OBSERVATION PLATFORMS

Contents

Balloons

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Introduction

Though a large number of high-performance satellite instruments have been placed into orbit during the last two decades, balloons are used more frequently than ever in studying the atmosphere, for several reasons. Indeed, if satellites are unique in providing a global view of the Earth's atmosphere, they also suffer several limitations. First, because of atmospheric attenuation and clouds, chemical species as well as meteorological parameters can only be observed from satellites with difficulty at altitudes below 16–18 km, i.e., in the lowermost stratosphere where ozone depletion takes place, and in the troposphere where the impact of human activities could be the largest. Moreover, the vertical resolution of the measurements from satellite is limited to 1–2 km at best, and several important chemical species cannot be derived by remote sensing techniques. Finally, satellites have a limited lifetime. Except for ozone, at present they do not allow the long-term monitoring of the composition of the atmosphere, a vital necessity in understanding the impact of anthropogenic sources and the relation between chemistry and climate.

In contrast, currently available balloons allow a variety of *in situ* and remote sensors, making measurements from the ground to about 40 km, to be carried at relatively low cost, thus allowing the repetition of the measurements over a long period. Importantly also, balloon flights can be performed within a shorter time frame than that required for the development of space projects, allowing the rapid checking of new ideas, concepts, or instruments for further use in space and later for the validation of the measurements of spaceborne instruments. Furthermore, long-duration balloon systems of various types are currently available or under development, which should allow greater use of balloons in atmospheric studies on a global scale at a relatively low cost.

Just as meteorological satellites did not replace the need for several hundred daily radiosonde ascents, so space instruments did not replace the use of balloons, but in contrast resulted in their considerable development. This, together with the use of space technology in the instruments, payloads, and data transmission, explains why scientific ballooning has been taken up by space agencies in most countries.

The objective of this article is to give an overview of the unmanned balloon systems currently available or under development for atmospheric research. After a brief historical recall of scientific ballooning and of those conceptual aspects needed to understand how balloons work and their limitations, the main systems currently available will be described from the point of view of the scientific user.

History

Balloons are not new vehicles. They all still rely on one of the two concepts both flown for the first time in 1783 in France: hot air by the Montgolfier brothers and gas by Charles and Robert. As a first step for about a century, these balloons were used primarily for spectacular events during celebrations, were all manned, and were used little for science. The first observations of scientific interest were those of Robertson in 1803 and of Gay-Lussac and Biot in 1804. They demonstrated the decrease of temperature, pressure, and moisture with height and the constant composition of air up to an altitude of 7000 m. But progress was slow, limited by the maximum altitude acceptable to the pilots. Only a handful of ascents of scientific interest were performed during the nineteenth century. Barral and Bixio in 1850 in France discovered the existence of ice particles – cirrus clouds – forming at low temperatures at 7000 m. In 1852 Welsh and in

1862 Glaisher in the United Kingdom extended observations to a record altitude of 8800 m. Then, Sivel, Croce-Spinelli, and Tissandier in France in 1875 made the first spectroscopic observations of astronomical bodies above the dense atmosphere at 8600 m, during an ascent in which the first two men perished. Finally, Berson in Germany, reaching 9150 m in 1894 and 10300 m in 1901, measured a record low temperature of −47.9°C.

Though manned flights were continued into the next century (Piccard in 1931 reached 15 781 m, followed shortly after by Prokofiev, Goudonov, and Brirnbam in the Soviet Union at 18 500 m, Settle in the United States at 18 665 m, and several others until Kittinger reached 30 000 m in the US in the 1960s), the greatest progress in atmospheric science and meteorology was to come from the use of unmanned balloons.

The first series of unmanned ascents for studying the upper atmosphere was launched by Hermite and Besançon in 1892 in France; they used an onboard recording thermometer, barometer, and hygrometer designed by the meteorological instrument manufacturer Richard. These were recovered after the flight. This was followed by the installation of the first upper-air sounding station at Trappes near Versailles by the meteorologist Tesserenc de Bort. Thanks to this effort, the stratosphere was discovered in 1898. The stratosphere was shown to be a region where the temperature did not continuously decrease to the absolute zero around 50 km as thought before, but instead leveled off or even increased above 12–13 km.The next important technical step forward was that of Assmann in Germany, who in 1901 suggested the use of small rubber dilatable balloons and a parachute for safe recovery of the instruments. With such a system, a record altitude of 37 700 m was reached at Pavia in Italy in 1912. The further significant step is due to Hergesell, who in Germany in 1910 performed the first wind sounding using a theodolite on the ground to follow the horizontal motion of the balloon during ascent, while the altitude of the balloon was reckoned using a simple stopwatch. But the major breakthrough in atmospheric science was the invention of the radiosonde by Idrac and Bureau in 1929, who added a radio transmitter to send the temperature, pressure, humidity, and wind information in real time, thus eliminating the need to wait for an unpredictable and sometimes very long recovery of the sonde. Though many improvements have been added since (e.g., neoprene balloon material, much more sensitive sensors, miniaturized electronics, Omega, and later the Global Positioning System for the location of the sonde), the radiosondes in use today in the upper-air network of the World Meteorological Organization are basically the same as in 1929.

