Cours Technique

Balloons for Science

2023

Vincent DUBOURG – DOA/BL

CONTENTS

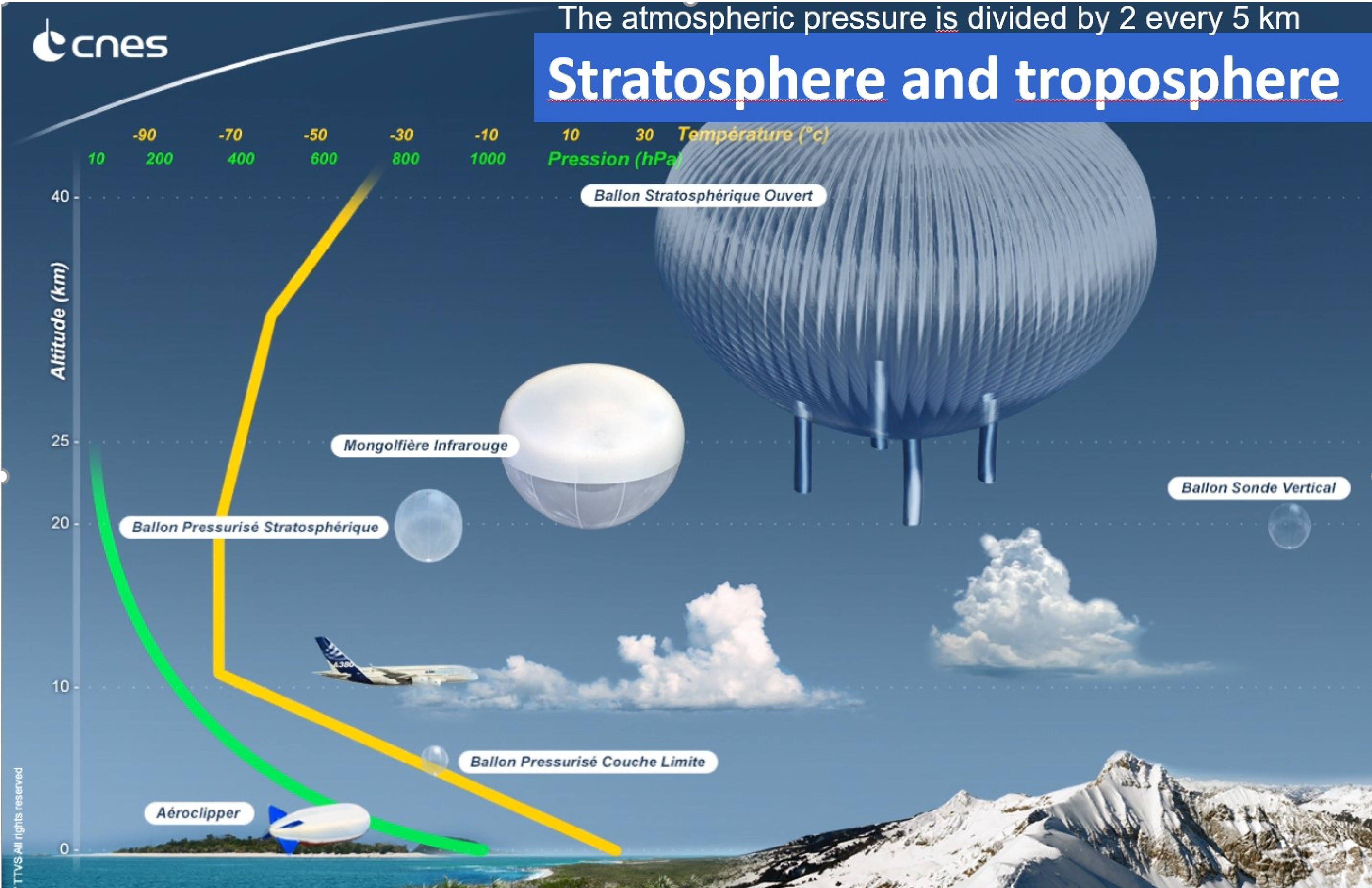
Introduction

- At the origin of the first flight of Man in the atmosphere, it kept its original simplicity: it moves only thanks to natural strengths

  - The buoyancy force lifts it,
  - The winds push it,
  - The gravity gets it down.

