ISTS 2004-m-13p

# JAPANESE POLAR PATROL BALLOON EXPERIMENTS FROM 2002 TO 2004

Yoshitaka Saito, Issei Iijima, Naoki Izutsu, Tomomi Kawasaki, Yukihiko Matsuzaka, Michiyoshi Namiki, Shigeo Ohta, Michihiko Toriumi, Takamasa Yamagami
Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency
3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
(E-mail: saito@balloon.isas.jaxa.jp)
Yusuke Ebihara, Masaki Ejiri, Akira Kadokura, Natsuo Sato, Hisao Yamagishi,
National Institute of Polar Research
9-10-1 Kaga, Itabashi, Tokyo 173-8515, Japan
Yusaku Katayose, Yuki Tomida*,
Yokohama National University,
79-5 Tokiwadai, Yokohama, Kanagawa 240-8501, Japan
Mori Fujii *,
Shibaura Institute of Technology
307 Fukasaku, Minuma, Saitama, Saitama 337-8570, Japan
Hiroyuki Murakami,
Rikkyo University
3-34-1 Nishiikebukuro, Toshima, Tokyo 171-8501
Sadayuki Uchiyama, Yuji Konno
Clear Pulse Ltd.
6-25-17 Chuo, Ohta, Tokyo 143-0024, Japan

## Abstract

Three polar patrol balloon (PPB) experiments were performed in Syowa station, Antarctica from the end of 2002 to the beginning of 2004. Two balloons were for the observation of phenomena in the polar atmosphere and one was for the observation of high energy cosmic electron. To support these experiments, we have newly developed 1) a communication system using the Iridium satellite communication system, 2) a power managing system using the solar batteries, and 3) an auto-level controller to keep the balloon altitude high. These balloons flew for 2 to 3 weeks successfully. Fruitful scientific results are expected.



*also ISAS/JAXA

## 1. Introduction

Balloon experiments in Antarctica are attractive from both scientific and technical points of view. There are many phenomena that are peculiar to the polar areas like the aurora. In addition, balloons can fly longer due to the midnight sun, even using zero-pressure balloons [1].

As a project in the 44th Japan Antarctic Research Expedition (JARE44), four polar patrol balloon (PPB) experiments were planned. Three balloons were for the study of the polar atmospheric phenomena by simultaneous observations from different locations using the balloons in formation flight. The other one was for the observation of the high energy cosmic electron in 100 to 1000 GeV region [2].

In Japan, the polar patrol balloon (PPB) experiments have been performed from the Japanese polar base, Syowa station, Antarctica and six balloons have been launched [3][4]. Unfortunately, we had no chance to perform the PPB experiment in the last 9 years and the last experiments date back to 1993. We revised the housekeeping system and developed a new system including an Iridium satellite communication and a power supply using solar cells.

Unfortunately, two of four balloons including the one for the cosmic electron observation were not successful due to the incorrect actions of the command system caused by static electricity in the dry Antarctic climate. We retried another experiments for the cosmic electron observation this year in 2004.

In this paper, first, the new housekeeping system will be introduced, second, the launching operation in Antarctica will be mentioned, third, the flight performance in 2003 will be described and then the retrial and its results will follow.

## 2. System overview

For long-duration experiments, it is important to ensure a communication system and a power managing system. For the last PPB experiment in 1993, we used the ARGOS satellite for the downlink and the Lithium batteries for the power supply. This time, we revised the housekeeping system and newly developed a satellite communication system using the Iridium satellite system, and a power management system using solar panels and Nickel-Metal Hydride (NiMH) batteries. In addition, we also developed a new auto-level controller to keep a level altitude.

Fig.1 shows the schematic view of the system. We used the conventional Lithium batteries for most of housekeeping equipments due to their low power consumption and certain operation. For the PI system, the 1680 MHz transmitter, and the Iridium comunication system, a power managing system supplying $\sim$ 140 W was used.

