RUSSIAN BALLOON RESEARCH

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ABSTRACT

The paper gives a brief retrospective of balloon research in atmosphere physics, geophysics and astrophysics in Russia. Current state of balloon systems research is discussed as well as prospects of Russian scientific participation in organizing and conducting international balloon research programmes in environmental studies, astrophysics and cosmology. Long-term cooperation with CNES is used to demonstrate possibilities and prospects of joint experiments and research programmes.

1. INTRODUCTION

Present-day Russia is somewhat lacking integrated organized coordination in balloon research. During an earlier period of 1980-1992, balloon experiments in studying cosmic rays, gamma-astronomy, magnetosphere, etc. were coordinated by a balloon commission of the Russian Academy of Sciences (RAS). The commission was organized under Lebedev Physical Institute of RAS and had its balloon launch base in Volsk, on the territory of the Russian Air Force Balloon Centre. The lack of integrated coordination in Russian balloon studies today precludes this presentation from being a full-fledged national report. But this paper will venture to both give a brief retrospective review of balloon research and describe present-day balloon activities in Russia.

2. HISTORICAL BACKGROUND

There is documented evidence that ballooning in Russia has been used for research purposes from its very beginning. On June 30, 1804, two months before Gay-Lussac's flight, Russian academician Ya. Zakharov and Belgian physicist E. Robertson made a charlier flight to perform observations of various physical phenomena. The research program and the corresponding equipment had been prepared specially for the flight. Occasional research balloon flights in Russia continued thereafter, resulting in a monograph "Scientific results of forty balloon flights in Russia" published in 1891. The paper was the first to sum up and give an account of previously conducted atmospheric research. Four Russian scientists became members of the first International Commission on scientific research ballooning.

The 20th century saw further progress in Russian balloon research. The "OSOAVIAKhIM" stratospheric balloon flight on January 30, 1934 was assigned an important scientific mission – a study of cosmic rays, magnetic effects and atmospheric composition as well as aerophoto-surveillance and medico-biological research. The programme had been prepared by Russia's leading research institutes: Main Geophysical Observatory, Ioffe Physics and Technology Institute and V.G. Khlopin Radium Institute. A research scientist was part of the crew. The balloon reached the at-the-time record altitude of 22 km. During the period of 1940-1960 the Central Aerological Observatory (CAO) conducted a long series of manned balloon research flights. Total number of flights exceeded 190, with dozens of flights reaching the altitude of 10-11 km. The flights were mainly devoted to studying atmospheric physics. Joint balloon experiments with Skobeltsyn Institute of Nuclear Physics of Moscow State University were also carried out to explore cosmic rays. Many flights, including those that reached 10-11 km altitude with an open gondola, were conducted for the purposes of aviation and aeromedicine.
The middle of the 20th century saw first unmanned stratospheric research balloon flights in Russia. In September of 1948 CAO first flew a system of meteorological balloons (referred to as AS-CAO stratospheric balloon) to a 22 km altitude. This balloon experiment permitted in-situ measurements of atmospheric characteristics and air sampling at different levels. AS-CAO system, which was simple, reliable and cost-saving, permitted dozens of flight experiments annually. The balloon system could be flown with a payload of up to 120 kg to the altitudes of 30-32 km for up to 2.5-4 hours. A similar balloon system performed over 490 research flights mainly devoted to atmospheric physics studies. The experiments were conducted at various locations in the central region (Kursk Region), in the southeast (Kazakhstan) and in the north (Salekhard). The research programme in atmospheric optics, aerosol scattering and optically active gas components fulfilled by Vavilov State Optical Institute is of the greatest interest.
Wide prospects for Russian scientific ballooning opened up with the development of applied ballooning infrastructure, mainly for military uses. Opening a ballooning centre in Volsk (Saratov Region), developing and manufacturing domestic polyethylene balloons and equipment to fly stratospheric balloons

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permitted interesting and important studies in various areas. Manufacture of open stratospheric balloons of up to 180,000 m^3 volume (some parameters listed in Tab. 1) as well as of launch and flight equipment made it possible to conduct research experiments in cosmic rays, astronomy and magnetosphere.

