THE FUTURE FOR RESEARCH BALLOONS IN EUROPE

Neil Harris[(1)], Hermann Oelhaf[(2)]

[(1)] European Ozone Research Coordinating Unit, Department of Chemistry, University of Cambridge, Lensfield Rd., Cambridge, UK, Email: Neil.Harris@ozone-sec.ch.cam.ac.uk

[(2)] Institut für Meteorologie und Klimaforschung, Karlsruhe Institute of Technology, Email: hermann.oelhaf@imk.fzk.de

ABSTRACT

The European programme of research ballooning is going through a period of reorganisation with changing scientific priorities and operational constraints. The uncertainties arising from revised interpretations of safety guidelines and the resultant poorer communications has led to a reduced number of balloon flights by the CNES (Centre National d'Etudes Spatiales) team. This paper summarises the contents of a report commissioned by CNES to address the main challenges facing European scientists interested in research balloons. It was prepared by a large number of atmospheric scientists in Europe and covers the emerging scientific priorities as well as the facilities and organisation structure required to address them. In parallel the priorities for astrophysicists and planetologists were discussed, and the two aspects were combined in the final set of recommendations.

1. BACKGROUND

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, changes in the application of safety measures have resulted in tighter constraints on flight planning and operations, particularly affecting 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. Fourth, the scientific rationale for the research continues to evolve with a new generation of important issues emerging. Finally other European agencies have increased their capability to perform balloon flights.

In response to this, the European research balloon community and CNES have reviewed the rationale for the balloon programme for the next 5-10 years. After wide consultation a document "The Future for Research Balloons in Europe" [1] was prepared by atmospheric scientists who met with astrophysicists and planetologists, and balloon experts from CNES and other operators at a workshop in Pau in September 2008. This document lists the main conclusions and recommendations from this process. It is intended to inform all interested in a productive balloon research programme, whether from the scientific community, balloon operators, space agencies or funding agencies.

2. Scientific Priorities

There remains a strong rationale for research balloon flights, with important and exciting science still to be done, with much driven by a need to better understand climate change. One of the implications of the increased connection to climate studies is the need for more regular measurements in order to investigate processes occurring on timescales of months to years and even decades. In the stratosphere, issues such as coupling between climate and stratospheric dynamics will be important for the foreseeable future with a good understanding of the stratosphere required when making decadal predictions of climate. Here, the effect of climate change on the stratosphere will interact with the effect of ozone recovery on the whole atmosphere through changing radiative forcing, circulation patterns and chemistry.

The upper troposphere and lower stratosphere (UTLS) is a sensitive region of the atmosphere which is already moving up in altitude and whose changes will most likely have significant impacts on stratosphere troposphere exchange. Scaling up from the local and regional up to the global will remain a very challenging and important issue.

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. Mesoscale

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phenomena are again of great importance, whether it be convective storms or the transport of material.

Finally many global monitoring programmes implicitly assume that much of the observational capacity of the atmosphere will be in the form of satellite instruments. In reality, there are doubts as to whether this can be maintained uninterrupted into the foreseeable future: the remote satellite measurements are also of lower quality than balloon measurements. As a result, there is a complementary role for balloons (a) to bridge satellite missions and (b) to provide additional scientific information which can be interpreted in the light of the wider view provided from satellites. Balloons also provide an excellent testbed for satellite instruments of the future.

3. THE ROLE FOR BALLOONS

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.

Research balloons with potential for future use fall into four main categories which are now discussed.

3.1 Boundary Layer and Lower Troposhere

Short duration pressurized balloons equipped with local transmission systems are very useful to follow air parcels in the boundary layer. This is a unique feature of balloons that makes it possible to evaluate and improve the representation of physico-chemical processes 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 sample some particular events.

Very light gondolas (e.g the CNES Nano balloons) are currently under development, with payloads lasting up to 15 days. Simple parameters such as wind, pressure, temperature and humidity are reported. These very small balloons could be used in clusters of tens to hundreds devices. This is a promising approach to study the dynamics of meso- to synoptic-scale systems and the transport of chemical species in these systems.

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 buoyancy of the balloon changes during the flight as a result of helium leaks, envelope stretch, solar heating and water-loading from condensation. This can modify the flight level of the balloon and lead to payload damage. Long duration pressurized balloons measurements in the boundary layer are thus difficult to obtain and exploit because of these uncontrolled altitude changes. Recently, improved control of the balloon altitude has been achieved using adjustable air ballast into the balloons. Evolution toward a full control of the altitude is needed, preferably including the ability to probe the continental air masses that are transported into the mid-troposphere over the oceans. If successful, these balloons give unique continuous measurements in regions of the open ocean where no other in situ measurement exists.