However, because of the restricted load permitted below rubber balloons, or the weight and therefore the altitude limitation of manned systems, the use of balloons for science other than meteorology remained limited until the arrival in 1947 of plastic film developed by Winzen at General Mills in the United States. Astronomers or cosmic ray scientists as well as atmospheric scientists were immediately interested in the new technique to carry heavy payloads above the absorbing atmosphere. Modern scientific ballooning had started by the late 1950s in the United States under the direction of Ney at the University of Minneapolis, later transferring to the National Center for Atmospheric Research, NCAR, and then to the National Aeronautic and Space Administration, NASA. Soon after, scientific ballooning activities were also started in France by Blamont at the Centre National de la Recherche Scientifique, CNRS, later transferring to the Centre National d'Etudes Spatiales, CNES. Thenceforth, the technology propagated rapidly in the 1960s in the Soviet Union, Japan, India, Indonesia, Brazil, and Argentina, though complete balloon manufacturing capabilities were not available in most of the latter countries.

A variety of balloons were progressively made available to atmospheric scientists, and ranged from open or zero-pressure balloons carrying heavy payloads for a few hours at high altitude or long duration for a few weeks or months in the lower atmosphere. Though their performances and uses varied, they all followed the same physical principles, which are recalled below before describing current available platforms.

Balloon Concepts

The lift of a balloon, derived from Archimedes' principle, can be expressed as

$$V(\rho_{\text{air}} - \rho_{\text{gas}}) = \sum M_{\text{s}}(1 + f) \qquad [1]$$

where V is the volume, ρ_{air} the density of air and ρ_{gas} that of the lifting gas (hydrogen, helium or hot air), $\sum M_{\text{s}}$ the sum of solid masses (balloon envelope and payload), and f the free lift. Getting off the ground requires a positive free lift or excess gas of generally 15–20% of the total $M_{\text{s}}(1 + f)$. Because of the exponential decrease of pressure with altitude, the balloon expands continuously in volume during the ascent, until it reaches its float altitude. While reaching and suspended at this level, the excess gas corresponding to the free lift has to be evacuated or else retained by a high-strength material – otherwise the balloon bursts.

In one type of balloon, the zero-pressure, large open ducts at the base of the envelope vent the excess gas, so that the pressure differential from inside and to outside remains small (**Figure 1**). In the other, the super-pressure sealed balloon, in which the excess gas converts into a differential pressure that is retained by the high-strength, and thus necessarily heavy, material.

Since the stress on the envelope is very small, a zero-pressure balloon can be manufactured in light 20–40 μm thin polyethylene material. Its volume can be as large as required – up to 2 million m^3 for carrying a load of several hundred kilograms up to 40 km. However, there are two limitations: launch operations and flight duration. Though efficient methods (crane or auxiliary balloon) have been developed to keep the payload off the ground at liftoff, the size of the balloon, which is only partially inflated at ground (300 m high for the largest balloons), makes a launch very sensitive to surface wind. The maximum acceptable wind speed is generally 2 m s^{-1} at 50 m height, or even at 200 m for the largest balloons, which sometimes means waiting for weeks for the right conditions. The second limitation is the duration of the flight. The cooling at sunset makes the balloon contract and descend, and this can be counteracted only by an irreversible drop of ballast. The duration of the flight is thus limited by the amount of ballast, which must be carried only at the expense of the scientific payload. Zero-pressure balloon flights are generally limited to few hours. However, long-duration cruises of upto 4–5 days across the Atlantic or the Soviet Union have been effected through carrying a large amount of ballast or alternatively by replacing the solid ballast by a reservoir of liquid helium to compensate the loss of gas. Longer flights have also been achieved in the specific case of permanent day or night in polar areas, thus requiring little dropping of ballast. Taking advantage of such conditions, zero-pressure circumnavigations of 2–3 weeks (1 month in 2002) have been achieved over Antarctica by NASA in the summer and also by the Japanese.

