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An update of the CNES stratospheric balloon activities

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Abstract
For nearly 60 years, the French Centre National d 'Etudes Spatiales (CNES) has been developing and operating stratospheric balloons to perform scientific measurements and technological tests in the upper atmosphere up to 40 km in altitude. To date, CNES operation teams have operated more than 4,000 flights at all latitudes. The following paper gives a synthesis of the launch campaigns of the past three years and their preliminary results.
Besides, the perspectives are shown, as the content of the next campaigns from 2023 to 2025, the new services and performances available, and the new innovative developments like the "persistent" balloon.

1. Introduction

For nearly 60 years, the CNES (National Centre for Space Studies) has been developing and operating balloons to perform scientific measurements and technological tests in the upper atmosphere. To date, more than 4,000 flights have been operated by CNES at all latitudes. Balloons are capable of remaining permanently at an altitude of 20 to 40 km in the stratosphere (and sometimes higher). The balloon remains a unique vehicle for collecting in situ data on the winds, the quantities of greenhouse gases, aerosols , radiation present at these flight levels, and for observing the Universe with telescopes weighing several hundred kilograms carried above the dense layers of the atmosphere. Thus, within the framework of a partnership with the CNRS and with various countries hosting launch sites, regular flight campaigns are organized around the world, including in France from Aire sur l'Adour operation centre., where 30 to 40 light balloons are operated each year. The Balloon infrastructure has its place among the infrastructures that contribute to CNES missions today.
To study the stratosphere, CNES implements three types of balloons: the well-known big Zero Pressure Balloons (ZPB), the Super Pressure Balloon (SPB) for long duration flights, and latex Sounding Balloons (SB) for very light payloads.
After a short overview of the stratospheric balloon infrastructure, this paper presents the summary of the French balloon scientific campaigns over the period 2020-2022, mainly:

- The ZPB campaigns: KLIMAT, from Kiruna, Sweden, in 2021, and STRATRO SCIENCE from Timmins, Canada, in 2022.
- The Strateole-2 first scientific campaign of 2021, using a flotilla of long duration balloons (SPB)
- The MAGIC campaigns using SB, Aircraft and ground measurements, but also ZPB in Kiruna 2021,
- The flights performed by CNES in the framework of HEMERA, the European balloon infrastructure.
- The FIREBALL scientific gondola preparation for the fall 2022 launch campaign in the USA

The flight campaigns for the next two years, and the roadmaps are also presented.

1. The CNES balloon infrastructure

1.1 The main players in France and in Europe
In France, the main partners of CNES for balloons are the space scientific laboratories of CNRS-INSU such as LMD, LATMOS, GSMA, LPC2E, LSCE and others for atmospheric sciences, IRAP, the LAM, the IAS and Al. for the sciences of the Universe, or the INSERM for on-board biology experiments. Other public bodies also participate in balloon projects, notably Météofrance for data assimilation, atmospheric

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modelling, the CEA for detectors for astronomy instruments, ONERA for simulation and environmental testing on balloon materials.
As far as the industrial context in France is concerned, CNES relies on equipment supplier partners and subcontractors from various backgrounds and sizes.
The French manufacturer of the stratospheric balloon envelopes, HEMERIA, is unique in Europe.
On-board electronics are entrusted to SMEs, even VSEs, suppliers to the space and aeronautical sectors, and even, for the sake of cost containment, consumer electronic equipment, the manufacture of which in large numbers or the destination (medical sector in particular) ensure reliability.
Over the past 5 years, the stratosphere has inspired new “New Space” missions: major groups such as Thales Alenia Space with its STRATOBUS stratospheric airship project, and Airbus with the ZEPHYR drone and soon the Steerable Balloon, with HEMERIA, aim to take a place in the world of HAPS (High Altitude Pseudo-Satellites), to complete the observation capacity of satellites. There are also start-ups like ZEPHALTO or STRATOFLIGHT, for tourism under stratospheric balloons, which are potential users of high atmospheric layers. CNES makes its technical expertise and experience, acquired over time and operational campaigns, available to these French actors.
In Europe, Sweden, via the Swedish Space Corporation (SSC) in Kiruna, operates flights of large stratospheric balloons, bought in France or the United States. Other European countries, players or new entrants in space, Germany, Italy, the United Kingdom, but also Belgium, the Netherlands, Spain, Poland, etc. develop instruments or payloads that they fly with the CNES or the SSC, notably recently under the European contract H2020 Hemera, piloted by the CNES. Via Hemera, the UE Europe funded balloon flights for innovative European and Canadian payloads, and federate a balloon user community.

