Winter long duration stratospheric balloons from Polar regions

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Abstract. A new opportunity for astronomy, cosmology, physics, and atmospheric observations is the possibility to fly stratospheric payloads at 30 - 40 km of altitude during the polar night. The absence of solar irradiation for long periods, and the extremely low temperature and stable environment of the winter stratosphere represent ideal environmental conditions while performing astrophysical observations. Here we present a small and efficient platform, able to communicate, supply power and navigate in the harsh environment of the polar stratosphere. After a balloon failure in January 2017, the payload was successfully flown in December 2017 from 78°N, in Longyearbyen, Svalbard, Norway. Duration was limited to 21 hr, due to a southern trajectory that caused solar illumination and loss of lift. The instrument acquired and transmitted environmental data, and the thermal performance of the power system are outstanding. The payload also included a set of attitude sensors, to monitor payload movements. The information collected on this flight is essential to qualify the attitude control system sensors, and for the design of the thermal and power system of the next generation LSPE-SWIPE telescope, devoted to the measurement of the polarization of the Cosmic Microwave Background radiation from a stratospheric balloon during the Arctic polar night.

Key words. Instrumentation: stratospheric balloon – Cosmology: observations

1. Introduction

Long duration winter polar stratospheric balloon flights are a unique opportunity for instrumentation devoted to astronomy, cosmology, physics, atmospheric and environmental measurements. For astronomical observations, winter polar ballooning offers the possibility of a total shade from solar illumination, long duration, due to stable temperature, a minimal residual atmospheric emission and absorption, a wide observable sky, and a stable and cold environment. These conditions are particularly useful for observations in the far infrared and millimetric wavelengths, where the signal from the Cosmic Microwave Background radiation is observable. See e.g. de Bernardis et al. (2012) and (Aiola et al. 2012).
In this paper, we present a technological payload, dedicated to testing the feasibility of winter polar long duration balloon flights. The most demanding challenges of winter polar ballooning are the extreme thermal conditions and the power system. Temperature drops to below \(-90\, ^\circ\text{C}\), and a power system can’t benefit from solar radiation. We describe how these critical aspects have been tackled, the chosen trade-offs, and briefly describe data from the 2017 flight campaign.

Previous experiences have been reported in Iarocci et al. (2008); Peterzen et al. (2010); Romeo et al. (2008); Peterzen et al. (2008, 2005).

2. Instrument

The instrument is assembled in a 30x30x30 cm cubic frame. The frame is suspended by kevlar rope, to minimise weight and thermal conductivity. Figure 1 illustrates the payload in its frame. The elements of the instrument are:

- An Iridium modem, connected to a telemetry and termination electronics, based on a PIC microcontroller;
- A power control system, to provide power regulation to the subsystems;
- A thermal control system, to monitor temperatures, and activate heaters;
- An attitude sensors system, based on a Motion Processor Unit.

The payload is completed by an independent piggy back system, consisting in a self powered cubesat CPU and sensors board, product of H8 robotics.

The total weight of the system is: payload: 13.30 kg; ARGOS telemetry system and piggy back system: 2.15 kg; flight train: 2.05 kg. Total: 17.50 kg.

2.1. Power system

One of the most challenging aspects of winter polar flight is the power system. The absence of solar illumination, require a power system fully based on batteries. Lithium batteries have the higher energy density (J/Kg), but significantly loose energy at low temperature. External temperature is expected to drop as low as \(-90\, ^\circ\text{C}\). Keeping batteries warm, on the other hand, requires extra power. It is clear the a crucial trade-off must be taken in the design of the power system and how critical thermal insulation is.

As battery cells, we have selected the SAFT LS33600 element, combined in a single battery of 90 cells, arranged in 15 parallel elements of 6 cells in series. A polyswitch RUE 600 limits the maximum current to 6 A. The assembly has a weight of 9.5 Kg, and it was designed and provided by ELTEC Italy. At room temperature, it provides a tension of 21.6 V, a capacity of 225 Ah, and an energy of 5508 Wh. From thermal modelling, we decided to set the heater switch-on temperature at \(-40\, ^\circ\text{C}\). At this temperature, the battery provides 15.6 V, a capacity of 97.5 Ah, and an energy of 1550 Wh, with a mere 28% of effi-
ciency in energy. Nevertheless, this is the best trade-off in terms of mission length, with a minimum intervention of the heaters.

The system produces 1.9 W of power when heaters are off. Heaters can provide an extra 8.8 W, with batteries at 15.6 V, for a total power of 10.7 W. With the heater switch-on temperature set at -40 °C we expect to have the heaters on 50% of the time, with an estimated duration of 12 days. If the heaters stay on all time, mission duration will be 6 days.

2.2. Thermal insulation system

External temperature is expected to drop to −90 °C during flight, while batteries must be kept at −40 °C. Thermal insulation is based on an Aerogel layer. The selected model is Cryogel x201, which is expected to have a thermal conductivity of 8 mW/mK in the temperature range between −90 and −40 °C, at a pressure of 10 mbar. The adopted aerogel consists of a 30x30 cm panels, with a thickness of 25 mm.