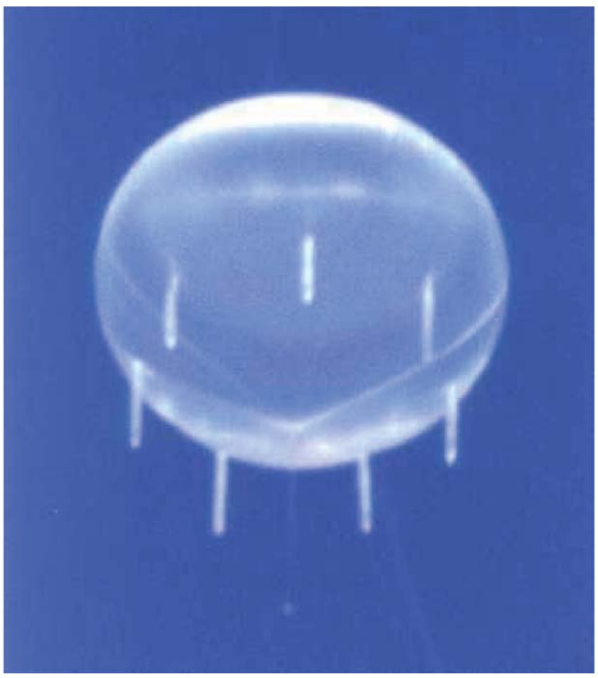


Figure 1 Zero-pressure balloon of 2 000 000 m^3 at float altitude. The excess gas is vented by seven open ducts at the bottom of the envelope. © NASA.

Long-duration flights generally require totally different approaches. Two successful ideas both currently in use have been suggested: super-pressure balloons and infra-red Montgolfier. The first, promoted by Lally at NCAR in the 1960s is derived from a concept of small spherical paper balloons used by the Japanese during World War II. The super-pressure balloon is a sealed sphere in which the excess gas corresponding to the free lift converts into overpressure. The pressure increases during daytime solar heating and decreases with the cooling at night. Since the volume and the mass of the system are constant, the balloon flies at a constant density (isopycnic) level. It remains aloft until leakage reduces the overpressure to zero in the night cold, when the balloon irreversibly drops. The system is limited by the thickness and thus the weight of the material – which is generally polyester, fabric, or polyethylene composite – that is required to maintain the overpressure. Since the stress of the envelope increases with the balloon's radius, the size of a super-pressure balloon for a given material is limited to the volume at which the balloon can carry its own unladen weight. For a spherical balloon of polyester, the limit is around 10 m diameter, allowing a payload of 20 kg at around 19 km altitude.

To overcome this limitation, a new design has been suggested in France (CNES Stratospheric Super-Pressure Balloons), in the USA (NASA Ultra Long Duration Balloons), and also in Japan, which consists of a 'pumpkin-shaped' balloon. In this design, Kevlar tendons take the meridional stress while the longitudinal stress is reduced by the small local radius of the pumpkin lobes or gores, which allows a reduction in the density of the balloon material. Though this solution seems promising, there are technical difficulties still to be overcome, particularly in the arrangement between the tendons and the envelope when reaching float altitude. Though a successful three-month flight was achieved in 1992 by CNES in South Africa, other attempts have failed, as did the first US test in Australia in 2001. However, there is no doubt that once these problems are solved, the pumpkin shape could offer a unique opportunity for long circumnavigations of large payloads at high altitude for the remote observation of the atmosphere.

A totally different concept, suggested by the present author and Hauchecorne in the late 1970s, is the use of a hot-air balloon heated at night by the Earth's thermal emission, and therefore named Montgolfier Infra-Rouge (MIR). This is achieved by adding a very low-thermal-emission aluminum layer to the upper half of the infrared absorbing polyester envelope, thus preventing the balloon from radiating toward space, the lower half being in transparent polyethylene. In this arrangement, the temperature differential of 20–30°C between the air inside the balloon and that ambient air in the cold stratosphere keeps the MIR stable at night. The extra lift provided by solar heating during daytime makes the balloon ascend and thus purge a large part of the lifting gas. But since this gas is air, it can be replaced during the evening descent by simply keeping open a large mouth at the bottom of the balloon. The system is thus reversible. The only limitation is during flying over very cold and low emissive clouds, such as high-altitude anvils in tropical regions, which reduces the temperature differential between the inside and outside by a few degrees, which is not enough to keep the balloon aloft for the whole night. In its present design, the MIR of 45 000 m^3 volume carries 60 kg at 28 km during daytime and between 18 and 24 km at night, depending on the cloud cover, for an average duration of 3 weeks, with a record flight of 2 months in the tropics.

The various techniques above could also be combined. An example occurred in the recent record manned flight round the world, which used a helium balloon on top of a hot-air system, both covered by an aluminized layer to reduce the radiative heat loss and carrying a ballast of propane to feed a burner in case of major cooling.

Current Scientific Balloon Systems and Their Use

Based on the above concepts, a variety of balloon systems are available to the scientist wanting to study the Earth's, or another planet's atmosphere, the characteristics and performances of which are summarized in **Table 1**. They are all described below from the point of view of the user, together with examples of their application.