1.2 Interest and applications of balloons

Balloons are platforms for innovation; simple and ecological, they have undeniable advantages:

- Able to evolve durably in the stratosphere, typically up to 40 km altitude, carrying experiments weighing up to more than one ton, balloons are unique vehicles for in situ measurements.
- They allow the development of end-to-end projects over short periods, typically 1 to 3 years, compatible with training cycles for engineers, academics or work-study students.
- They provide subjects for international cooperation at moderate cost, and allow the production of instrument demonstrators for satellites, thus quickly tested in operational situations.
- All equipment that lands under parachute is recovered after the flight, and can be reused, after any repairs or technological improvements.
- The preparation and implementation operations are relatively simple, and make it possible to accommodate various release sites with reduced logistical means.
- The layout constraints and mechanical resistance to shocks and vibrations are less strict than for a satellite subjected to the shocks and vibrations of the launcher.
- Short schedules, low cost, easy access to balloon flights and the entire system implemented make it an excellent tool for training young generations of space engineers and researchers.

1.3 The CNES Balloon product line

To meet the missions requested by their users, French and foreign scientists, industrialists and institutions, CNES balloons must carry payloads of a few hundred grams to more than one tonne, from the ground to the upper stratosphere. , for periods ranging from a few hours to more than 4 months. CNES meets these needs with an optimized range of vehicles (see figure 2), whose envelope materials, dimensions and various on-board and ground systems are adapted to the required performance.

- The Zero pressure balloon (ZPB): The huge ZPB, which can reach nearly a million m3, made of transparent polyethylene 15 to 25 µm thick, can carry nearly 2 tons (including 1 ton of payload gondola) to its hook and flies from a few hours to a few days up to 40 km altitude. It can perform altitude excursions and controlled descents thanks to a valve which allows helium venting, to slow down the ascent or initiate the descent, and a reserve of steel ball ballast, the release of which allows to gain altitude, or to stabilize in descent (see Figure 1 below the synoptic of the ZPB).

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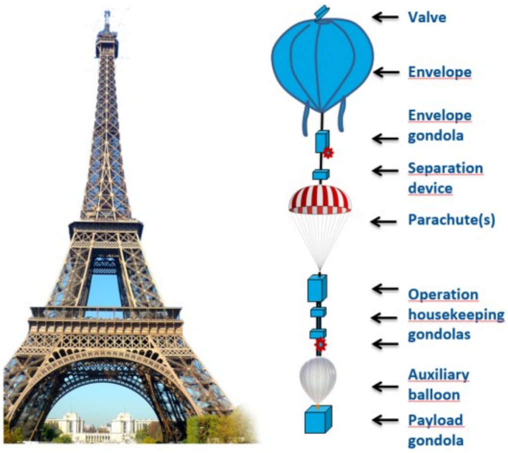

Figure 1: The ZPB flight system

Annual campaigns in Sweden, Canada, Australia and soon Brazil are implementing the ZPB for astronomy experiments like the PILOT telescope, developed with IRAP, the IAS and the CEA, or flights of instruments dedicated to atmospheric measurements as SPECIES of the LPC2E of the CNRS. As a partner of the scientific laboratories, the CNES provides them with payload platforms equipped with high-performance 3-axis pointing systems (better than the second of arc) and all on-board services (power supply, on-board management system, data transmission).

- The Spherical Pressurized Balloon (SPB, see figure 2 below): For longer flights, up to several months, it takes a closed balloon, to keep the lifting gas (helium) throughout the flight, and prevent the balloon from deflating in cold cases (at night). The CNES has developed, for the STRATEOLE-2 program currently underway, for the study of the equatorial stratosphere, an SPB system, with a diameter of 8 to 13 m, whose shell is a 70 µm polyester and polyamide multilayer complex, ultra-violet resistant, and capable of carrying 50 kg between 18 and 20 km of altitude for more than 3 months.
  Designed to keep a constant volume at float, this balloon flies at constant level (it is a quasi Lagrangian tracer), depending on its diameter and of the total floating mass. Manufactured in a cleanroom with strict quality control, folded with great care the balloons are shipped in a dedicated container conditioned under vacuum. They are then softly handled during launch. Under these conditions, this type of balloon reaches flight durations, depending on gas leakage, of up to 3 months


Figure 2: An SPB ready to launch (Credit CNES, R. Gaboriaud 2019)

- The BLD (see Figure 3 below), a light sounding balloon: The stratosphere can also be reached by simple latex balloons, called light balloons in the sense of ICAO (International Civil Aviation Organization, which dictates the rules of the Air). These balloons, carrying less than 4 kg, allow atmospheric soundings up to 30 to 35 km of altitude. Two to three flights are carried out monthly by the CNES in Aire-sur-l'Adour throughout the year.

