Preface to second draft

The understanding of the atmosphere has improved significantly in the last few decades. Research balloons have made a major contribution to this progress, particularly in the areas of atmospheric chemistry and dynamics. In Europe, the CNES research balloon programme has led the way in operations and in technological development. Recently, a number of new factors have come into play which will have a great influence on the future uses of research balloons. First, increased safety concerns have resulted in tighter constraints on flight operations, particularly with respect to where research balloons can fly over. Second, new platforms, most notably unmanned aircraft, have been developed which can be considered as rivals to research balloons in some applications. Third, the scientific rationale for the research continues to evolve with a new generation of important issues emerging as the politically supported research on stratospheric ozone depletion reduces.

It is therefore timely to assess the scientific rationale that will underlie for atmospheric research over the next 5-10 years and to define the likely role for research balloons. This is done in the context of the history of research balloon use and development described in Chapter 1. The general scientific issues (and the links between them) that will be important for the next five years are discussed in Chapter 2. The role of research balloons in addressing these issues is described in Chapter 3, as well as a discussion of what unique capabilities the different types of research balloons can offer. Finally some thoughts are presented about the future balloon programme in Europe with specific ideas about scientific foci, technological developments and their operational requirements. These ideas will be developed during the discussion of this draft and during the CNES Balloon Workshop in Pau in September 2008.

In order to help prepare this draft, contributions were solicited from the atmospheric balloon community. These contributions are available on the CNES website. They are listed in an Annex in the second and subsequent drafts. In general these contributions were related to specific proposals and projects that are too detailed for consideration here. We have tried to draw out the underlying themes that connect these contributions.

All comments on this second draft are welcome. It is important to check that the comments and suggestions received about the first draft have been fairly dealt with. Not all comments could be included, but all have been carefully considered. Specific comments / requests are highlighted in the draft. In addition, greater consistency in the use of references will be needed. Suggestions for figures are welcome – the final selection will be made after the Pau workshop. A list of acronyms will be prepared.

Please send comments and suggested text using the page and line numbers. Please do ***not*** *use tracked changes or comments inserted in documents.*

It is extremely helpful if written comments can be provided during or after the workshop (deadline Mon 29th Sept.). A final version will be prepared after the workshop to take into account the discussions that take place

Please distribute this draft to all those interested in the future balloon programme.

1. Historic view (and lessons learnt / applicable)

Ever since the pioneering efforts of the Montgolfier brothers, French engineers and scientists have played a leading role in the development of balloons. Sounding balloons were developed by Teisserenc de Bort who launched them in 1898 from Trappes to make the first measurements in the stratosphere. Modern scientific ballooning in Europe started with Jacques Blamont in 1961 who used balloons to make high altitude spectroscopic observations in the UV and IR with the objective of astronomical, solar and ionospheric studies. Manufactured in the laboratory, they were first launched from Trappes in the Paris suburbs and then from Aire-sur-l'Adour in 1965 when the launch activity was transferred from CNRS to CNES. Atmospheric studies were also conducted using constant level, superpressure balloons developed by V. Lally in the US. The priority in this period was the study of the meteorology of the Southern Hemisphere. For example, 400 BPS (Ballon Pressuré Stratosphèrique) balloons were flown at 200 hPa in 1971-72 in the EOLE project with a dedicated satellite controlling the balloons, the ancestor of the ARGOS system. Larger constant pressure balloons were launched from Christchurch in New Zealand and Pretoria in South Africa to study the temperature and the dynamics at 100 hPa in and around the polar vortex. At the same time US scientists performed flights with larger superpressure balloons at 50, 30 and even 18 hPa with a maximum flight duration of 212 days. Launches of isentropic balloons were carried from Pretoria and Kourou in Guyana which showed the fast meridional exchange between the tropics and the mid-latitudes at altitudes near 380-400 K.

Chemistry studies using stratospheric balloon started in the early 1970s prompted by the discovery of the NOx catalytic cycle and the possible impact of the French-British Concorde supersonic aircraft on the ozone layer. The priority was the measurement of nitrogen oxides (NOx) by a number of recently developed instruments flown on 50,000-100,000 m^3 volume BSO (Ballon Stratospheric Ouvert) developed by CNES in France and NSBF in the US. The large differences between individual NOx observations, partly due to their diurnal cycle, led to the Balloon Intercomparison Campaign (BIC) in 1981-83 with simultaneous measurements on the same gondola under 400,000 m^3 balloons. BIC was supported by NASA and for the first time by the European Commission. The effort was continued in 1983-85 in France during the MAP-GLOBUS campaigns at the CNES range in Aire-sur-l'Adour. Many new instruments were developed in this period, and the CNES balloon range was quite busy with an average of 30 flights every year of payloads between 100 and 500 kg including a few flights for astronomy and solar observations from Aire-sur-l'Adour in spring and autumn and Gap in summer. In parallel, a number of new balloons were developed by CNES in close cooperation with scientists. These included the Capsphere and Meduse balloons, larger isentropic systems, high altitude tethered balloons, solar balloons, and combined BSO and superpressure balloons, many of which were flown from Kourou or Pretoria. Of these developments, only the Montgolfier Infrared balloon (MIR) survived to be used as a core CNES vehicle alongside BPS and BSO balloons.

From these beginnings, atmospheric research balloons have been used primarily in (a) campaigns which have been organised to investigate specific scientific issues; (b) regular, relatively frequent flights to observe the trends in atmospheric composition; and (c) satellite instrument validation. These are now considered in turn.

Scientific Campaigns

The discovery of the Antarctic Ozone Hole led to an international effort, with a major European component, to investigate whether an Arctic Ozone Hole might occur. The response included a great effort by CNES to develop systems capable of flights at low surface and stratospheric temperatures. The first attempts were principally Franco-German collaborations. They took place at Esrange in Kiruna, Sweden with the CHEOPS I and II campaigns in 1987 (2 flights) and 1988 (7 flights). However problems were encountered due to the low temperatures. These problems were solved by CNES the following year in the TECHNOPS campaign (four flights) using a new material tested at low temperature and improved in-flight control. This success led first to the CHEOPS 3 campaign (eleven flights) in Esrange in 1990, and then to a series of European ozone campaigns over the following 10 years.

Forty nine flights were made from Esrange during EASOE in 1991-92, among them 14 of the new smaller, more easily launched balloons (5,000 and 10,000m^3). The aim of these smaller balloons was to allow frequent flights at relatively low cost needed for capturing the high variability of the atmosphere. EASOE was followed in 1994-95 by SESAME for studying the impact of Arctic ozone loss on mid-latitudes. In total, 52 balloon flights were launched in the Arctic from Esrange and Andoya and at mid-latitude in Aire sur l'Adour, Gap, and Leon in Spain. In 1997 a French-Japanese-German campaign of 20 flights for validating the ILAS-ADEOS measurements was held in Esrange where for the first time 2 MIR were flown for 20 and 22 days flights circumnavigating in the Polar vortex. Finally, the major European campaigns looking at Arctic ozone loss concluded with the THESEO campaign (18 flights) in 1998/99, followed in 1999/2000 by SOLVE-THESEO-2000 (31 flights) in collaboration with NASA involving BSO, small and long duration balloons, and several aircraft.

The scientific recognition that the processes leading to polar ozone depletion couple chemical and dynamical phenomena in an intricate way was the main motivation for the Stratéole project in the mid 90's. In particular, the project was designed to address the problem of how the exchange of air masses between the high and mid latitudes could vary with altitude in the lower stratosphere. In contrast with the Arctic campaigns, for which the emphasis was put on chemical processes and which essentially used large balloons with heavily instrumented payloads, Stratéole needed balloons that could both stay in flight for several weeks and be good tracers of atmospheric motions. These requirements were only compatible with the use of superpressure balloons, and the development of such balloons able to fly in the stratosphere (i.e., larger than those used by CNES in the 1970s in the troposphere) was a major technological challenge. The development took several years and several technological campaigns (Equator 1998, Sweden 1999-2002), and CNES teams succeeded in designing a line of stratospheric superpressure balloons with (a) a much lower failure rate in flight than those developed in the US in the 70's, and (b) the ability to fly in the severe conditions encountered in the winter polar stratosphere. The results are described in the section on Recent Evolution.