Open Zero-Pressure Balloons

The most commonly used scientific balloon is the zero-pressure (**Figure 2**). Its volume varies from 50 000 m^3 to 2 Mm^3 or more, which can carry between 100 kg and 2000 kg (the record is 3600 kg) between 25 and 40 km (the record is 42 km), see **Figure 3**. It is equipped with powerful telemetry and remote control transmissions of up to 500 bps. For many purposes the gondola is stabilized or oriented toward the Sun or an astronomical object, or even stabilizes with respect to a magnetic or geographic heading. In most applications, flight is limited to within the telemetry range from the control station of 300–400 km, that is for a duration of a few hours, though it can be extended by using a down-range receiving station. The size of the balloon (up to 300 m high at liftoff), as well as the weight of the payload, requires the use of a mobile crane or else auxiliary balloons to keep the gondola off the ground during the launch operation, which has to be performed by a well-trained team. The descent of the payload for recovery below one or several parachutes terminates the flight. However, and this is of great interest for atmospheric research, the ascent or descent speed and altitude of the balloon can also be adjusted by alternately valving gas and dropping ballast. This facility is now in common use for studying a specific layer, e.g., stratospheric clouds in polar areas, or setting a slow descent speed across the whole stratosphere for air sampling or chemical analysis.

In the United States, the balloons manufactured by Raven Industry are operated by the NASA Wallops Flight Facility (25 flights per year, with payloads of up to 2000 kg) at the National Scientific Balloon Facility (NSBF) at Palestine, Texas, or the Scientific Balloon Flight Facility (SBFF) at Fort Summer, New Mexico. In France they are manufactured by Zodiac-Espace and operated by the CNES space agency at the Centre de Lancement de Ballons at Aire sur l'Adour, or Gap in the summer, in southern France (20 flights per year,

Table 1 Performances of scientific balloons

Balloon	*Volume (m^3)*	*Payload (kg)*	*Altitude (km)*	*Duration*
Zero-pressure	5 000 to 2 000 000	50 to 2 000	25–40	Hours – days
Pressurized sphere	50–600	2–20	12–19	Weeks – months
Pressurized tracers	3–8	2–3	1–5	Weeks
Pressurized pumpkin	1 000 000	1 000	35	(Goal 100 days)
IR Montgolfier	45 000	60	27 (day) 18 (night)	Weeks – months

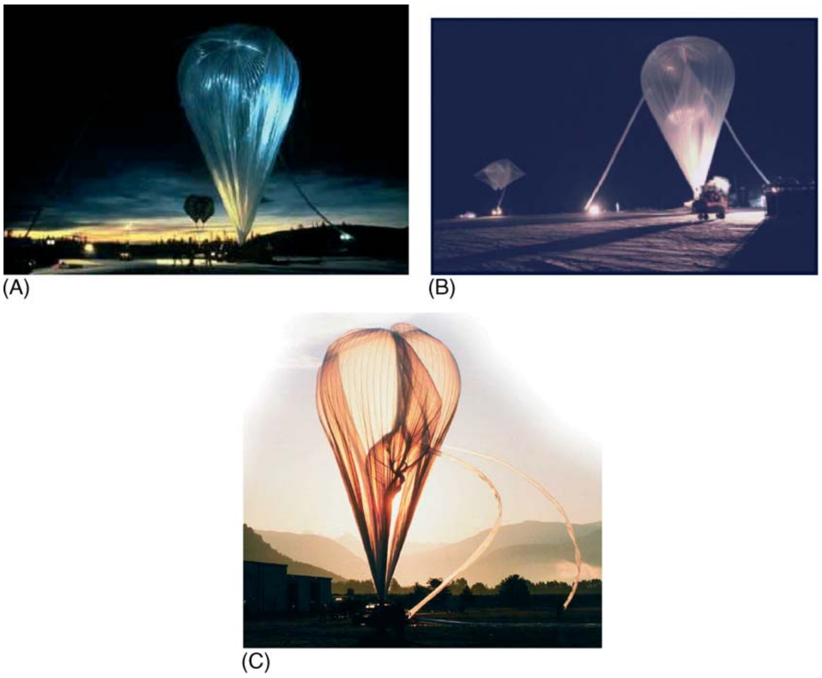


Figure 2 (A) + (B) Inflation of a 100 000 m^3 zero-pressure balloon in the polar night in northern Sweden in January 2000 for studying stratospheric clouds and ozone depletion. The two small balloons in the background are auxiliary balloons used to keep the payload off the ground during liftoff. © CNRS. (C) Early-morning inflation of a 100 000 m^3 zero-pressure balloon at Gap in the Alps. © CNES.

with maximum payloads of 500 kg for safety reasons). Several other countries are also conducting smaller programs on their own or in cooperation with the USA and France: Japan, India, Canada, Australia, Norway, Sweden, Brazil, Argentina, and Indonesia. The Soviet Union has had an extensive program in the past, including 4–5-day flights from European Russia to Siberia in the winter and from Kamchatka to the Urals in the summer, but this has been suspended for the moment.

