division team is enhancing onboard telemetry and remote control systems to offer the scientists the best tools for stratospheric investigation.

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