Following the substantial progress made in understanding polar ozone depletion during the European Arctic campaigns, scientific interest shifted largely to the tropics which is where air enters the stratosphere. The tropical atmosphere is thus critical in determining the composition of the stratosphere, and understanding the processes in detail with the goal to improve the quality of the predictions of how the stratosphere will be affected by climate change.

The first "small balloon" campaign in the tropics was carried by SA and CNES in cooperation with the University of the State of Sao Paulo in Bauru in 1997. The success of this first attempt led to three campaigns in Bauru in 2000-01, 2003 and 2004 in the European project HIBISCUS. In total, 14 small balloons, 8 MIRs (7-71 days durations) and 8 BPSs (10-80 days) were flown leading to a number of important new results regarding the impact of convection.

After several years looking for a suitable tropical base for large balloons, the first campaigns took place in Teresina, at 5°, in NE Brazil, in Nov./Dec. 2004 (2 flights) and June/July 2005 (9 flights), followed by a third campaign in May/June 2008 (7 flights).

Another use of balloons is the study of dynamics and chemistry of the boundary layer for which several platforms have been developed by the CNES since the mid-70s. A version of superpressure balloons adapted to long flights in the tropical marine boundary layer (Ballons Pressurisés Couche Limite or BPCL) was developed which carryied an Argos transmitter, pressure, temperature and moisture devices, were used during the MONEX BALSAMINE experiment to study the monsoon in the Indian Ocean (Reverdin and Sommeria 1983). BPCL have been used to measure turbulence, diffusion and transport properties of different chemical species, in particular over urban areas (see Businger et al. 1996 for a review). These balloons have a life expectancy of a few hours and require a local receiver system. These balloons, used for ~50 years (Angell et al, 1960), fly in various configurations, and were successfully operated by the CNES and French laboratories in recent field experiments such as:

- PYREX in 1990 to characterize the streamlines above and around the Pyrenees;
- SOFIA/ASTEX in 1992 to document the wake of an island in the Azores archipelago;
- ETEX in 1994 to validate trace species transport models;
- MAP in 1999 to document the flow in an Alpine area;
- INDOEX in 1999 to investigate the Indian ocean;
- ESCOMPTE in 2000 and 2001 to follow the sea-breeze circulations and the Lagrangian evolution of the ozone concentration in the pollution plumes; and
- CERES in 2005 to monitor the air mass evolution in a Lagrangian experiment of the carbon dioxide concentration monitoring at the regional scale;
- AMMA to study cyclogenesis in 2006; and
- VASCO in 2007

During VASCO, the new Aeroclipper system (Duvel et al. 2008) was also successfully tested. This kind of balloon is able to do measurements at the air-sea interface during long flights in the open oceans. The unique feature of this system is also its ability to converge into cyclone eye and then to perform long duration measurements into the eye, even after the transformation of the cyclone in an extra-tropical disturbance.

Regular measurements

Regular observations by smaller groups of scientists have been an important component of the overall programme of balloon-borne observations. Most notably in Europe, a long data set on stratospheric trace gas observations has been made using CNES-launched balloons since the late 1970s. These measurements were started at the FZ Jülich and are now being continued at the University of Frankfurt. These regular long-term measurements of the concentrations of chlorofluorocarbons and other long-lived gases in the stratosphere have been used to assess the long-term evolution and variability of the stratosphere, including the speed of the stratospheric circulation (e.g. Schmidt and Khedim, 1991, Engel et al., 1998, Engel et al., 2002, Engel et al., 2003, Rohs et al., 2006). Other European measurement records started in the early 1990s and there are now time series for species such as O_3, NO_2, H_2O, aerosols, BrO as well as chlorine and nitrogen species.

An alternative operational approach has been carried out in the USA by the University of Wyoming (UW). Their approximately monthly balloon-borne measurements began in the early 1970s using small (~15 kg, since increased) aerosol instruments. The relatively small size of their instruments has permitted fairly easy deployment so that the measurement record from Laramie (~650 flights) has been extended to the Antarctic (~60 flights), Arctic (~20 flights), southern mid-latitudes (12 flights) and now the tropics (6 flights). The scientific productivity from this record is extensive. On their own the measurements characterize the size distributions of stratospheric aerosol: volcanic, background, PSC, and tropical. Together with other measurements they have helped to calibrate/validate satellite and lidar measurements, establish the composition of stratospheric aerosol, understand changes in nitrous oxides and ozone due to volcanic activity, and test microphysical models.

The success of the UW measurement program relies on simple, relatively light-weight instruments which provide directly the kind of detail (size resolved number concentration) that most stratospheric aerosol measurements must derive, and the ability of UW personnel to manage all aspects of a balloon-borne measurement. This has resulted in relatively easy, far field and local deployments of the instruments to the stratosphere. This approach has run counter to the major trends in the community which has been to more complex balloon operations and, in many cases, more complex instruments.

The value of such long term data sets increases with the length of time that they are taken under well constrained conditions. In particular such long time series exist for observations from mid-latitudes and specifically from Aire-sur-l'Adour. Several payloads have now been flown in this manner for shorter periods of up to 15-20 years. However flights at mid-latitude from Aire-sur-l'Adour or Gap have not really been feasible for several years.

Satellite validation

In addition to scientific studies and the development of new instrumentation which could be further used in space, an essential role of the balloons is the validation of satellite measurements, which has been documented in a large number of validation papers. A number of instruments providing data on ozone, chemistry and dynamics were put into orbit since LIMS in 1979: notably SAGE II; HALOE and MLS on UARS; POAM II and III on SPOT satellites; ILAS on ADEOS; GOME on ERS-2; SMR and OSIRIS on ODIN; GOMOS, SCIAMACHY and MIPAS on ENVISAT; MLS, HIRDLS and OMI on AURA; FTS and MAESTRO on ACE; and most recently IASI and GOME-2 on METOP in 2006. A considerable number of balloon flights have been carried for their validation, from mid-latitude in France and Spain, from the Arctic in Kiruna and Andoya and more recently in the subtropics and tropics from Bauru and Teresina in Brazil. Particularly extensive validation programmes with balloons have been initiated and supported by Japanese agencies for ILAS-I and ILAS-II, by CNES for ODIN and by ESA for the chemistry instruments on Envisat. When coupled with a high degree of rigorous planning, balloon-borne measurements have proven invaluable in providing 'ground-truth' for the satellite instrument measurements by investigating systematic biases in the quality of the measurements over a wide altitude range.

Recent evolution

SCOUT-O3 campaigns - entering the tropics

Several campaigns were planned during the EU SCOUT-O3 Integrated Project (2004-2009): small balloons and heavy sondes in Niamey, Africa in collaboration with the AMMA project in 2006; and successive BSO and MIR campaigns originally planned for October-November 2007 in Teresina in Brazil. Problems were encountered with all these campaigns to large degree as a result of evolving operational procedures in CNES and the slow development of collaborations with third parties, coupled to a shortage of information from CNES about these developments.

In Niamey, the light-weight telemetry previously used for the small balloons had been replaced by the older 65 kg heavy system. This resulted in a need to use larger balloons with longer preparation on the field. In addition, flights could only be made with the authorisation of the president of CNES(!). Overall only 6 of the 10 flights planned could be carried in Africa, and most of scientific results came from the "heavy sondes" programme operated by the scientists themselves.

There were large delays in obtaining cooperation and flight authorisations from Brazil, and so the MIR Teresina campaign was shifted to the Seychelles Islands in February 2008. However hardly any scientific results were obtained after the revision of CNES safety rules during the course of the campaign and the failure of newly developed telemetry / remote control systems. This failure is the subject of an on-going CNES review.

The large balloon campaign was successfully completed from Teresina in May/June 2008 (after a delay of 7 months) with 7 flights in a 4 weeks period. Important components of this success have been the CNES balloon profiling capabilities by making use of the QBO winds, the good and fast communication between the operational team and the scientists, and the obvious motivation on the part of the CNES operational team to make this campaign a big success. From the scientific perspective this was a welcome step back towards the flexibility of the operational approach of CNES in the 1990s which was driven by scientific aims. For example three large balloon flights were performed by CNES within 24 hours during the SESAME campaign. The success of the 2008 Teresina campaign proves the potential of this site for doing balloon science in the inner tropics.