Depending on scientific objectives, both NASA and CNES frequently carry out series of balloon launches at remote sites at all latitudes in Canada, Brazil, Australia, Alaska, Sweden, Antarctica, etc. Among others, recent examples are the series of winter campaigns conducted since 1990 by the CNES for the European Commission at the Swedish ESRANGE facility at Kiruna for studying stratospheric ozone depletion; those included THESEO-SOLVE in the winter of 2000, which involved both CNES and NASA.

The use of zero-pressure balloons in atmospheric science is twofold: (1) for the remote observation from the float level of the vertical profile of chemical species by techniques similar to that in use from orbit; (2) for *in-situ* measurement, during ascent or slow descent, of aerosols, stratospheric clouds particles, tracer gases, and chemical species by a variety of techniques close to those in use in the laboratory. Remote sensing techniques include absorption measurements in the

Figure 3 1 000 000 m^3 zero-pressure balloon ready for release at MacMurdo, Antarctica, in December 2001. The 1100 kg payload is suspended from a mobile crane. Taking advantage of the polar day, a record flight of one month was achieved. © NASA.

UV, visible, and infrared regions by solar, star, or lunar occultation, and emission techniques in the IR and microwave wavelengths. Most of the atmospheric instruments subsequently placed in orbit, such as the ATMOS Fourier Transform Spectrometer on the Space Shuttle, the Microwave Limb Sounder onboard the NASA Upper Air Research Satellite, or the MIPAS Fourier Transform Spectrometer on the ESA ENVISAT satellite, have been flown first on balloons. Besides the new science which could be derived a long time ahead from the long leadtime development of a space project, the advantage is the advanced maturity of the retrieval algorithms as well as later, the validation of the measurements from space by direct comparison with colocated balloon observations.

But the unique contribution of balloons to atmospheric science is the measurement *in situ* of a number of parameters and species, and their altitude and time variations, which cannot be done by other methods, particularly in the stratosphere. Examples include the profiles of the organic chlorine and bromine species (CFCs and halons) responsible for the destruction of ozone; the profile of OH, the hydroxyl radical involved in many chemical cycles; the composition of the crystals of polar stratospheric clouds which trigger the ozone loss process in polar areas, and high-resolution profiles of long-lived species or tracers needed to understand transport processes. The list of instruments flown includes mass spectrometers, gas chromatographs, samplers, fluorescence–resonance chemical reactors, aerosols, and condensation nuclei counters, tunable diode lasers associated to multiple-path-length cells, etc.

Light, Small, Zero-Pressure Balloons

Large zero-pressure balloons as described above are powerful tools, but since they are extremely sensitive to surface wind, and hence cannot often be launched when required, they are difficult to use in atmospheric science. In addition, their operation needs heavy equipment and large facilities, while finally their relatively high cost does not allow them to be flown as frequently as is desirable for recording atmospheric variability. An alternative approach, explored during recent years by CNES, is the reduction of the size of the balloons (**Figure 4**). This is achieved by using lighter material, 16 μm and more recently 12 μm thick, but reinforced at the gores assembly, and also by reducing dramatically the weight of the payload by applying miniaturization techniques to scientific instruments as well as to operational subsystems. Finally, launch techniques have also been revised. The payloads are designed to be dragged, perhaps on a sledge, on the launch pad, thus not requiring auxiliary balloons or a crane. In such design a 10 000 m^3 balloon carrying 100 kg of apparatus at 2 km could be launched in a surface wind at up to 7 m s^{-1} (30 km h), that is, in most meteorological conditions. This flexibility meets a variety of scientific requirements such as those imposed by sunset or sunrise, the presence of polar stratospheric clouds, satellite overpass, tropical storms, etc.

Figure 4 Small, light, zero-pressure balloon of 10 000 m^3 ready for launch at the ESRANGE facility at Kiruna in northern Sweden during the Ozone THESEO-SOLVE campaign in February 2000. Five complementary scientific instruments for measuring chemicals and aerosols by a variety of techniques are shown ready to be flown together in separate packages which at launch slip along the launch pad. © CNRS.

A number of lightweight atmospheric instruments in the 5–20 kg range have been developed in Europe and in the US for use with these smaller, lighter balloons: UV-visible solar or moon occultation spectrometers, tunable diode lasers, air samplers, aerosol counters, gas chromatographs, and resonance fluorescence reactors, measuring a broad range of chemical species. Such instruments are frequently flown together on the same balloon from unprepared or wind-exposed ranges, in order to study polar ozone chemistry, stratospheric clouds, tropical convection, seasonal and diurnal cycles, long-term trends, satellite validations, etc.