In order to further reduce the thermal conductivity 6 layers of aluminized mylar have been added, 3 on the internal side and 3 on the external side of the aerogel.

2.3. Telemetry system

The telemetry system is based on an Iridium Short Bust Data (SBD), model SBD 9202N, with a dual GPS/Iridium active antenna. Short messages can be sent from payload to ground, and from ground to payload. The payload sends a message every 120 seconds. The message contains coordinates and time from GPS, and data from all the sensors onboard. More frequent data are saved on a solid state memory card on-board. Data are received as e-mail messages on ground and converted by the ground segment into data-stream. Each e-mail message also contains coordinates as obtained from triangulation of Iridium receiving satellites. This provided redundancy on the payload tracking.

An other redundant tracking system is connected to the balloon, and consists of an ARGOS-System tracker. This tracker is only activated after termination by a pull-and-activate system. In this way, a heavy battery system is not required for the ARGOS tracker, and 8 battery cells (2 series of 4 cells in parallel) are enough to provide power after termination, and locate the balloon for at least 24 hrs.

2.4. Sensors

The payload is equipped with environmental and attitude sensors.

Environmental sensors include: GPS (longitude, latitude, altitude); battery tension sensor; heater activation sensor; temperature sensors: a PT100 for external temperature, an AD780 for power control unit temperature, an AD590 for electronics board temperature, an other AD590 on battery pack;

The payload is also equipped with a Flight Controller Board (CRIUS All In One PRO unit) based on Arduino platform. The sensors present on the board are: 6-axis gyro/accel with Motion Processor Unit, 3-axis digital magnetometer, high precision altimeter with metal cup and thermometer. The system logs data on an external SD memory, ans sends a fraction of the data to the Iridium SBD board by serial communication link.

3. Flight and performance

For Arctic winter flights Longyearbyen (Svalbard, Norway), at 78°N, represents an ideal location to guarantee total darkness during operation. The payload was first flown in January 2017, but the balloon suffered a failure during launch. The payload never lifted, and it was recovered undamaged. A second successful launch was organized in December 2017. Both launches and campaign management were orchestrated by The ISTAR Group1.

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3.1. Balloon

The balloon is an Aerostar International, model SF4-0.327-.6/0-TA, with a volume of 9288 cubic meters. It weighs 37 kg and can lift up to 20 kg. Figure 2 shows pictures of balloon and payload during launch. An heavy dry snow didn’t disturb operations.

3.2. Flight

Balloon was inflated in the Longyearbyen airlift, after coordination with local Air Traffic Control. External temperature was $-11^\circ C$. Inflation took about 30 minutes. During inflation a heavy dry snow hit the airport, without damage to operations. The Balloon lifted at 18:58 UTC, 19:58 local time, on December 17, 2017. Ascent took 93 minutes, up to 33200 meters, with an ascent rate of 5.9 m/s. The ascent stopped at 33200 meters, without overshooting.

During ascent, temperature dropped to $-94^\circ C$, and then stabilised at $-80^\circ C$. At 2 AM UT (Dec 18) temperature and altitude started dropping again. Stratospheric wind pushed the balloon toward SW. At about 73.5N, 6.0E the balloon turned towards SE. At 9AM the Sun hit the balloon causing a rise in temperature and altitude. External temperature raised to above $-60^\circ C$. The maximum altitude was 33480, with a sharp stop probably due to balloon venting. Temperature and altitude remained stable until 13 UT. During cruise, the internal tem-
perature never dropped below $-32\, ^\circ C$, and the heater, set at $-40\, ^\circ C$, never switched on.

At 13 UT, on December 18, 2017, solar illumination ceased, the temperature dropped again with a minimum of $-96\, ^\circ C$. The altitude dropped too, with a constant descent at a speed of 1.7 m/s. At 15:56 UT, after 21 hours of flight the altitude was ad 16480 meters, with constant descent rate. We decided to terminate the flight, after contact with the Swedish Air Traffic Control. Termination worked perfectly, and the payload dropped smoothly in an inhabited area of Lappland, in the region of Arvidsjaur, just a few km North of Jerfjoaur, not far from a country road.

Altitude, temperature data and trajectory are reported in figure 3.

4. Conclusions

Long duration winter polar flights are becoming a real possibility for instrumentation requiring a dark environment for long time.

The payload, launched on December 2017 from Longyearbyen (Norway) suffered stratospheric wind towards South, which caused early termination. Nevertheless all the subsystems worked without failures in the harsh condition. In particular the thermal insulation confirmed performance declared by the producer, and granted an efficient battery power system. This opens the path to a larger power system, such as the one needed for the forthcoming LSPE-SWIPE balloon experiment, planned for 2020 (de Bernardis et al. 2012).

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