The atmospheric pressure is divided by 2 every 5 km

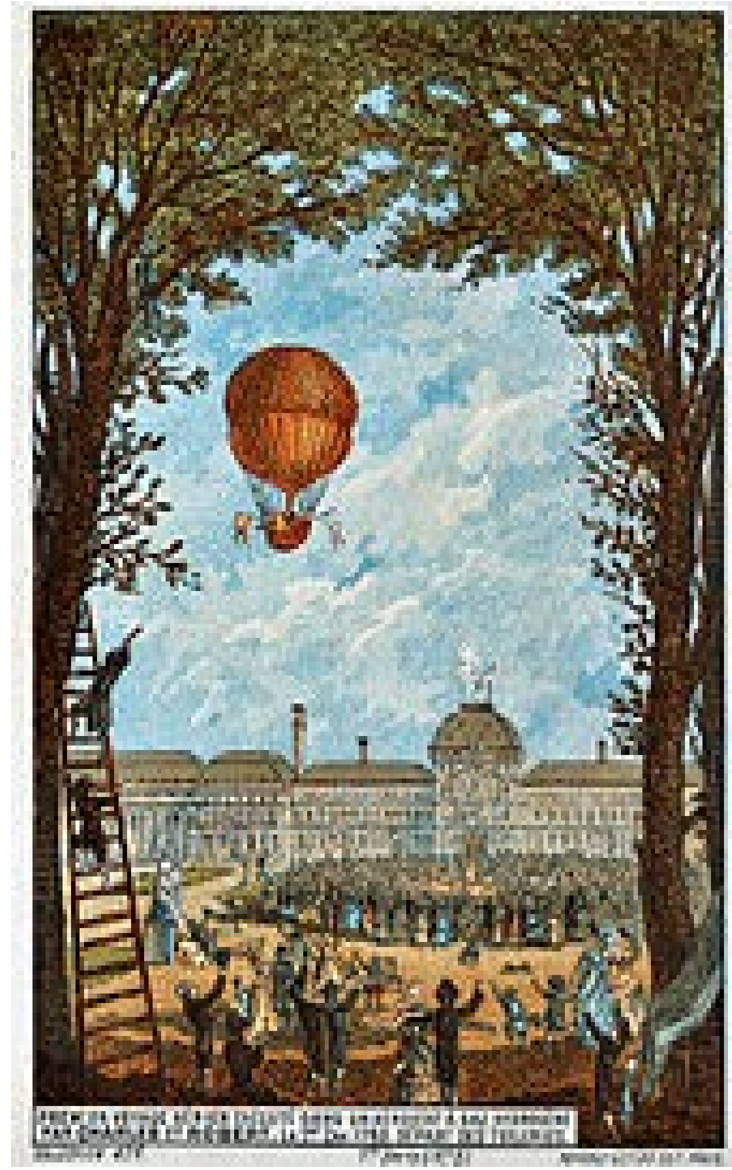
Stratosphere and troposphere



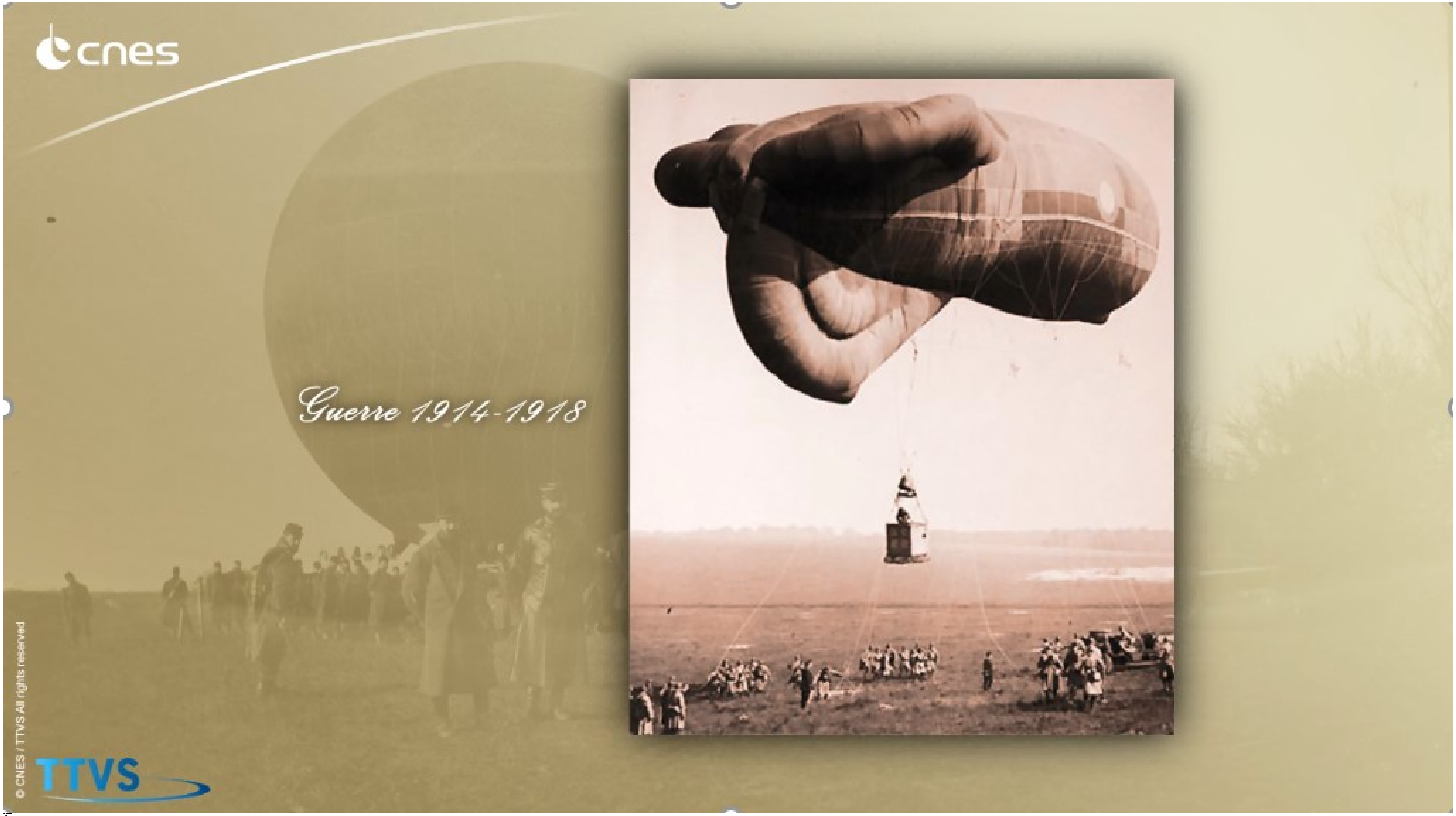
A bit of history: The Balloon, a French invention !

A bit of history: 1783, first scientific experiments

Montgolfiere:
Pilâtre de Rozier & Marquis d'Arlandes



Hydrogene balloon:
J. Charles & M.N. Robert


Guerre 1914-1918
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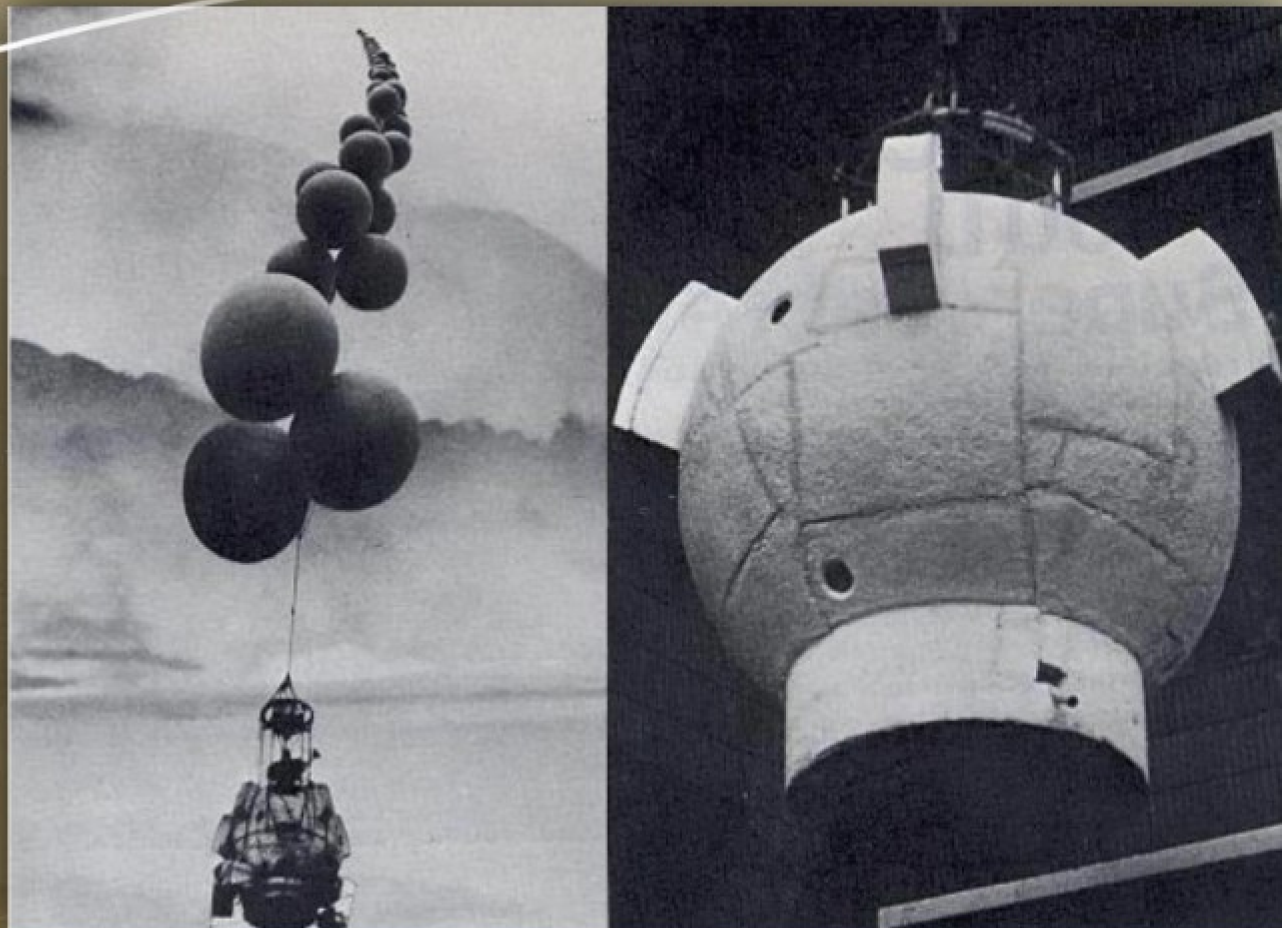
2e guerre mondiale Météorologie opérationnelle