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They address technological tests at reduced cost, but also scientific measurements, particularly of greenhouse gases (CO2, CH4, H20) and aerosols, for regular monitoring of these climate variables, and calibration of observation satellites such as OCO, IASI, Sentinel 5, and soon Microcarb, IASI NG and Merlin.

Figure 3: Launch of a light sounding balloon

2. Recent zero pressure balloon campaigns

2.1 The KLIMAT 2021 campaign in Kiruna:

The campaign was carried out from August 3rd to August 30th from the SSC Esrange facility (Sweden). Four ZPB flights were on schedule and were successfully performed: Two of them for the French scientific community and for technological purposes, and two funded by the European Community in the framework of HEMERA (European Infrastructure for scientific ballooning).

The scientific payloads are described below:

- The TWIN gondola (HEMERA#1), composed of 4 Aircore instruments (greenhouse gas measurement by air sampling in flight, and analysis on ground) from Frankfort & Groningen universities, one Mega-Aircore from the University of East Anglia (UK), one LISA sampler from the University of Groningen (NL) for CO2, CH4, CO measurements, a cryogenic air sampler from the University of Frankfurt (Ozone and sulphur concentration), and two Pico-SDLA from French GSMA of Reims and DT-INSU (Infra-Red spectrometer for C02/CH4 measurements).
- The CARMEN CNES pointed gondola (HEMERA#2): GLORIA-B from the Karlsruhe Institute of Technology (GE), Fourier transform spectrometer; ALI (University of Saskatoon, Canada), Aerosol Limb Imager for radiative impact; and TotalBRO from the University of Heidelberg (GE), a UV spectrometer for Brome measurement.
- The CARMENCITA#1 CNES pointed gondola including XENON from the IPGP-CNRS of Paris, (Xenon isotopic concentration), NLC (SW) three cameras to observe polar mesospheric clouds (HEMERA payload), Bernadotte from INSERM Lyon (to test the impact of cosmic irradiance on culture human cells. Also on board, BRAD from CNES, for in situ atmospheric radiation measurements and MEDOR technological payload from CNES (deployable/retractable solar panels, with independent pivot for azimuth orientation, and reusable for cost reduction and sustainable development reasons)

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Figure 4: The Xenon Carmencita pointed gondola

- The Super Climate gondola (CNES CARMENCITA#2), composed of SPECIES from the LPC2E-CNRS of Orléans (laser IR spectrometer), one AirCore HR from the LMD of Paris (gas measurement by air coring), two AirCore(s) light from the LMD of Paris; and one bi-gases AMULSE plus one Sample from the GSMA of Reims (Laser diode spectrometer for CO2, CH4).

Two kinds of flight profiles were performed, to comply with the scientific missions specifications: Stabilized constant level ceiling for Gloria, and regulated slow descent from 31 to 13 km in altitude, for TWIN (see Figures 4, 5 below), and Super CLIMAT.

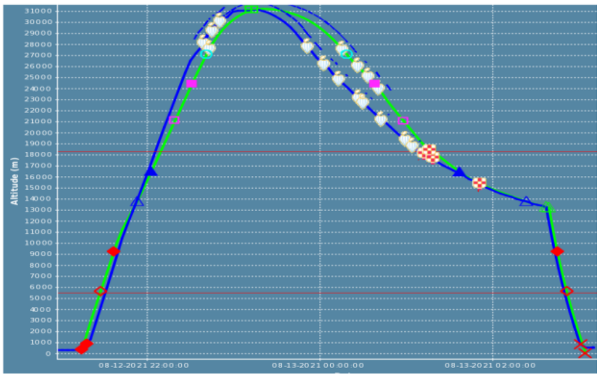

Figure 5: The TWIN piloted slow descent

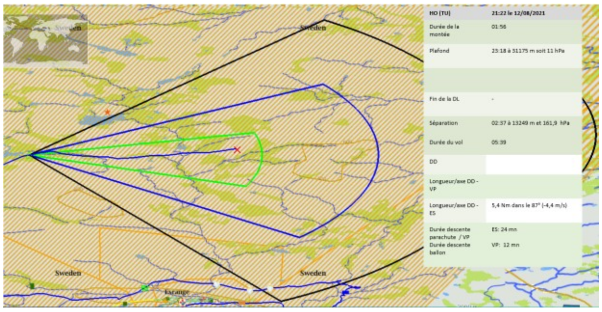

Figure 6: The TWIN horizontal drift descent and landing zone

Several technological in flight validations were achieved during the KLIMAT 2021 campaign, such as:

- MEDOR: An innovative deployable and reusable solar panel delivering 1 kW
- NEV-NG: A new envelope gondola, lighter and cheaper than the previous one

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Figure 7: The MEDOR deployable solar panel

2.2 The STRATO SCIENCE 2022 campaign in Timmins

The Timmins 2022 launch campaign took place from August 1st to September 2nd just before and during the turnaround period of late summer. Four flights were successfully performed, two of them for the French and European scientific communities and for technological purposes, and two for the Canadian community. The payload gondolas were composed of the following instruments:

- CALASET, composed of 2 Canadian absorption spectrometers (CALASET & NG), a light measurement camera HABLAN, a Zephyr (STRATEOLE 2 French payload platform) integrating VATA, BIS and XStorm, a gamma ray scintillator (GRASS) and a radiation detector (PIX)
- SOLAR, consisting of a CNES-ESA solar cell calibration plate (CASOLBA), an Italian imaging coronograph (CORMAG), a human cells exposure to cosmic radiation (BERNADOTTE) from French INSERM, an ionic radiation detector (ECAPS) and a CNES radiation detector (PIX), see flight profile in Figure 8 below,
- IFTS, an Italian scientific gondola, composed of a Fourier transform spectrometer for the measurement of CO2 and methane (IFTS), an HD low-light imaging camera (HIPTA), a device for detecting and locating stars and/or space objects (RSOnar) and a Aerosol Imager (ALI)
- The HEMERA 3 flight, composed of an IR spectrometer (GLORIA, Germany), a spectrometer dedicated to the measurement of Brome (TotalBro, Germany), another water vapour spectrometer (FIRMOS, Italia), a radiation detector (AIRE, Spain), a proton detector capable of triggering single event effects (SEE) in embedded electronics (BRAD-PIX, France), an Ozone electrochemical sensor, a fine particle optical sensor and a LORA communication module composing the BallonBus French student payload.

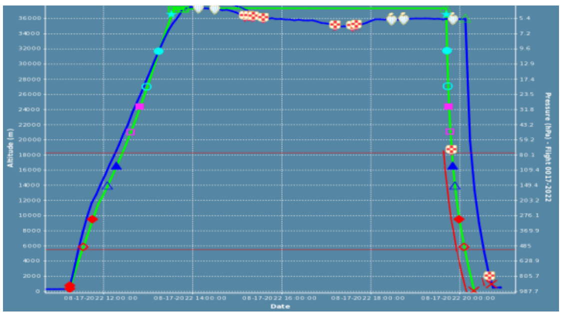

Figure 8. The SOLAR flight profile

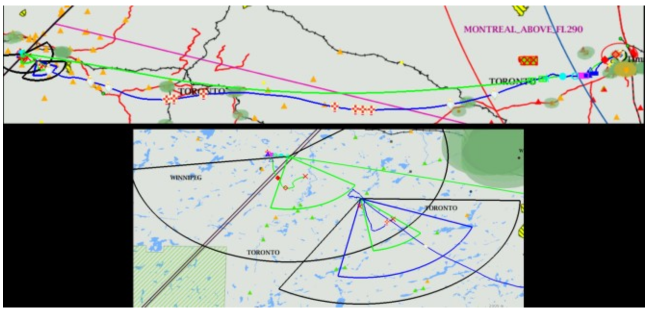

Figure 9: The SOLAR trajectory and landing zone

3. The NASA/CSBF campaign in Fort Sumner 2023

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FIREBall (the Faint Intergalactic Redshifted Emission Balloon) is a balloon-borne 1-m telescope coupled to an ultraviolet multi objects spectrograph. FIREBall is designed to study the faint and diffuse emission of the intergalactic medium

As part of an international collaboration, the CNES has designed and manufactured the FIREBall pointed gondola structure and system, with its flight services, to accommodate the instrument developed by LAM (Astrophysics Laboratory of Marseille) and US labs (University of Columbia and Caltech). This 2.4 tons gondola has a sophisticated 4 axis attitude and pointing control system, yielding better than 0,5 arcsec RMS over long integration periods.

After the first operational flight in 2009, the instrument was improved to gain a significant factor of sensitivity. The 2nd flight of the FIREBall gondola took place during the fall 2018 campaign at Fort Sumner (see the payload gondola in Figure 10 below):

Figure 10: The FIREBall scientific gondola in Fort Sumner

A gas leakage on the balloon envelope reduced the telescope's observations duration, in required conditions, to 1 hour. However, the processing of the collected data made it possible to validate the instrument by obtaining first scientific results.

