



The history of ballooning, early science, past advances and discoveries, scientific interest

Claude Camy-Peyret, IPSL
<claude.camy-peyret@upmc.fr>

Outline

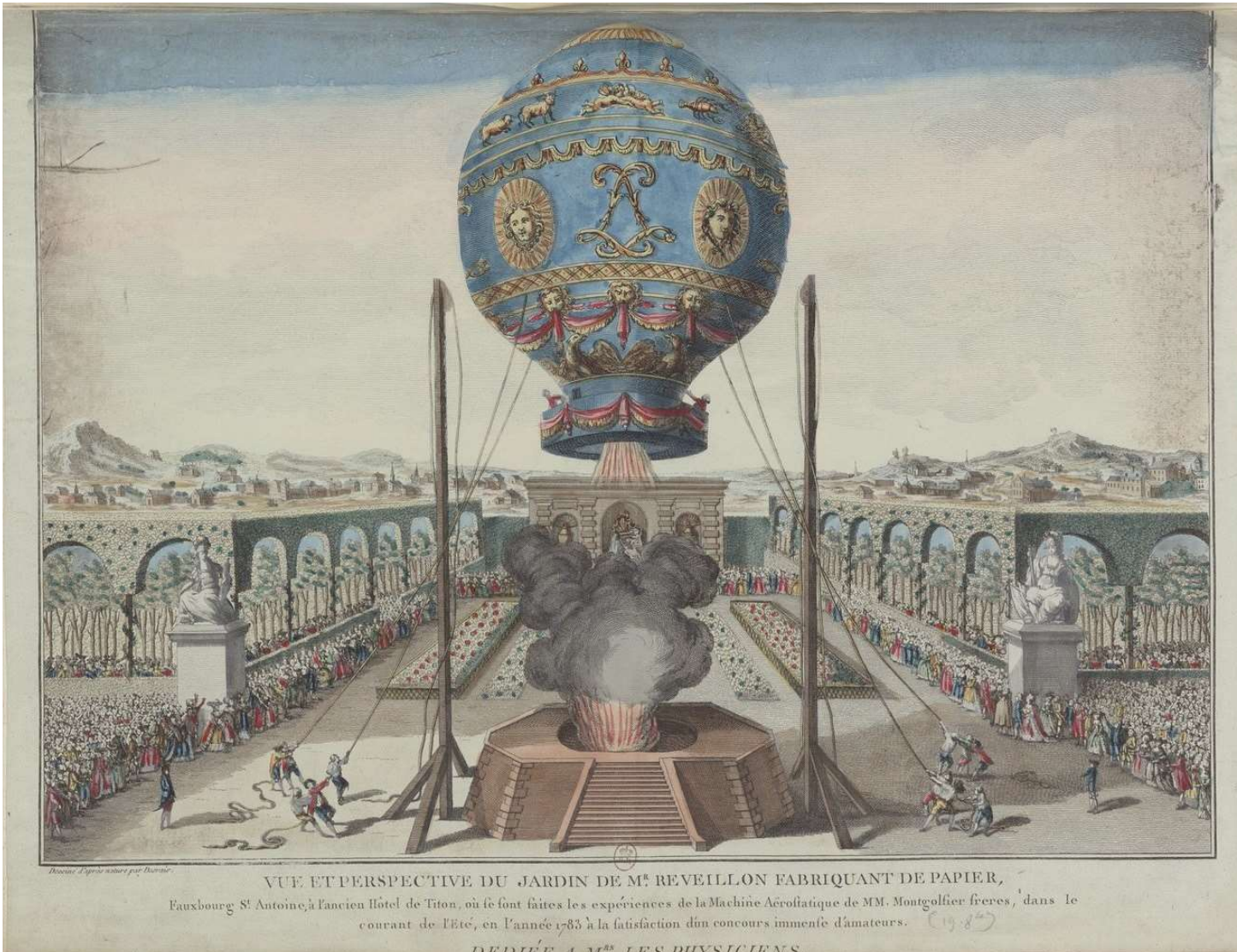
- The history of ballooning and the **first balloon flights**
- The **discovery of the stratosphere** using balloons
- The atmospheric **ozone distribution using balloons**
- Early balloon measurements of **atmospheric composition**
- Current scientific ballooning capabilities
- Future scientific ballooning and **Earth Observation missions**
- Outlook

Disclaimer:

- Several of the topics covered in this talk will be presented and detailed in the following talks of this HEMERA summer school
- French bias through the availability of CNES balloon vehicles
- Personal bias for atmospheric spectroscopy and atmospheric remote sensing
- Planetary atmospheres and astrophysics using balloon observations are not covered
- Military and defense as well as commercial and leisure balloon activities are not covered

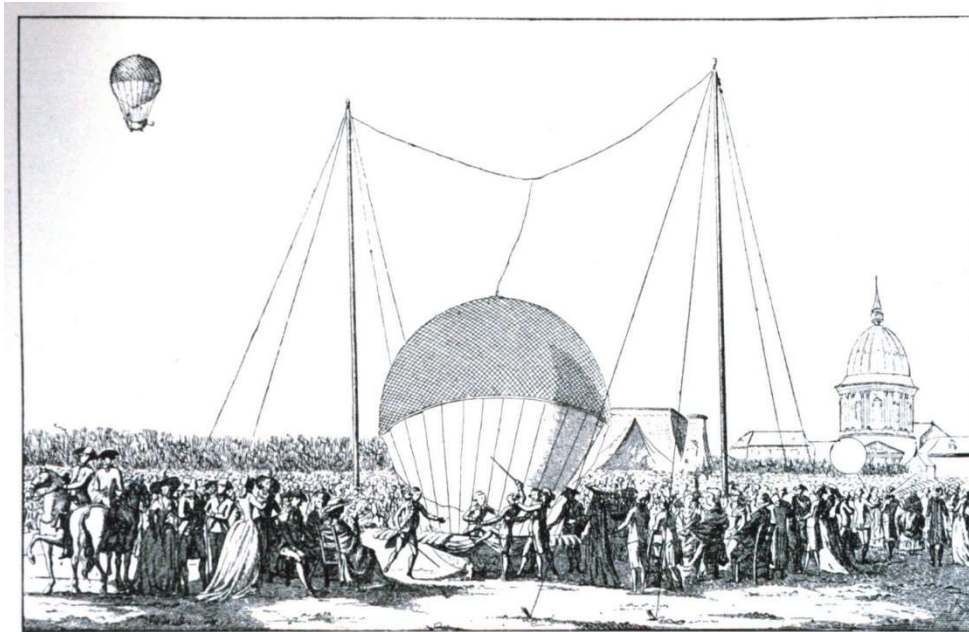
The history of ballooning

The first hot air captive balloon flight



Captive balloon
(tethered is now used)
Jean-François
Pilâtre de Rozier
19 October 1783
in Paris
"Aerostatic machine"
of
Montgolfier brothers
Paper envelope from
Réveillon manufacturer
of painted papers
Test of the technology
available at the time!

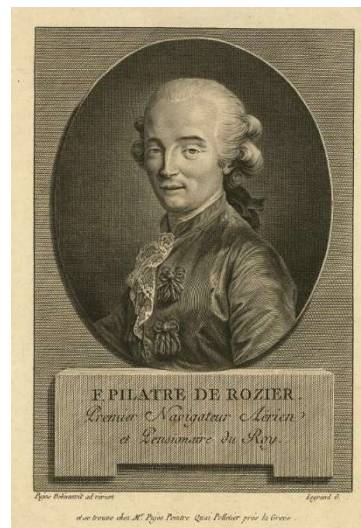
The first hot air balloon free flights



21 November 1783 in Paris, from La Muette (West) to La Butte aux Cailles (South East)
Duration 20 minutes with **Pilâtre de Rozier** and "marquis" **d'Arlandes**. Improvements in the fireplace and burning material.

23 June 1784, flight of **de Rozier** and **Proust** from Versailles of the "Marie Antoinette" balloon up to 3000 m. Drift to the North and flight above the cloud deck. In the cold and turbulence, decide to descent.

Touch down 52 km from Paris near Chantilly



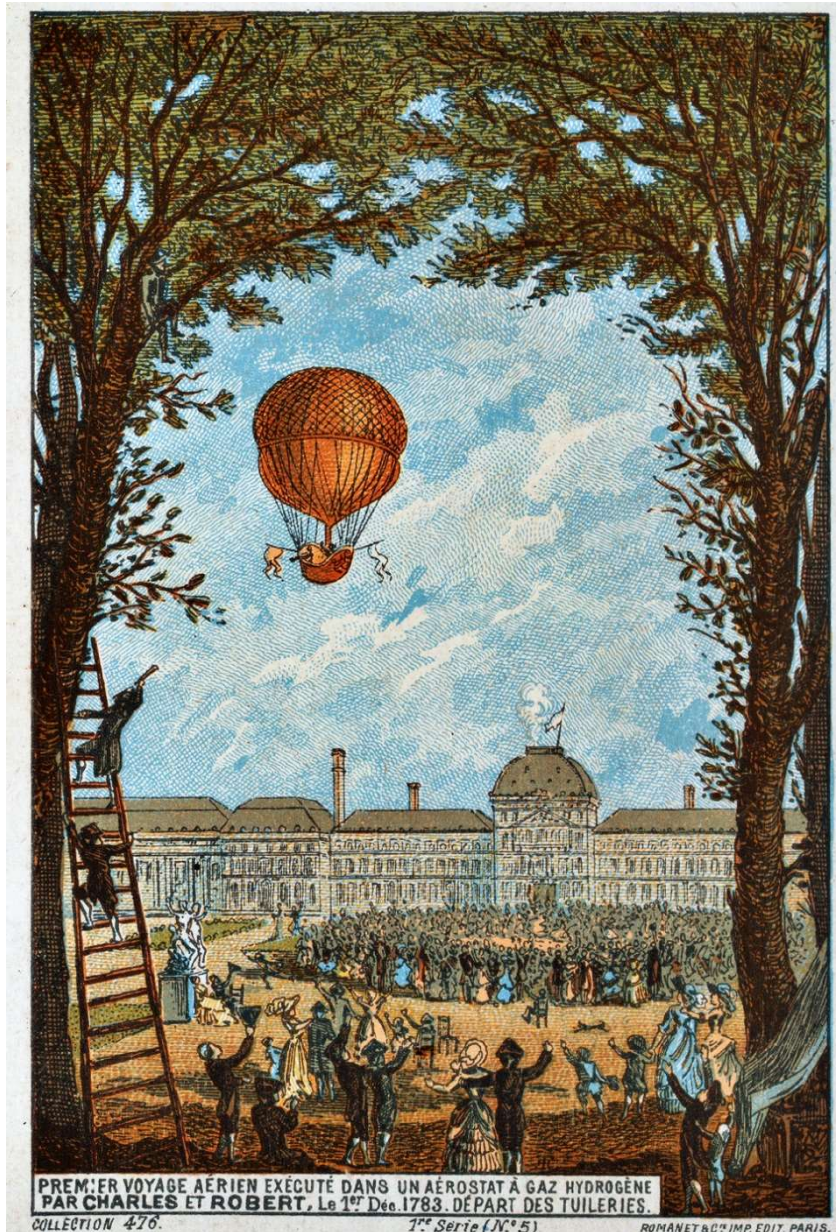
The balloon envelope (paper) took fire at landing. Angry crowd destroyed the rest

Louis Joseph Proust chemist, **first scientist on board**, flight assistant!

Joseph (manager) Étienne (engineer)
Montgolfier brothers (paper makers)

Pilâtre de Rozier, aeronaut
(aristocrat, support from the Queen)

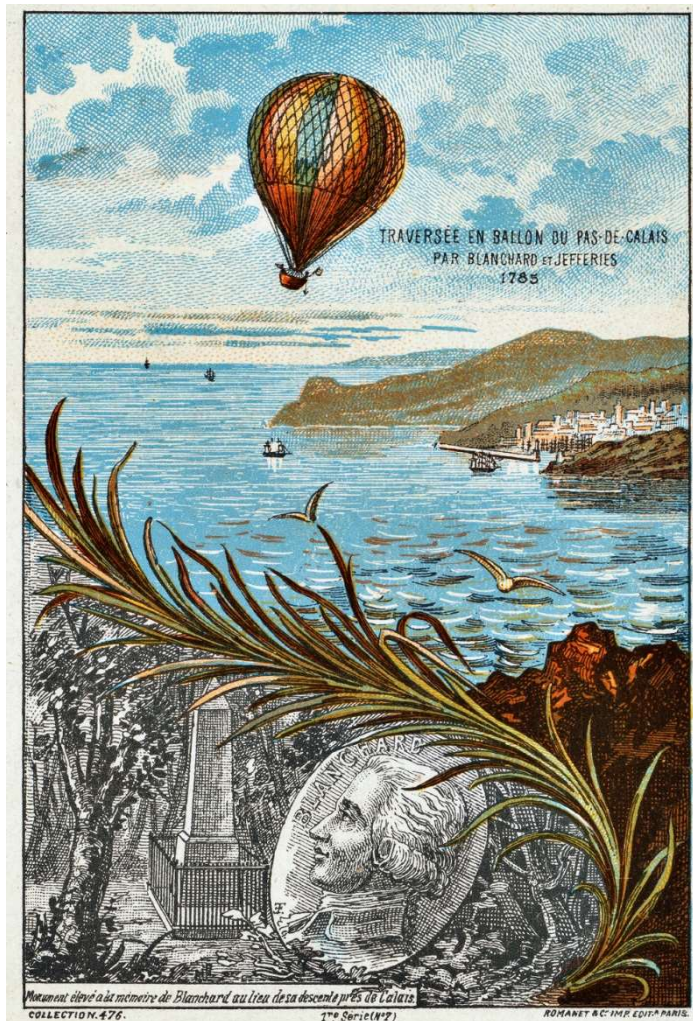
Competition between techniques



Jacques Charles (1763-1823) Physicist and chemist, he confirmed the discovery of H_2 by Henry Cavendish showing that **hydrogen is 1/14 lighter than atmospheric air**. Able to generate H_2 by reacting H_2SO_4 on Fe. Early discoverer of the perfect gas law later published by Gay-Lussac.