For the line-of-sight communication, we used 1680 MHz for the downlink and 72.3 MHz for the uplink as is in Japan. To keep in touch with the balloons beyond the line of sight, we have newly developed a system using the Iridium satellite communication system [5]. The Iridium system uses 66 satellites in the low earth orbit at 780 km altitude. They have six separate orbital planes linking the northern and southern hemispheres, and each of them is occupied with 11 satellites. By means of satellite-to-satellite relay, cellular phone communication is available even

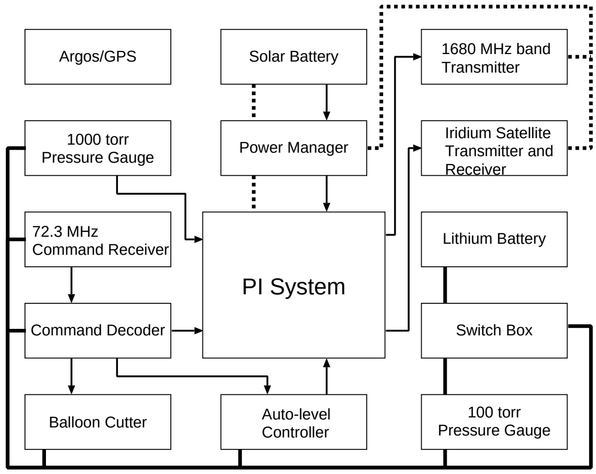


Figure 1: PPB HK system.

in the polar area, through a ground station located in Arizona, USA. It supports Dial-Up Data Service using a RS232C protocol of 8 data between one start bit and one stop bit format with a transfer rate of 2.4 kbps. We used a Motorola 9505 portable satellite phone whose power consumption is 7 W.

Our communication system is as follows. First, scientific data is stored in a silicon disk as a sum of separate event files. Then the on-board cellular phone calls a ground station located in Japan every ten minutes. Once the communication line is established, first, a command list file is uploaded, second, data files are downloaded and then the line is closed. If the line was broken during the communication, it calls again after three minutes wait and then begins transferring from the unsent data.

For the long-duration power supply, we developed a system using solar batteries and NiMH batteries. We used a Sharp NT3436 for the solar battery, which consists of 36 crystal Silicon cells with an area of 70 cm $\times$ 30 cm, and provides the open voltage of 22.1 V, the short current of 2.7 A, and the maximum power of 45.0 W under the consumption of the illumination of 1000 W$\cdot$m$^{-2}$ at 25 °C. It weights only 660 g and is often used for solar cars. We made a panel attaching five solar panels on an Aluminum honeycomb board and attached the panel at the four sides of the gondolas.

Since the latitude of the Syowa station is not high enough, balloons have to survive short nighttimes and a storage battery is required for continuous power supply. We used a Sanyo HR-D for this purpose. It can provide the normal voltage of 1.2 V with the capacity of 7.3 Ah by a single cell with a size of 3.4 cm (D) $\times$ 5.9 cm (H). We packed connecting 10 cells in series and used four packs in parallel.

To maintain the balloon altitude, ballasting operation is sometimes required. We developed an auto-level controller using a CPU with a procedure as follows. It always monitors the atmospheric pressure and sets the ballasting pressure as 1.15 (in '03) or 1.34 (in '04) times the lowest pressure. If the pressure exceeds the ballasting pressure, it goes into the ballasting mode. During the mode, it drops 2 kg of the ballast and waits for 4 minutes and after that, compares the pressure with the ballasting pressure. If the former is lower than the latter, it exits the mode, and if not, it again drops the ballast and stays in the mode.

Figure 2: Gondolas being ready for launching.

## 3. Launching operations

The Japanese Antarctic base, Syowa station is located at the south latitude of 69.0 and the west longitude of 39.6. We launched the balloons during the midnight sun season. We used the C heliport for the launching field which width is 30 m and length is 110 m, and an old rocket telemeter station for the tracking station. After landing on the Syowa base on Dec. 20 2002, we checked the payload and prepared the launching field and the tracking station.

We launched four balloons using the static launching method . The parameters of the balloons are summarized in Table 1. Unfortunately, two of them resulted in failure due to the incorrect actions of the command system caused by static electricity.

Figure 3: Launching of a balloon at Syowa station.