VORCORE campaign

In parallel to the SCOUT-O3 campaigns, the Vorcore campaign (first phase of Stratéole) was held in McMurdo, Antarctica, in September/October 2005. 27 superpressure balloons (BPS) were launched and flew in the lower stratosphere at 50 and 70 hPa, depending on the balloon size (respectively 10 and 8.5 m diameter). An overall flight duration of 2 months was achieved, the longest flights lasting for 109 days. More than 150,000 meteorological observations were gathered during the campaign, which enabled an excellent coverage of the stratosphere south of 50°S. The campaign was a real technological success, and opens the door to a renewed use of stratospheric superpressure balloons. Although the scientific objectives had evolved along with our increasing knowledge of stratospheric dynamics and transport since VORCORE's conception, such long-duration superpressure balloons proved to be unique devices able to document with a very high accuracy small- and meso-scale phenomena on wide geographical areas. Vorcore has for instance provided so far unprecedented results on gravity waves above Antarctica and the surrounding ocean, including the description of sporadic extreme events. The scientific success of Vorcore was however compromised by on-going changes to the flight domain which initially extended from the South Pole to 10°N. Three weeks before VORCORE started, CNES decided on safety grounds that the balloons were not allowed to fly north of 50°S which was changed to 40°S as a result of negotiations with civil aviation authorities in Australia, New-Zealand, Argentine, and Chile during the first few weeks of the campaign.

Perspectives

Overall, the scientific opportunities available using CNES balloon capabilities have decreased significantly in recent years. Two main issues connect the problems encountered in recent years. First, the safety rules and flight authorizations have become a real limitation, with the effects of stricter regulations being unnecessarily compounded by an almost complete lack of transparency about the regulations are. This comment applies, to differing degrees, to all types of balloon. Until more is known about the application of the more stringent safety rules, it is impossible to assess what their impact will be on the various parts of the balloon programme. More importantly and of greatest concern to the scientists has been the poor dialogue with CNES management. This has occurred despite the extensive discussion of these issues (e.g. on safety, cost and technological development) and high priority given to them by the CNES balloon audit committee in 2005, the balloon workshop in Paris in late 2005 and finally again at the ESA Symposium on Rocket and Balloon research in 2006. Many balloon scientists have a real anxiety about whether their own interests will remain viable. It is hoped that the balloon workshop in Pau will help restarting contacts between CNES and users, and that clear views on what is still feasible or not can be provided to scientific balloon users.

2. General scientific challenges

As comprehensively described in the 2007 IPCC report, climate is inexorably changing due to the radiative forcing resulting from the rising atmospheric concentrations of greenhouse gases. This climate change, that is basically a surface global warming, appears in an environment that is simultaneously varying due to human activities (deforestation, urbanisation, industrial emissions in the air and in the ocean, etc.). The knowledge and the prediction of these entwined changes requires increasing observation and modelling efforts.

This section gives a short summary of some current scientific challenges with an accent on the chemical composition of the atmosphere. This composition depends on anthropogenic emissions and on natural exchanges with the earth surface (land and ocean). Anthropogenic emissions will be driven by the global economic activity. Natural emissions will change due to variation in global surface temperature and to the evolution of land use, ocean productivity or ocean surface state. The resulting atmospheric concentration of a particular compound in a given region will be also determined by chemical and physical processes (e.g. rain-out, role of cloud formation) eventually controlling its formation and/or its destruction. These complex processes, which may also be perturbed by the climate change, need to be well understood in order to make reliable predictions of our future environment. An efficient observation network is needed in which balloons could be an important component.

Due to the characteristics of the balloon technology, and as a preamble to the remaining of this report, we separate this section into two main topics, one related to the stratosphere, with an emphasis on ozone depletion, and the other to the troposphere. Stratosphere-troposphere links are discussed in both sections. An additional subsection highlights the need for validation of satellite products.

Stratospheric Ozone and Climate Change

Ozone depletion and the consequent increase in surface ultraviolet (UV) radiation has been a matter of major public and societal concern for the past 30 years. Increasing evidence about the causal role of chlorofluorocarbons (CFCs) and other ozone-depleting substances (ODS) led first to national limits on emissions of CFCs in some countries, then to the Montreal Protocol which initially put a cap on future international emissions of ODS and finally to amendments of the Montreal Protocol with a globally agreed phase-out of ODS. Over the years, further amendments have been introduced which extended the agreed phase-out to the hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) which had (respectively) smaller and no potential to deplete ozone. These more recent amendments, particularly the one in 2007, were to a large degree approved to reduce the impact of HCFCs and HFCs on climate change: while better for ozone depletion than the CFCs, HCFCs and HFCs are strong greenhouse gases. In parallel to the increasing recognition of this link between ozone depletion and climate change on the policy side of the Montreal Protocol process, there has been increasing acknowledgement and interest in the important scientific links between them. The emphasis of stratospheric research is gradually shifting away from ozone depletion and toward climate-stratosphere interactions.

Increases in greenhouse gases due to human activity have had a significant effect on the troposphere and stratosphere. In particular there has been a warming of the troposphere, most notably in the tropical upper troposphere and the high latitude lower troposphere, and a cooling in the stratosphere (Figure 1(c)). Figure 1 also shows the contribution of the five main factors responsible for decadal changes in temperatures during the 20th century. These changes have been accompanied by an increase in the tropopause height, with larger changes at higher than at lower latitudes. It is clear that the physical structure of - and balance between - the troposphere and stratosphere is changing.

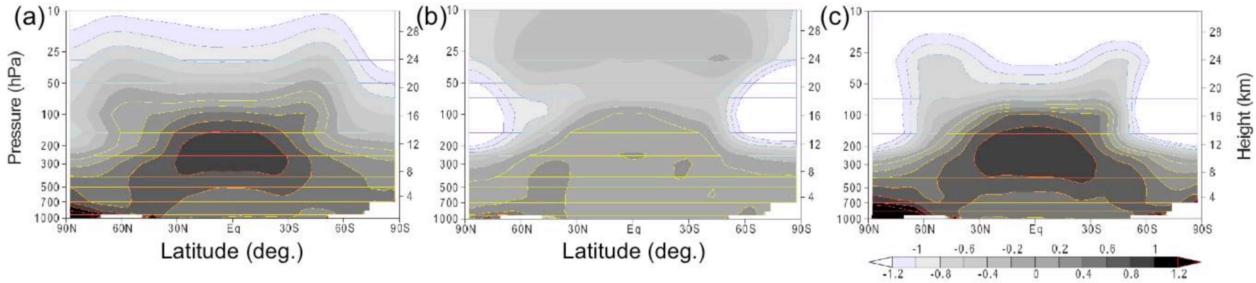


Figure 1. Zonal mean atmospheric temperature change from 1890 to 1999 (°C per century) as simulated by the PCM model from (a) well-mixed greenhouse gases, (b) tropospheric and stratospheric ozone changes and (c) the sum of all forcings including solar cycle, volcanoes and direct aerosol effect. Plot is from 1,000 hPa to 10 hPa (shown on left scale) and from 0 km to 30 km (shown on right). [Derived from IPCC WGI, Chap 9, 2007, based on Santer et al. (2003a).]

These temperature changes are calculated to continue into the future as the strength of the effect of the well-mixed greenhouse gases (Figure 1(a)) increases and as the effect of stratospheric ozone depletion from CFCs (the upper part of Figure 1(b)) diminishes. Calculations by the ensemble of IPCC AR4 climate models show that the contrast between the tropospheric warming (again, particularly in the tropical upper troposphere) and the stratospheric cooling is likely to increase dramatically during the 21st century.