Charles and **Noël Robert** flew the first **balloon inflated with hydrogen** from Tuileries garden on **1st December 1783** to Nesles-la-Vallée 35 km. Once landed the balloon achieved a second fast ascent up to 3300 m, an altitude measured with a **barometer** that Charles was using in his gas studies. This was the invention of the **altimeter**. Caught in the very cold winter air, he managed to descent during the night near Nesles-la-Vallée. He became very popular, but probably deeply marked by this experience, he never flew again. However, **he kept making science!**

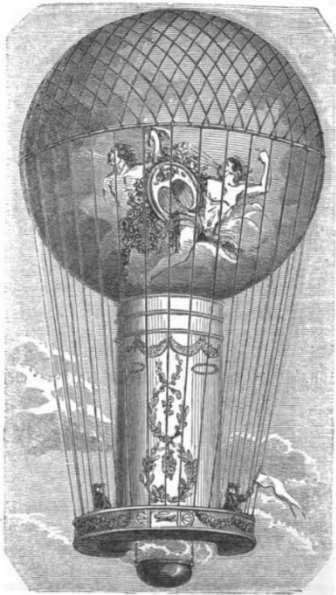
Competition between techniques



Even during his first flight **Charles** (as a scientist) “invented” several balloon equipments for his **charliere** that have been used by all his successors: gondola, varnished envelope (to reduce leaks), net, **valve**, lest or **ballast**, anchor (later guide rope), parachute.

On **7 January 1785**, **Jean-Pierre Blanchard** and his american friend (and financial support!) John Jeffries, with a **H₂ gaz balloon** from Charles, managed to cross the Channel (Pas-de-Calais) (in the favourable wind direction) from Dover (England) to Guînes (France) landing in a forest. They were lucky! **Importance of proper recovery**

Competition between techniques



- **Pilâtre** was also wanting to cross the Channel (La Manche) from France to England (against the usual wind direction). Since Montgolfiere type balloons were not very reliable (and aware of **Charles** progress), he worked hard to get financial support and designed an **aero-mongolfiere**. This is a mixed type balloon composed of a H_2 gas sphere (or **charliere** on top) and a cylindrical envelope (or **montgolfiere** below).
- After many technical difficulties and unsuccessful attempts, Pilâtre de Rozier et Pierre Romain lift off on **15 June 1785** from Boulogne-sur-mer in favorable wind conditions on ground. But 5 km away from the coast, the mid-altitude wind brought them back over land. Trying to activate the valve to get down, they probably tore the gas envelope and a free fall occurred. The impact on ground was near Wimille (now Wimereux near Boulogne-sur-Mer) about 300 m from the sea. Both died in the event and they were **the two first victims of "human" or manned balloon flights** (with sadly many more to occur later)!
- Importance of good knowledge of **wind profiles** and **landing conditions** (see **A. Vargas**, presentation 4.1)



Successful and less successful human balloon flights



In **March 1999** the **roziere** (hot air + He) type balloon Breitling-Orbiter III with **Bertrand Piccard** and **Brian Jones** on board achieved an **uninterrupted flight around the globe**: total distance: 45755 km, flight duration: 19 days 21 hr 47 min, maximum altitude: 11755 m, maximum ground speed: 240 km/hr, overflight of 26 countries
Importance of **proper trajectory optimization** (using the right wind direction at the right altitude) with near real-time help from experienced ground-based "routers" and good satellite communication means. No specific scientific measurement.

In **April 2010** the **roziere** from **Jean-Louis Etienne** flew above North pole with a launch from Longyearbyen at 06:10 on 5/04/2010 and landing in Siberia at 07:40 on 10/04/2010, 280 km from Batagai. Duration 121.5 hr. Distance 3631 km. Gondola 320 kg, **helicopter recovery**. Trial of a small hand-held sensors (CO₂, O₃, aerosol)



H₂ balloon flight of **Salomon August Andrée** in **July 1897** from Svalbard



Ice sheet Landing **Tragic end**

The discovery of the stratosphere

The "discovery" of the stratosphere



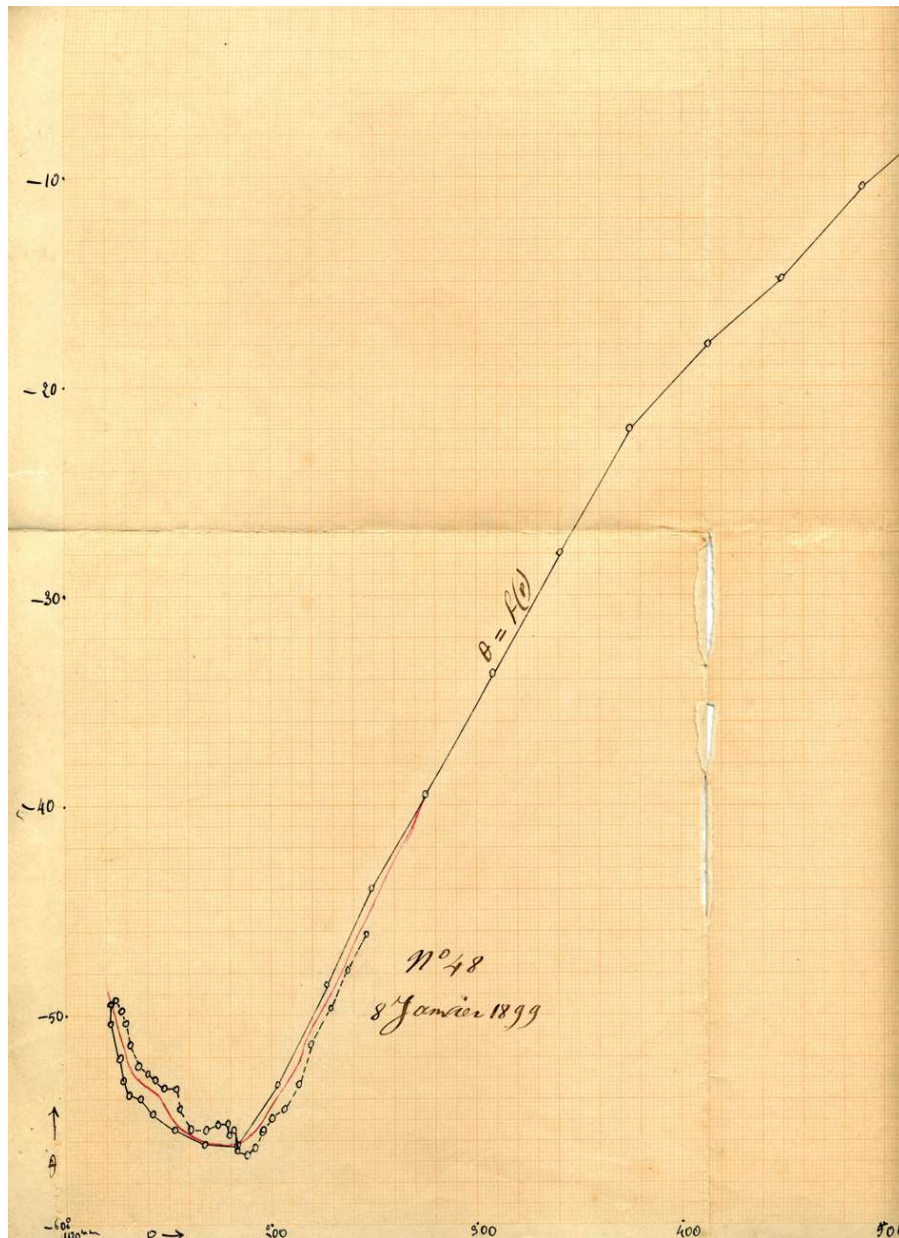
Léon Philippe **Teisserenc de Bort**
(1855-1913)

Aristocratic descent from the city of Bort (near Limoges)
Very active and productive
early meteorologist
Spent his time and fortune on this hobby (amateur but well know scientist at the time)

Gondola used by **Teisserenc** for balloon soundings from his ship Otaria in the Southern part of the North Atlantic ocean
He funded his own research by selling some of his properties
He published many papers (and a book) on the (then) growing science of **dynamic meteorology**



The strange results from a balloon flight



Temperature profile: P in mb (now hPa) along the horizontal axis, T in °C along the vertical axis. Launch at 6:37 (LT) from **Trappes** (South West of Paris, altitude 170 m asl) with ceiling at 7:25 LT (half an hour before sunrise). The site founded in 1898 (with Teisserenc as director) was named "**observatoire de Météorologie dynamique**"

Plotted by hand (Teisserenc) on millimetric paper from the original recording (aluminum drum with black carbon) of the instruments after recovery of the gondola on **8 January 1899** (sounding #48!) . Note the minimum of temperature of **t=-56.2 °C** (ascent) at 10389 m with an increase to **t=-49.5 °C** at 12984 m Teisserenc was aware of the difficulty of the temperature measurements at low pressure when the thermalization of the thermometer bulb was becoming less efficient. For a time, not sure of himself, he just called this phenomenon "**isothermal zone**"

More on the “discovery” of Teisserenc

In standard soundings (of the time) the curve temperature versus pressure was extrapolated with a constant (negative) lapse rate (no change in the vertical gradient). In this specific sounding Teisserenc was wanting to better understand the situation.

The region above 10 km (much “calmer” for turbulence) was called in 1908 by Teisserenc “**the stratosphere**”. And at the same time he called the lower layer “**the troposphere**”.

Teisserenc wrote many papers in “Comptes rendus de l’Académie des sciences”.

He was more worried (as a meteorologist) by the variation of the absolute value of the temperature as a function of the location and the meteorological conditions.

German meteorologists [Labitzke and van Loon (1999); Steinhagen (2005); Emeis (2008)] claimed that what is now known as “**tropopause**” has been co-discovered by **Richard Aßmann** (1845-1918). This german scientist was active at the same time as Teisserenc and with **Arthur Berson** visited the Trappes observatory in 1899. Aßmann and Berson were wanting to use similar measurement techniques and to reproduce the same type of observatory in Germany (Lindenberg founded in 1905). **Teisserenc** and **Aßmann** both were members of the “Commission aéronautique internationale”.

Teisserenc launched 236 **varnished paper** balloons reaching more than 11 km (74 above 14 km) keeping the term “**isothermal zone**” → the tropical tropopause layer (TTL) is indeed isothermal

In 1901 Aßmann launched 6 **rubber** balloons (all over 12 km) using the term “**upper inversion**”

Understanding why is the atmospheric temperature is rising again above the tropopause would only be achieved 30 years → **ozone!**

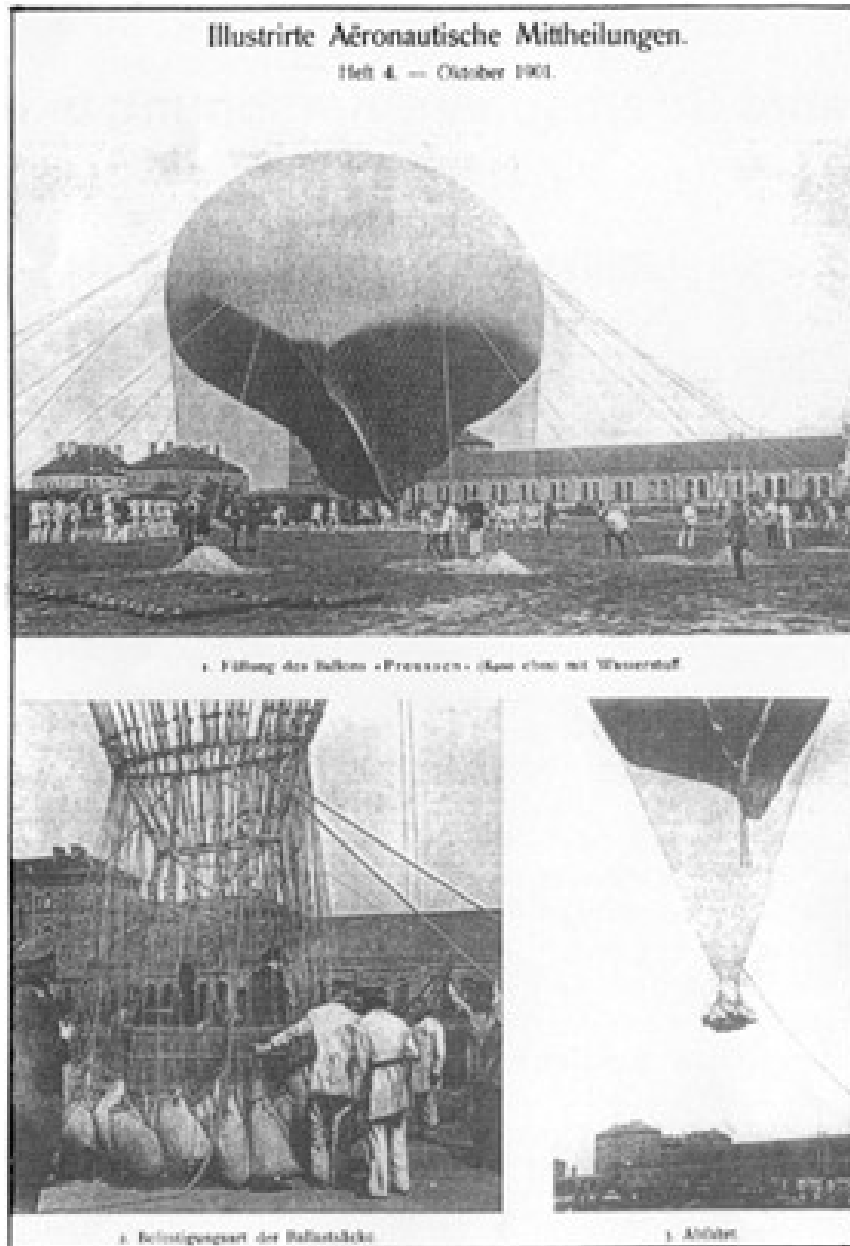
The flight from Süring and Berson

Süring and Berson's Balloon Ascent on 31 July 1901

Their balloon named "Prussia" was inflated with 5400 m³ of hydrogen from Tempelhofer Feld. They were experienced and reliable and scientific balloonists. Berson was chief assistant of Professor **Richard Aßmann**.

Report from **Reinhard Süring** and **Arthur Berson** (1901)
"... After 40 minutes the balloon had reached a height of 5000 m. It was only up to this height that the balloon reached its spherical shape. The temperature had sunk by over 30°C to minus -7°C. At an altitude between 5 km and 6 km, we began regularly to breathe oxygen. After about 3 hr we had reached a height of 8000 m, after 4 hr it was 9000 m. The influence of the air now thinned by one third due to atmospheric pressure and cooled to a temperature of -32°C was evidenced in an increased sleepiness. The last observation series covering both pressure and temperature was written down promptly and clearly at 10225 m. Soon after that, we both fell into deep unconsciousness. Berson pulled the safety valve several times immediately beforehand, when he saw his companion (Süring) already asleep ... "

But the inversion was not "measured" during this flight. After this mishap, Aßmann decided to only launch **unmanned rubber sounding balloons** (more easily available than in France!)