Table 1: Characteristics of scientific research balloons

Specification name	Saturn	Volga	VAL-120
Equilibrium altitude Ballasting altitude	20	25	32,5 25
Flight distance, km:			8000
Flight mass, kg	7500	1300	2050
Payload mass, kg:	6100	1200	400…1200
Balloon, m^3	107 000	72 000	180 000
Balloon, kg	1400	950	650

The above-mentioned balloon systems were used in a number of major research programmes. In 1962 balloonists P.Dolgov and E.Andreev made a flight on a 72,900 m^3 "Volga" stratospheric balloon reaching the altitude of 25458 m. The pilots used individual parachutes for descent and landing. Various medico-biological studies were carried out during the flight, which included developing equipment and techniques for emergency operations to rescue astronauts and stratospheric aircraft pilots. Another experiment used a balloon designed to fly at 20 km level, carrying a 6000 kg "Saturn" astronomical station. The station included a telescope with a mirror of 900 mm in diameter. The telescope took unique photos of the sun. During the same period "GALAXY" astronomical balloon station, designed for taking photos of the stars from the altitude of 30 km, was built and successfully flight tested.

3. INTERNATIONAL COOPERATION

Highly interesting scientific balloon projects have been carried out within the framework of international cooperation. Among them the "OMEGA" project marked a successful stating point in France-Russia joint balloon studies. The project involved both Russian scientists and Russian balloons (1968-1971). Balloons were flown simultaneously from the north of Russia (near Arkhangelsk) and from the Kerguelen Islands. The French party was represented by Toulouse Centre for Space Radiation Studies, Aire-sur-Adour Balloon Centre, National Communication Research Centre, Paris Institute of the Earth Physics, Aerophysics Institute and Astrophysical Observatory.

The (then) USSR party included the Institute of Earth Magnetism, Ionosphere and Radiowaves (IZMIRAN), the Polar Geophysical Institute, Moscow University, Leningrad University and Volsk Balloon Centre. The "OMEGA" balloon experiments were conducted at the altitudes of 30-40 km with 30-100 kg payload. Both French and Russian research balloons (up to 130,000 m^3) were launched from locations on the Kerguelen Islands and near Arkhangelsk (10 flights with Russian balloons and 27 flights with French balloons). In January-February of 1971, during the final stage of the project, ground-based and balloon observations were carried out in two pairs of magnetically-connected areas: Carpogory, Sogra near Arkhangelsk – the Kerguelen Islands and Mezen, Dolgoshchelye near Arkhangelsk – Herd Island in the south of the Indian Ocean. The observations provided a lot of information that widened the scope of our knowledge about electromagnetic phenomena, confirmed and specified the results of earlier studies using drift-ice research stations in magnetically-connected areas.

The "OMEGA" project was succeeded by "SAMBO" (Synchronous Auroral Multiple Balloon Observations), which was conducted in five stages: February-March 1974, November-December 1978, January-March 1979, November-January 1980 and November-February 1982. Along with French and Russian specialists, Swedish and Austrian scientists were involved in the project. "SAMBO" was one of the early balloon projects based at Esrange (Sweden). Later, the same Russian research teams joined Brazilian scientists in research experiments in Brazilian tropics.

Early successful cooperation between France and Russia in balloon research included joint testing of a parachute system for "MARS" project, which involved specialists from CNES and, on the Russian part, from the Physics Institute of the Russian Academy of Sciences, the Institute for Space Research, Babakin Space Centre and Volsk Balloon Centre. For experimental testing of MARS balloon probe in the Earth's upper atmosphere, a specific parachute system was designed, manufactured and tested in three high-altitude balloon flights (with balloon volumes of 130000 and 180000 m^3, payloads of 500-900 kg and maximum flight altitude of 32 km). The experiments showed that a one-canopy 1200 m^2 parachute system had certain advantages over a four-canopy one and could be used both in "MARS" balloon tests in the Earth's stratosphere and as a parachute system of the descent module to be employed in exploration of Mars.