These changes in temperature will be accompanied by significant changes in the composition and meteorology of the troposphere and stratosphere, as well as by changes in anthropogenic and natural emissions. The strong two-way dynamical coupling between the troposphere and the stratosphere is not well understood nor are any likely changes – changes in the stratosphere cannot simply be regarded as passive responses to changes in tropospheric circulation and in composition, but as part of the response of the coupled troposphere-stratosphere system. The input into the stratosphere will be affected by the changes in temperature and humidity. For example the balance between gradual uplift into the stratosphere and fast uplift in intense convection is likely to change and hence change stratospheric composition. One recognised, but poorly quantified mechanism is the transport of very short-lived substances (e.g. $CHBr_3$) from the Earth's surface to the stratosphere. The lifetime of these compounds is such that rapid uplift in convection is the only plausible way in which they can enter the stratosphere in large enough amounts to explain the discrepancy between the observed concentration of stratospheric bromine and the amount which can be attributed to the long-lived bromine-containing compounds. Improved knowledge of strong convection and its effects would have a wider importance as any substance released at the Earth's surface in a convectively active region can thus reach the upper troposphere or lower stratosphere.

Tropospheric processes

Many scientific challenges to understand and predict the earth climate are related to the troposphere, and in particular to the boundary layer. There is indeed a continuous exchange of heat, momentum, water and other gases between the atmosphere and the surface of oceanic and continental regions. Most of the atmospheric water cycle takes place in the troposphere and water has an important impact on radiation exchange between the Earth and space, either as a greenhouse gas, or as liquid/ice droplets in cloud. There are still large uncertainties in the radiative role of cloud in the climate sensitivity.

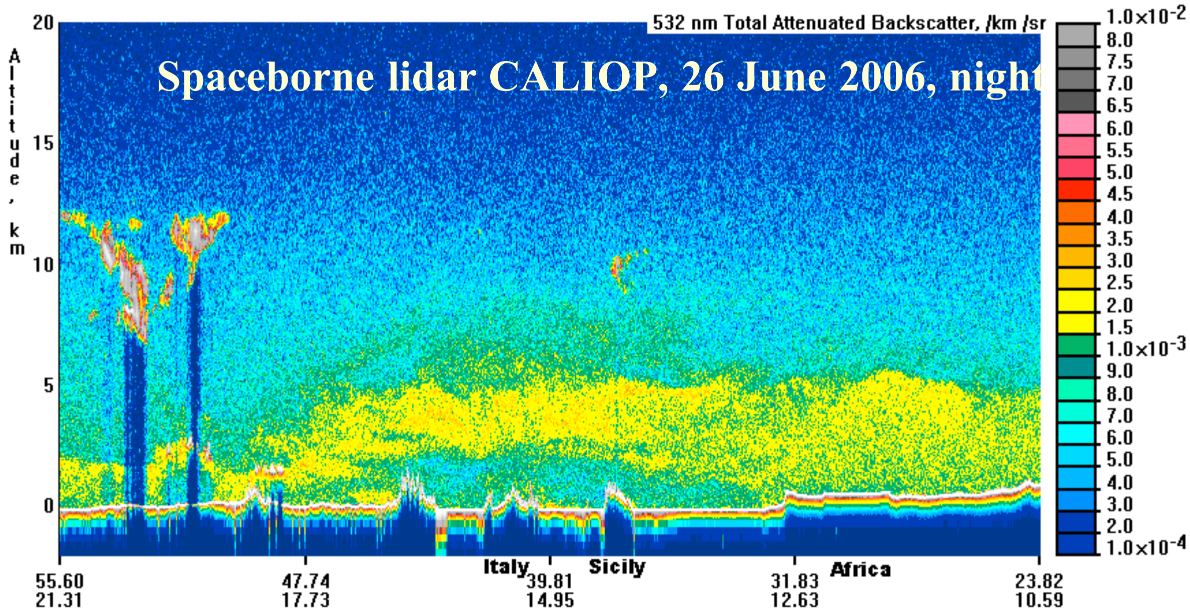
Climate change will also induce changes in the atmospheric circulation and in its variability at different time scales. These changes may give significant increases in the occurrence of extreme events such as heat waves, floods or cyclones. To this end, the different processes which cause the atmospheric fluctuations must be better understood, in particular in the tropics. Indeed, while the synoptic perturbations are relatively well understood and simulated in mid-latitudes, the tropical climate variability is still poorly simulated; especially when ocean-atmosphere coupled models (the model used in climate sensitivity tests) are used.

Major progress is needed if we are to better understand and simulate different aspects of the tropical climate such as monsoons or intraseasonal perturbations (Madden-Julian oscillations). These tropical features are indeed controlling different aspects of the general circulation of the atmosphere and thus the transport of different chemical species. Because of the large oceanic fraction in the tropics (especially near the equator) and of economical problems of some tropical countries, there is a lack of in-situ measurements in the tropical areas. This poor in-situ measurement sampling in the tropics is not totally compensated by satellite instruments, and field campaigns are thus very important to understand the physical processes at the origin of the tropical weather and climate variability. Improvements are also needed in the observation and the forecast of the tropical cyclone track and intensity, and in the evaluation of the impact of climate change on the tropical cyclone activity (including their impact on mid-latitudes after their transformation in extra-tropical disturbances).

As noted above, global change will modify the distribution of the different sources and sinks of different chemical species. In addition, the vertical transport, entrainment and detrainment of these chemical species at various levels in convective clouds are also sources of uncertainties in the knowledge and the simulation of their distribution. The effect of long-range (continental and inter-continental scales) transport of pollutants on the atmospheric composition of a particular region remains an important scientific and political issue. Conceptually the primary processes are well understood, but the quantification remains poor. The extent of such long-range transport depends on the vertical transport out of the boundary layer and into the upper troposphere. For this process, an eventual change in the distribution and the intensity of the convective activity in relation to global climate change could be important. Conversely, the transport of ozone from the stratosphere to the troposphere at higher latitudes remains one of the major uncertainties in the current and future budget of tropospheric ozone.

Many programmes are devoted to the forecast of the air-quality. These forecasts are based on physico-chemical models that need to be evaluated and improved by using Lagrangian measurements of the atmospheric composition. The chemical evolution of polluted plumes during transport, the exchange between the boundary layer and the free troposphere, and the coupling between atmospheric chemistry and radiation are all still need of further study. For example, better understanding and quantification of the radiative heating of turbid layers and other processes could help explain the formation and long-range transport of relatively thin pollution layers observed in the free troposphere. The picture below is an illustration of a dust layer, captured by the spaceborne lidar Caliop, travelling from North Africa over the Mediterranean, and climbing above the marine boundary layer. Quasi-Lagrangian balloons, flying in and/or below the dust layer, and equipped to document the thermodynamics and aerosol characteristics of this layer, are probably among the best tools to help to characterize the impact at the regional scale of such phenomena

The fluxes of gases and radiation between the Earth's surface and the boundary layer are critically important for the hydrological cycle and for the physical and chemical structure of the atmosphere. While these fluxes have been extensively studied in many parts of the world, there are still significant gaps. For example, conditions before during and after severe storms, particularly over the oceans, are not well characterised, a situation which is not helped by the relative scarcity of routine meteorological measurements over the oceans. In the tropics, the perturbation of air-sea flux of water and heat by deep convective events are very important for a correct simulation of monsoon variability.



N-S vertical cross-section over the Mediterranean and North-Africa of a dust layer episode, as measured by the spaceborne lidar Caliop. The dust layer is characterized by the yellow areas.

The cumulative effect of a large number of small- and meso-scale meteorological phenomena on the global atmosphere can be large – and is certainly not well quantified. Moreover, these phenomena will be influenced by climate change and so their frequency and/or strength may well change. Among these processes, deep convection in the tropics has a significant role in determining the stratospheric composition. In addition, lofting of air from the ground to the upper troposphere is an important process in determining the amount of air pollution which is transported on inter-continental scales.

Another such phenomenon is mesoscale waves, so called gravity waves. Such waves, generated in the troposphere, play an important role in determining the atmospheric circulation and temperature in the stratosphere and mesosphere, and significantly contribute to the driving of global-scale oscillations, like the quasi-biennial oscillation (QBO). They are furthermore implied in the formation of Polar Stratospheric Clouds (PSCs) above mountain ridges during winter. Their impact on the global middle atmosphere circulation is expected to vary with climate change, especially because their propagation from the troposphere to higher altitudes is very dependent on temperature and wind gradients in the atmosphere. Estimating the effect of gravity waves on the global atmosphere is quite challenging, as these phenomena are very sporadic in time and heterogeneously distributed in space. These characteristics are nevertheless essential when one wants to assess how gravity waves drive the general middle atmosphere circulation, for steady and homogeneous sources will not produce the same atmospheric response than intermittent and scattered ones.