Since then, new improvements were applied to the instrument; the gondola was tested and repaired at CNES, and shipped to Fort Sumner in fall 2021. After a first unsuccessful attempt in 2022 due to a flaw on the instrument, the new integration and tests campaign at gondola and instrument levels has been carried out in Pasadena (CALTECH) in the 1st half of 2023. The performances of the system are ready to make science, so the next flight is on schedule during the fall 2023 NASA-CSBF campaign in Fort Sumner, New Mexico.

4. The Strateole-2 campaigns

4.1 Context

Since the VORCORE and CONCORDIASI campaigns in Antarctica with the CNRS and the US-NSF in 2005 and 2010, CNES has been developing a unique know how in the field of super pressure long duration balloons (SPB), able to carry up to 50 kg at hook at 20 km in altitude, for up to 3 months. Further to a deep renovation of all the ground and onboard command control system in the period 2015-2019, CNES has been able to propose an adequate solution to the needs of the Strateole 2 project, aiming at studying the low stratosphere at the Equator.

First, a quick overview of the project and system, is given below.

4.2 The Strateole-2 project

The Strateole-2 program was proposed by the French LMD-CNRS laboratory, backed by French and international scientific communities and agencies. In France, the labs LPC2E, GSMA, CNRM, LATMOS, DT-INSU are participating, with the CNES for the project management and the funding of French labs.

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Regarding international partnerships, collaboration with the USA is established, with NSF (National Science Foundation) and several research institutes in the field of atmospheric sciences: The Laboratory for Atmospheric and Space Physics in Boulder, the Scripps Institution in San Diego and the NorthWest Research Associates/CoRA in Boulder. Other countries like Italy (CNR-ISAC), India (NARL) and Russia (TSAO) are also participating.

The Strateole-2 project aims at improving our knowledge of coupling processes between the troposphere and the stratosphere in the deep tropics. Strateole-2 will provide information relevant to horizontal and vertical transport in the Tropical Tropopause Layer, penetrating convection, dehydration, cirrus occurrence, gravity-wave generation, propagation and driving of tropical stratospheric oscillations (QBO, SAO), which are all critical dynamical and physical processes in tropical and global climate. Strateole-2 will furthermore provide near-real time observations to improve weather analyses and forecasts in the tropics during the campaigns, and contribute to the validation of the Aeolus space borne wind lidar of ESA.

In order to document the UTLS (Upper Troposphere/Lower Stratosphere) under different stages of the QBO, two scientific campaigns are scheduled, about three years apart. They involve stratospheric balloons as a research platform carrying several types of instruments, both for in situ and remote measurements in the atmosphere. These measurements are performed in association with space borne observations (e.g. IASI, Aeolus space borne wind lidar), as well as with radiosonde soundings and other ground-based observations conducted from several stations in the tropics (like from NARL).

The main period of interest for Strateole-2 extends from early October to late March. A 2-month period (October-December) is needed to release 20 balloons per campaign. Once launched, the balloons will then nominally fly for 3 months, behaving as quasi-Lagrangian tracers of air parcels motions. The launch site, selected for the campaigns, is Victoria Airport / Republic of Seychelles [4° 40’ S], where the pre-Concordiasi campaign took place in 2010.

The scientific instruments are:

- TSEN (LMD) performs in-situ measurements of temperature, and pressure.
- SAWfPHY (LMD): a lightweight frost point hygrometer.
- B-BOP (LMD): an ozone photometer.
- ROC (Scripps): an improved dual frequency GPS receiver, used for position and occultation measurements, giving information on waves dynamics, and on temperature and moisture variations.
- BOLDAIR (LATMOS): radiometer for the measurements of upwelling infrared flux and albedo.
- BeCOOL (LATMOS & CNR-ISAC) nadir pointing lidar measurements to detect cirrus.
- Pico-SDLA (GSMA): measurements of water vapor and carbon dioxide based on laser absorption spectroscopy in an open atmospheric cell.
- LPC (LASP): aerosol counter.
- LOAC (LPC2E): aerosol optical counter.
- RAChuTS (LASP): package, deployed 2 km below the balloon, combining different instruments for measurements of water vapor (FLASH-B / TSAO), of temperature and pressure (light version of TSEN / LMD & FLOAT / LASP) and aerosol profiler (RACHuTS / LASP).