The atmospheric ozone distribution using balloons

See presentations in **session 2: Atmosphere**
2.1 T. Birner, 2.2 N. Huret, 2.3 A. Hertzog, 2.4 A. Butz

Short history of atmospheric ozone

1774 J. Priestley and C.W. Scheele, discovery of (molecular) oxygen in air

1839 C.F. Schönbein, discovery of ozone (ozein = to smell in Greek)

1864 J.L. Soret, molecular "weight" $M=48$ g, but chemical form not well understood (non linear triatomic O_3 much later)

1879 A. Cornu, "breaking of the solar spectrum for $\lambda < 300$ nm

1880 J. Chappuis, discovery of the ozone band in the visible

1881 W.N. Hartley, discovery of the ozone band in the UV 200-320 nm

1890 W. Huggins, UV absorption in the region 320-360 nm (Sirius spectrum)

1902 L. Teisserenc de Bort and R. Assmann, discovery of the tropopause and naming of the stratosphere

1924 G.M.B. Dobson, ground-based UV spectrophotometer with photographic recording

1928 G.M.B. Dobson, UV spectrophotometer with photoelectric recording

1929 F.W.P. Götz, "Umkehr" effect, ground-based UV, maximum of O_3 concentration not higher than 25 km

1930 S. Chapman, first photochemical theory of the stratosphere

1934 E. and V.H. Regener, first in situ measurement of the vertical O_3 distribution up to 31 km

1938 V.H. Regener, potassium iodide technique for very small samples

1939 W.W. Coblentz and R. Stair, first optical ozone radiosonde, Cd photoelectric cell

1941 A. and H. Ehmert, transform V.H. Regener method into a portable instrument, first aircraft measurement of O_3 (4300 m)

1941 F.A. Panneth and E. Glückauf, experiments for electric measurement of iodine, eliminated from potassium iodide solution by O_3

1960 A.W. Brewer and D.R. Milford, Brewer-Mast balloon electrochemical ozone sonde (ECC) manufactured by the Mast company

1966 First publications of UV backscatter measurements (BUV) of O_3 from satellite (USA and USSR)

1974 R.S. Stolarsky and R.J. Cicerone as well as J.M. Molina and F.S. Rowland, role of chlorine compounds

1984 S. Chubachi, Dobson measurements at the Japanese Antarctic Syowa station (reported at the Ozone Symposium 1984)

1985 J.C. Farman, B.G. Gardiner and J.D. Shanklin, alarming decrease of the total ozone column from ~ 1975 to 1982

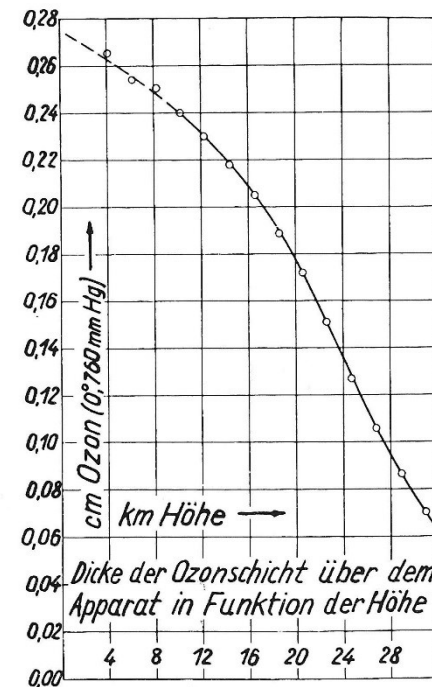
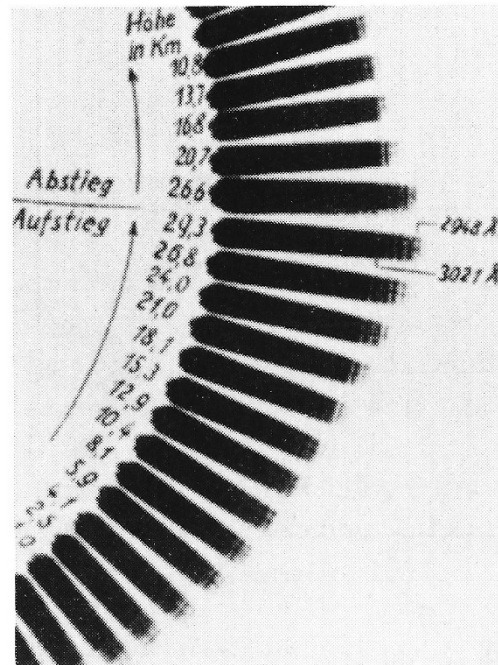
In October 1982, lowest ever measured O_3 column values throughout the world (< 200 DU) → the ozone hole

Extracts from Manfred Schmidt, "Pioneers of ozone research, a historical survey"

First ozone profile measurements by a balloon-borne instrument

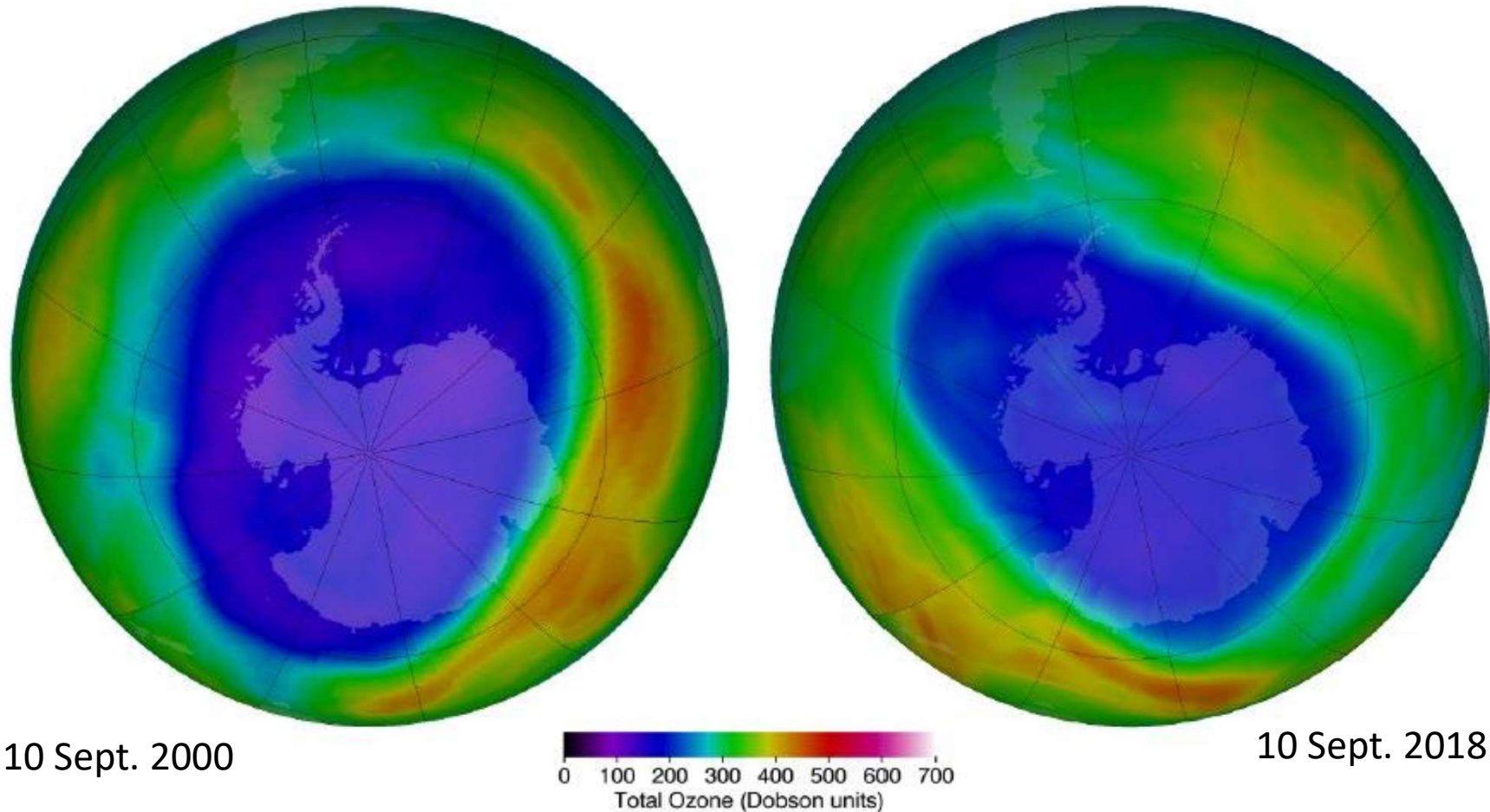


Erich Regener
(1881-1955)
(MPI for the physics of the stratosphere)
Wiessenau, Württemberg
(with his son Victor H. Regener)



Original spectra of the first measurement of the vertical ozone distribution by E. and V.H. Regener on **31 July 1934**, and the evaluated total ozone above the balloon from these spectra. The spectrograph looked downward at a magnesium oxide scattering disk **illuminated by direct sunlight**. A **photographic record** of the spectrum was made at regular intervals during ascent. As the altitude increased, **the spectrum extended farther into the UV**

The ozone hole as seen by combined satellite and balloon measurements



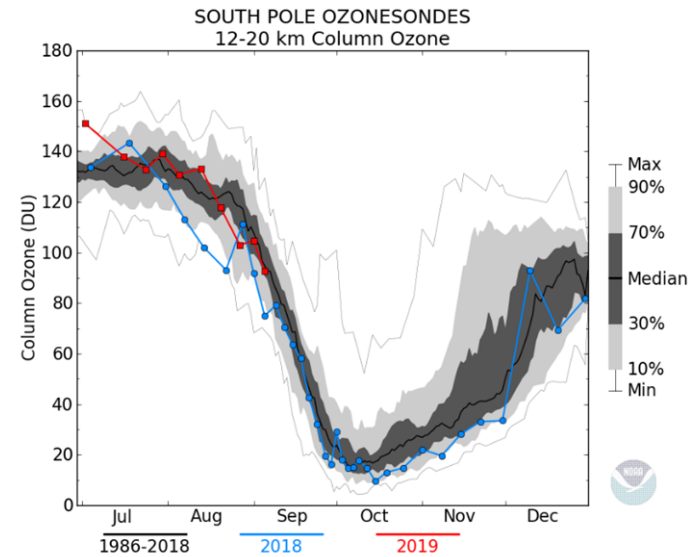
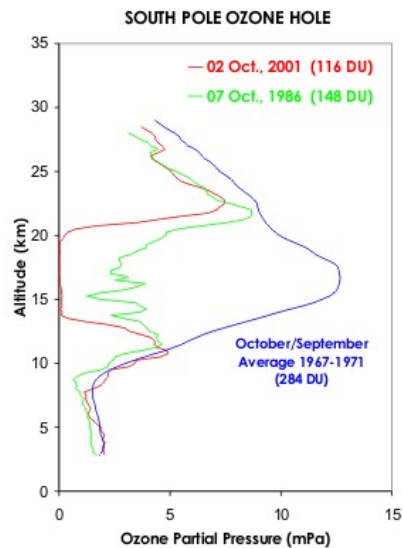
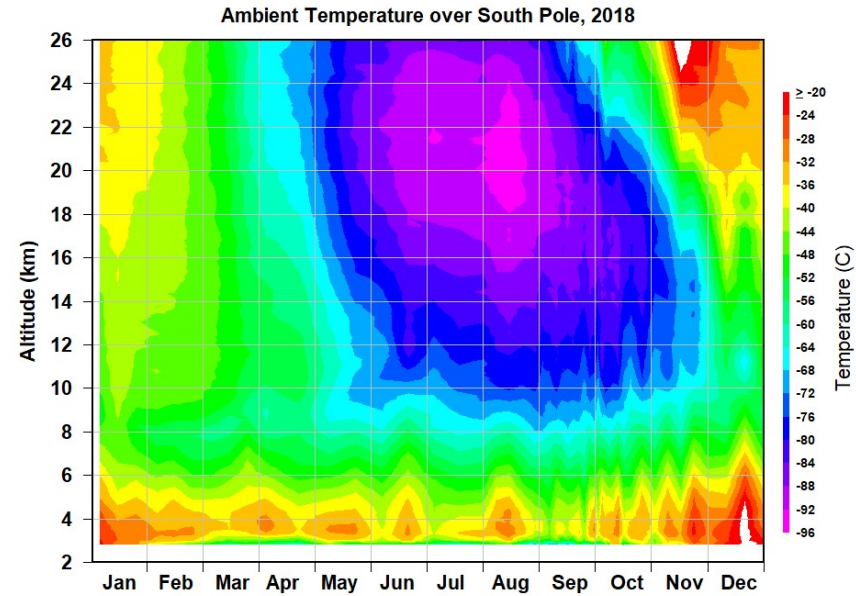
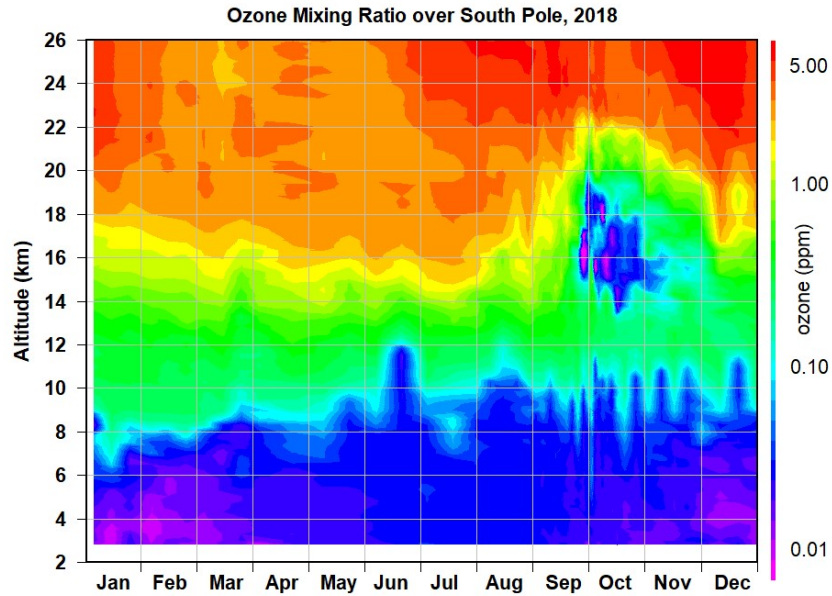
The meteorological conditions for these two years were similar with a stable and cold Antarctic vortex in place. Such conditions are conducive to the formation of **polar stratospheric clouds**, the presence of which provides a catalyst for ozone destruction. However, owing to an 11% decline in ozone-destroying substances in the ensuing years, while still quite large in areal extent compared to the values of the early 1980s, **the ozone hole in 2018 is substantially smaller than the ozone hole of 2000**, when the concentrations of ozone-destroying substances were at their peak. This Figure provides evidence that **the expected recovery of the ozone hole after the enactment of the Montreal Protocol is slowly but surely taking place**. Image credit: NASA Ozone Watch

The ozone hole as seen by combined satellite and balloon measurements



Time-lapse photo from 10 September 2018 of the flight path of an ozonesonde as it rises into the atmosphere over the South Pole from the Amundsen-Scott South Pole Station.
Image credit: Robert Schwarz/ University of Minnesota