Tethered Balloons

Basically, tethered balloons are open balloons that are only a little pressurized, the excess gas being vented through a valve. Though the concept is simple, tethered balloons have been of little use in atmospheric research except in the lowermost boundary layer. Attempts to build permanent atmospheric observatories in the lower stratosphere around 20 km in France in the 1980s, using newly available Kevlar cables, failed totally, mainly because of gusty winds but also because of air safety constraints. The use of tethered balloons seems thus to be limited to the lowermost 1–2 km levels in light wind and in areas with little air traffic. However, a promising system for studying the sea–air interface in remote oceanic regions is the drifting balloon attached to a floating guide rope as tested in 2000 by the CNES in the tropical Atlantic.

Super-Pressure Balloons

As noted earlier, super-pressure balloons were developed originally in the USA at NCAR for studying the

Figure 5 Launch of a tracer super-pressure balloon at Ushuaia, Argentina, in February 2000 for studying the meteorology of the lower atmosphere over the Southern Atlantic. The electronics are located inside the balloon for protection against rainfall.

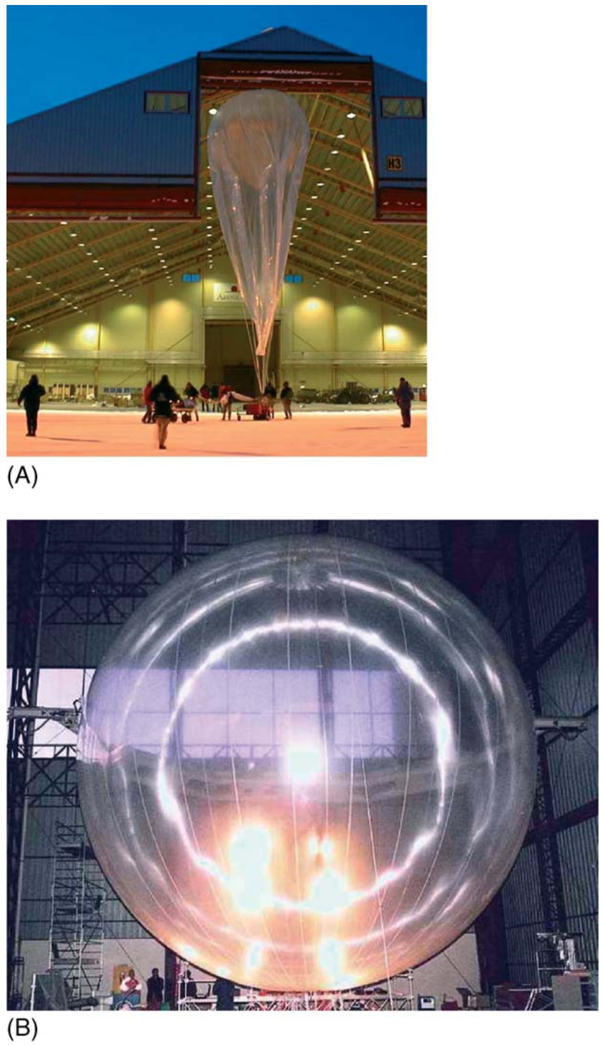


Figure 6 (A) Launch of a 10 m diameter super-pressure constant-level balloon at Kiruna, northern Sweden, in January 1999 for studying the dynamics of the stratosphere. © CNES. (B) 10 m diameter super-pressure balloon under testing at the CNES facility at Toulouse. © CNES.

meteorology of the upper troposphere. They were spherical balloons of 43 μm thick polyester and 2.70 m diameter, able to carry a 2.5 kg payload at 200 hPa (12 km). In the late 1960s and early 1970s more than 400 balloons were flown by NCAR within a GHOST project from New Zealand in the frame of the GARP (the international Global Atmospheric Research Program). In addition, another 400 of similar size were flown by the French from South America using a dedicated satellite, EOLE, to track them with a new receiving system at the origin of the ARGOS satellite data collection in broad use in ballooning nowadays. On both projects, the average flight duration was around 3 months, with a record of 1.5 years.

In order to meet the scientific demand, super-pressure balloon programs have evolved in two directions: small tracer balloons in the planetary boundary layer and relatively large ones for studying transport in the lower stratosphere. The first type, with the payload mounted inside the envelope to protect the electronics from rainfall (**Figure 5**) were, for example, flown for several weeks in the 1980s over the Indian Ocean for investigating the atmospheric circulation associated with the monsoon. The experiment was repeated in 2000 in India, during the recent INDOEX international project, as well as in Argentina.