The high potential of international balloon research cooperation with Russian scientists and on the Russian territory can be illustrated by the Japan-Russia experiment 'RUNJOB' (RUssia-Nippon JOint Balloon Experiment) in cosmic rays research. This project involved Volsk Balloon Centre and used a unique stratospheric balloon path at the altitude over 30-33 km, extending from Kamchatka (Kluchi) to the Volga. A balloon flown from Kamchatka in summer was brought by stratospheric flows to the Volga within 6-8 days. The experiments were initiated in the 1970s. In 1995-1999 a series of eleven balloon flights along that path were conducted under the Japan-Russia project to study primeval cosmic rays. Experimental data were processed by the Skobeltsyn Institute of Nuclear Physics of Moscow State University in 2004. The project made it possible to obtain information on the energy spectra of protons, helium nuclei and three groups of heavy metals, within a wide range of energies from 10 to 1000 TeV/particle.

4. MAIN AREAS OF BALLOON RESEARCH

4.1. Cosmic rays research

As stated above, cosmic rays have been studied in Russia since the 1930s with many of the experiments using manned balloons. The research has never ceased, and present-day experiments are led by Skobeltsyn Institute of Nuclear Physics of Moscow State University, Lebedev Physics Institute of the Russian Academy of Sciences, the Moscow Engineering Physics Institute and Ioffe Physics and Technology Institute (IPTI). Many of the experiments were and are conducted in collaboration with international research teams. For instance, research experiments in cooperation with Indian scientists were conducted in 1977-1979. Researchers from China took part in experiments performed with Russian balloons. At present, the Institute of High Energy Physics of China and the Physics Institute of the Russian Academy of Sciences are jointly working on balloon studies in the field of cosmic ray physics, high and super-high energy astrophysics, IR and sub-millimetre range astrophysics.
The search for antimatter in the universe is part of the history of Ioffe Physics and Technology Institute (IPTI). Spacecraft and high-altitude balloon experiments in that field started in the 1960s and yielded data obtained through observations of explosive processes in stars and galaxies, which evidenced either the presence or absence of antimatter there. Antiprotons with energies of 2-5 GeV in galactic cosmic rays were observed at the end of the 1970s in balloon experiments by the Cosmic Spectrometry Laboratory of IPTI. The balloons were launched with technical support of specialists from Volsk Balloon Centre. This research was conducted with a magnetic spectrometer at altitudes with 10 g/cm^2 residual pressure. First measurements of a flux of galactic antiprotons with energies of 0.2-2 GeV in high-latitude experiments in the 1980s gave some indication of the mechanism by which they are generated. Subsequent balloon experiments by research teams from the USA and Japan, using magnetic spectrometers, confirmed the results obtained by the IPTI. Experimental and theoretical work to detect antiparticles in cosmic rays is being summarized, and astrophysical consequences of this research are discussed. The obtained experimental data show that there are no objects made of antimatter in the observable galaxies.