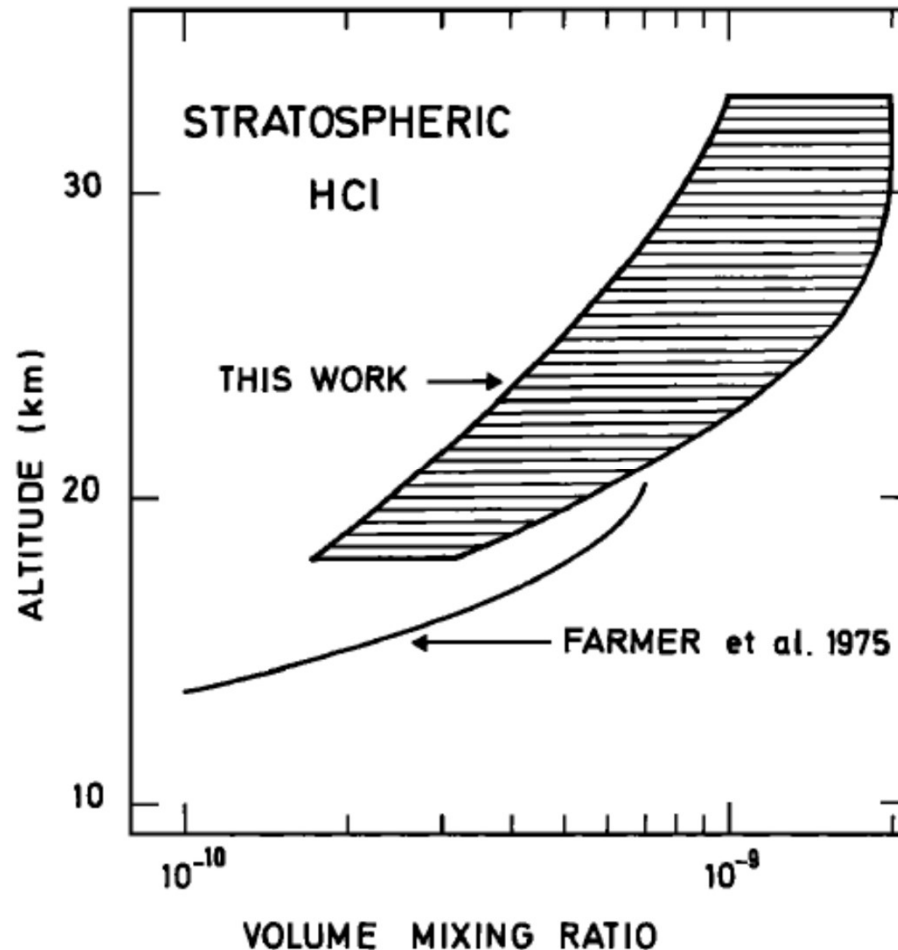
Ozone hole balloon measurements at South Pole



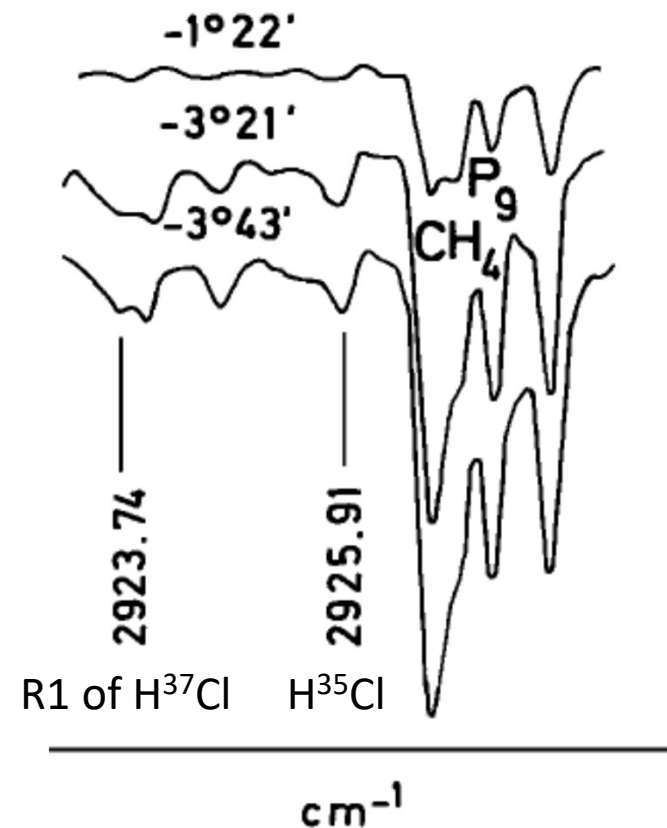
Early balloon measurements of atmospheric composition

See several presentations in [session 2: Atmosphere](#)

Early balloon-borne chlorine measurements

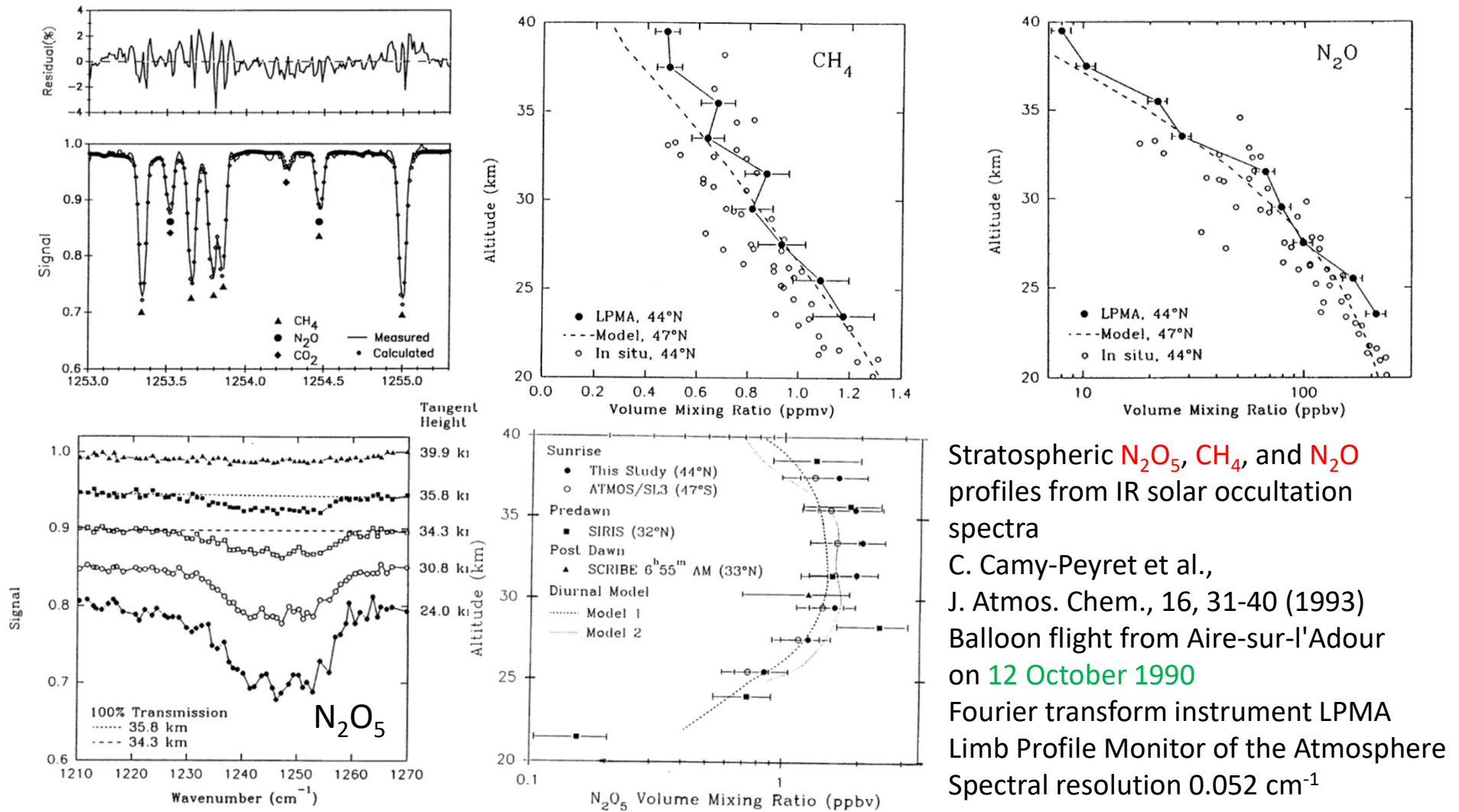


Resolution of recorded spectra of 0.22 cm^{-1} (\sim atmospheric transmission)



Stratospheric HCl from infrared spectra, M. Ackerman D. Frimout A. Girard M. Gottignies C. Muller
Solar occultation measurements (remote sensing) with a Grille modulation/grating spectrometer
Flight from Aire-sur-l'Adour, **2 October 1975**, ceiling (float altitude) 35 km, 100Z balloon, 217 kg payload

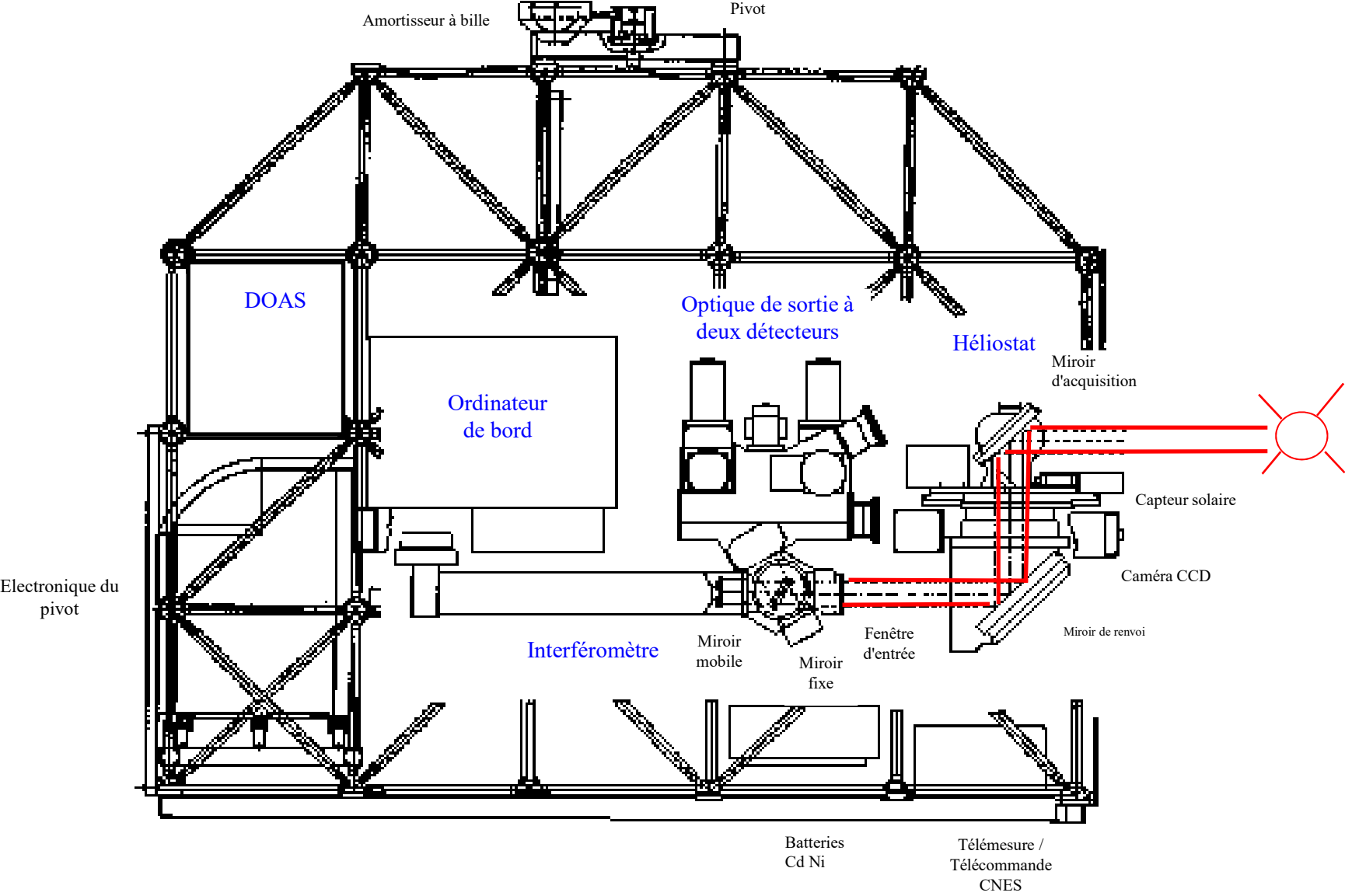
Balloon-borne measurements of atmospheric composition



Stratospheric N_2O_5 , CH_4 , and N_2O profiles from IR solar occultation spectra
 C. Camy-Peyret et al.,
 J. Atmos. Chem., 16, 31-40 (1993)
 Balloon flight from Aire-sur-l'Adour on 12 October 1990
 Fourier transform instrument LPMA
 Limb Profile Monitor of the Atmosphere
 Spectral resolution 0.052 cm⁻¹

Further improvements:
LPMA and IASI-balloon

Solar occultation configuration: LPMA (Limb Profile Monitor of the Atmosphere)



DOAS = Differential Optical Absorption Spectroscopy → see [A. Butz, presentation 2.4](#)
University of Heidelberg

An example of LPMA lift-off



1



2



3



4



5

Flight LPMA20 flight on 23 March 2003

from Esrange (Kiruna, Sweden)