Les originalités . . . Charles Dollfus


Les records Octobre 2012
Roswell, Nouveau Mexique : Félix Baumgartner franchit le mur du son
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ZENITH
STRATOS

A Bit of history: CNES Balloon activities

- **1958**: Beginning of Scientific Balloon activities (J. Blamont, Service d'Aéronomie CNRS)
- **July 1961**: settlement of fabrication means (R. Regipa)
- **13/10/1961**: 1st launch of a 3000 m3 balloon (tetrahedral) from Trappes (78, near Paris)
- **1962**:
  - Launch campaign from the Kerguelen Islands
  - Settlement of the Aire sur l'Adour (40) launch base
  - First flights from Kiruna (Sweden)
- **12/09/1964**: inauguration of the Aire sur l'Adour launch base
- **1965**: Delegation of balloon activities to CNES
- **1968**: Launch of a 100 000 m3 zero pressure balloon (ZPB)
- **1982**: Launch of a 1 000 000 m3 ZPB from Aire

  Ceiling reached: 47 km

Varied advantages

- **Short development** durations (some months to a few years vs. ~ 10-20 for a satellite project)
- Gondolas and equipment can be **recovered and reused**. The same equipment and instruments can fly twice in the same campaign
- **Complementarity** to aircraft, sounding rockets, and satellite missions (calibration of satellite instruments by in situ balloon measurements)
- **Flexibility and simplicity** of the launch operations: No specific spaceport is required > large diversity of launch sites, function of scientific requirements
- **Few constraints on payloads**:
  They can be heavy, voluminous, there are no drastic requirements in terms of acceleration (vibrations, shocks) compared to launchers
- Moderate operational cost: a ZPB campaign costs ~ 1,5 M€

Balloons are good candidates to train new comers in space and for cooperation!

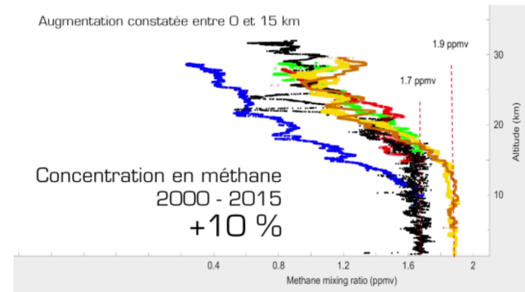
Scientific interest

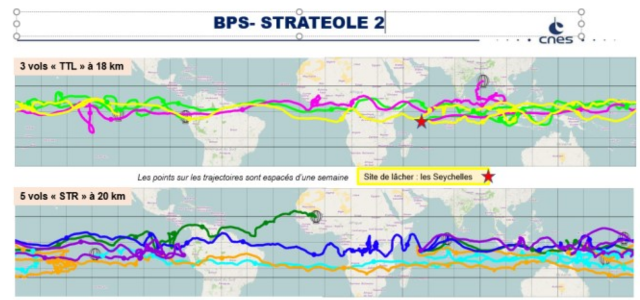
Study of the atmosphere, its chemistry and its dynamics

- Experiments fly in the site of measurements

  (sampling of air or measurement of constituents concentration)

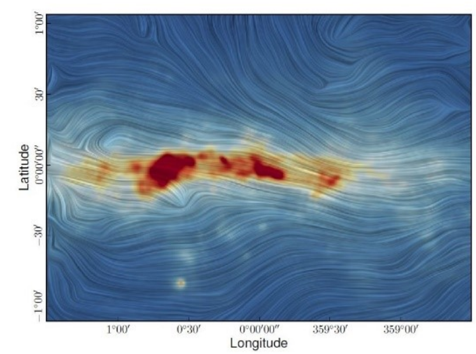
- Meteorology and aeronomy: The balloon, pushed by the winds, helps to know the movement of the air masses





Astronomy

- Above the dense layers of the atmosphere, telescopes can observe radiations almost invisible from the ground
  - infrared, ultraviolet
  - X-rays and gamma rays



Interest of Balloons


CASOLBA: Test of solar cells

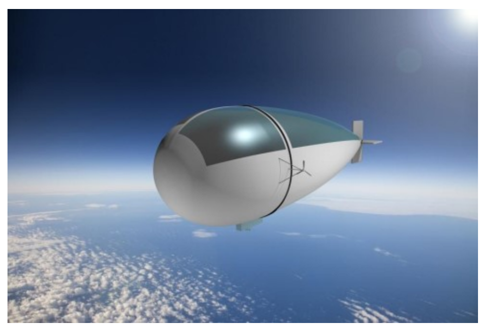
Other fields

- Biology (study of the effects of the cosmic radiations on living cells)
- Geophysics (Earth underground layers, magnetic field)
- Technology:
  - * Calibration / validation of satellite equipment and instruments:
    ENVISAT, IASI, AEOLUS, Earth Care, tests of solar cells…
  - * Drop tests of re-entry objects: Aerostatic crane
    ARD Shield, EXOMARS parachutes, HIDRON Canadian glider


Aircore Air sampler, credit: LMD-CNRS

- Telecom, Observation, Surveillance and Security

Credit: Google-Loon


Credit: TAS-Stratobus


Credit: CSA-Hidron

Organization / Actors in France

CNES

Finances, develops and operates the French balloon systems for science and technology

Industry

Equipment and subsystems: HEMERIA (balloon envelopes, unique in Europe),

ELTA, MICROTEC, ADENEO, EREMS, CROSSWAY (onboard systems), CS, CAP GEMINI (Ground segments)

French scientific partners: INSU/IN2P3/CNRS

Develop the scientific instruments and work on the data collected,

Several laboratories are involved:

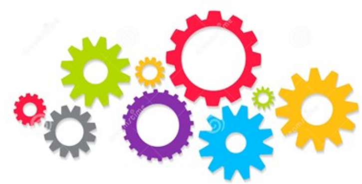
LPC2E, LMD, LATMOS, LERMA, GSMA, LAM, APC, LA, IRAP, DT INSU, CEA, ONERA, INSERM, LSCE, IMCCE…

New comers in the stratosphere

Thalès Alenia Space (Stratobus HAPS project)

Airbus developed the ZEPHYR drone, and participates in the Persistent balloon project with HEMERIA

Zephalto: A startup to develop tourism in the stratosphere under a balloon



cnes

Organization / Actors abroad

Europe:

- SSC (Swedish Space Corporation): Operates Stratospheric balloons in Kiruna
- ASI, INAPS (Italie), SNSB (Suède), DLR, KIT, Universities of Heidelberg, Frankfort (Germany), Cambridge (GB): develop payloads, and/or use balloon data.