While the meteorological aspects of these mesoscale events have often been intensively studied, there are many aspects which are not well understood, one of which is their global impact on the transport of trace species. Furthermore, because of their small scales, these processes are parameterized in global circulation models used to perform climatic runs, and constitute major sources of uncertainty in our prediction of the future climate. Assessing their global effect and how it could change in the future therefore demands further and better observations to validate and improve the current parameterizations.

Satellite instruments

Using satellites is the only approach to obtain global homogeneous measurements of different properties of the Earth system. However, satellite measurements are always indirect (conversion between radiances and different physical variables) and require sophisticated processing algorithms based on physical relations and careful absolute calibration or calibration using statistical relations. These algorithms and the reliability of the calibration need thus to be validated for various locations and atmospheric conditions.

A number of satellite instruments making measurements of the stratosphere and UTLS will be operational for the next few years. ENVISAT, ODIN and Aura are currently planned to remain active until around 2012-13, after which satellite coverage of the stratosphere will decrease significantly. As a result, continued validation will be required during the next few years, after which non-satellite systems will be more important in the year-to-year observation of the stratosphere. Observing the effect of climate change on the stratosphere for the next 10-20 years will thus depend principally on non-satellite platforms unless new satellite programmes are decided quickly. Those satellite instruments which are already launched or planned (e.g. EUMETSAT's Meteosat series and possibly ESA Sentinel) will (a) require additional validation; and (b) offer opportunities for associated scientific research projects to be developed. One such example is the study of sprites in conjunction with the TARANIS satellite. In addition, new satellite instruments devoted to the observation of the troposphere, such as Megha-Tropiques or ADM-Aeolus, will be launched in the years to come and will require in situ validation measurements.

3. The role of the balloons (5pp)

Balloons are one of many platforms (satellites, aircraft, ground stations, ships) available for making measurements of the atmosphere. These other platforms are in some senses rivals to balloons, a fact that is important to remember in planning for the future. In particular, there have been great advances in the development of unmanned aircraft and these are becoming increasingly available for atmospheric research. At the same time, technological advances are allowing major advances in the design of the instruments used to make atmospheric measurements with the result that instruments can be made lighter or have greater capabilities.

Overall there is a societal need to study the atmosphere in the most suitable and most cost efficient way. As a result balloons should be considered as part of a broad observational suite of platforms, and it is essential here to identify a unique role for balloons which is complementary to other approaches. Improved understanding of long-term changes (natural variability and sustained trends) is a critical issue and cost efficiency of making the observations will be an important factor in determining how the necessary studies are performed. In parallel the accelerating move to the use of highly complex Earth System Models means that more integrated measurement strategies will be needed.

In this section the special characteristics of the various types of balloon are highlighted along with the implications for the types of studies (including launch strategies and balloon types) that should involve research balloons.

Boundary layer and lower troposphere

Short duration pressurized balloons equipped with local transmission systems are very useful to follow air parcels along quasi-Lagrangian trajectories in the boundary layer. This is a unique feature of balloons that makes it possible to evaluate and improve the representation of physico-chemical process in numerical models designed to forecast, for example, air quality in or in the vicinity of large urban areas. These balloons can thus complement other field experiments by giving information on the transport and the evolution of different chemical species. The main advantage of these balloons compared to unmanned aircraft is the ability to do these quasi-Lagrangian measurements and to follow the evolution of an air parcel. In addition, these balloons are relatively cheap and it is thus possible to launch a relatively large amount of balloons in order to well sample some particular events. Developments of new small sensors for probing various chemical species or aerosols, which is occurring in other fields, would be a great benefi.

Very light gondolas are currently under development (Nano at CNES, Wisdom balloons in the US). These payloads are currently developed to report only wind vectors and can last up to 15 days. The transmission system is also local, but with a possibility to use each payload as a transmitter for the other balloons (each balloon is a node of a network). These very small balloons could be used in clusters of tens to hundreds devices. This is a new and promising approach to study the dynamics of meso- to synoptic-scale systems and the transport of chemical species in these systems. This could be especially useful to probe mesoscale convective systems and cyclones in regions where no radar data exist.

For long lasting balloons equipped with satellite transmission, the role is mainly to probe the low-level circulation over remote oceanic areas. For these balloons however, the density of the balloon changes during the flight as a result of helium leaks, envelope stretch or diurnal solar heating. Further, water-loading forces resulting from condensation and rain can modify the mass, and thus the flight level of the balloon. Sometimes, this forces the balloon down to the sea surface where the atmospheric sensors are damaged. Long duration pressurized balloons measurements in the boundary layer are thus difficult to obtain and exploit because of these uncontrolled altitude changes. Recently, National Oceanic and Atmospheric Administration (NOAA) Air Resources

Laboratory Field Research Division (ARLFRD) made an improvement by controlling the balloon altitude using adjustable air ballast into the balloons. This concept was validated by a flight of 12 days above the North Atlantic during the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) field experiment held in the summer of 2004 (Businger et al. 2006). Evolution toward a full control of the altitude is needed. Evolution for flight rather in the middle troposphere could be useful. To be more useful, development of new small sensors for probing various chemical species or aerosols is also requested (as for short duration BL balloons above). If successful, these balloons give unique continuous measurements in regions of the open ocean where no other in situ measurement exists. Equivalent aircraft measurements are likely to be more expensive, and they do not give measurements for quasi-Lagrangian trajectories. These balloons could be used to validate wind estimates of the ADM-Aeolus mission.

The new Aeroclipper system (Duvel et al. 2008) is a device designed to perform relatively long flights (of up to 30 days) in the surface layer (under 50 m) over remote ocean regions. As such it gives unique measurements at the air-sea interface in remote oceanic regions, in particular near and under convective systems. The Aeroclipper is a streamlined balloon vertically stabilized by a guide rope. The guide rope keeps the balloon close to the surface and prevents the instrument gondola from dropping into the ocean in case of rain or condensation loading. The Aeroclipper may be equipped with an atmospheric and an oceanic gondola giving estimates of surface parameters and of the turbulent fluxes at the interface. The Aeroclipper is naturally attracted in low-level convergence generated by large tropical convective systems and thus improves the measurement sampling around and under these features. During the VASCO experiment (January 2007), two Aeroclippers launched from the Mahé Island converged into tropical cyclone Dora and remained within the eye of the cyclone the following days. Continuous measurements of various surface parameters including the surface pressure made in the eye of a cyclone reveal its evolution and intensity. Near real-time transmission is a new and unique capability of the Aeroclipper for cyclone nowcasting by providing input data for assimilation in operational cyclone forecast models. Moreover, surface pressure measurements taken in the eye could validate and improve the accuracy of the Dvorak technique which estimates cyclone intensity from satellite pictures; (e.g. Velden et al. 2006). The Aeroclipper development should be completed and its ability to track cyclone intensity proven. Evolution for other measurements including chemical species, aerosols, radiative fluxes, precipitation must be considered. A lighter version of the Aeroclipper should also be studied.

Long duration in UTLS and above

In the past ten years or so, CNES was the only institution which flew long-duration balloons (other than BSO) in the stratosphere. The experience of CNES teams in the development and use of such balloons is therefore really unique.

Long-duration balloons (i.e., flights that can last for a few weeks to a few months) first offer an access to remote areas that can hardly be sampled by any other ground-based instruments or even airborne platforms. Each long-duration flight also provides a wide geographical coverage, which allows the instruments to sample various meteorological situations or fly over various terrains. This last aspect renders the long-duration balloons very similar to satellites (for a significantly smaller cost), and distinguishes them from any other terrestrial platform. The measurements made during such long-duration flights are therefore well suited for documenting the variability of stratospheric phenomena or chemical composition, and can also help to assess the impact of “localized” processes (like for instance continental convection or mountain waves) on the global atmosphere.