1 Test of the lift of the auxiliary balloons

2 Main balloon at the end of the inflation phase

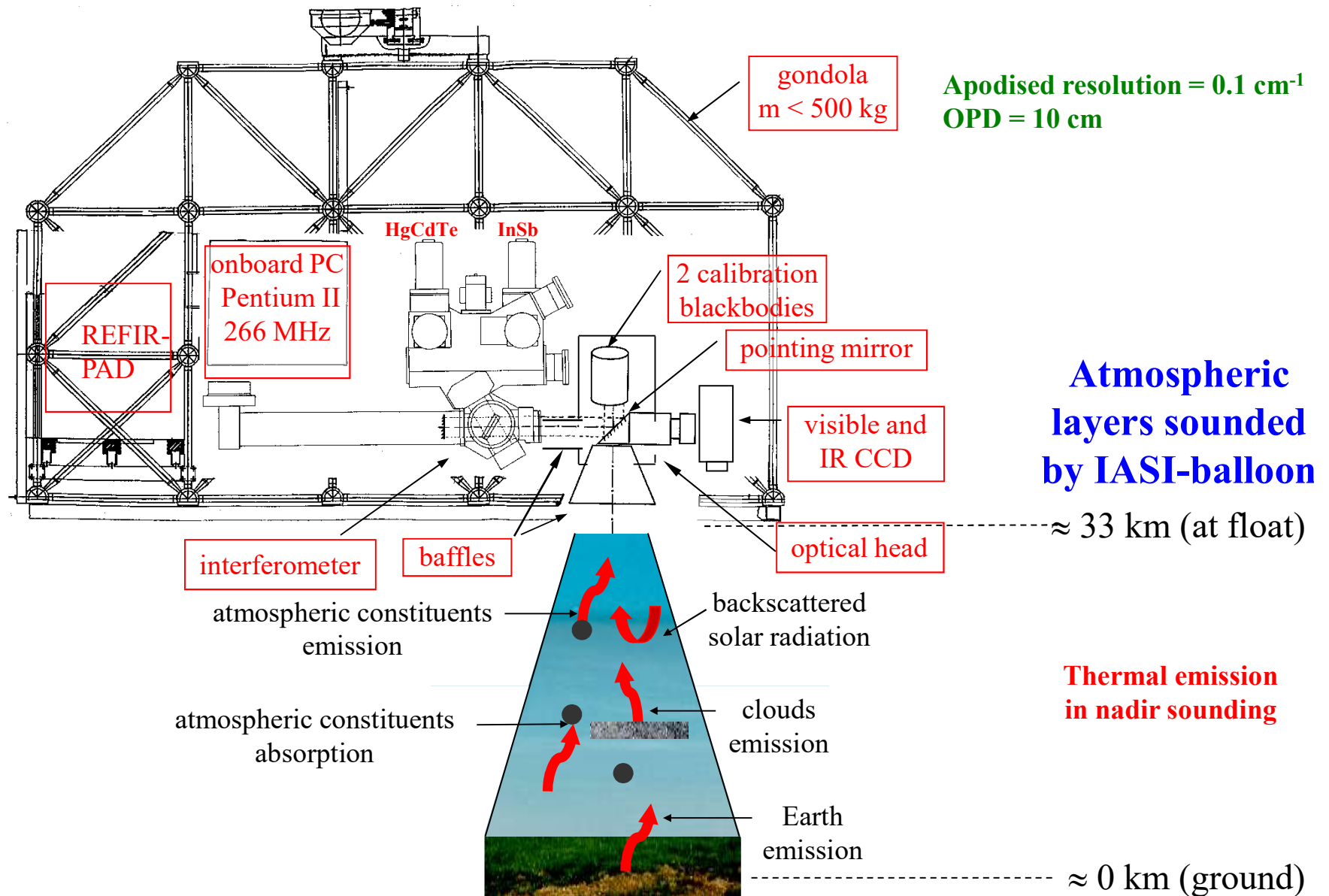
3 Gondola under the auxiliary balloon just after launch

4 Separation from the auxiliary balloon

5 Ascent under the main balloon

See A. Vargas, presentation 4.1, CNES launching techniques

Emission configuration: IASI-balloon (Infrared Atmospheric Sounding Interferometer-balloon)



IASI-balloon experiment



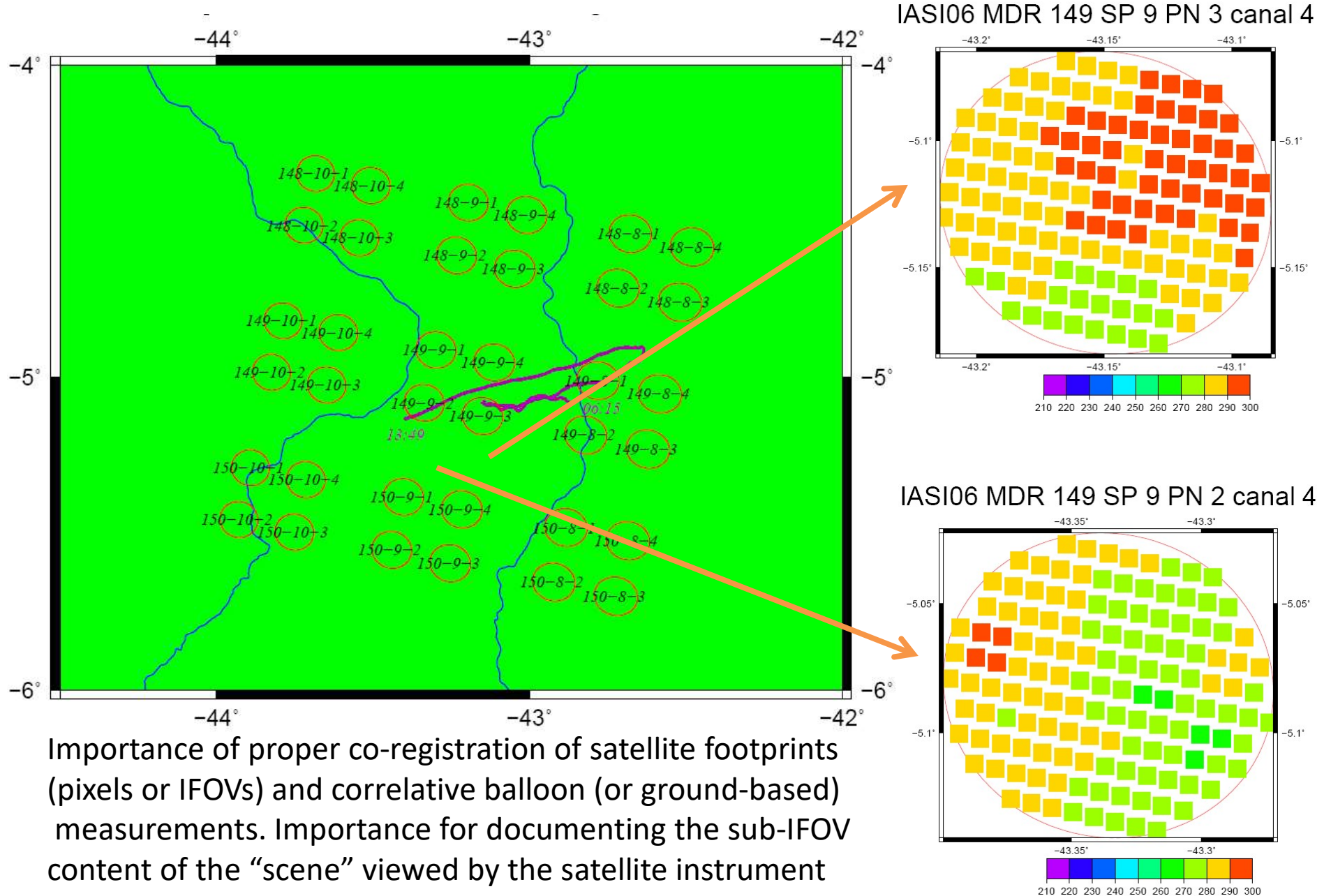
Mass : **456 kg**

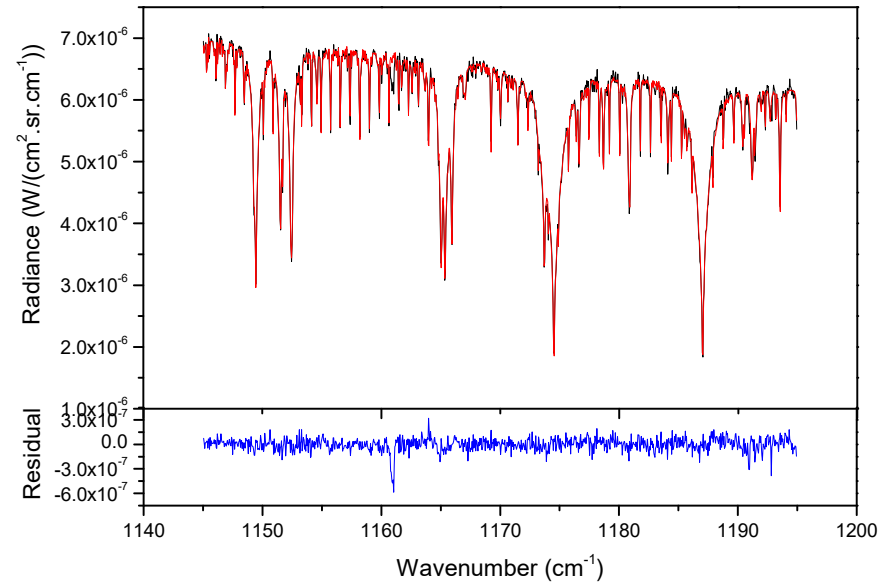
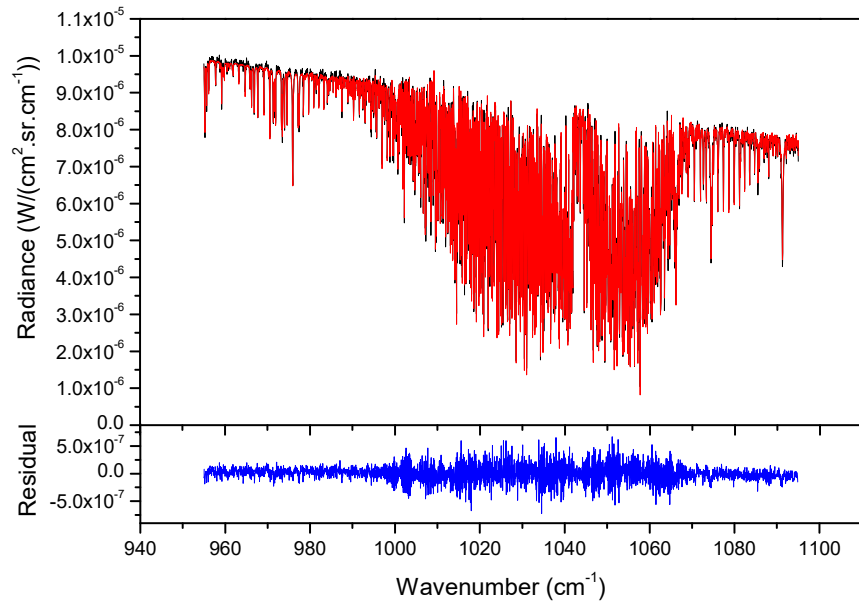


Preparation for flight IASI03 on 2 July 2005
from Teresina (Brazil)

Accommodation of 2 infrared FTS instruments:
IASI-balloon operating in the TIR ($650\text{-}3000\text{ cm}^{-1}$)
REFIR-Pad operating in the FIR ($200\text{-}1600\text{ cm}^{-1}$)
Comparison in the common spectral region

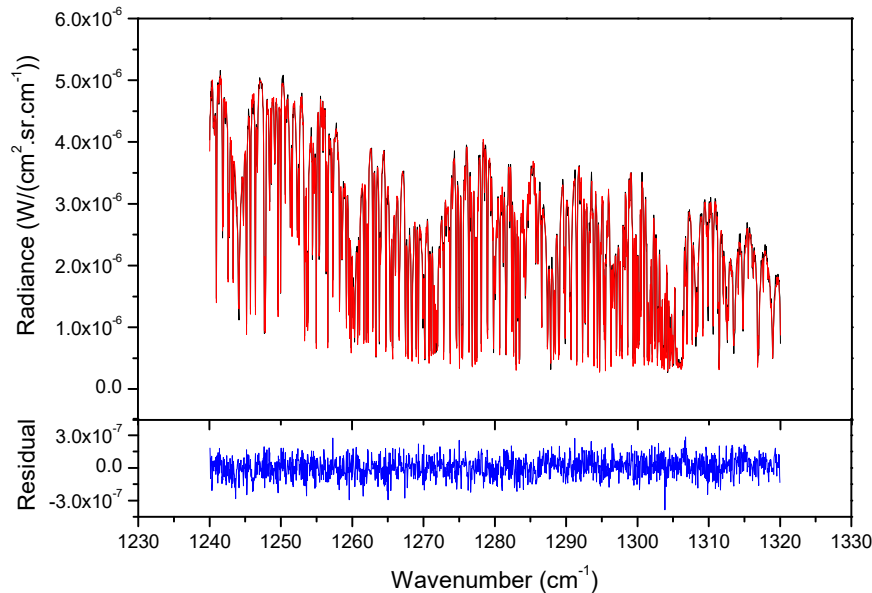
IASI and IASI-balloon (13 June 2008) from Teresina





O₃, N₂O and CH₄ retrievals

[#370]



Retrieved multiplicative factors :

O ₃ :	0.93423
H ₂ O with O ₃ :	1.4641
H ₂ O with N ₂ O :	1.5618
H ₂ O with CH ₄ :	1.5779
N ₂ O :	1.0677
N ₂ O with CH ₄ :	1.0751
CH ₄ :	1.1438

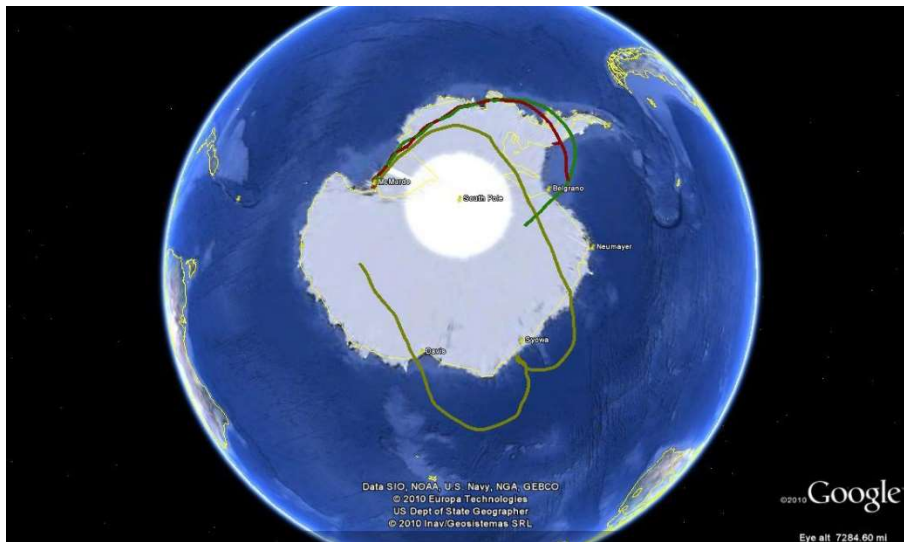
CFC-12 not taken into account here

See S. Payan, presentation 5.2

Concordiasi (see A. Hertzog, presentations 1.5 and 2.3)



The set-up for launch



Trajectories of Concordiasi balloons
(as of 18 September 2100 UT)



Launch of the PSC17 balloon on 14 September 2010 under clear skies in Antarctica. End of flight on 12 October 2010
(Courtesy Concordiasi team)

Scientific ballooning since 1962 (creation of CNES balloon division)