USA:

- Most important balloon activity in the World: NASA, scientific laboratories, RAVEN-AEROSTAR (envelopes and systems manuffacturing and operation), private companies (World View…)

Canada:

- CSA and scientific labs: Develop payloads, fly under CNES Balloons in the Canadian site of Timmins and elsewhere

Asia: Japan (JAXA-ISAS), India (NBF, Hyderabad), China, develop and operate balloons

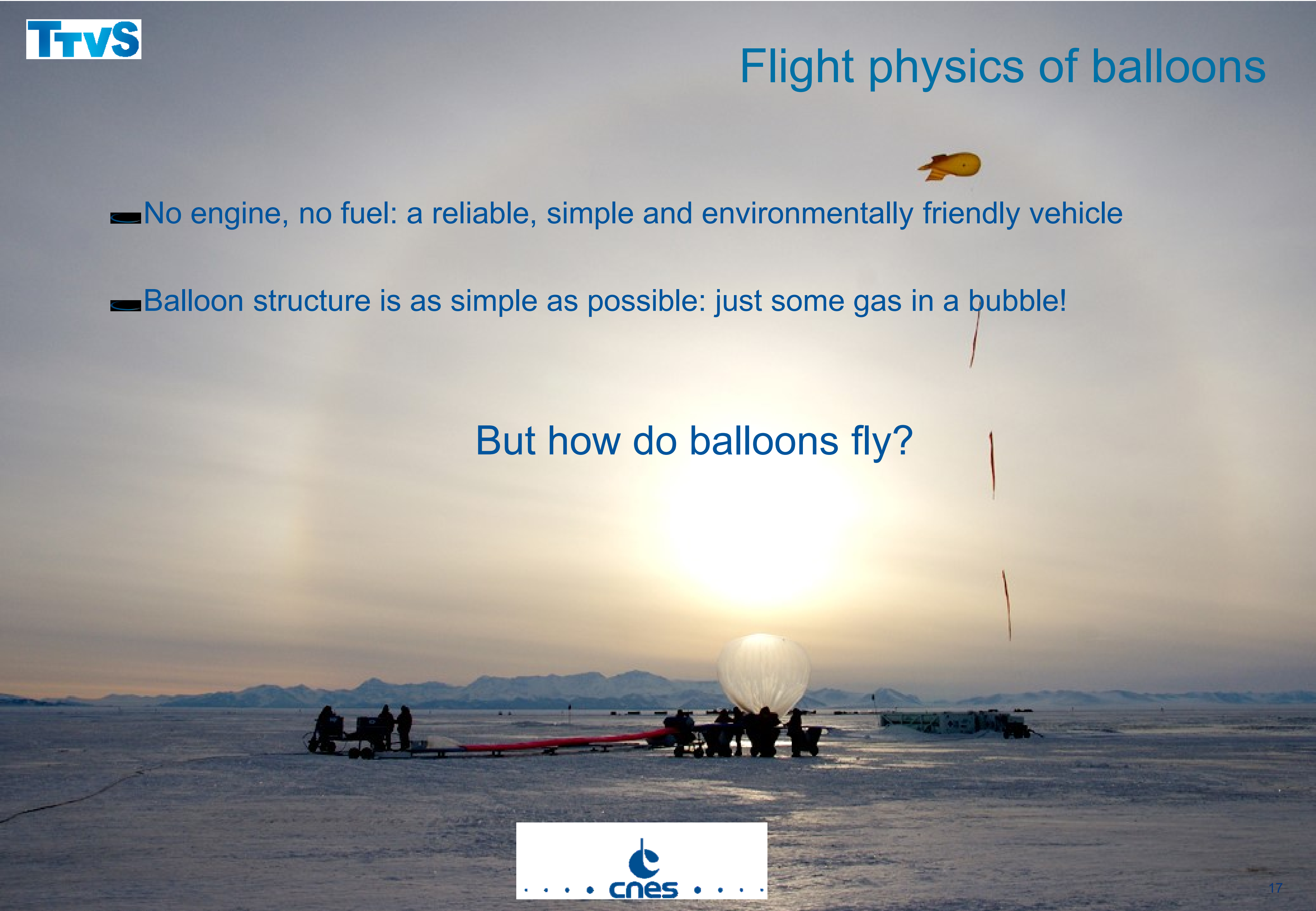
Oceania: CSIRO and UNSW to access to Alice Springs launch base

→Cooperations ongoing between CNES and almost all these actors:

En particular, the HEMERA european balloon infrastructure, lead by CNES

→ CNES Balloon activity is unique in Europe… comparable to the US one.

CNES's know-how is recognized all over the world!



Flight physics of balloons

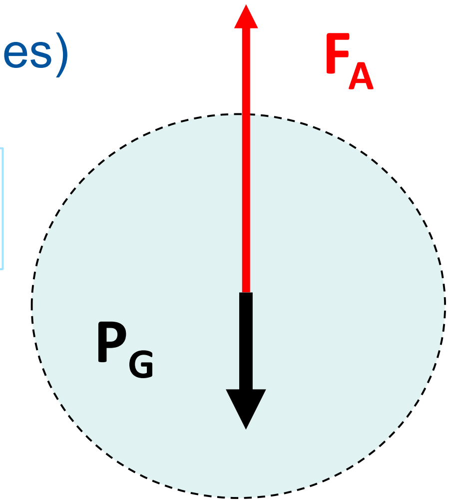
- No engine, no fuel: a reliable, simple and environmentally friendly vehicle
- Balloon structure is as simple as possible: just some gas in a bubble!

But how do balloons fly?

Equation
Flight physics of balloons

- The **total-lift force** FAT is defined as the **buoyant force** (cf. Archimedes) minus the weight of the gas:

$$FAT = F_A - P_G = (\rho_A \times V \times g) - (\rho_G \times V \times g) = (\rho_A - \rho_G) \times V \times g$$

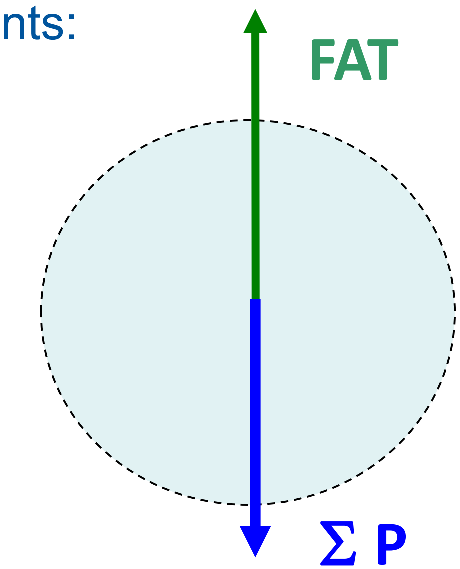


- FAT is opposed to the weight of all the solid elements:

$$FAT \longleftrightarrow \Sigma P$$

- The **free-lift force** FAL is the FAT minus the weight of the solid elements:

$$FAL = FAT - \Sigma P = [(\rho_A \times V) - (\rho_G \times V)] \times g - \Sigma P$$