There are currently two types of stratospheric balloons available for long-duration flights (MIR and BPS), with different capabilities and constraints. MIRs fly at 25 km during day and 18-20 km during night, and can carry weights of about 50 kg. MIR flights can last for several weeks, and generally terminate when the balloons encounter low upgoing infrared fluxes (like high clouds in the tropics). The vertical excursions during day-night transition performed by the MIR have been used to document the vertical distribution of chemical species (water vapour, ozone, nitrogen dioxide) in the lower stratosphere, and their evolution with time. In particular MIRs were used in the recent years in the EU-sponsored projects LAGRANGIAN (in the Arctic) to study mechanisms involved in ozone depletion, and HIBISCUS and SCOUT (in the southern tropics) to document the impact of tropical convection on the composition of the lower stratosphere.

In contrast, BPSs perform flights on constant-density surfaces in the lower stratosphere (80-50 hPa depending on the balloon size). This feature is important in dynamical studies, as the balloon behaviour is known and can be taken into account during data analysis. BPS flights can last for several months. Moreover, on time-scales of days (and even longer when the activity of planetary waves is reduced), BPS behave as quasi-Lagragian devices. BPSs were developed in the framework of the CNES-funded Stratéole project to document the dynamics and transport inside the wintertime vortices, and the exchange of air through the vortex edge. BPSs have also been used in the HIBISCUS project, as well as during the French-EU AMMA initiative to help assessing the impact of the African Monsoon on the cyclogenesis in the tropical Atlantic.

Long-duration MIR and BPS balloons are smaller than BSO, and consequently require only modest infrastructures on the ground to be launched. The issue of payload recovery is also less stringent than for BSO. They thus generally offer some versatility in launching sites, as well as in the time periods when they can be launched, and they were historically launched from a large number of places (e.g. Pretoria in South Africa, Latacunga in Ecuador, Bauru in Brazil, McMurdo in Antarctica). On the other hand, their small sizes impose strong constraints on the scientific instruments, which have to be light and low power consumers, as the energy available onboard is limited. These requirements restricted the number of instruments that were able to fly under these balloons, but the miniaturization of electronics and sensors has recently enabled further payloads (including e.g. lidars) to be involved in long-duration flights. This trend should continue in the near future, in particular with the expected development of a renewable energy module by CNES, which will extend the duration of flights, as well as with the availability of larger BPSs (12-m diameter) that can carry payloads with similar weight to those flown under MIRs. Recently Iridium-based communication during long-duration flights has greatly increased the amount of data that can be sent to ground and allowed some control during flight.

In principle it is possible to use BSO balloons on long duration. This approach would have the advantage of carrying payloads of similar weight (maybe 50-200kg) to the instruments currently deployed on large balloons. A number of scientists have expressed interest in examining their feasibility, and this does seem to be an avenue which is worth exploring. Like BPSs, they are most suited to carrying remote-sensing instruments which can measure vertical profiles of trace species at altitudes below them.

Last, all long-duration stratospheric balloons raise specific issues in terms of safety, policy and coordination with aviation authorities, since the flights are not restricted to one country and may cross populated areas. It is vital for the future development of long-duration ballooning activities that a reasonable and long-lasting agreement between CNES and scientists could be found in such issues, since the setting of new campaigns will be otherwise subject of too many uncertainties.

In the future, long-duration balloons will be essential to address the following issues:

Dynamics

The Vorcore campaign has shown that BPSs are unique devices to characterize mesoscale dynamical processes in the lower stratosphere, and to diagnose their impact at global scale. The current largest uncertainty on these processes is located in the deep tropics, where gravity waves generated by convection are still poorly known. Yet, these waves are expected to provide a major contribution to the driving of the QBO, which is ill represented in most general circulation models although it is one of the major climatic oscillations. The ability of BPSs to sample both oceanic and continental convection is a unique advantage of these balloons in such studies. There is a real paucity of dynamical observations in the deep tropics whose effect is enhanced by the fact that the geostrophic balance can no longer be used at low latitudes to infer winds from spaceborne observations of atmospheric radiance. There are thus some concerns on the accuracy of the winds simulated by operational models in that region, although they are routinely used to diagnose the transport (and dehydration) of air in the TTL.

Interaction between dynamics and microphysics or chemistry

The progressive development of new payloads for long-duration flights in the stratosphere will allow the use of these balloons to address scientific issues where dynamics impacts the chemistry of the UTLS (through the transport of chemical species), or provide modulate the formation of clouds. For instance, in the tropics, the ascending rate of the Brewer Dobson circulation and its effect on the global budget of ozone can be deduced from the measurement of stratospheric trace gas species onboard MIRs. On the other hand, one can take advantage of the quasi-Lagragian behaviour of BPSs to study the evolution of the chemical composition of air parcels, as will be done during the Concordiasi project (McMurdo, 2009) where ozone measurements will be made onboard BPS. Close to the Equator, the recent field campaigns have stressed the importance of deep convection in troposphere-stratosphere transport, whereas modelling studies generally consider that slow upwelling is the main mechanism. New information on the relative contribution of both processes to the ventilation of the global TTL can be provided by ozone and water vapour observations during tropical BPS flights. Associated measurements of particles (like those that will be undertaken during Concordiasi) will help to assess the role played by planetary and gravity waves in the formation of PSCs (in the polar stratosphere) and cirrus clouds (in the tropics).

Assimilation and satellite validation

The fact that long-duration balloons provide wide geographical coverage can be further exploited in the future. First, the observations collected during those flights can be placed in near real time on the GTS and serve to feed operational models with observations on otherwise poorly sampled places. Such an approach has already been attempted during AMMA, where some of the dropsondes ejected from the flight trains have been used for data assimilation. This approach can be generalized to the routine observations performed during the long-duration flights (like the in-situ meteorological measurements), especially in the deep tropics where the lack of dynamical observations is critical. The wide spatial coverage provided by long-duration balloons can also be favourably used to validate satellite observations, since in this case each flight offers many opportunities to cross the satellite swath. As before, these balloons also provide opportunities to validate satellite observations in very remote and various places, which is a significant advantage when the observed quantities present significant heterogeneities, as is for instance the case of the composition of air or the dynamical variables in the TTL. In particular, long-duration balloons could serve in the near future to validate wind observations that will be provided by the ESA ADM/Aeolus mission.

Large payloads

Although it is somewhat arbitrary to differentiate between large and small balloons we think that there are clear requirements for maintaining the European skills to manage large balloons. The balloon sizes used for large payloads typically range from 35,000 m^3 to 400,000 m^3 (though larger balloons up to more than 1,000,000 m^3 are available). Open stratospheric balloons are used for this purpose allowing flight duration of typically 6 to 20 hours with typical maximum altitudes of between 30 and 40 km. Scientific payloads flown under large balloons are usually composed of sophisticated in-situ or/and remote sensing instruments covering a large number of atmospheric parameters and constituents with high accuracy/precision. Payload masses (including all service modules - gondola, pointing devices, TM/TC equipment, power supply, etc.) are typically between

200 and 700 kg. Several instruments are often combined on one gondola to increase the scientific value that can be derived from simultaneous measurements of a large suite of parameters. Balloon instruments are usually developed and operated by established groups that have extensive experience in all aspects of balloon-based research for many years. Many of the instruments and payloads are unique world-wide.

Large balloons have played a major role in focused large field campaigns over past decades funded by the European Commission, national funding agencies and space agencies. Most activities took place in the 1980s and 1990s linked to the ozone loss discussion, mostly in Arctic regions. Since then, the focus has largely moved to scientific issues connected with dynamics and chemistry in the tropics and adjacent regions. Again driven by the scientific demand, CNES has extended the launching possibilities to allow for measurements in the inner tropics, using large balloons, by opening an additional base in Timon, near Teresina in Brazil with the first launches being performed in 2004. The first full campaign was in 2005 and was for the validation of the Envisat satellite and for the understanding of transport and chemistry in the tropics from the Tropical tropopause layer (TTL) into the middle stratosphere. A further campaign carried out in Teresina in May/June 2008 was completed with great success. Teresina has proven to be an excellent tropical balloon launching site offering stable weather conditions (at least in the dry season) and a great potential for doing boomerang flights of 20 hours and more.