- Impossible to mention all "as flown" experiments
- Early scientists involved in the co-development with agencies of balloon activities in the period 1960-1970
- 1970-1980, interest in the stratosphere for the impact of "planned" stratospheric aircrafts (NO_x)
- 1980-1990, era of **UARS** and early **EU support**, early warning for the ozone hole (Montreal Protocol 1987)
- 1990-2010, ozone hole chemistry, era of **Envisat** and satellite validation (ILAS, MIPAS, SCIAMACHY, GOMOS,...)
- Coordination between balloon agencies (**ESA-PAC**)
- 2010-2020, renewal of the **CNES** balloons (strong focus on safety), new cooperation with **CSA** (Canada)

Current scientific ballooning capabilities

See several presentations in **session 3: Balloon system**

See presentation in **session 5** for **balloon instrumentation**

Exemples of balloons according to their useful range of altitude

BSO (**ZPB=Zero Pressure Balloon**)

only vehicule for the altitude range 20-40 km

BPS (**SPB=Super Pressure Balloon**)

most suitable for the UT/LS (18-22 km) and possibility of long duration flights, but payloads < 25 kg

BLD (**ELB=Expandable Lightweight Balloon**)

0-30 km, short flights, easy launch, small payloads (3 kg)

BPCL (**BLPB=Boundary Layer Pressurized Balloon**)








most useful over ocean, small payloads

AER (**Aeroclipper**): very interesting for tracking hurricanes

MIR (**IRM=InfraRed Montgolfiere**)

long duration flights in the UT/LS, but payloads < 30 kg

The CNES balloons

	Stratospheric balloons					Tropospheric balloons	
Type	BSO ZPB 	MIR IRM 	BPS SPB 	BPL(Loon) 	BLD 	BPCL BLPB and nanos 	AER 
Status	2014: duration 24 hr CU> 120 kg 2017: a few days (long duration infrastructure)	Return to flight : post 2017 ? (long duration infrastructure and balloon qualification)	Return to flight (long duration infrastructure)	Prototype 2017 (Loon project) and long duration infrastructure	2014: available	2014: BPCL available, measurement of T _{air} to be improved	2014: balloon available 2017 : operational gondola to be qualified
Scientific use	Physics, chemistry and dynamics of the stratosphere Astronomy	Chemistry and dynamics of the stratosphere, geophysics	Dynamics and chemistry of the atmosphere	Dynamics and chemistry of the atmosphere	Test of light instruments and vertical profiles	Meteorology and tropospheric chemistry	Sea surface and atmospheric marine boundary layer, typhoons
Balloon type	Open, non pressurised	Open, non pressurised	Pressurised	Pressurised with lobes (pumpkin)	Expanding envelope	Pressurised	Tetraedron or fish shape, closed + guiderope
Volume	from 3000 to 1 200 000 m ³	45 000 m ³	300-900 m ³	~ 2000 m ³	8 m ³ max	8 m ³ max	40 m ³ 110 m ³
Flight duration	A few hours to several days	A few weeks	3 months	3 months	2 to 3 hr	1 month	1 month
Scientific payload	from 120 to 1050 kg Recovery	25 kg No recovery	15 kg No recovery	15 kg No recovery	< 3 kg + 1 kg Possible recovery	3 kg + 1 kg No recovery	A few kg No recovery
Altitude	Ceiling at float or vertical excursion (slow descent) controlled between 15 and 40 km	Day : 26-29 km Night : 18-24 km	Constant level 18-21 km	Vertical excursion between 18-21 km if "ballonnet"	Ascent to 35-40 km	Constant level 500 to 3000 m	Balloon stable at 60 m altitude
TM/TC Scientific payload	TM(visibility)< 1,0 Mbps TC < 50 kbps	TM < 5 Mbyte/day TC : TBD bytes / 2000 bps			I/F meteo rawinsonde	TM < 0,5 Mbyte/jour TC : < 280 bytes / 2000 bps	

- Launching sites for BSO : Timmins since 2013, Kiruna 2016, Alice Springs 2017 et equatorial (site prospection)
- 35 ● Launching sites for BPS, BPL, MIR, BPCL et AEC (flexible, to be defined according to the scientific missions)
- Technical expertise on planetary balloons and tethered balloons (see S. Venel, presentation 3.2 and I. Zenone, presentation 3.4)

Expected near future of balloons
for the atmosphere and the ocean
(my own personal view!)

See several presentations in **session 6: Outlook**
and final **round table discussion**

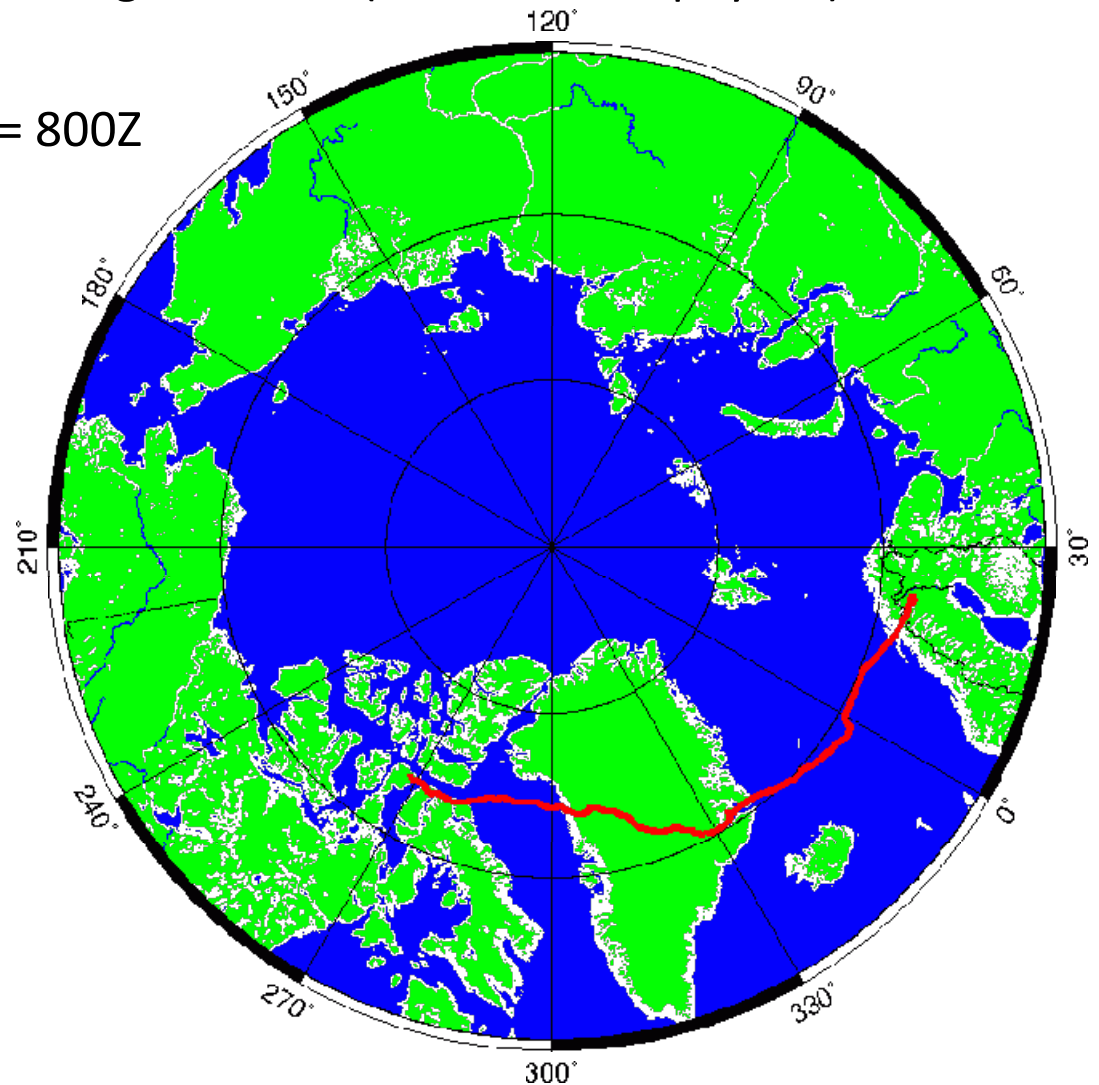
Validation and calibration of space missions

Mission	Launch	Variable to validate	Type of balloon
ADM-Aeolus	2016	Wind profile	BPS (Strateole 2)
Metop (IASI) Metop-SG (IASI-NG,3MI)	2006/2012/2018	T, H ₂ O, cirrus Gas & aerosols SST,surface pressure	BPS (T, H ₂ O,...) BSO/BLD Aeroclipper
CALIPSO/EarthCare	2009/2017	Clouds & aerosols	BSO/BLD
Merlin	2019	CH ₄ total column	BSO/BLD
GOSAT, GOSAT-2 OCO-2,OCO-3 TEMPO Sentinel 4/5P/5 MicroCarb/Sentinel Carbon	2017/2019/2021 2020	Total or partial gas columns	BSO/BLD

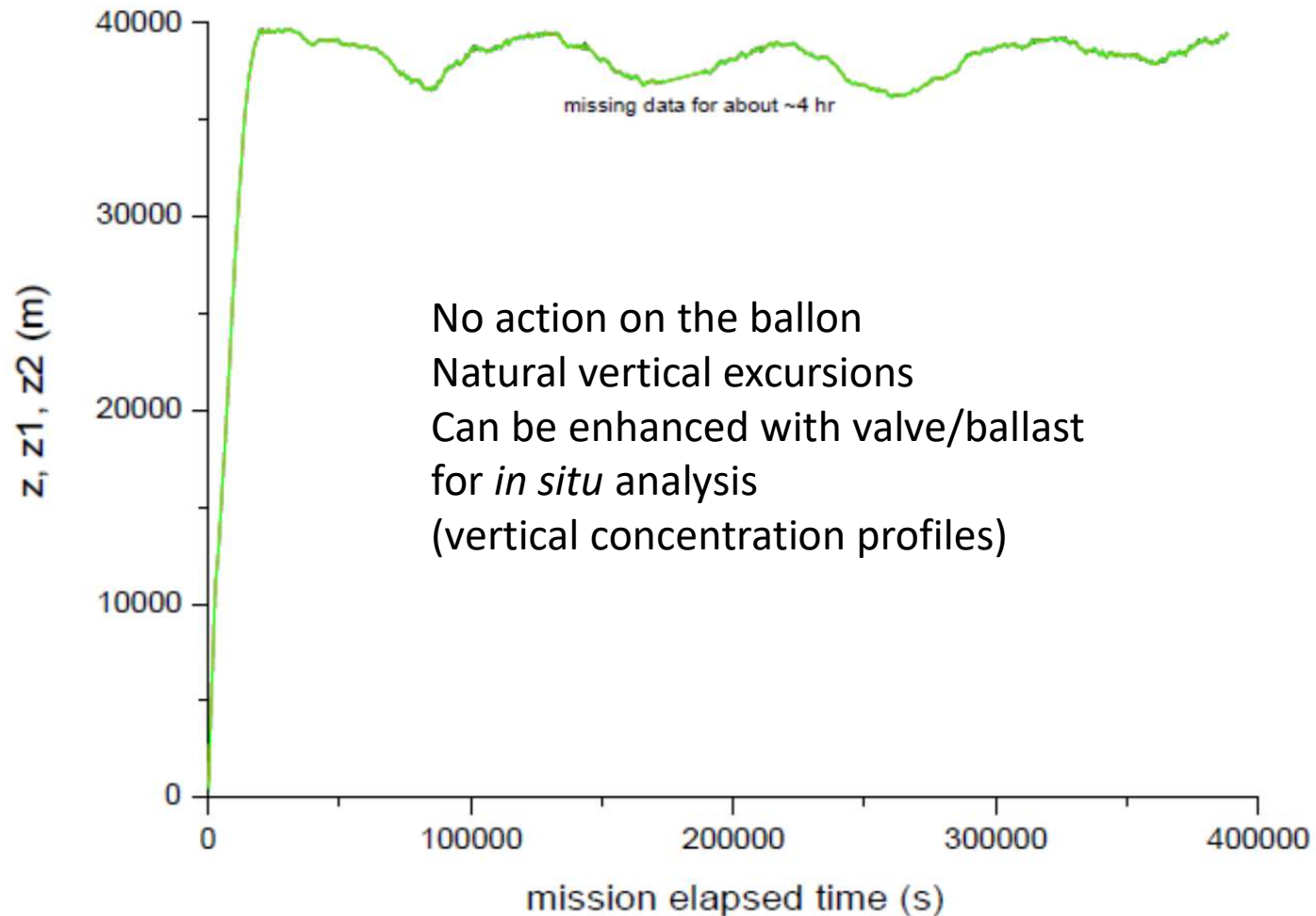
Medium duration flights

TRACER (Transition Radiation Array for Cosmic Energetic Radiation) : an example of a balloon flight from Kiruna to Northern Canada

- Objective: long observation time at high altitude (here for astrophysics)
- Duration ~ 4.5 days in July 2006
- Balloon $40\,106\text{ ft}^3 \sim 800\,000\text{ m}^3 = 800\text{Z}$