## 4. Results

Fig. 4, 5 show the trajectories and the altitude curves of the PPB8 and the PPB10. First, the balloons rotated around the south pole counterclockwise, then changed the direction to a clockwise rotation descending in latitude, and finally dropped on the sea near South America. The altitudes of the balloons were kept above 30 km during the first ten days dropping ballasts controlled by the auto-level controller. While there

Table 1: balloon parameters

| Code name | PPB7 | PPB8 | PPB9 | PPB10 |
|---|---|---|---|---|
| Purpose | Electron | Polar events | Polar events | Polar events |
| Balloon Volume | 100,000 $m^3$ | 50,000 $m^3$ | 50,000 $m^3$ | 50,000 $m^3$ |
| Length | 89.0 m | 70.6 m | 70.6 m | 70.6 m |
| Collar line | 20.5 m | 18.5 m | 18.5 m | 18.5 m |
| Launch (UTC) | 2002/12/30 8:20 | 2003/1/13 6:49 | 2003/1/6 7:35 | 2003/1/13 12:15 |
| Ground Temp. | $-1.8$°C | 1.5 °C | 1.7 °C | 1.7 °C |
| Atmoph. Pres. | 991.8 hPa | 990.9 hPa | 993.4 hPa | 989.1 hPa |
| Wind Speed | 1.9 $m{\cdot}s^{-1}$ | 1.5 $m{\cdot}s^{-1}$ | 1.4 $m{\cdot}s^{-1}$ | 1.2 $m{\cdot}s^{-1}$ |
| Wind Direction | 45 ° | 310 ° | 60 ° | 360 ° |
| Weather | Fine | Fine | Fine | Fine |
| Balloon | 270.0 kg | 177.55 kg | 179.0 kg | 180.5 kg |
| Gondola | 230.0 kg | 153.0 kg | 142.0 kg | 146.0 kg |
| Sub Gondola | 14.0 kg | 53.0 kg | 53.0 kg | 53.0 kg |
| Ballast | 225.0 kg | 204.0 kg | 200.0 kg | 200.0 kg |
| Total | 739.0 kg | 587.55 kg | 574.0 kg | 579.5 kg |
| Free Lift | 95.0 kg | 72.3 kg | 45.3 kg | 76.4 kg |
| | (12.9 %) | (12.3 %) | (7.9 %) | (13.2 %) |
| Total Lift | 828.0 kg | 658.55 kg | 619.3 kg | 654.8 kg |
| Launcher Lift | 560.0 kg | 496.0 kg | 456.0 kg | 488.0 kg |
| Measured F.L. | 81.0 kg | 86.0 kg | 61.0 kg | 89.0 kg |
| # of Gas Cylinder | 160 | 116 | 112 | 120 |

were no more ballast after that, the balloons survived for more than a week. The flight duration of the PPB8 and the PPB10 were 25 days and 18 days, respectively.

The continuous plots of the trajectories and the altitude curves indicate the fundamental success of our new housekeeping system, since they are based on data obtained through the Iridium satellite communication from the on-board phone powered by the solar battery system.

From detail analyses, we know the following properties of the Iridium communication system:

- We were able to get whole data obtained on-board successfully.
- We can not find any data errors. The Iridium system might have used some error correction methods.
- The averaged data transfer rate was 2.35 kbps, once the communication line is established.
- Sometimes, the line was broken. The emergence rate of the brake does not depend either on the latitude nor on the altitude, but depends on the phone.

Fig. 6 shows the supplied voltage, current and power from the solar batteries on the PPB8. While the voltage of the panel changes as a function of the solar elevation and the direction of the gondola, the supplied power is always kept constant. The two lines of the power consumption are due to the on/off of the Iridium communication phone. The temperature of the solar panels ranged from $-40$ to 100 °C as we expected.

The intervals where we could not obtain data are due to an unexpected long survival of the balloons. Since the altitude of the balloon descent down to 15 km, where the atmosphere is cold, the temperature of the NiMH batteries became low as shown in Fig. 7. Since it tends to show a higher voltage at lower temperatures, the power manager stopped charging the batteries during daytime, though it was not full. The temperature of the on-board equipments were comparable to those of the NiMH batteries and around the room temperature while the altitude of the balloon was high. The on-board sensors were kept in nice condition.