The second type of balloon was the large spherical one flown in the lower stratosphere (**Figure 6**). But as explained earlier, and shown for example by the unsuccessful attempt by NCAR in the 1980s to develop a 24 m diameter balloon to carry a drop sondes package at 24 km, these balloons are at the limit of technology. The largest system, currently under testing at CNES with some success after several years of hard work, is a 10 m diameter balloon carrying a 20 kg payload at 19 km for studying the dynamics of the winter Antarctic stratosphere.

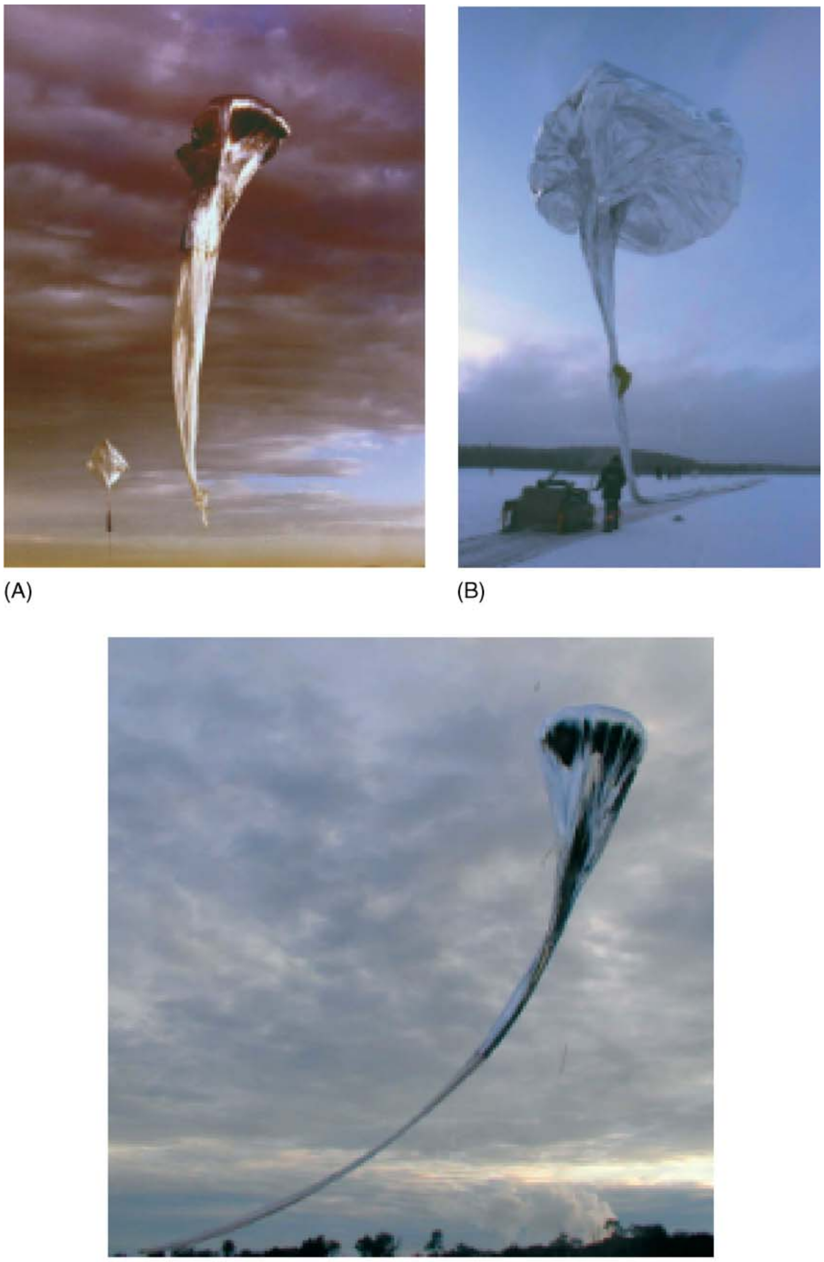
Ultra-Long-Duration Balloons (ULDB)

Unless a new, high-strength material appears in the future, the size and therefore the altitude of spherical super-pressure balloons will be limited. The only way to overcome the limit is to change completely the architecture of the balloon and adopt a pumpkin shape (**Figure 7**). A large pumpkin balloon of 58 m diameter for carrying 1.6 tonnes at 33.5 km for 100 days is under development at NASA. Though a 3 days' successful test was conducted in June 2000 in the US, the first attempt at a long-duration flight from Australia in 2001 failed, illustrating the difficulty of the project. However, the program will continue. There is no doubt that when successful, ULDBs will be powerful tools in enabling atmospheric observation to be made by new passive or active remote sensing instruments long before such instruments are able to be placed in orbit.

Figure 7 Artist's view of the ULDB pumpkin super-pressure balloon at float. Designed for carrying one tonne at 35 km altitude during 100 days, such balloons could allow the remote sensing of the atmosphere on a global scale at far less cost than that of using satellites. © NASA.