Two main types of flights are performed:

- Flights in the upper part of the Tropospheric Layer (~70 hPa / ~120 g/m3) with mainly in-situ measurements (notably trace species and particles), and “in situ” profiling down to a few km below the balloons (denominated “TTL”).
- Flights higher up in the lower stratosphere (~50 hPa / ~90 g/m3) with mainly remote sensing measurements, denominated “STR” for Stratospheric.

4.3 The new long duration flight system

The architecture for SPB system of the Strateole 2 project is as follows:

- A SPB balloon with a diameter of 11.0 m or 13.0 m, filled with helium
- The flight chain comprises a release pyrotechnical mechanism, a parachute, an operational fail safe gondola (EUROS) for flight control, a ballast tank and a scientific payload gondola (ZEPHYR).
- The control segment, operated by CNES, with a nominal and a redundant control center, are located in Toulouse and in Aire sur l’Adour.

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- A separate mission center, is located in Paris.
- The ZEPHYR payload gondola and the mission center are developed and operated by the scientific team led by LMD.
- Telemetry flow monitoring, flight termination activation.

4.4 The validation campaign 2019-2020:

Before the two scientific campaigns foreseen in fall 2021 and 2024, a flight validation campaign was conducted, with the dual purpose of validating the CNES system and the science system. A unit of each one of the flight configurations was flown. This campaign took place in 2019-2020, from Mahé, in the Seychelles Islands.
The flight validation campaign was a great success: The 8 balloons, launched from November 11th to December 6th 2021, achieved a total of 630 days of flight, an average of 85 days per balloon, and a record of 107 days for the longest duration !
Circling the world, the balloons overflew 63 countries among the 96 possible on their track (see trajectories on Figure 11 below).
Both the housekeeping system and the payloads were validated, pre-STRATEOLE 2 data were used by ESA to calibrate the AEOLUS satellite wind lidar measurements, several publications were issued, and the system was declared qualified for the scientific campaigns.

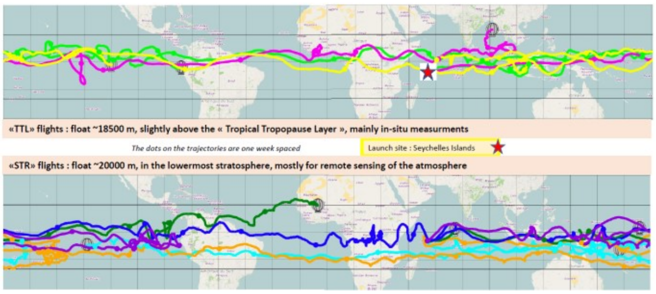

Figure 11: Trajectory of the 8 SPBs during the Pre-Strateole 2 campaign (2019-2020)

4.5 The first scientific Campaign 2021:

The first scientific campaign began on Mahé, Seychelles, on September 23rd by the installation of the infrastructures, two tents for balloons and gondolas preparation and 5 offices, and the preparation of all the ground means for AIT and the control centers. The first SPB was ready to fly on October 11.
We had to cope with the 4 to 5 night slots per week given by the Victoria airport authority, that lasted between 1,5 and 8 hours depending on the day and the month (according to the number of aircraft, that increased towards the end of the year).
17 launches were carried out from October 19 to November 25, i.e. an average of 3 launches per week as foreseen, thanks to 5 “double launches” during a launch window given by the airport.
Regarding the weather at ground, we experienced a “dry” season compared to usual climatology, but 50% of the airport slots could not be used mainly because of surface winds.
Among the 17 flights, some balloon envelope failures occurred quite early during the campaign, and balloons were then (partially) controlled on the launch table before launch. The first impression is that the failures were most likely due to a faulty fold on the quite rigid three-laminated envelope material. The rest of the system, ground and onboard, and the operational procedures functioned perfectly.
To give figures, the balloons yielded a total of 632 days of flight, an average of 42 days per balloon, without counting the two shorter flights. The longest flight lasted 71 days.
The fact remains that this first scientific campaign was a scientific success despite the shorter average durations of flights, as unique data were retrieved regarding the winds, the greenhouse gases concentrations, the air temperature and pressure, in the lower equatorial stratosphere.
In particular, temperature and pressure data could be assimilated in real time in the MeteoFrance Arpege model, and the results are quite promising.

