—研究ノート—
Scientific Notes

Polar Patrol Balloon (PPB) Experiment of the 30th Japanese Antarctic Research Expedition (1989–1990)

Akira KADOKURA[1], Masaki EJIRI[1], Shigeo OHTA[2]
and Hiromitsu AKIYAMA[2]

第 30 次南極地域観測隊 (1989–1990) における PPB 実験結果の一考察

門倉　昭[1]・江尻全機[1]・太田茂雄[2]・秋山弘光[2]

要旨: 第 30 次南極地域観測隊では 1990 年 1 月に 1 機の極域周回気球 (PPB) 実験を行った. 放球日は 1 月 5 日で, アルゴスシステムを利用して 2 月 2 日までの位置データ, 2 月 7 日までの house keeping (HK) データを取得することが出来た. 完全周回は実現出来なかったものの, 南極大陸の回りを約 7/8 周し, 気球工学上の様々な情報を得ることが出来た. 高度を一定に保つためのオートバラストシステムは正常に動作し, 放球後 15 日目にすべてのバラストを消費してしまうまで気球高度を 27 km 以上に維持した. それ以後気球高度は次第に低下していった. 15 日目まで気球は西回りに約 18.7°/日の安定した速さで周回していたが, 次第に周回速度が落ち, 1 月 25 日には停滞し, 1 月 29 日からは逆に東回りに動き始めた. 気球高度での時々刻々の太陽天頂角と幾何学的日没時の太陽天頂角を計算し, バラスト投下量との関係を調べたところ, 1 日のうちの太陽天頂角の最大値が 92.4° より大きくなる頃からバラスト投下量が増大していることがわかった. また昭和基地上空の東西風の変化から気球の周回速度や周回方向の変化を説明することが出来た.

Abstract: The 30th Japanese Antarctic Research Expedition (JARE-30) performed a Polar Patrol Balloon (PPB) experiment in January 1990. The launching date was January 5th. We could obtain position data until February 2nd and house keeping data until February 7th through ARGOS system. The trajectory of the PPB was about seven-eighth of a perfect circumpolar one. Auto-ballast system was normally operated to keep the flight level above 27 km until 15 days after launch when all the ballast had been consumed, and then the balloon height became lower and lower. Before the ballast was completely consumed, the balloon drifted westward with a constant speed of about 18.7° per day by an easterly wind. After that the drifting speed gradually slowed down, eventually became zero on January 25th. On January 29th the balloon started drifting eastward. We calculated solar zenith angle and sunset angle at balloon height and found that the increase of ballast consumption began at the time when the maximum solar zenith angle became greater than a critical angle, in our case 92.4°. In order to understand the balloon drifting motion we referred to height profile data of zonal wind at Syowa Station during our flight. It was shown that when the balloon changed its drifting direction, the zonal wind direction was westerly at the balloon height.

---

[1] 国立極地研究所. National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173.

[2] 宇宙科学研究所. Institute of Space and Astronautical Science, 1–1, Yoshinodai 3-chome, Sagamihara 229.

南極資料, Vol. 35, No. 2, 143–154, 1991
Nankyoku Shiryô (Antarctic Record), Vol. 35, No. 2, 143–154, 1991

1. Introduction

In austral summer, a zonal wind in the stratosphere becomes stable with low velocity and westward direction. If we launch a balloon during this time, we can expect it should make a circular trajectory around Antarctica and return to the launching area several weeks later. Various geophysical and astrophysical observations by using these two characters, *i. e.* long duration and recurrence, can be expected with this balloon. This project called "Polar Patrol Balloon (PPB) project" has started in 1984 as a 5-year project. In early years of the 5 years several balloon technological systems to support PPB were developed; for example, auto-ballast system which can maintain flight level above any desirable height, and data acquisition system through ARGOS system which makes it possible to obtain observed data even when a balloon floats outside of the direct communication area from a launching site. In December 1987 the 28th Japanese Antarctic Research Expedition (JARE-28) performed two PPB experiments at Syowa Station. Unfortunately these balloons could not accomplish full circular trajectories, but their trajectories followed fairly well the predicted one by YAMANAKA *et al.* (1988). They could obtain many important technological and meteorological data (MIYAOKA *et al.*, 1988). In January 1990, JARE-30 executed another PPB experiment whose purpose was focused onto accomplishing a full circular trajectory. We describe the result of the JARE-30's PPB experiment in this paper. The details of the development and scientific purposes of PPB are described in FUJII *et al.* (1989).