At present Russia's leading institutes for cosmic ray research are continuing with balloon studies in this field. Skobeltsyn Institute of Nuclear Physics, in cooperation with international partners, is participating in the well-known ATIC experiment (Advanced Thin Ionization Calorimeter) involving balloon flights over Antarctica (McMurdo Station). Skobeltsyn Institute of Nuclear Physics and Lebedev Physics Institute are jointly developing a project referred to as "SFERA", aimed at exploring ultra-high energy cosmic rays ($E>10^{19}$ eV). The behaviour of their energy spectrum at energies over $5*10^{19}$ eV is one of the major problems in modern astrophysics. The new method of exploring super- and ultra-high energy cosmic rays employed in "SFERA" project has never been experimentally tested before and constitutes the development of the idea previously advanced by Russian scientists. A balloon-borne system, when above a snow-covered earth surface, registers Air Shower Cherenkov light reflected by the snow and Air Shower fluorescent track in the atmosphere. The image of the Cherenkov light spot and Air Shower track is projected onto a photomultiplier mosaic with a 1.5-m diameter spherical mirror. This technique permits analyzing energy spectrum structure and atomic composition of primeval radiation and also provides a large effective registration area. In 1995-2000 "SFERA-1" was designed, which made it possible to further develop the technique and obtain experimental data on cosmic rays energy spectrum within a 10^16 - 10^17 eV range. The system was flown on a tethered balloon from a launch site near Volsk. In 2004 the first Antarctica "SFERA-1" test flight was performed near the Russian station of Novolazarevskaya. At present a more advanced "SFERA-2" system is nearing completion. The experiment is being jointly conducted by Skobeltsyn Institute of Nuclear Physics and Lebedev Physical Institute, with participation of Karl University (Czech Republic) and Lodz University (Poland). The final phase of this research is planned to be conducted in a circumpolar flight at the height of more than 30 km over Antarctica.
IDEA & Proposal for future cooperation by the Lebedev Physical Institute of the Russian Academy of Sciences is very promising for future international scientific projects. This proposal concerns stratospheric measurements of the alignment phenomena in cosmic ray nuclear interactions at $\sqrt{s} > 6$ TeV. A circumpolar balloon flight experiment around the North Pole is proposed for measuring primary cosmic-ray composition and the alignment effect at energies above $\sim10^{16}$ eV with an X-Ray emulsion detector.

4.2. Magnetospherics research

The Institute of Earth Magnetism, Ionosphere and Radiowaves of the Russian Academy of Sciences has been over the years the undisputed leader in this research field. As stated above, IZMIRAN initiated and organized important international scientific programmes of "OMEGA" and "SAMBO". It should be noted that IZMIRAN is continuing balloon studies of magnetosphere today. The most recent experiment was completed at Volsk Balloon Centre in 2010. IZMIRAN specialists proposed a new method of detecting the Earth's anomaly magnetic field. This method is based on stratospheric balloon measurements. The new independent method is aimed at assessing the errors of global analytical models of the Earth's normal magnetic field. So it can be expected that in the nearest future balloons will be flown to make gradient magnetic measurements along a 6 km vertical path. A sufficiently detailed description of the technique, equipment and some results will be given in the author's paper presented at the Symposium.

4.3. Atmospheric research

Research programmes carried out by the Vavilov State Optical Institute over the years (1958-1991) are of special significance. The institute specialists used spectral instruments to measure spectra of absorption, to study atmospheric optical characteristics and aerosol scattering and to measure the concentration of atmospheric radiation-active gas components. Measurements were taken during AS-CAO stratospheric balloon flights (more than 400 flights) at various locations in Russia.
CAO specialists have designed a small balloon-borne resonance-fluorescence hygrometer (FLASH-B) to measure water vapour concentration in the stratosphere. The hygrometer has been further developed through in-flight balloon testing and is now suitable for taking measurements even on meteorological balloons. Designers of the hygrometer express their great appreciation of the long-term assistance rendered by CNES specialists during the research, development and testing stages. Since EASOE campaign the FLASH-B flight hygrometer has been used in many programmes (LAUTLOS-WAVVAP, SCOUT-O3, SCOUT-AMMA, NASA TC4, STRATEOLE, LAPBIAT-FMI, RECONCILE). The instrument is undergoing constant development. Description of the latest modification of this payload will be given in the author's paper presented at the Symposium.
A flight System for Test of Aerological Sensors (STAS) was designed by CAO to test and compare different types of sensors of radiosondes under actual flight atmospheric conditions. In 2009-2010 STAS was used as piggyback in six balloon flights during CNES campaigns. Due to assistance rendered by CNES balloon staff, the system has been tested and developed. Now it can be used for upgrading radiosonde sensors and for simultaneous comparison of radiosondes. STAS designers wish to express their gratitude to Air-sur-Adour Centre team for their long-standing support and cooperation.