- If FAL > 0, then the balloon will take off!

$$(\rho_A.V - M_G - \Sigma M_S).g - \frac{1}{2}.\rho_A.S.C_x.\left(\frac{dz}{dt}\right)^2 = (\rho_G.V + \Sigma M_s + C_F.\rho_A.V).\frac{d^2z}{dt^2}$$

Equation of the vertical movement

Flight physics of balloons
Shape of the balloons at flight level

Closed Pressurised balloons - SPB, BLPB

FAL converted into Pressurization
Local stress: DeltaP x R / (2e)
Film: Multitilayer, rigid

Open Zero pressure balloons - ZPB, MIR

FAL evacuated at float through exhaust sleeves
No circumferential effort
Film: Thin polyéthylène layer

The CNES Balloon line of products

Stratospheric balloons

Altitude Km

40

NEW concept with HEMERIA:

Steerable balloon BALMAN (ref. Loon)

- **Post STRATEOLE**
- **Observation, Defence**
- **Flight >=3 months**
- **P/L 20 kg**
- **Alt. ~20 km**

BLD Sounding balloon, MAGIC, …

2 h ascent up to 25 to 35 km

P/L: <=3 kg

25

SPB STRATEOLE 2, …

Flight >= 3 mois

Alt. 18-20 km

P/L: 20 kg

ZPB (PILOT, HEMERA, …)
3 000 to 800 000 m3
Flight: Some hours to a few days
Alt.: 15-40 km ,
Ceiling or slow descent
P/L: Up to 1 Ton