Apart from the large co-ordinated campaigns, regular observations by individual groups have played an important part of the observational strategy. For instance, a long data set on stratospheric trace gas observations has become available from whole air sampling starting in the 1970s, allowing studies of the variability and long-term evolution of certain parameters in the stratosphere (cf. section 1) whose value increases non-linearly with the length of the record. In particular, such long time series exist for observations from mid-latitudes and specifically from Aire-sur-l'Adour.

Apart from the scientifically driven campaigns, large balloons have played a major role in satellite validation for many years (satellites from the US, Japan and Europe) with intensified activities linked to the Japanese satellite instruments ILAS-I/-II, as well as the ESA/EUMETSAT satellites Envisat, GOME and Metop/IASI. Although the statistics are limited with balloon observations, balloon-borne validation has proven very valuable, partly due to their large altitude coverage and partly due to the dedicated balloon profile/measurement programme planning tailored to the satellite overpasses and to sophisticated trajectory mapping for increasing the number of coincidences.

For the future, the availability of large balloons is required for the following issues:

<u>1. Long term trends of trace gases in the stratosphere</u>

Continuation of atmospheric monitoring in a changing climate is critically important in quantifying the chemical evolution (e.g. chlorine and bromine content) of the stratosphere and also for observation of long term dynamical change. For the investigation of the dynamical change the observation of very long lived gases like CO_2 and SF_6 is important: changes in tracer-tracer correlations can also give indications on changes in dynamics. Long-term observations require long-term sites. For Aire-sur-l'Adour and Kiruna such long-term series exists already. The large vertical coverage of balloons is unmatched by any other platform. Of major concern here is that launches from Aire sur l'Adour have become almost impossible in recent years due to more strict safety regulations.

<u>2. Bridging the gap between aircraft and satellite measurements: High quality science with complex instrumentation or with multi-instrument payloads and support to GMES.</u>

Several payloads are capable of measuring many parameters precisely and simultaneously in areas which are not accessible with aircraft. These balloon instruments are generally superior to satellite instruments in terms of accuracy and comprehensiveness of measured parameters. These properties are very useful for a variety of process studies of the atmosphere in a changing climate and for investigating new (unexpected) scientific issues that require fast responses. Both remote sensing and in-situ instruments have their own advantages for studying those scientific issues.

A special class are down looking remote sensing instruments for studying radiative effects connected with global warming. Our understanding of global warming depends on the accuracy with which the atmospheric components that modulate the Earth's radiation budget are known. Many uncertainties still exist e.g. as regards the radiative effect of water in the different spectral regions, the cloud radiative forcing and its connection to the occurrence of natural and man-made aerosols in the terrestrial atmosphere. In this context, an assessment of the atmospheric outgoing flux over wide spectral regions with sufficient resolution and radiometric accuracy obtained from balloon-borne platforms may contribute significantly to a better understanding of the underlying processes of climate change, e.g., by the improvement of radiation codes used in climate models.

<u>3. Satellite validation and integrated approaches to utilize synergies by combining satellite and balloon data.</u>

Balloon observations are unique for satellite validation due to their large altitude coverage. Correlative measurements must be more accurate than the satellite measurements themselves, which is generally fulfilled by the sophisticated instrumentation flown under large balloons instruments. Recently, the lifetime for Envisat has been secured to at least 2012 which calls for the validation of the long-term quality of the satellite measurements, especially with respect to trend studies. IASI and GOME-2 on Metop will be operated in a series of missions over at least the next decade. Future satellite missions such as the SMILES mission (2010 time frame) managed by JAXA/Japan have expressed their interest in balloon-borne validation. Other programmes that could benefit from balloon measurements are Japanese, European and French space missions (particularly the CNES micro-satellite TARANIS) that are designed to explore sprites and blue jets. Generally, future balloon programmes should exceed the pure validation purpose but aim at an integrated approach of combining the mutual strengths of the space and balloon observations towards a synergistic use of these data sets.

<u>4. Proof of concept of new (space-dedicated) instrumentation.</u>

Large balloons provide a measurement platform that is physically similar to a satellite but has the flexibility to be used in shorter time periods with relaxed constraints, less financial investment and a recovered instrument. They provide a good platform for gaining experience with planned satellite instruments and proving their scientific value. Often, these missions are called pathfinder missions. A number of new generation remote sensing instruments are currently under discussion for ESA's Earth Explorer and Sentinel programmes. For several of these possible space-borne instruments, airborne versions are in development at European labs that are planned to be flown under balloons both as pathfinder missions and for scientific objectives.

<u>5. Bridging the gap between satellite missions with the help of longer duration BSOs</u>

Right now, it seems likely that there will be a gap of several years after the Envisat and AURA missions with no satellite instrument in space that is able to address adequately scientific issues connected with the response of the stratosphere to climate change. Such gaps could be filled at least partly with innovative medium-sized balloon instruments operated under open stratospheric balloons capable of flying for days or weeks (as it is done already for astronomical payloads).

Small payloads

Increased demand for smaller balloons with more flexible operations has been evident for the last 20 or so years, and CNES have responded by developing the 5,000 and 10,000 m^3 ZL balloons. However, the potential of these balloons has not been realised in recent years due to the reduction in the CNES' operational flexibility and responsiveness. Recent technological developments have allowed lighter instruments to be produced which can be flown under large weather balloons. To date, these have not been launched by CNES but by small teams of scientists with local support for operations. This approach has resulted in a significantly greater launch flexibility than has been possible with CNES. It is likely that this type of flight will become more popular over time as it has great potential for making a large number of relatively low cost measurements which are suited for studies of interannual and longer term changes as well as studies of specific events (e.g. strong convection) where launch flexibility is required. This approach to balloon operations has been outside CNES's recent experience and area of interest and it will be critical for CNES to decide how they wish to support and be involved in this potentially very fruitful balloon activity. Options include offering such low cost flights at an existing manned base (e.g. Kourou) or in collaboration with a partner organisation in the region of interest (e.g. Bauru). Recent observational plans discussed by scientists include launches in Brazil, Niger, East Africa and India to study mesoscale processes and long-range transport in the UTLS.

4. Future programme (3pp)

This chapter can only really be completed after the Pau workshop. We have deliberately not gone into the level of detail in most of the scientific submissions that were submitted as they are more related to individual projects rather than to programmes as we are trying to address here.

A successful European balloon programme will require several elements to all be in place. The elements include:

a) Strong scientific rationale
b) Reason to use balloons
c) Joint use for science and satellite validation
d) Access to suitable launch sites
e) Efficient launch and flight operations
f) Improved balloon technology to expand the range of scientific opportunities
g) Continued instrument development to use the latest technologies
h) Continued use of reference instruments for consistency in long time series
i) Funding and planning at the European level

These are now considered in turn. *{needs more text here when chapter complete}*

Strong scientific rationale

The most important factor in planning and making atmospheric measurement has to be the scientific rationale. Without that, using balloons becomes flying for flying's sake. In this document we have highlighted a number of the main areas where atmospheric research will be needed over the next 5-10 years.

In the area of stratospheric research, the emphasis is shifting toward understanding how climate change will affect ozone recovery and how it will be modified by the stratosphere. Balloons can be used to study various aspects of this, and it is likely that these measurements will become even more integrated with other measurements e.g. ground and satellite whose broader temporal perspective complements the more detailed information available from balloon instruments. In addition, issues of more focussed measurement campaigns still exist (e.g. convection, sprites) and others will emerge, but there are none as overarching as Arctic ozone depletion was 20 years ago.

The UTLS will remain a region of interest as it is particularly sensitive to changes in climate, especially in the tropics and sub-tropics. The importance of convective transport of chemicals from near the ground or ocean into the UTLS and the exchange of air between the troposphere and stratosphere both remain the subject of much debate. Use of long durations balloons with small sensors measuring dynamical and chemical quantities would be productive.