5. FUTURE OF RUSSIAN BALLOON RESEARCH

Due to the difficulties in obtaining balloon flight permits over the Russian territory and current uncertainty about achieving a positive result, without significant steps in integrating Russia in the European balloon infrastructures the development of scientific ballooning in the northern hemisphere will be considerably limited. The most recent and clear illustration of this situation is CNES campaign of February-March 2011. The atmospheric conditions being very specific and thus all the more interesting for research, launching the balloon flights was largely complicated due to limitations of polygon range. As a result CNES faced great difficulties in conducting basic programme experiments. In this connection it is worth remembering the positive experience of EASOE (1991-1992) in enhancing operational capabilities.
To solve current problems, setting up an intermediate TM/TC station on the Kola Peninsula may expand the polygon by as much as 250-300 km (Fig. 1) and enable balloon flights over the sparsely populated eastern part of the peninsula.

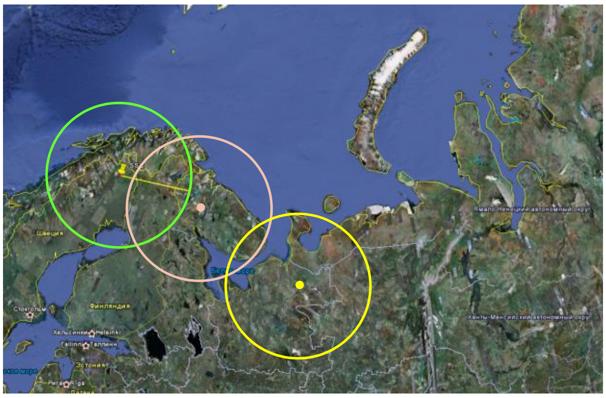

Figure 1: Nearest Russian part of the polygon for balloon flights from Esrange

Despite expectations associated with national projects such as "SFERA", realistic future of Russian balloon research is seen today to be largely dependent on participation in international projects. Thus, for example, along with the studies of cosmic rays by Skobeltsyn Institute of Nuclear Physics and Lebedev Physics Institute and atmospheric studies by CAO on the Russian territory, further cooperation with CNES can be expected. Future balloon research projects may also involve the SNSB largely interested in this cooperation.
Russian participation in organizing and conducting major balloon campaigns should be described in more detail. Within the last twenty years 14 major

programmes (EASOE, SESAME, THESEO, ARCHEOPS, ENVISAT validation, etc.) have been carried out with Russian participation. Over 40 balloon flights were conducted on the Russian territory, including both short-duration flights and long-duration flights that covered thousands of kilometres. Long-duration super-pressure balloons with several months' flight duration were also flown. All of these projects were coordinated by CNES. The payloads were prepared and balloons were launched from Esrange. That can be considered very successful and productive French-Russian cooperation. At present, preparation for a future PILOT experiment is being discussed. Similar to earlier ARHEOPS experiment, PILOT experiment requires solution to numerous problems associated with long-distance balloon flights, science data reception from all over the part of the trajectory and equipment recovery from central and eastern parts of Russia. Solving these complicated problems will widen the scope of cooperation between the two countries in this field of research. And the long-standing collaboration of the Swedish and Russian specialists and scientists may lay the foundation for a successful experiment under the PoGOLite program – the first circumpolar balloon flight in the northern hemisphere with such top-class payload.

CONCLUSION

For the purposes of research planning and implementation feasibility of the planned activities is essential. Therefore, it is vital that there should be positive understanding of the importance of international cooperation in balloon research at the top administrative level in Russia. To achieve this understanding at the top level of Russian administration joint efforts are required, including those of the ESA and top management of the involved agencies. Sole efforts of Russian specialists will not be enough to carry the message of scientific significance of international balloon research to Russian top administration.

At present Russian scientific ballooning is facing many difficulties. But what's important is it is certainly alive and active. The future of Russian scientific balloon research is closely connected with the prospects of international balloon research.

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