20

18

Tropospheric balloons

5

BLPB

1 month: 500 m to 3km

P/L: 3 kg

AEC AEroClipper

1 mois

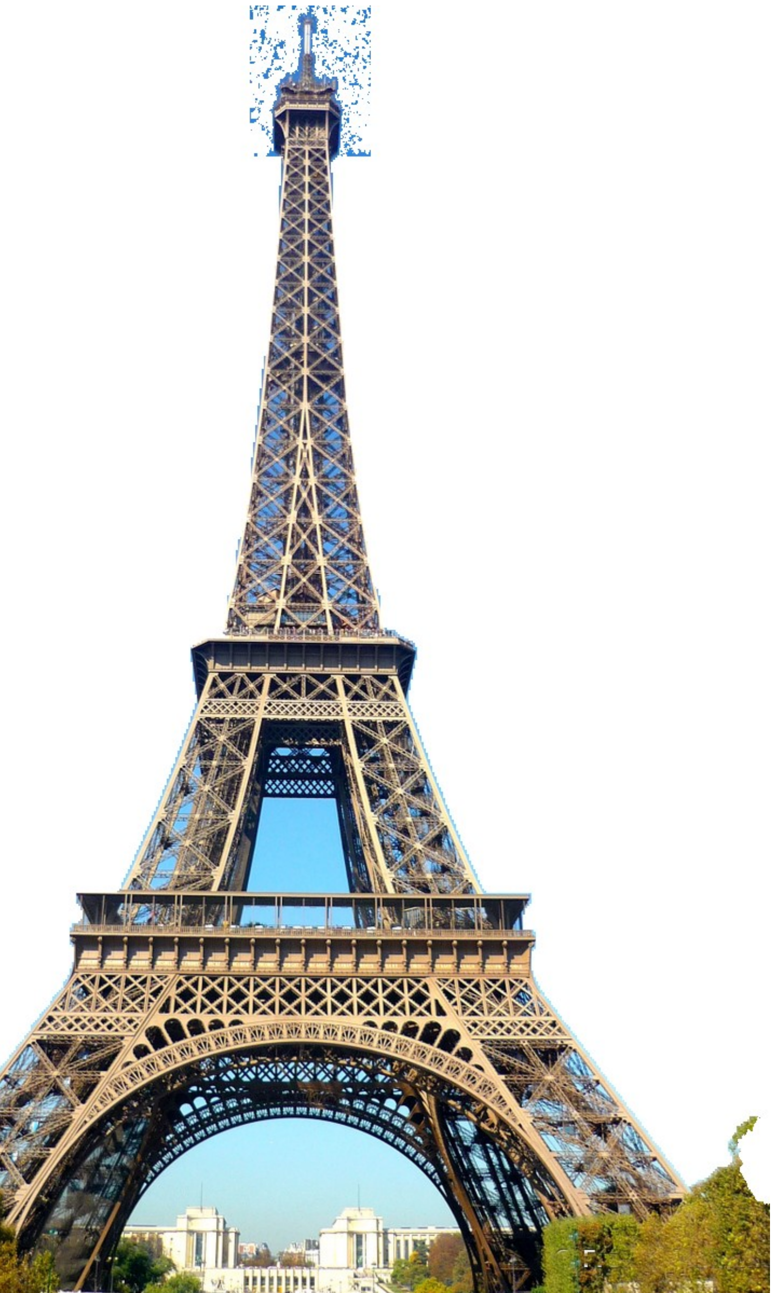
CU: <5 kg

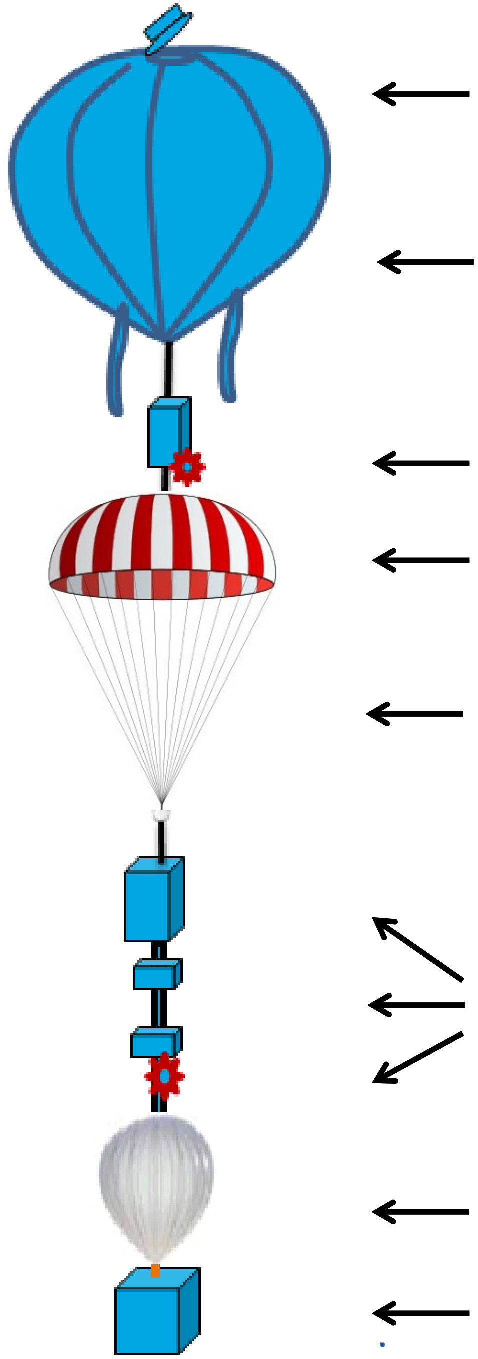
1

0,05

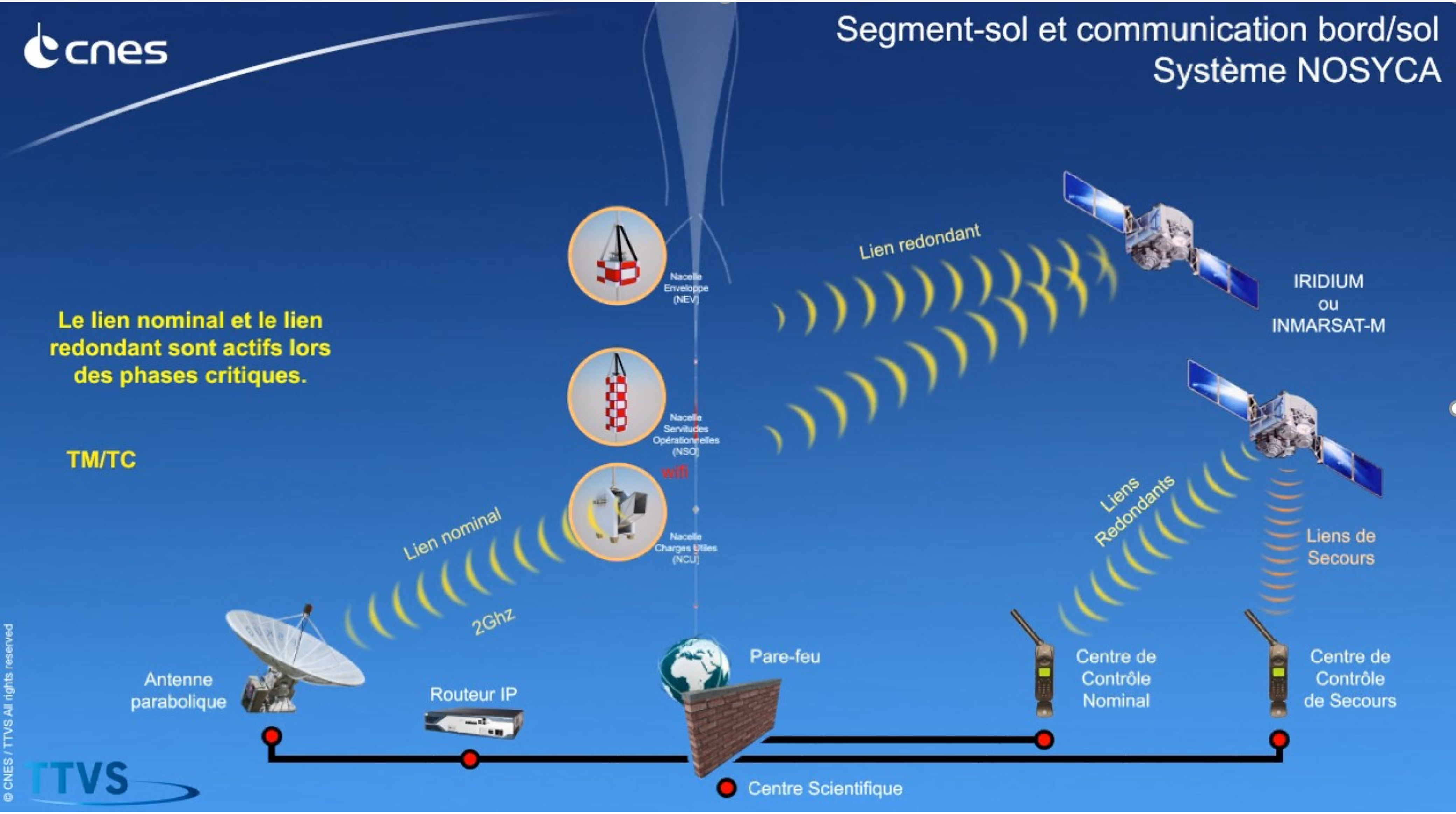
TTVS

The ZPB Aerostat



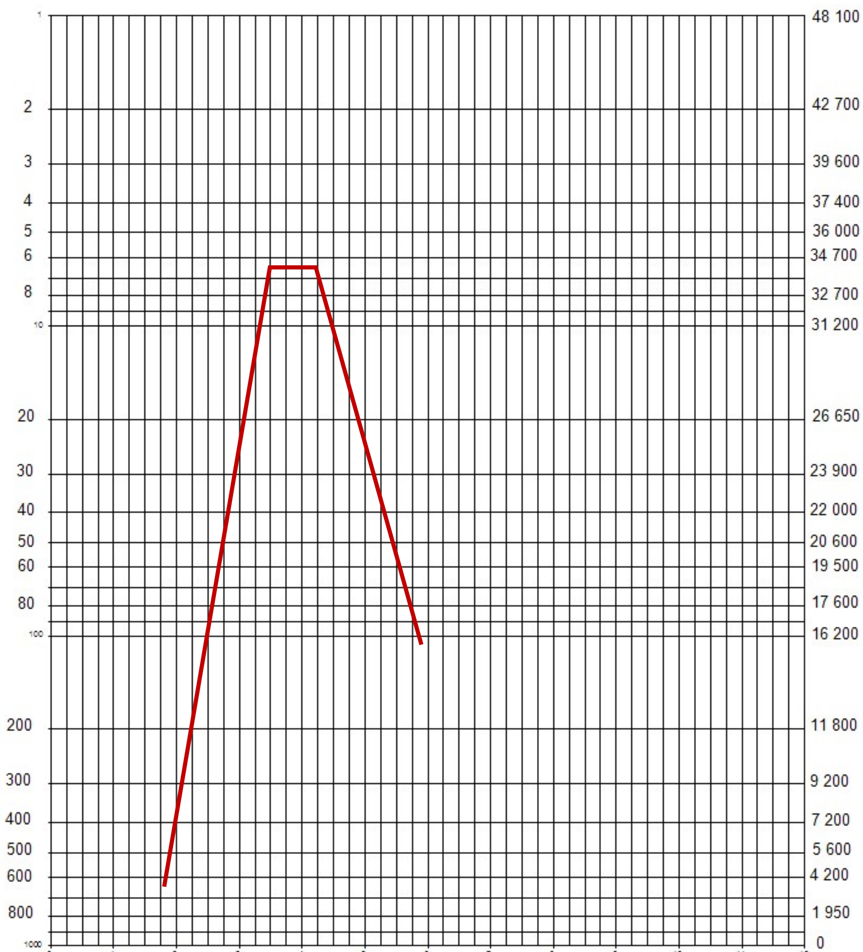


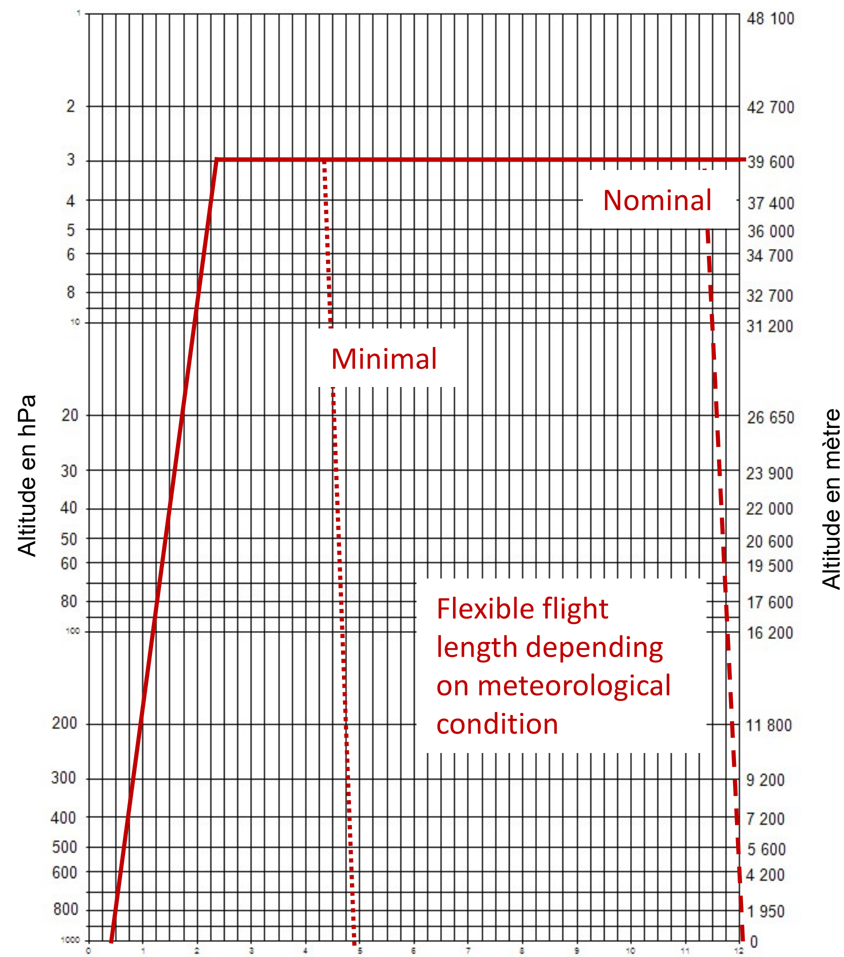
Balloon Communications: A fail safe system



Various phases of a ZPB flight
Mission requirements

- Aerostatic phases of a flight are highly variable:
  - function of the kind of balloon
  - function of the scientific requirements defined in a "flight profile" addressed to operational teams several months before launch





Scientific payloads

- Various scientific payloads, according to:
  - The kind of measurement
  - The flight mission requirements (duration, altitude, launch site)
  - Instrument mass and size
  - The balloon family capabilities (ZPB, SPB, etc.)

- Two major families for ZPB gondolas: pointed or not