2. System Design of JARE-30's PPB

Figure 1 shows a launching configuration of JARE-30's PPB. We used a B_{15} zero-pressure balloon of 1467 m^3 full volume and 77.1 kg in weight. The payload weight was 124.6 kg including 91.1 kg ballast, so the total weight was 201.7 kg. Figure 2 shows a payload design configuration. We installed a high accuracy pressure gauge, four thermometers and four small solar battery cells to monitor solar radiation. Obtained data were transmitted by ARGOS system transmitter to the NOAA satellites and by two FM transmitters to the ground station. We had a command receiver which could react to two command signals of ranging and ballast casting-down. The electric circuit consisted of three parts of auto-ballast, amplifier and PCM. All electric power was provided from lithium batteries. The purpose of JARE-30's PPB was to accomplish a full circular trajectory, so that any other scientific instruments were not installed in our payload. Some fixed amount of ballast is cast down from the payload automatically if the payload height becomes lower than a preset level, which is called "auto-ballast control". In our case the auto-ballast control was activated at height lower than 20.3 mb (about 27 km) when the balloon descended and ceased at height higher than 20.2 mb when it ascended. The time interval and the casting amount of ballast when the auto-ballast control was activated was 1 kg per 3 min. The auto-ballast control was set not to be able to work for safety until 5 hours after launch. We used ARGOS system to obtain data when the balloon was outside of direct communication range from Syowa Station. Our ARGOS telemetry consisted of 16 channels 1 byte data, and a transmitting interval was 40 s.

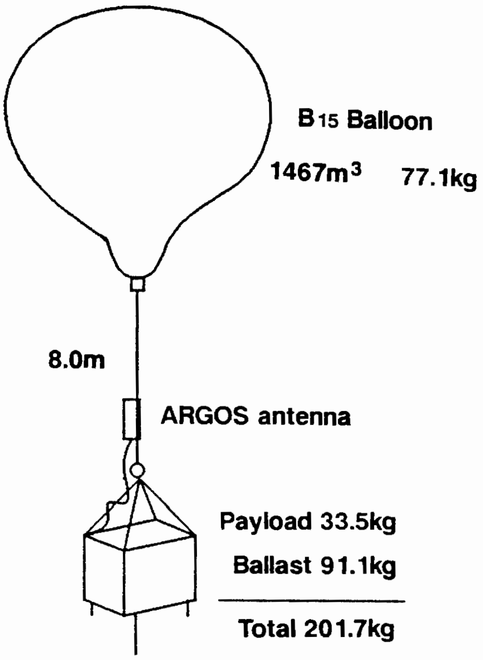

Fig. 1. *Launching configuration of JARE-30's PPB.*

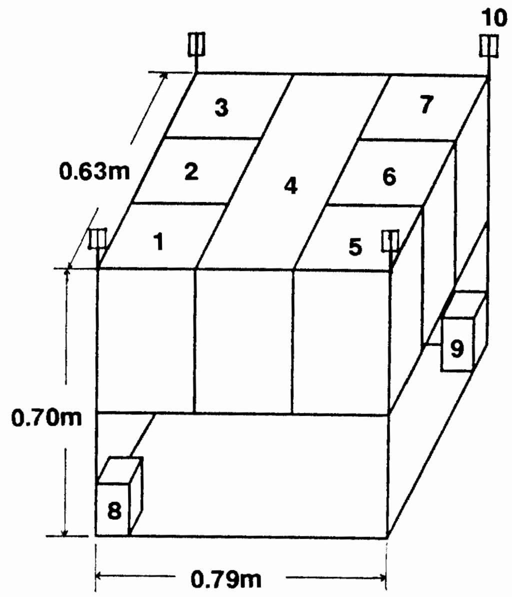

Fig. 2. *Payload configuration of JARE-30's PPB. 1: pressure gauge; 2: Li battery 1; 3: ARGOS telemeter; 4: ballast; 5: command receiver; 6: Li battery 2; 7: electric circuits; 8: FM transmitter 1; 9: FM transmitter 2; 10: solar battery cell.*