This experiment was also successful from a

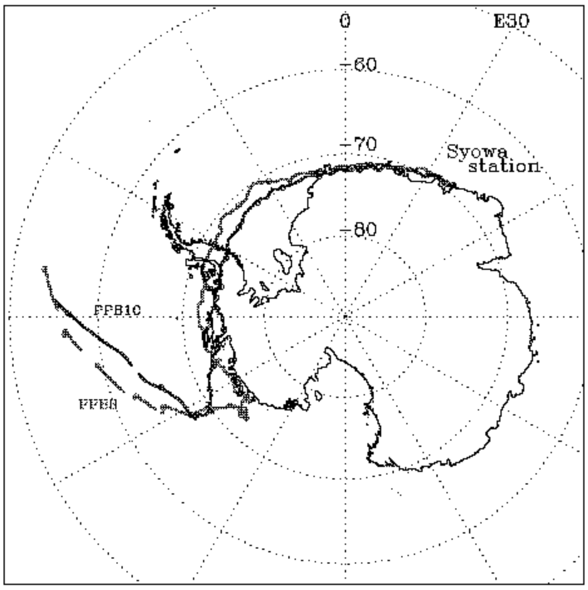


Figure 4: Trajectories of PPB8 and PPB10.

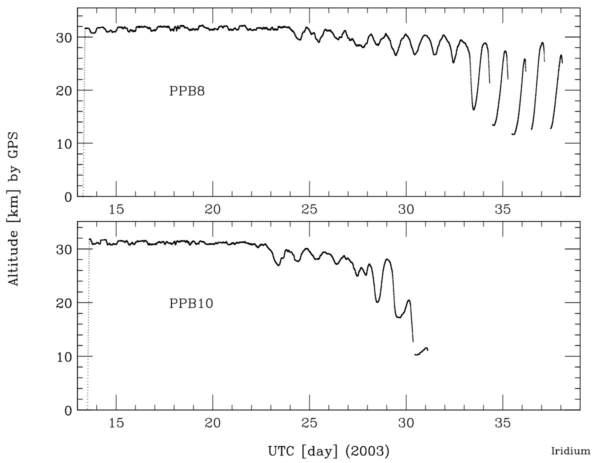


Figure 5: Altitude curves of PPB8 and PPB10.

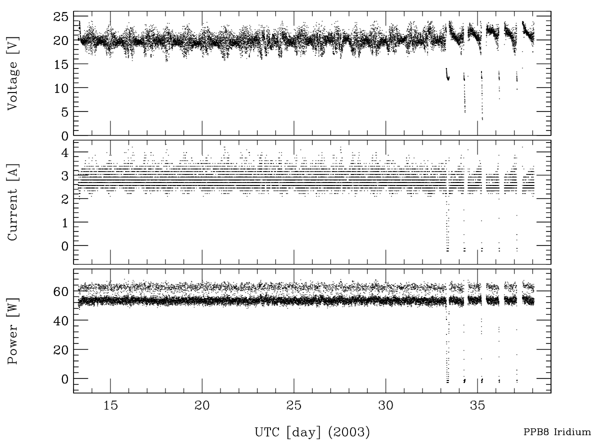


Figure 6: The solar panel voltage, consumed current and power for PPB8.

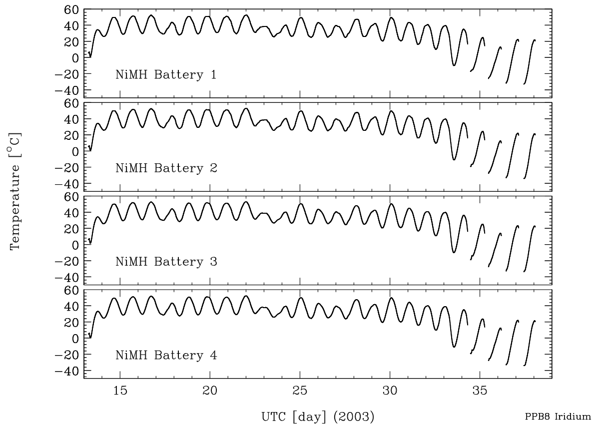


Figure 7: Temperatures of NiMH batteries on PPB8.

scientific point of view. Fortunately, bacause the balloons encounted magnetic storms during the flight, the preliminary analysis has indicated some interesting phenomena. In addition, since the separation of the two balloons ranged from 150 km to 1500 km depending on time, correlation of events at various kinds of scale is possible to be studied using the simultaneous observations.