  - Size: mass of the payload can be significant
  - Offer:
    - Primary structure
    - Power
    - Housekeeping interfaces
    - Thermal control
  - Primary stabilization in azimuth: few minutes of arc
  - Fine stabilization: better than one second of arc
  - Applications in astrophysics and atmospheric studies (occultation or nadir)

PILOT

Polarized Instrument for Long-wavelength Observations of the Tenuous interstellar matter

Pointed gondola

- Aluminium bars and nodes
- Total payload gondola mass: 1 050 kg
- Use of a diurnal stellar sensor

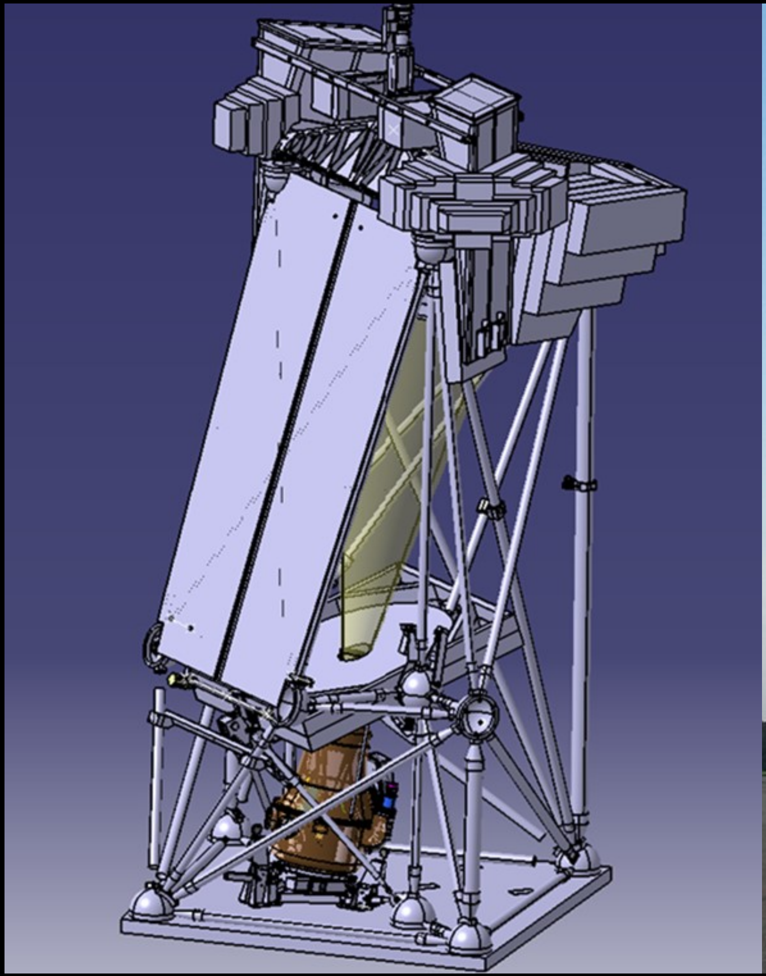
PILOT instrument (IRAP, CEA, IAS)

- Telescope 0.9 m
- 2048 bolometers cooled at 0.3 Kelvin

Flights

- First: September 2015, Timmins (Ontario Canada)
- Second Flight: April 2017, Alice Spring (Australia)
- Third Flight: August 2019, Timmins

Fireball Gondola

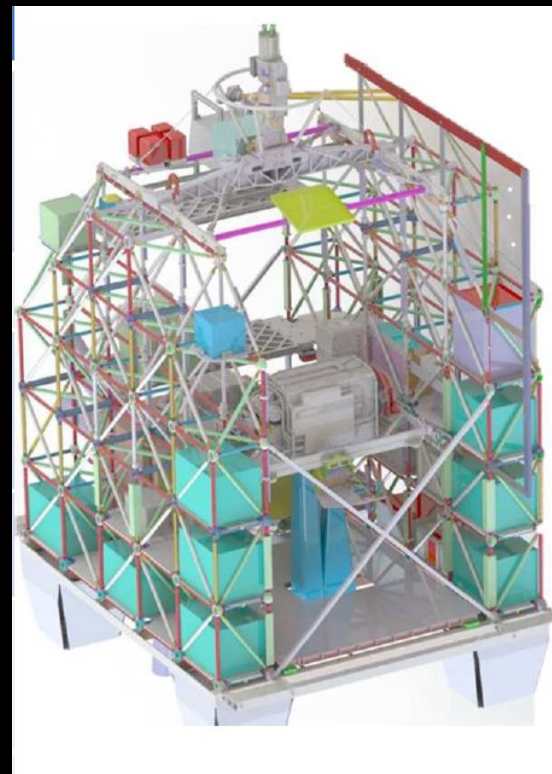



One meter aperture telescope, near UV, with multi-object spectrograph. 2.4 T. Study of the galactic environment