3. Launching

We launched the balloon at 0822 UT on January 5th, 1990 from Syowa Station in Antarctica. Because we could not give enough lifting force to the balloon before launching, we needed to cast down 12 kg ballast just after launching and 4 kg during ascending to a ceiling level. Mean ascending speed was 171 m/min, and the balloon reached the ceiling level of about 32 km after about 190 min from the launching. Total weight was 185.7 kg and total ballast weight was 75.1 kg at that time. The balloon drifted westward and went out of the telemetry receiving range of Syowa Station at 0030 UT on January 6th. Figures 3 and 4 show the height time profile and the trajectory of the balloon within the telemetry range of Syowa Station, respectively.

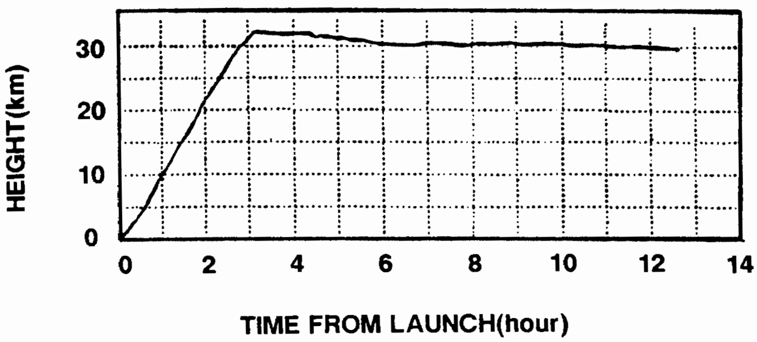

Fig. 3. *Height time profile of PPB within the telemetry range of Syowa Station.*

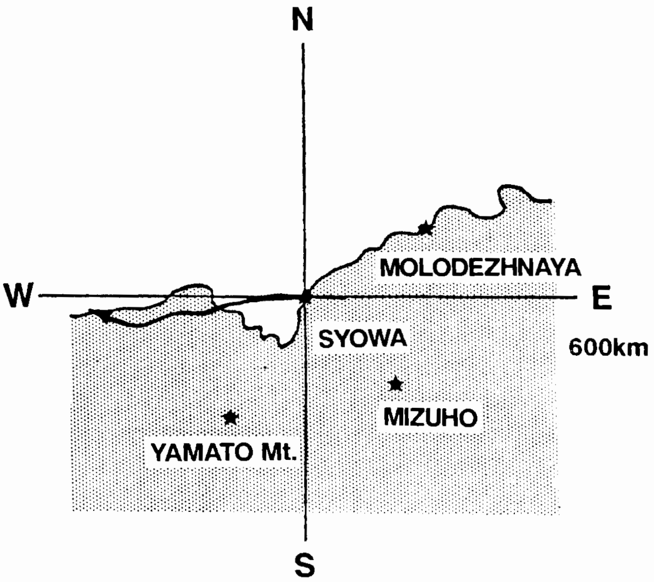

Fig. 4. Trajectory of PPB within the telemety range of Syowa Station.