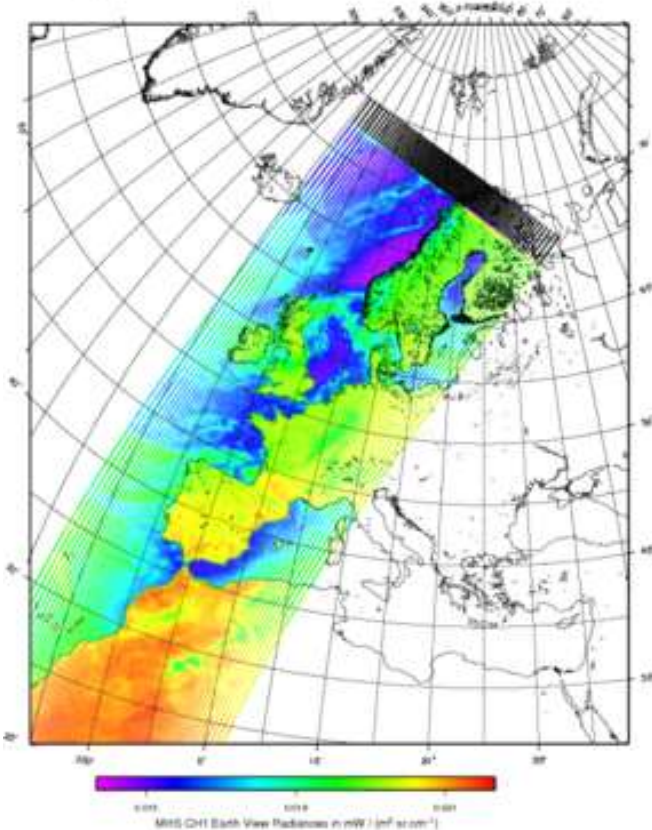
Medium duration flights



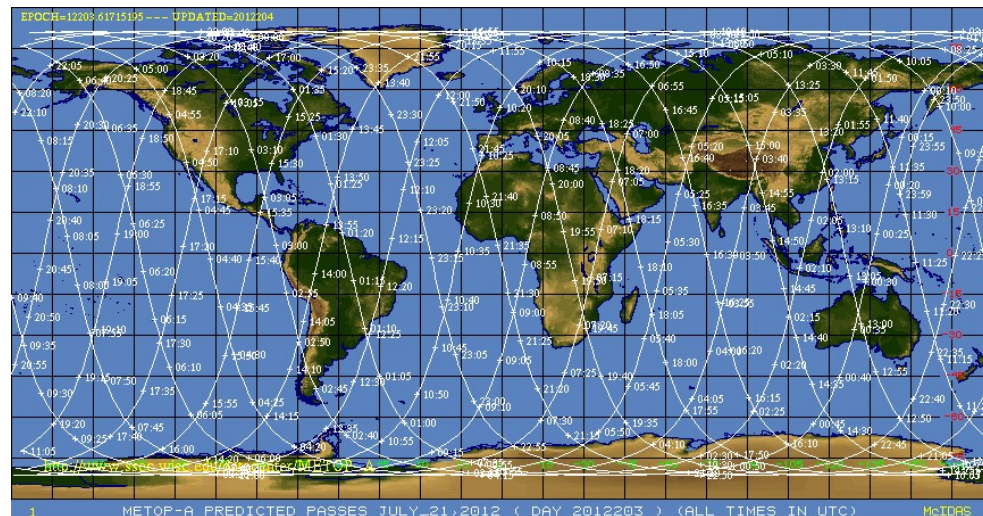
Satellite validation with balloons

Metop passes
At least 8 matchups

Metop-B MHS, Orbit 110, 25/09/12 10:06:51 to 10:24:51



Metop-B
First MHS data
First ASCAT images



Possible science and satellite validation project with mid-duration flights from Esrange/Kiruna to Northern Canada

- Use “big” BSO (803Z) with a payload (pointed gondola) accommodating several instruments (possibly GLORIA-B, HALESIS, REFIR-PAD, MicroCarb, Canadian instruments, ...)
- Combine *in situ*, nadir, occultation, limb remote sensing instruments
- Make sure that the instruments are operating at the time (and location) of the satellite overpasses
- Possibility of vertical excursions for vertical profile determination
- In a 5 days balloon mission, more than 8 crossing for one LEO satellite (Metop-A,B,C, Sentinel 5P, 5) → many possible coincidences
- Potential to embark dropsonde system (see Concordiasi or Strateole 2)
- Need international partnership between scientific teams (synergies) and with agencies (CNES, DLR, ESA, EU Copernicus, Eumetsat)

Need for equatorial/tropical launching base

- Polar (Esrange/Kiruna), mid-latitude (Timmins, NH and Alice Springs, SH) are not fulfilling the scientific needs to **further study the tropical atmosphere**
- **BPS** launches can be performed from several places in the equatorial region: Strateole 2 is considering **Seychelles** (but not only)
- But **BSO** launches need a **more established** equatorial/tropical infrastructure (bigger payloads, integration of several instruments, need for recovery)
- An equatorial/tropical site for this type of infrastructure could be looked for and developed in **partnership between key players** (CNES, DLR, ...) with interested nations (see example of Teresina in Brazil)

Outlook

- Balloons experiments are a very efficient way for **training young scientists** (see **M. Becker**, presentation 6.5; **N. Callens**, presentation 6.7), for **testing instrument concepts** and for **acquiring early data sets** needed for planned/future satellite Earth observation missions
- **Wide variety of balloon vehicles** available allowing to cover the different atmospheric layers between the surface and ~ 40 km (see Japanese record height of 53.7 km)
- **Wide range of scientific questions** for the atmosphere/ocean coupled system
- Balloon measurements should be used when they are **unique** and must often be combined with groundbased, aircraft, satellite measurements and models to get the **full picture**
- **International cooperation on balloon missions** should be enhanced (equatorial site, satellite validation, ECVs, trends in climate change) to **optimise resources** and use at best Earth Observation satellite data, often operational as with **ESA (Sentinels)**, **Eumetsat (Metop-SG, Meteosat)** and **EU (Copernicus)** → need inter-agency collaboration, planning, cost sharing

Acknowledgments



and all the scientists that provided material for this general presentation on atmospheric and oceanic science

Backup slides

“Effet de Serre” flight: StratoScience 2014 campaign from Timmins

Simultaneous measurements of greenhouse gas profiles (here CH₄)

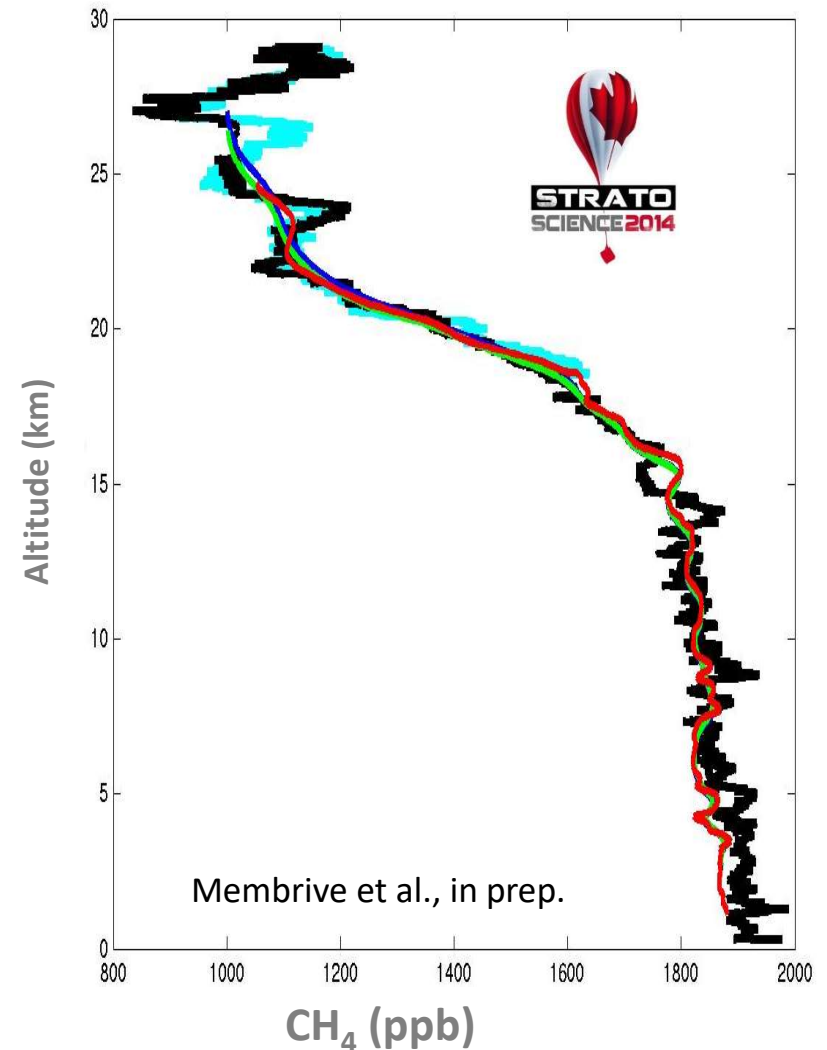
- AirCore-HR (LMD)
- AirCore-GUF1 (U. of Frankfurt)
- AirCore-GUF2 (U. of Frankfurt)
- Pico-SDLA (GSMA)

- Good agreement between different instruments
- Information on profile from the surface to 35 km
- Instrument development for calibrating and validating space missions (Merlin, MicroCarb, etc.)

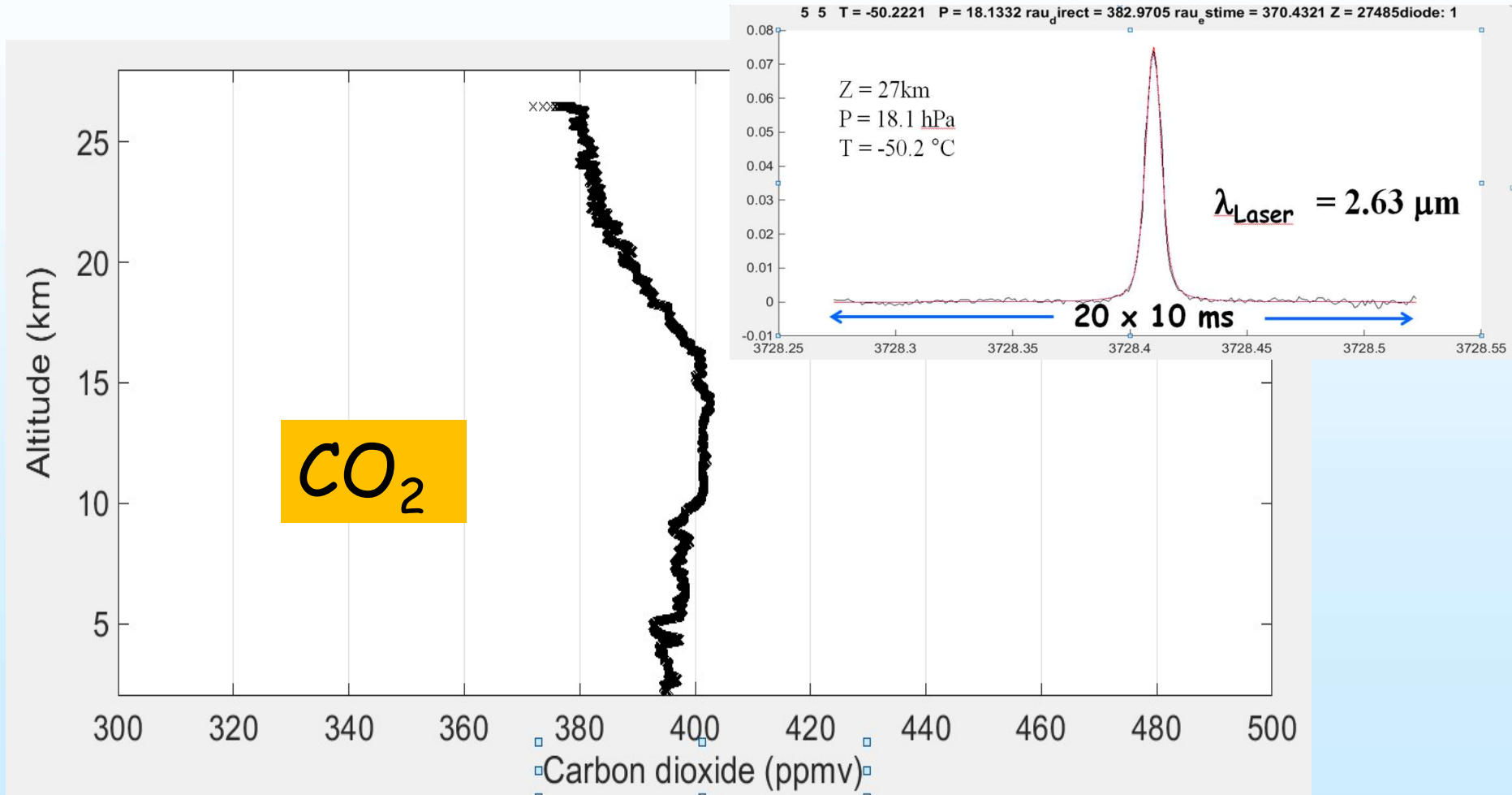
Launch



Multi-instrument gondola



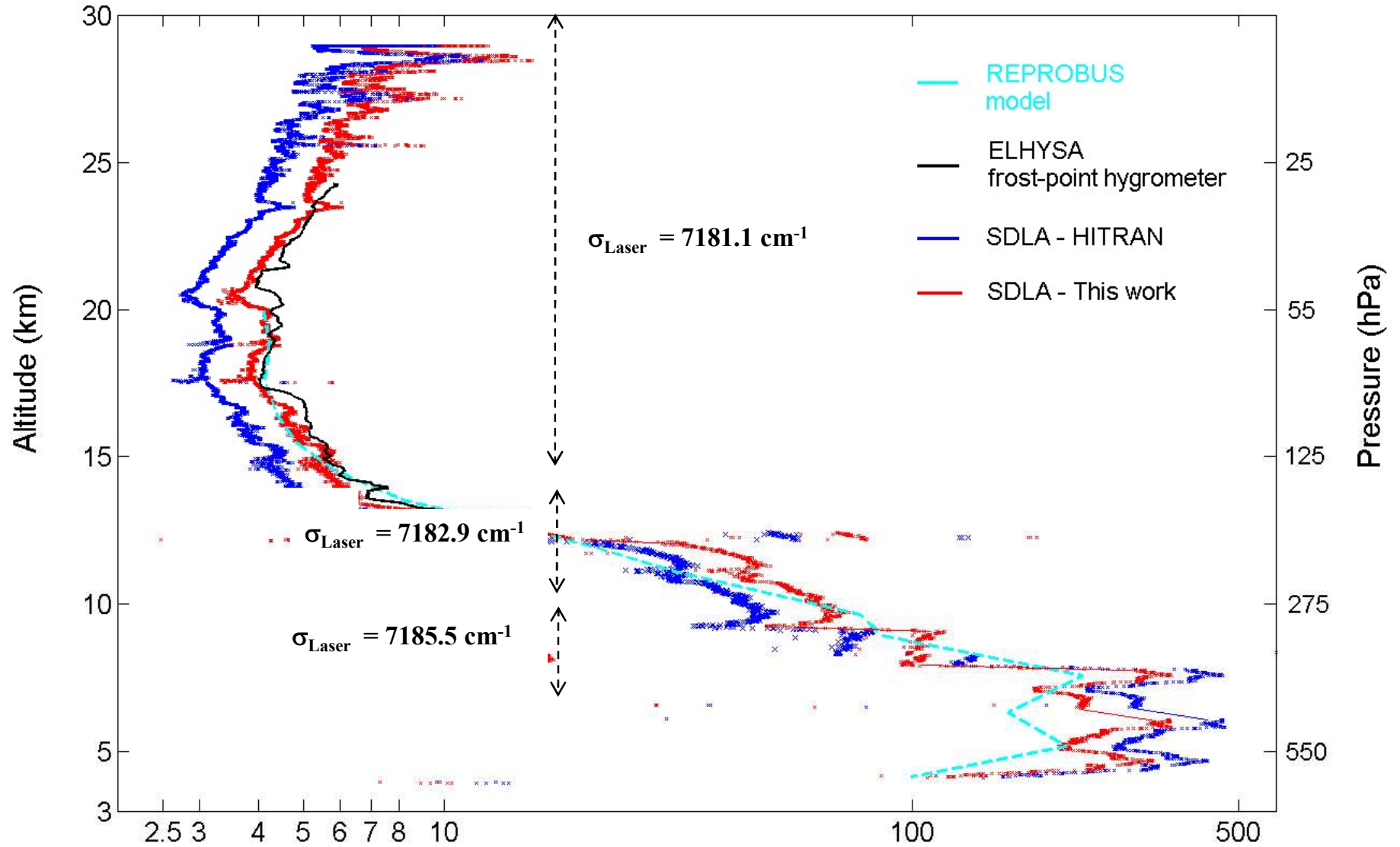
PicoSDLA-CO₂ Canada, Timmins, August 2014, ...