CARMEN Generic Gondola for ZPB

A service oriented architecture

- Payload gondola: up to 1100 kg
- Payload : up to 700 kg
- > 4,5 m3 available
- Thermal cover
- Power supply: up to 1 kW
- On board computer
- 3D pointing: < 1 arcsec



SPB: The STRATEOLE 2 project

Study of the equatorial lower stratosphere by flotillas of SPB

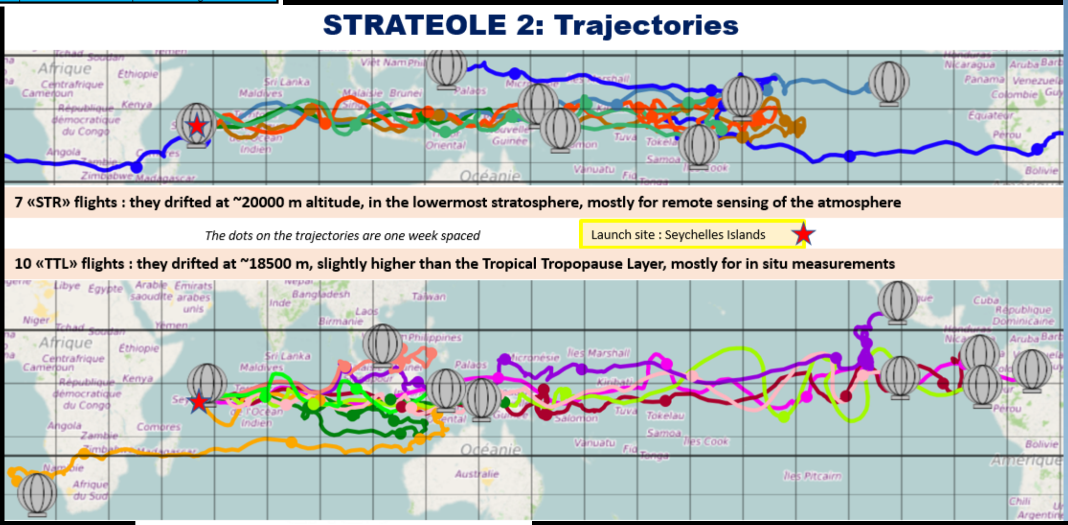
Led by CNES and French CNRS (LMD, LATMOS, GSMA), with a participation of US labs and NSF

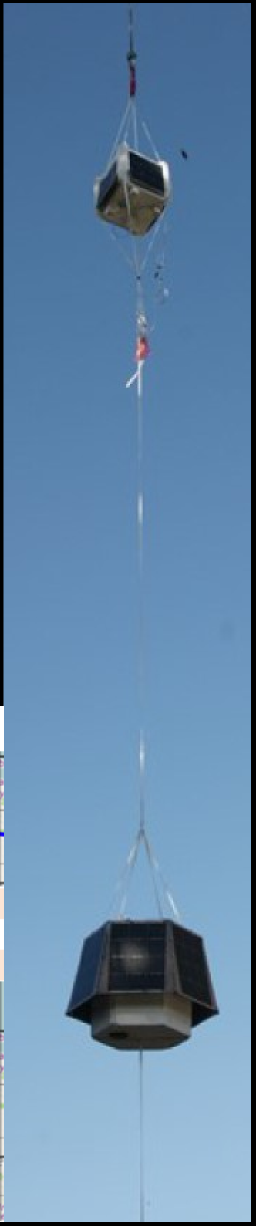
8 institutes, 12 payloads; 3 campaigns from the Seychelles, 2019, 2021, 2024

Instrument	Purpose	Institute	Meas. Type	Altitudes	Meas. Rate	Geophysical quantities
GPS (Euros)	Wind (through position)	CNES	in-situ	flight level	every 30 s	3D positions horizontal winds
TSEN	Air Pressure and Temperature	CNRS-LMD	in-situ	flight level	every 30 s every 1 s	temperature pressure
SAWFPHY	Water Vapor (through dew-point)	CNRS-LMD	in-situ	flight level	every 10-15 min (only night)	H2O mixing ratio
B-Bop	Ozone Photometer	CNRS-LMD	in-situ	flight level	every 10-15 min	O3 mixing ratio
LOAC	Optical Particle Counter	CNRS-LPC2E	in-situ	flight level		size resolved particle #
pico-SDLA	Water Vapor and Carbon Dioxide (through light absorption)	CNRS-GSMA / DT-INSU	in-situ	flight level		H2O mixing ratio CO2 mixing ratio
FLOATS	Local Profiler Air Temperature	LASP (USA)	in-situ	flight level down to 2-3 km below	2 profile every 5-10 min	temperature
LOPC	LASP Optical Particle Counter	LASP (USA)	in-situ	flight level	every 8 min	size resolved (8 bins) aerosol number concentration
RACHuTS	Local Profiler Air Temp., Water Vap., Cloud Detection	LASP (USA) & NOAA (USA)	in-situ	flight level down to 2 km below	3/4 profiles per night	temperature H2O mixing ratio Cloud detection
BeCOOL	Nadir Cloud detection trough Long Distance Lidar	LATMOS / CNR France / Italy	remote (nadir)	flight level down to ~5 km below	1 profile every 5-10 min	attenuated backscatter
ROC	Atm. Sounding through GPS Occultation High accuracy GPS position	Scripps Oceanography (USA)	remote (limb)	flight level down to z~4 km	tens of profiles per day	high-precision 3D positions temperature
BOL-DAIR	Up-Welling Infrared Flux	CNRS-LATMOS	in-situ	flight level	every 1 min	total upwelling flux total long wave flux

Up to 90 days flight duration

Overflying up to 96 countries





Operations
CNES balloons launch sites

There would be many other things to say about balloons...

- Two Russian balloons flew over the planet Venus over 45 hours each in 1985 at an altitude of 50 km

- CNES, in collaboration with the Russians, carried out a Martian aerostat project in the early 1990s

- A hot air balloon was designed to go on Titan

- CNES balloon expertise is regularly requested and even involved in the development of new stratospheric vehicles
- Innovation in progress: A steerable balloon

To conclude

- **If Archimedes' principle is simple, complexity with balloons can happen quick!**

- **Thermal:**

  Thermal studies on envelope and gas are very complex

  Thermal studies on gondolas are not simple

  (The external environment is extremely variable in terms of atmospheric temperatures and in terms of radiation fluxes)

- **The mechanics of flexible structures:**

  Mechanical calculations on the envelopes are very complicated.

- **Pointing systems and stabilization:**

  Pointing a telescope with precision better than a second of arc from a real swing is not easy at all!

- **The routing of a “steerable” balloon: A new challenge !**

  Use of meteo models and onboard measurements of the winds

Some References

https://ballons.cnes.fr/fr

https://fr-fr.facebook.com/stratospheric.balloons/

https://www.hemera-h2020.eu/

Book « Les Ballons au service de la Recherche » (Institut français d'histoire de l'Espace, 2011)
Edition Edite, 79 rue Amelot, 75011 Paris

END

Thank you
for your attention

Any questions for me?