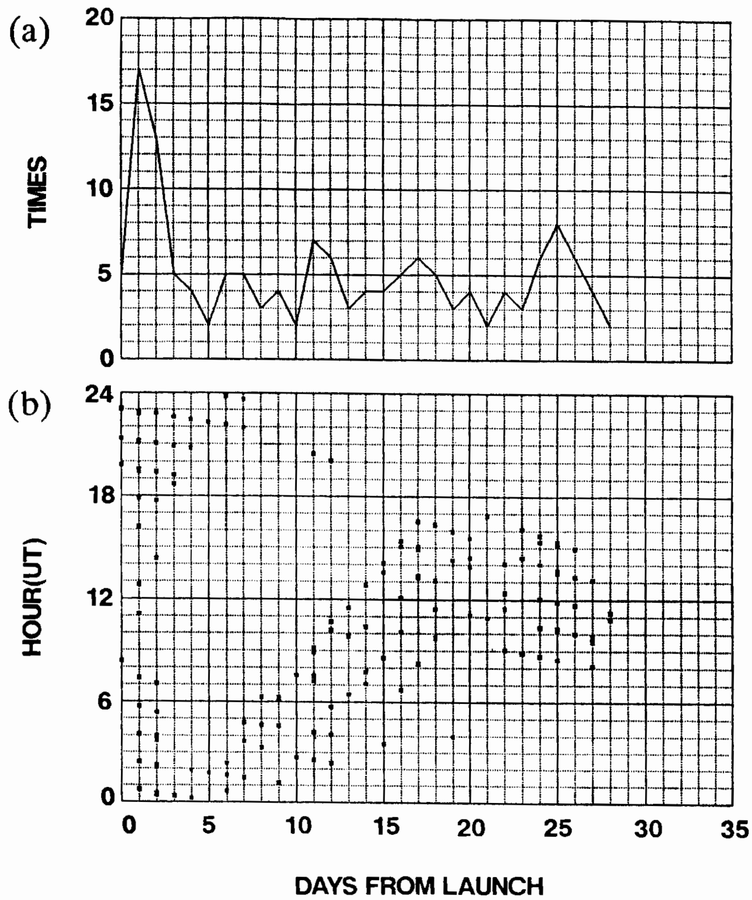

Fig. 5. Frequency of the position data acquisition by ARGOS system. Ordinates show how many times (a) and when (b) the position data was acquired in a day, respectively. The abscissa is time from launch.

4. Results

By using ARGOS system we obtained position data until February 2nd and observation data until February 7th. Figure 5 shows how many times (a) and when (b) the position data was acquired in a day, the abscissa being a time after launch. Figure 6 is almost same as Fig. 5, but shows how many minutes (a) and when (b) the observation data was collected in a day. In Fig. 5 we can see that the position of the balloon, from the 3rd day after launch to the end, was determined at 4 times on an average for some limited hours in a day. Observation data collection was made rather continuously, from start to the end, for 339 min in a day on an average, as can be seen in Fig. 6.

A thick line in Fig. 7 shows the full trajectory of our PPB. Shaded area corresponds to a region between calculated monthly averaged wind stream line at 31 km in January and in December from YAMANAKA *et al.* (1988). After launch the balloon drifted steadily westward around Antarctica. Its drifting speed got gradually slow down from January 20th, become stagnant on 26th and the balloon started moving reversely eastward from 29th. Eventually we could not accomplish a full circular trajectory. In Fig. 7 we can see that our trajectory follows fairly well the calculated