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Also the fine air pressure variations measurements with the onboard ultra-accurate barometer allowed to detect the impact of the Hunga Tonga volcano activity during the period, paving the way to detection of seismic activity from the stratosphere (see Work by Garcia and Al., ISAE).
A work group on balloon anomalies has been nominated at CNES to investigate further and to define the corrections necessary to regain the duration performances of the 2019 validation campaign.
It is expected to resume the balloon production for early 2023, still early enough to foresee the next campaign in late 2024, or 2025 as a backup.
From now on, the maintenance in operational condition of all services is ongoing, for the control centre, the command-control tools and interfaces, the flight physic tools, the system and numerical benches, the launch means. The supplies are ongoing for the AIT of the gondolas flight models that should start in fall 2022.

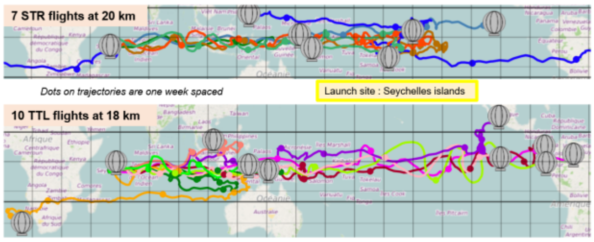

Figure 12: Trajectories of the Strateole 2 scientific campaign #1 2021-22

5. The sounding balloons (SB) campaigns

With the help of the miniaturization of electronic systems, instruments weighing less than 3 kg can now accurately measure the atmospheric content of greenhouse gases and aerosols under small balloons, and contribute to the study of climate change. Latex light balloons, capable of carrying 3 kg at an altitude of 35 km, are a means increasingly used by CNES and the CNRS during regular scientific measurement campaigns, carried out in particular from the CNES balloon operations centre in Aire sur l'Adour and from other CNRS and MétéoFrance sites. These light balloons are also suitable for technological tests in the stratosphere of small instrumental systems, in particular developed by students who are then trained to space technologies at low cost. CNES has launched about 100 sounding balloons from Aire sur l'Adour from 2019 to 2021.
In particular, MAGIC campaigns (Monitoring of Atmospheric composition and Greenhouse gases through multi-Instruments Campaigns), led by French CNRS, have used sounding balloons (SB), instrumented airplanes (SAFIRE fleet) and ground resources (like EM27/SUN spectrometers) to calibrate the greenhouse gas measurements made by the observation satellites like ESA-Sentinel 5, OCO, and soon Microcarb or Merlin. The 2019 and 2020 editions took place in France, notably in Aire sur Adour (CNES), GSMA Reims (CNRS) and Trainou (CNRS).
The MAGIC campaign of 2021 was conducted in the Arctic, mainly in Kiruna, during the KLIMAT campaign, to benefit from the additional measurements carried out by heavier instruments flying under a ZPB, such as SPECIES of the LPC2E Orléans (see Figure 13 below).
The instruments flying under sounding balloons for the MAGIC campaign were AIRCORE light, from LMD-CNRS Palaiseau, for profile measurements by air sampling 0-30 km of CO_2, CH_4, CO, Temperature, H_2O, wind, isotopes of C, N_2O, and AMULSE, from GSMA-CNRS in Reims, a laser diode spectrometer for profile measurements 0-30 km of CO_2, CH_4, H_2O, and temperature.

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Figure13: MAGIC 2021 Combined flights

6. The HEMERA European balloon infrastructure

The HEMERA balloon infrastructure is funded by the European Commission within its program Horizon 2020 Infraia 02-17. The major objective of HEMERA is to enlarge the user community of stratospheric balloons in the field of research and technology. The project is coordinated by the CNES and involves 13 partners including space agencies and scientific institutions in Europe and Canada. The project was kicked-off in late January 2018 and is in process of execution from 2018 to October 2022.
Six ZPB flights, with a target total payload mass of 150 kg each (typically 3 payloads of 50kg each per flight), were foreseen. The HEMERA infrastructure offered free of charge balloon flights to users and scientists from various science fields and/or for technology tests. Individual payload masses could vary from one to several tenths of kg. In addition, sounding balloon flights were foreseen for payloads up to 3 kg.
Many fields of science are addressed: atmospheric chemistry, aerosols, IR measurements, climate, solar science, high energies.
The launch sites are Esrange in Sweden, Timmins in Canada, and Aire sur l'Adour in France (for SB).
CNES and SSC operate the flights.
Further to the 1st call for proposals of 2018, 39 payloads have been proposed out of which 23 from 11 countries have been selected for 4 planned ZPB flights in Kiruna in 2019 and 2020.
The second call for proposals took place in October 2019, and yielded 31 proposals from 10 countries. 16 payloads from 8 countries were selected for the realization of 2 ZPB flights, one in Kiruna by SSC and the other in Timmins by CNES, in August 2022.
CNES carried out 2 HEMERA flights in Kiruna in 2021, in particular for the GLORIA (KIT, GE, see Figure 14 below) and TWIN (GE) payloads.