Infra-Red Montgolfier (MIR)

Because of the smaller lift of hot air compared with hydrogen or helium, the MIR (**Figure 8**) requires a larger volume than gas balloons for the same payload. But, in turn, it is a zero-pressure balloon and so the stress applied on the material is weak. The MIR is thus a robust balloon whose duration is limited only by the capacity to fly over very low-emitting, high-altitude clouds. In its present design of 45 000 m^3 volume, the MIR available at CNES in France can carry a payload of 60 kg for several weeks around the world. It has been flown successfully for more than 2 months in the tropics and for up to 3 weeks in the Arctic in the winter and spring, where the limitation comes more from the restriction of flights to north of



(A) (B) (C)

Figure 8 (A) Test flight of MIR 5600 m^3 prototype in the early 1980s at Pretoria, South Africa. © CNES. (B) Release of an aluminized 45 000 m^3 MIR at Kiruna in February 2000 for studying ozone depletion in the winter Arctic stratosphere. After 18 days the flight was terminated and the payload recovered in Russia. © CNES. (C) Release of an aluminized 45 000 m^3 MIR in Brazil in February 2001. The balloon flew for 34 days and two circumnavigations over the tropics before recovery in northern Argentina. © CNES.

55° N for air safety reasons, than from adverse meteorology.

Taking advantage of the diurnal change of altitude from 18–20 km during night-time to 27–28 km during the day, a number of atmospheric observations could be performed, ranging from passive or active remote sensing by solar occultation or lidar to profiling *in situ* by a variety of techniques. In its current design, the MIR is fully operational. However, further tests of thinner and lighter balloon material are in progress for extending the duration of flight. When successful, and together with new, powerful low-orbit satellite transmissions, it will be a unique tool for combining *in-situ* and remote measurements for studying several processes of importance at work in the global stratosphere and climate.

Planetary Ballooning

Though the composition of their atmospheres is different to that of the Earth, several planets in the solar system could also be explored by balloon systems. Of particular interest are those totally covered by clouds and thus where the surface is invisible from space, such as Venus and Titan. But this could apply also to the study of the meteorology and the surface of Mars, where a balloon could help observe a variety of landscapes with a single station. Several concepts have been studied in the past and sometimes fully developed and tested in France, the USA, and the Soviet Union. Among them, the most advanced space mission projects were a heavy, 10 m diameter Kevlar cloth super-pressure balloon for Venus and a thin, 6 μm super-pressure balloon for Mars landing at night and dragging a long instrumented guide-rope on the surface. Unfortunately and for various technical and programmatic reasons, they have been all cancelled but one: a highly successful Teflon balloon designed and flown by the Russian Institute for Cosmic Research (IKI) in the atmosphere of Venus during the Russian–US–French VEGA mission in 1985. Teflon was chosen instead of polyester because of the presence of sulfuric acid clouds in the Venusian atmosphere, resulting in a new concept of sealed, super-pressurized, and slowly expandable balloon. Injected on the night side of the planet at 53 km, in the high-altitude 4-day circulation, the balloon performed beautifully for 48 hours as expected, allowing the observation of pressure, wind, and temperature change along a night–day transition and for the full following day. Though this success still remains unique, several concepts of zero-pressure, super-pressure, and Montgolfier autonomous systems, named Aerobots for Robotic Balloons, continue under study in the USA and France, for further planetary exploration missions.

See also

Observation Platforms: Buoys; Kites; Rockets. **Observations for Chemistry (*In Situ*):** Ozone Sondes; Water Vapor Sondes. **Radiosondes**.

Further Reading

Details on balloon national programs can be found at ballon.cnes.fr:8180 for France, www.wff.nasa.gov/~code820 for the US, www.isas.ac.jp/info/balloon-e3.html for Japan, www.dan.sp-agency.ca/ for Canada, www.rocketrange.no for Norway, www.ssc.se/ for Sweden, and www.das.inpe.br/slb/ for Brazil.

Descriptions of most recent balloon systems and test flight results could be found in the series of proceedings of the biennial symposia on European Rocket and Balloon Programs and Related Research (European Space Agency Publication Division, ESTEC, Noordwijk, The Netherlands).

Buoys

J M Hemsley, National Data Buoy Center, Stennis Space Center, MS, USA

Introduction

The need to collect real-time meteorological data to be used in forecasting is commonly accepted as important to the protection of life and property. Indeed, one can find observers or packages of automated instruments tasked with collection of meteorological data spread, often densely, across many countries of the world. Unfortunately, the world's oceans are much less densely populated with observing systems. It is difficult to acquire meteorological data at sea. Observers aboard ships are sometimes too busy to take observations when they are most needed. Satellite sensors can be foiled by clouds. The best solution for collecting data at sea is from buoys, either moored or drifting. This article will discuss the types of buoys often used,