The Aeroclipper [2] is 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 Aeroclipper may be equipped with atmospheric and oceanic gondolas giving estimates of surface parameters and of the turbulent fluxes at the interface. The Aeroclipper is naturally attracted to the low-level convergence generated by large tropical convective systems. Continuous measurements of various surface parameters including the surface pressure made in the eye of a cyclone reveal its evolution and intensity. Eventually, short-term flexibility on the launch site for a given campaign would allow better targeted measurements to sample particular occasional situations. 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.

Development of new small sensors for probing various chemical and physical parameters, which is occurring in other fields, is required to use the full capabilities of all these tropospheric balloons.

3.2 Long duration in UTLS and Stratosphere

Long-duration balloons (i.e., flights that can last for a few weeks to a few months) offer access to remote areas that can hardly be sampled by any other ground-based instruments or even airborne platforms. Each long-duration flight provides wide geographical coverage, which allows the instruments to sample various meteorological situations and fly over various terrains. The measurements made during 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 (e.g., continental convection or mountain waves) on the global atmosphere. The experience of CNES teams in the development and use of such balloons is unique.

There are currently two types of stratospheric balloons available for long-duration flights MIR (Montgolfière Infra Rouge) and BPS (Ballon Pressurisé Stratosphérique, Engl. stratospheric pressurized balloons), with different capabilities and constraints. MIRs fly at 28 km during day and 18-20 km during night, and can carry weights of about 50 kg. MIR flights can last for several weeks. 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-scale of days, BPS behave as quasi-Lagrangian devices. In addition, a CNES-NCAR (National Center for Atmospheric Research) collaboration yielded the so-called "driftsonde payload". This payload is equipped with dropsondes that can be launched on demand. Such device allows the measurements of the physical and dynamical structure of the lower stratosphere and troposphere below the balloon.

Long-duration MIR and BPS balloons are smaller than BSO (Ballon Stratosphérique Ouvert, Engl. zero-pressure balloons), and consequently require only modest infrastructures on the ground to be launched. They thus generally offer some versatility in launching sites, as well as in the time periods when they can be launched. They have been launched from many places (e.g. South Africa, Ecuador, Brazil and Antarctica). On the other hand, their small sizes impose 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 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 that can carry payloads with similar weight to those flown under MIRs. Iridium-based communication during long-duration flights has 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 as well, particularly during polar day, as demonstrated (e.g.) by the Swedish Space Corporation (SSC) in cooperation with NASA. The duration is limited by the outgassing of the balloon during day which requires the use of a certain amount of ballast for every diurnal cycle to keep the balloon in flight. The actual achievable durations depend on a number of factors that are being currently studied by CNES. Atmospheric research would benefit from longer duration flights, particularly in view of the upcoming gap in related satellite missions. 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 is 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 planning new campaigns will otherwise be subject to too much uncertainty.

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

(i) dynamics in the polar and tropical regions;

(ii) Interaction between dynamics and microphysics or chemistry; and

(iii) Assimilation and satellite validation

3.3. Large Payloads

The balloon sizes used for large payloads typically range from 35,000 m^3 to 400,000 m^3 (though larger balloons >1,000,000 m^3 are available). Open stratospheric balloons are used for this purpose allowing flight duration of typically 6-20 hours with typical maximum altitudes of between 30 and 40 km. Scientific payloads flown under large balloons are composed of in-situ or/and remote sensing instruments covering a large number of atmospheric parameters and constituents with high accuracy/precision. Total payload masses are typically 200-700 kg. Several instruments can be combined on one gondola as greater scientific value 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.

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 have been linked to the ozone loss discussion, mostly in Arctic regions. Recently, 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. 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.

Regular observations have also provided important scientific information. For instance, a long data set on stratospheric trace gas observations is available from sampling starting in the 1970s, allowing studies of the variability and long-term evolution of certain parameters in the stratosphere 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 with intensified activities linked to satellites from the US, Japan and Europe. The value of balloon-borne validation lies in the large altitude coverage and in the measurement programme tailored to the satellite overpasses and linked to sophisticated trajectory mapping for increasing the number of coincidences.