Figure 14 The Gloria payload pointed gondola

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The last HEMERA flight conducted by CNES will take place in Timmins in August 2022, for the following payloads:
AIRE (Atmospheric Ionization Radiation Evaluator, Spain), TOTALBRO (UV spectrometer for total stratospheric bromine measurement, Germany), GLORIA (Fourier transform spectrometer, Germany), FIRMOS (far infrared radiative closure study, Italy), CORMAG (Italy), ECAPS (Experimental Characterization of Advanced Photovoltaics in the Stratosphere, Italy).
Further to the success of the HEMERA initiative, the HEMERA working group goes on coordinating and promoting balloon flights for European payloads, and already the partners decided to support the project to provide launch opportunities at marginal costs.

7. A major innovation, the steerable balloon

Giving the capability to a simple balloon to be steerable and to follow a controlled trajectory to go from one point to another, or to remain overflying a dedicated area is for CNES the major innovation of the coming years in the field of stratospheric balloons. This endeavour is now in progress with the HEMERIA French company, and the first steps of the project have been funded by France reliance and CNES Defence credits. This bi-balloon is consisting of a pressurized pumpkin balloon filled with air, of about 20m in diameter, and containing a helium balloon. It is capable of controlled vertical excursions between 16 and 22 km, to use the stratified winds of the stratosphere, variable in directions and velocity, to move towards a target area and to stay there sustainably. It is the increase of the mass of air sucked through an onboard compressor that allows the balloon to go down (it is heavier), and the venting of this air that allows it to ascend (it is lighter), see principle in Figure 15 below.
This “persistent” balloon, whose concept has been proved by Google’s Loon project, paves the way to new scientific and technological applications, as well as Earth observation imagery, civilian and defence security and surveillance. The first technological flights operated by CNES are foreseen in 2024 – 2025.

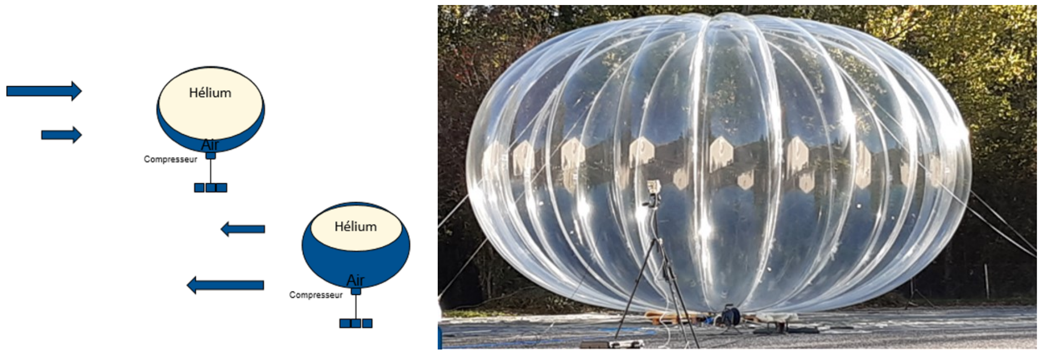

Figure 15: The CNES-HEMERIA steerable balloon principle and mock-up

8. Conclusion

Since 2021, CNES, SSC, CSA and their scientific partners have successfully implemented 2 ZPB scientific campaigns in Kiruna 2021 and Timmins 2022. Next campaigns will take place in Timmins (2023) and Kiruna (2024).
CNES plans now to expand its ZPB balloon offer by proposing, from 2024, transatlantic flights between Kiruna (Sweden) and northern Canada in the early summer, aiming at 5 to 7 days of flight between 35 and 40 km during the 24h day phase of the Arctic summer. Moreover, a preliminary survey of potential equatorial launch sites has been started with the Brazilian Space Agency (AEB), on the basis of the scientific needs for flights at the Equator.
The next flight of the FIREBall gondola, is now on schedule this fall 2023 from the USA.
The STRATEOLE 2 validation and first scientific campaigns have been conducted using long duration pressurized balloons, first scientific results have been published. The second scientific campaign is foreseen in late 2025, again from the Seychelles Islands.

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To prepare the future, several studies are underway to increase the performances of the SPB in terms of payload mass, higher flight altitude, longer duration, and trajectory piloting. In particular, a persistent balloon demonstrator, inspired from the Google-Loon vehicle in under development with HEMERIA, the French balloon manufacturer, that should open new capabilities and new markets to the stratospheric balloons family.

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