In the lower atmosphere, balloons are suited to the study of meteorological phenomena such as cyclones which may be sensitive to climate change and to studies of the air/sea interface and fluxes across it. In temperate latitudes, there is an increasing interest on the Mediterranean basin, with several projects under construction, among them at least two could benefit from low-altitude balloon flights: HyMEx, which is focused on the hydrological cycle of this area, with a specific interest in the generation processes of strong rainfall events, and ChArMEx whose interest lies in the budget of reactive species (gases and aerosols) in the area of the basin. Both projects are expected to perform long-term measurements (~2 years) and dedicated short-term campaigns, during which airborne (aircraft and balloon) systems will be deployed.

Reason to use balloons

As already discussed, a number of atmospheric platforms are available to make atmospheric measurements. As a result, scientists will have more options available to them and it will be important for balloon programmes to focus on areas and developments where balloons really offer something special or different. Thus in addition to having a strong scientific rationale, there will have to be clear reasons to use balloons rather than another platform.

For low-altitude (boundary-layer and lower free-troposphere) measurements, drifting balloons present the enormous advantage of giving a field-truth of the airmass trajectories. (In other applications, the lack of control can be a disadvantage and other platforms may be more suitable.) Meso- and regional-scale programmes, like those under construction in the Mediterranean area, are well adapted to the performances of these balloons (a N-S crossing of the Med. basin would last few days). Furthermore, they are able to document fundamental parameters for air-quality concerns, like the (quasi) Lagrangian evolution of the photooxidant pollution, and/or the aerosol characteristics and radiative impact. Similarly , the Aeroclipper is a new and unique tool that is able to do measurements in a cyclone eye for several days and to transmit it in near real time.

For high altitude balloons, three aspects are worth noting: (i) balloons are currently the only platform available for measuring above 20km; (ii) no platform can currently fly as long as MIR or super-pressure balloons and (iii) balloons provide a quieter and less disturbed environment for complex instrumentation than aircraft do (vibrations, inlet problems, etc.).

Joint use for science and satellite validation

Maximising the scientific benefit from balloon flights will require the efficient use of resources and support. At the operational level, satellite validation has been successfully combined with scientific flights for the last decade or so. This has led to improved satellite validation (and presumably satellite data quality) and to a greater scientific return as a result of the additional flights and improved access to satellite data. The mechanism to achieve this is working pretty well and the main requirement is to keep the space agencies and particularly ESA closely involved in the planning of the balloon activities.

Access to suitable launch sites

If the future programme is to be driven by scientific demand, it will be important to maintain access to launch sites at several latitudes and at different times of year. The site at SSC Esrange is the most used for Arctic measurements – meanwhile even used for trans-Atlantic flights - and NSC/ASI are developing the opportunity for long duration, large balloon flights from Svalbard. The mid-latitude sites have hardly been used in recent years, mainly as a result of the changing practical safety constraints. This site is a very important one as it is (a) where the long records have been established; and (b) the easiest for instrument development flights. The conditions governing the flights that can be made from Aire sur l'Adour (and Gap) need to be clarified and carefully considered by scientists so that the future viability is clear. Another mid-latitude site that has been discussed for a long time is Trapani or a site on Sardinia. Those sites could offer flights of about 20-40 hrs over the Mediterranean Sea to Spain in summer or to Turkey in winter. CNES in cooperation with the Italian partner ASI should clarify if this opportunity could be developed into reality and for what types of flight. Finally, there remains considerable interest in making tropical measurements, and so there is still demand for sites in this region. Successful campaigns have been made from Teresina and Bauru in Brazil, and the conditions there are well understood by the scientists involved and by CNES launch team. The two sites have different qualities (latitude, ability to do frequent measurements, ability to handle large balloons, etc). Continued access to these sites will depend on true collaborations being maintained and further developed with Brazilian scientists. Both the recent, good experiences and the scientific possibilities show that it is worthwhile pursuing this cooperation. In parallel, others tropical sites (e.g. Seychelles, Kourou) should be also considered for more flexible, long-duration or boundary layer balloons, which require lighter operations."

Efficient launch and flight operations

The experience of the last few years, with changing safety rules and severe, unknown constraints on flight operations is not at all satisfactory. It is important that there is much greater clarity about what scientists can and cannot expect operationally from the balloon launch teams, and that this clarity exists from an early stage in the planning of balloon activities. This implies that mechanisms to enable closer cooperation and discussion need to be invoked. This will also enable scientists to be kept informed of any problems that arise and to participate in identifying the best responses in both the planning and the operational phases.

Improved balloon technology to expand the range of scientific opportunities

Improvements in available technologies and materials could boost the potential of scientific ballooning. One critical issue is the demand for better control and prediction of the balloon trajectories during flight and during the fast parachute descent. Measures such as guided parachutes or dual-stage parachutes have been considered by CNES for a long time but it is not clear by when or whether these techniques could become operational. Such measures could make flights at Aire sur l'Adour and Gap more feasible. Another example is the recent improvement in power storage technologies (new generation of Lithium batteries) and solar cells as well as satellite communication techniques which together with smart valve/ballasting devices may allow to operate balloons (adapted BSOs or pumpkin-shaped superpressure balloons) for days and weeks even for mid-sized gondolas. The scientific interest in such 'long' duration flights has been expressed in several proposals and appears to become increasingly interesting in view of the upcoming gap of satellite missions addressing the UTLS region after 2013. Representative scientists should have regular input into the development programme in order to ensure that the scientific evaluation of the relative benefits of each system are taken into account by CNES.

Continued instrument development to use the latest technologies

There are many technological developments which offer opportunities to instrumental scientists to make smaller instruments and/or the ability to make better or more measurements. Examples are given in the individual contributions listed in the annex. In addition, balloons are ideal carriers for scientific and technical path-finder missions in preparation of future decided or considered satellite measurements to test those new instruments and to use them for research. Thus, path-finder missions shall be understood as balloon experiments being used to test both instruments and observing methods, either for addressing novel fields or novel approaches.

Continued use of reference instruments for consistency in long time series

Long measurement time series only provide real scientific value if they are internally consistent. This implies either that the instrument involved should not change (hard to achieve in an era of rapidly changing technology) or that the performance of the instruments involved must be well characterised over time. Both approaches require a great deal of diligent work, but this is work which is essential if any changes derived from these long-term records are to be believed.

Funding and planning at the European level

The funding mechanisms available to balloon groups in Europe vary substantially from country to country, and even within countries there are often significantly different structures for universities and for research institutes. Research funding can be somewhat simplistically categorised as (i) 'Blue Skies' research where proposals cover a wide range of topics and which are judged solely on scientific merit and (ii) programmatic research where the overall package of research projects address stated aims which can be scientific, technological or political (e.g. in support of international agreements). For example, in the United Kingdom, the main support comes through NERC whose core funding stream is 'Blue Skies' research for which proposals are judged solely on scientific merit. Scientific programmes form a smaller part of the overall NERC funding and none are directed specifically at balloon research. Conversely in France, there is more active encouragement for balloon-based research through a number of joint CNES – CNRS initiatives. At European level there are possibilities for support through the EC and through ESA, but it has to be noted that the overall EC support for atmospheric research has been declining over the last 10 years and ESA's budget has typically been smaller. However in the past both EC and ESA funding has led to the organisation of European projects. Finally, it is self-evident, but easily forgotten that the attractiveness of balloons as a payload will depend on the cost and flexibility/reliability – flight costs are a large part of any project involving balloons.

The implications for future balloon activities is that the planning stages must include the organisation of financial support, and that this is complicated because of the diversity in funding sources in Europe. The only possible exception to this would be the organisation of small payload activities with their much lower costs and infrastructure requirements. Even here, however, planning and coordination between different countries will be required. The involvement of a pan-European institution (e.g. ESA or the EC) in the planning of future balloon activities would be hugely beneficial, if not essential. This should include improved cooperation between CNES, SSC, ASI and other European balloon facilities so that the users can benefit more fully from the resulting synergies and efficiencies.

Conclusion

A common feature of all the issues described above is the need for early planning of future coordinated balloon activities. The implied need is for a standing committee (with flexible membership) involving scientists and representatives from balloon operations to develop ideas for the campaigns and plans for raising the necessary funding. Without such a planning mechanism, it is hard to see how European campaigns will actually occur given the long lead times involved in taking a scientific idea through to a campaign and eventually analysis and interpretation of the measurements.

Database needed

More following discussions at Pau