Stratospheric water vapour

- Need for very accurate measurements of profiles from the upper troposphere to the stratosphere for **trend analyses and climate change**
- Essential contribution of laboratory laser spectroscopy with instruments similar to those used for in situ measurements under balloons → **spectroscopic data bases for all satellite remote sensing instruments**

Example of **picoSDLA-H₂O**



Multi-species characterisation of stratospheric chemistry

See presentation by H. Oelhaf [A-143] (Tuesday afternoon, part 1)

Hyperspectral limb imaging with GLORIA, presently with the aircraft version, in the future with a balloon version **GLORIA-B** (precursor of Premier)

New instruments will use this same viewing geometry: example of **HALESIS**

See other presentations by:

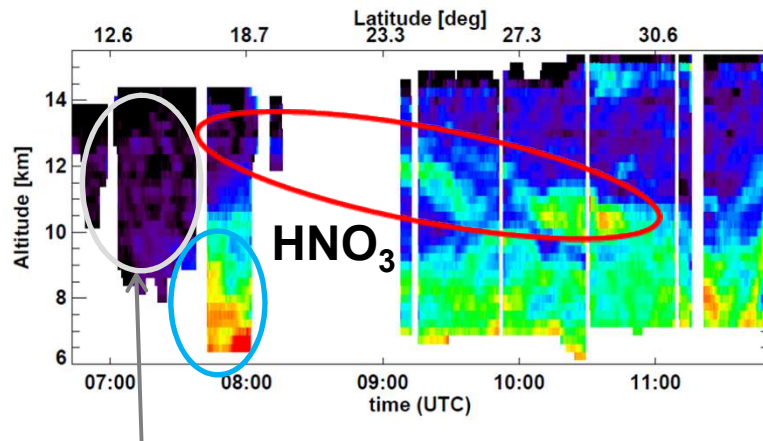
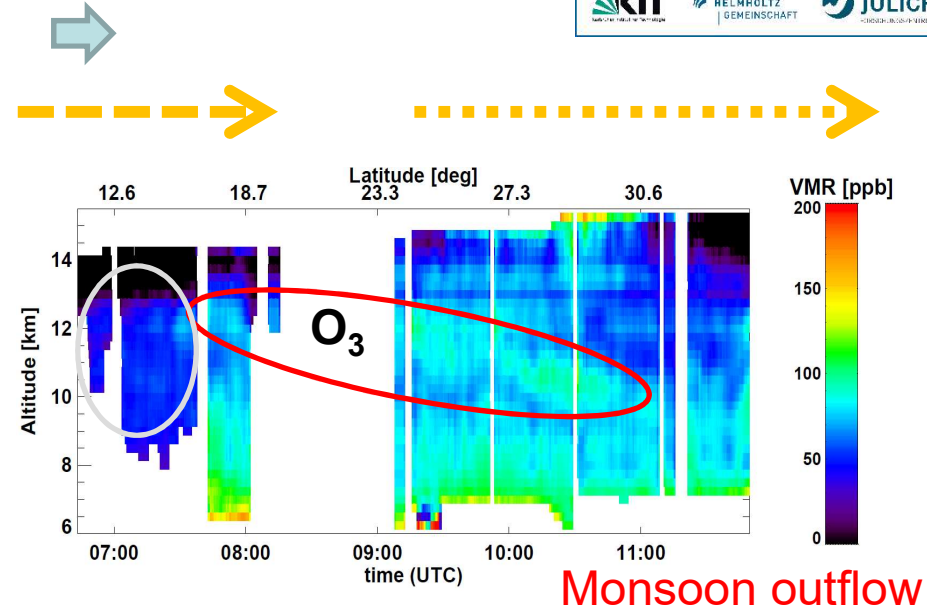
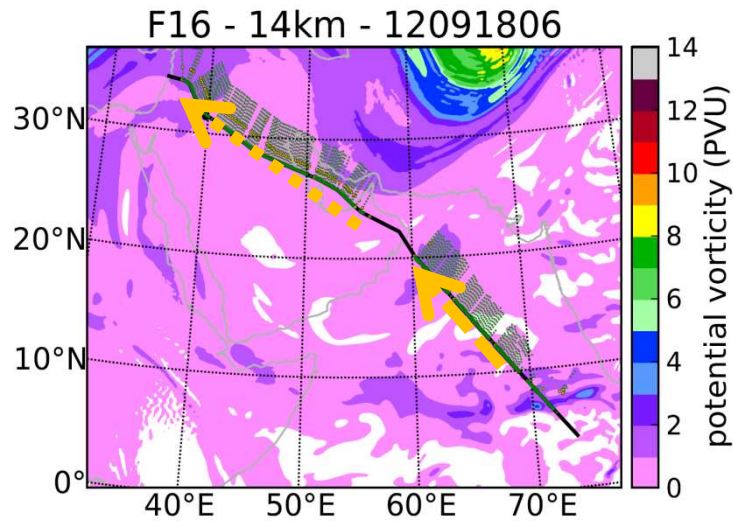
M. Kozun, [A-119] CATS (Tuesday morning, part 2)

B.J. Elash, [A-150] ALI (Tuesday afternoon, part 1)

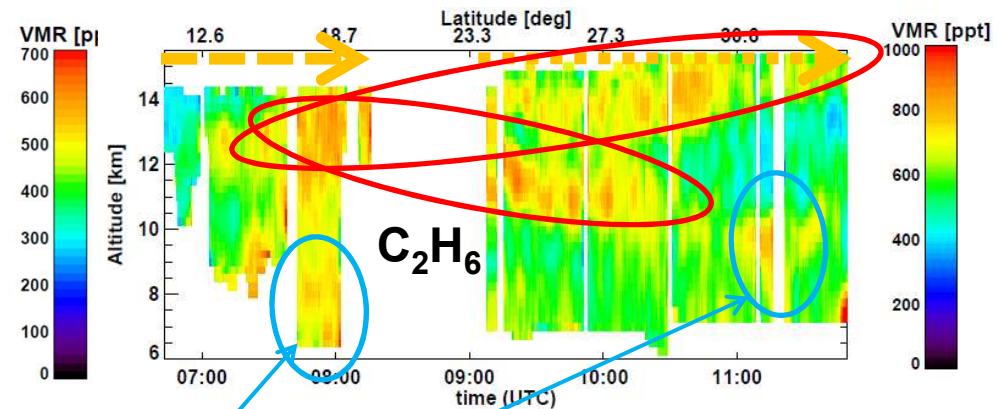
B. Taylor, [A-120] OSIRIS (Tuesday afternoon, part 2)

Analysing UTLS monsoon outflow & pollution signals

O_3 , HNO_3 and C_2H_6 VMR cross-sections



Very 'clean' air above convective active region



Local pollution from oil&gas fires and/or aircraft routes?

Aerosols

Need for frequent profile measurements of aerosols from the surface to the stratosphere (high space/time variability)

LOAC

See presentation by D. Vignelles [A-166] (Tuesday afternoon, part 2)

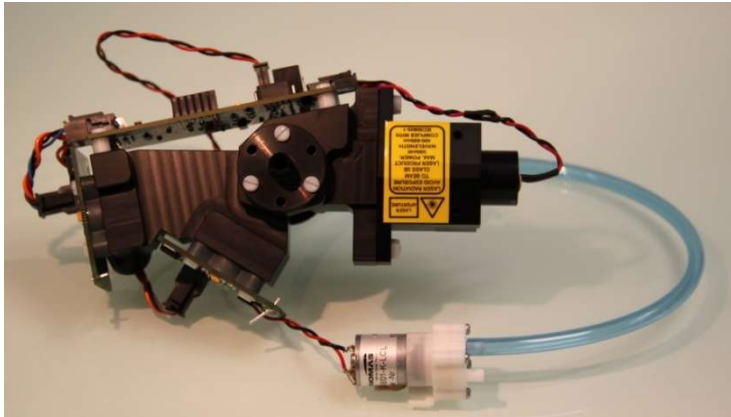
See also presentation by E. Brattich [A-166]

(BEXUS 18, Monday afternoon, part 1)

LOAC (Light Optical Aerosol Counter)



Developed by **LPC2E** (J.-B. Renard) and commercialised by Meteomodem
19 bins for aerosol sizes between 0.2 and 100 μm
Autonomous system for BLD (1 kg avec TM)
Passenger for BSO flights (to be combined with other atmospheric instruments)
CNES gondola under **BPCL** during the **ChArMEx** campaigns (summer 2013)



LOAC



BLD gondola



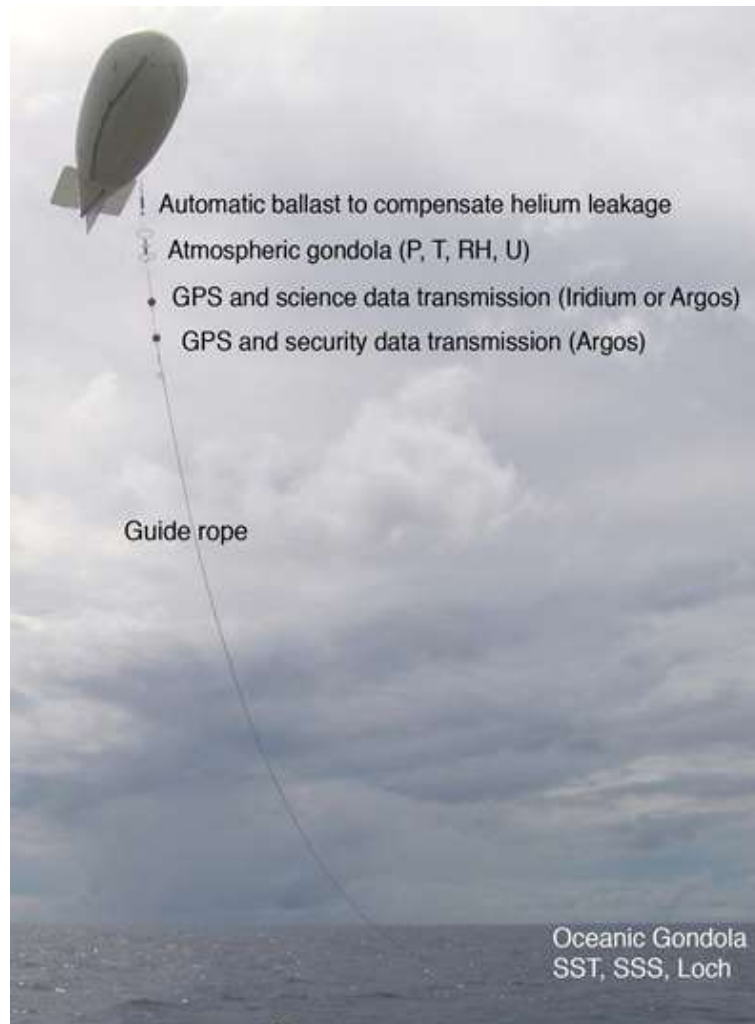
BPCL gondola

Atmosphere-ocean interface

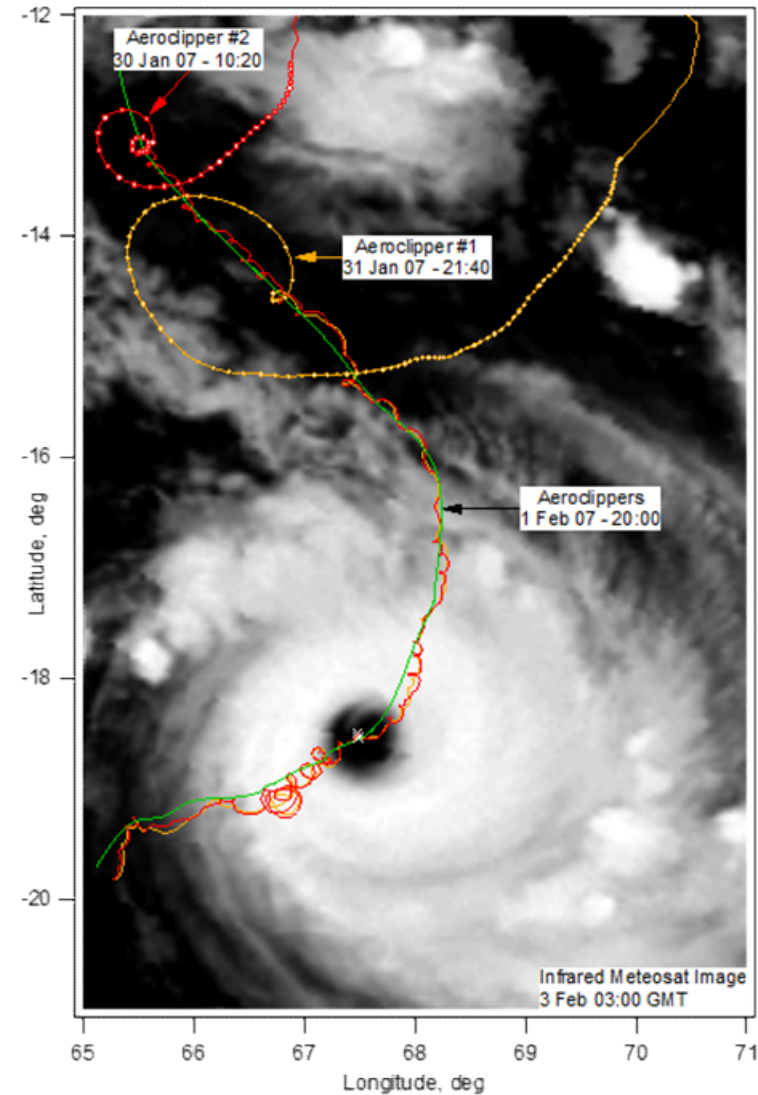
- Oceanic science and **atmosphere-ocean interactions** is presently covered either by research vessels or by satellite instruments
- But there are places where only some “special” balloons can go the **eye of hurricanes** (typhoon, cyclones)
- Measuring the **barometric pressure** (very low) in the eye of typhoons, will help improving models for predicting organized convective systems developing above tropical oceans and turning into (devastating) hurricanes

Example of **Aeroclipper**

Aeroclipper



VASCO prototype



Trajectory of two aeroclippers (all times in UTC),
green = track of DORA from 12:00 29 Jan to 00:00 6 Feb 2007,
superimposed on Metosat IR image taken at 03:00 3 Feb 2007