There are clear requirements for maintaining the European skills to manage large balloons, and the future availability of large balloons is required for the following issues:

(i) Long term trends of trace gases in the stratosphere;

(ii) Bridging the gap between aircraft and satellite measurements: High quality science with complex instrumentation or with multi-instrument payloads and support to GMES;

(iii) Satellite validation and integrated approaches to utilize synergies by combining satellite and balloon data;

(iv) Proof of concept of new space instrumentation; and

(v) Bridging the gap between satellite missions with the help of longer duration BSOs.

3.4 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 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. CONCLUSIONS & RECOMMENDATIONS

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

- Strong scientific rationale
- Reason to use balloons
- Joint use for science and satellite validation
- Access to suitable launch sites
- Efficient launch and flight operations

- Improved balloon technology to expand the range of scientific opportunities
- Cost
- Continued instrument development to use the latest technologies
- The European dimension: funding, planning and operations

These elements were discussed at length during the preparation of the report, and the main conclusions are now summarised. Here the recommendations from the astrophysics and planetology communities are included for sake of completeness.

4.1 Atmospheric Science

1. Scientific ballooning has a major role to play in European research on atmospheric science. The range of challenges is great and balloons have unique characteristics that justify their place alongside other platforms in a scientific research programme. Balloons provide access to parts of the atmosphere that cannot otherwise be reached; they could fill the gap in a period of declining satellite measurements; and they provide a distinctively European capacity.

2. As climate issues remain at the forefront of scientific challenges, there is likely to be an increased demand for regular measurements to be using research balloons at low, mid- and high latitudes. This implies that, for all types of balloons, a launch capability should be consolidated in the Tropics, that the mid-latitude site in France should be re-invigorated and that a high latitude site should be maintained.

3. There is currently no issue as over-arching as polar ozone depletion has been. Assuming that no similar issue emerges, future campaigns will be more focussed on specific topics. The preparation of these campaigns needs to be tackled jointly by scientists and balloon operators with early planning and a flexible approach to including local assistance and collaboration.

4. The atmospheric observation programmes of ESA and the national European space agencies show strong common interests with the atmospheric research balloon community, and close contact and co-operation should be maintained. Balloon flights can be used as Pathfinder missions for future satellite instruments, to validate the measurements from existing satellite instruments, and to study atmospheric phenomena in conjunction with satellite measurements.

4.2 Astrophysics and Planetology

5. A number of balloon projects within the fields of astrophysics and planetology fit scientifically and programmatically into a bigger "satellite-dominated" picture. As well as conducting unique and competitive scientific observations the projects can be used as Path Finder Missions (scientific as well as technical) for more ambitious missions or scientific gap fillers. Synergies and complementarity with the ESA (European Space Agency) science programme should be identified and appropriately addressed.

6. Balloon projects can open new "astrophysical windows"– in very much the same way as was done in the early times of ballooning. However, compared to the beginning it has become hard to come up with simple and cheap projects.

7. For some projects the latitude of the launch site does not play a role, but for some it does. The position in the sky of a specific, high-priority target may influence the choice of launch site. Sky surveys covering significant portions of the sky naturally require more than one site. In other cases the need for either sunlight or darkness is the determining factor.

8. Long duration flights with heavy payloads producing large data volumes are often requested. This requirement demands appropriate capabilities as regards infrastructure of the involved launch sites.

4.3 General conclusions and recommendations

9. Cooperation and communication between scientists and balloon operators as well as between the balloon operators themselves should be substantially improved if the best use is to be made of the overall European capability in balloon science.

10. A common feature of all the above issues 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. This committee should have good communication with the relevant research funding agencies. 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. Of central importance here is a much greater clarity about the application of appropriate and relevant safety rules as early in the planning process as possible.

11. A clearer focus is needed on the relative benefits of the various technical developments that are

being considered. This should maximise the considerable synergies that could exist between the different operators and to avoid unnecessary duplication of effort.

12. In parallel, a clear and efficient mechanism is needed to assess how the recommendations in this strategy are put into practice and to evaluate the effectiveness of any changes made. This mechanism should involve balloon operators, scientists and possibly funding agencies.

13. The establishment of a balloon infrastructure at European level would provide much better and more secure facilities to the scientists who use balloons for their research. Any proposal should involve European balloon operators and atmospheric and space scientists as partners. The European balloon operators should immediately and jointly investigate the possible sources of support at European level with a view to developing a European infrastructure. A deep and joint involvement of operators and users is a necessary condition of success.

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