## 5. Retrial in 2004

The unlaunched PPB7 was retried in 2004 as a project of JARE45 (PPB7'). To avoid the problem caused by the static electricity, we changed the command system. In addition, parameters for the power managing system and the auto-level controller were tuned based on the last experiments and a pressure switch was set to terminate the operation if the altitude of the balloon decreased below 20 km.

The balloon was launched from the C heliport of Syowa station again on Jan. 4, 2004 using the static launching method. During the launching operation, at first, the wind speed was around 4 $m \cdot s^{-1}$, then it gradually sped up, and at last, it was around 6 $m \cdot s^{-1}$. While it was launched successfully, the film may have been damaged while beubg held by the roller during the launch operation.

Fig. 8 and 9 show the trajectory and the altitude curve of the balloon. It flew for 13 days supported by the perfect operation of the housekeeping system. The ballast consumption was 3 to 4 % for each night this time. The electron sensor was also operated well in obtaining a few hundreds of high energy electrons successfully.

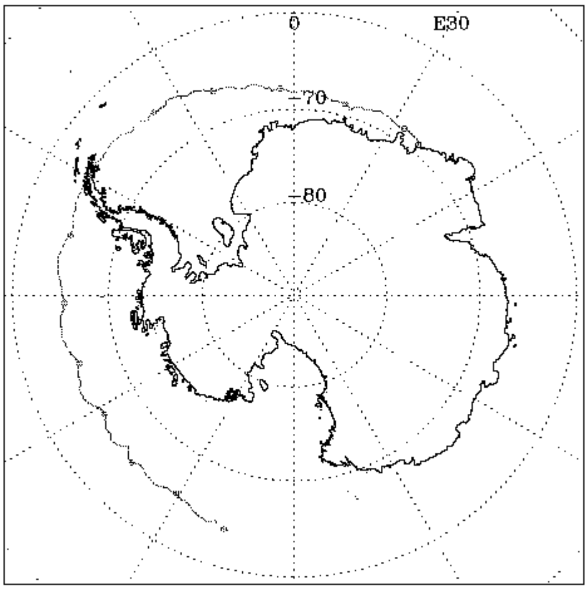


Figure 8: Trajectory of PPB7'.

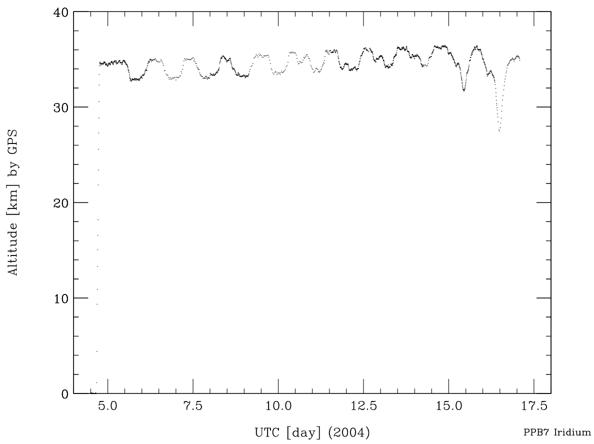


Figure 9: Altitude curve of PPB7'.

## Acknowledgment

The PPB experiments were performed as projects of JARE44 and JARE45. The launching operation were performed with the kind assistance of the members of JARE43, JARE44 and JARE45. The safe and comfortable voyages across the Antarctic sea were thanks to the Shirase members. We thank all the members who have helped us with this PPB project.

## References

[1] J. Nishimura *et al.*, "Feasibility Studies of Polar Patrol Balloon", *Adv. Space Res.* Vol.5, Issue 1, pp.87-90, 1985
[2] S. Torii *et al.* "Observations of high-energy electrons with the bets instrument and the future prospects" *Adv. Space Res.* Vol.30, Issue 5, pp.1273-1282, 2002
[3] M. Ejiri *et al.* "Polar patrol balloon experiment in Antarctica" *Adv. Space Res.* Vol.13, Issue 2, pp.127-130, 1993
[4] M. Ejiri *et al.* "Polar patrol balloon project in Japan" *Adv. Space Res.* Vol.14, Issue 2, pp201-209, 1994
[5] Iridium Satellite Solutions, http://www.iridium.com/