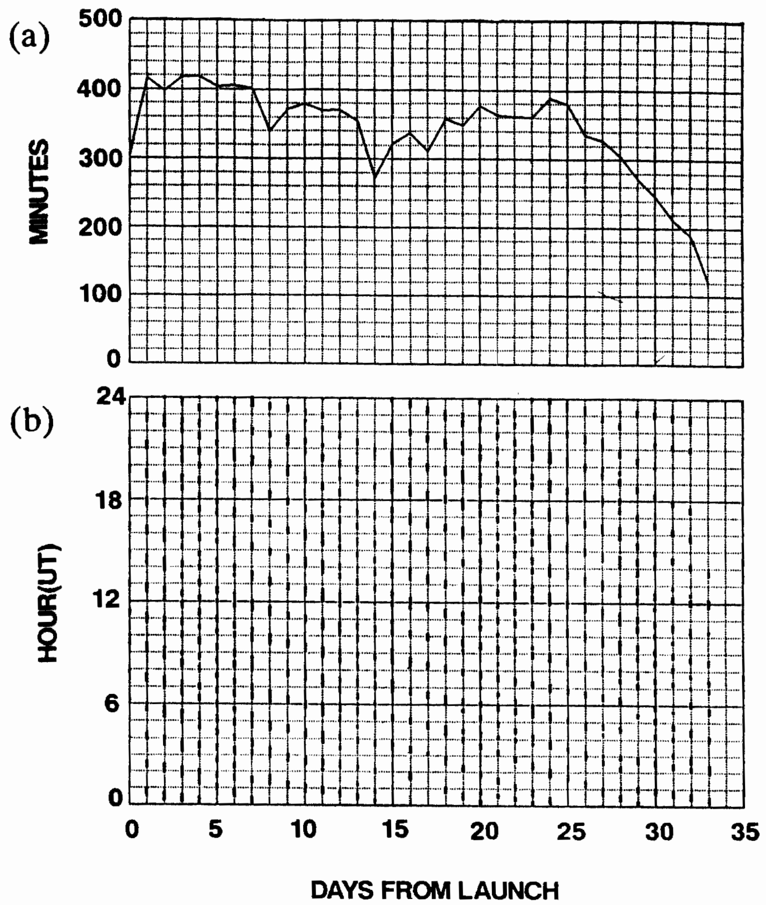

Fig. 6. Frequency of the observed data acquisition by ARGOS system. Ordinates show for how many minutes (a) and when (b) the position data was collected in a day, respectively. The abscissa is time from launch.

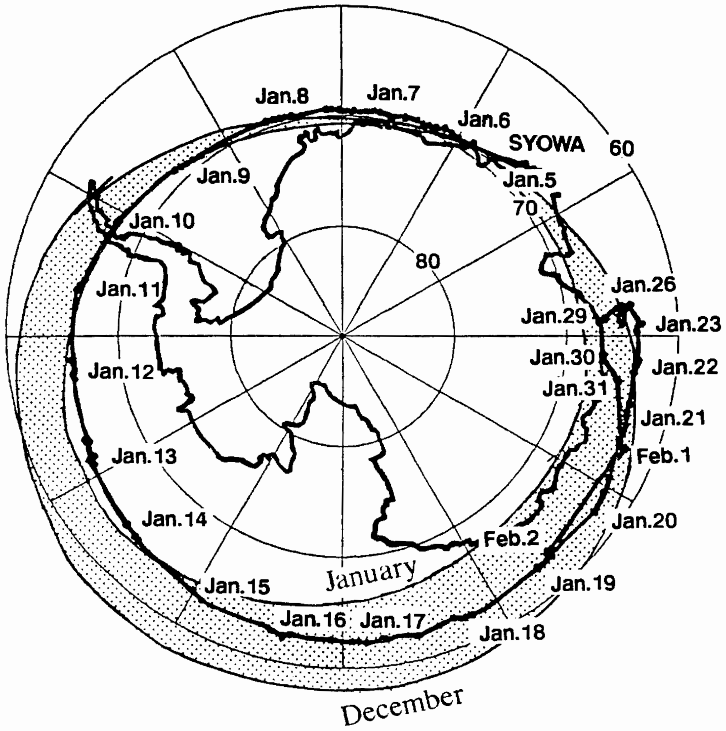

Fig. 7. Full trajectory of PPB (thick line). Shaded area corresponds to the region between calculated monthly averaged wind stream line at 31 km in January and in December from YAMANAKA *et al. (1988).*

stream lines.

Figure 8 shows the pressure gauge output in high gain mode (a) and low gain mode (b). The abscissa is a time from the launching day, and the ordinate is a pressure in mb. The solid triangles and numbers below them in Fig. 8a show time and amount of ballast casting, respectively. Auto-ballast control began to work on the 3rd day after launch, and from the 5th day it worked continuously in each up-and-down motion to maintain flight level above the preset height of about 20 mb which corresponded to about 27 km. The amount of casting ballast began to increase from the 8th day, and total ballast mounted in the payload has been consumed on the 15th day. We could not control the flight level after that day, and both the maximum and the minimum balloon heights were going down and the height difference became larger than before. On January 29th when the balloon changed its drifting direction, the minimum height reached down to about 90 mb (about 16.5 km). Because the battery voltage for amplifier circuit gradually went down from around the 28th day, observed data were very doubtful after that day. Tip marks at the top of each panel show the time of position data acquisition by ARGOS system. We can see that almost all position determination was made during downward motion of the balloon, which was the case especially in auto-ballast control working period. Figure 9 shows the time history of the casting ballast amount.

Figure 10 shows latitude (a) and longitude (b) time profile of the balloon. Ballast casting time and amount are also shown in the same manner as in Fig. 8a. After the launching the balloon drifted to lower latitudes, and casting ballast amount increased

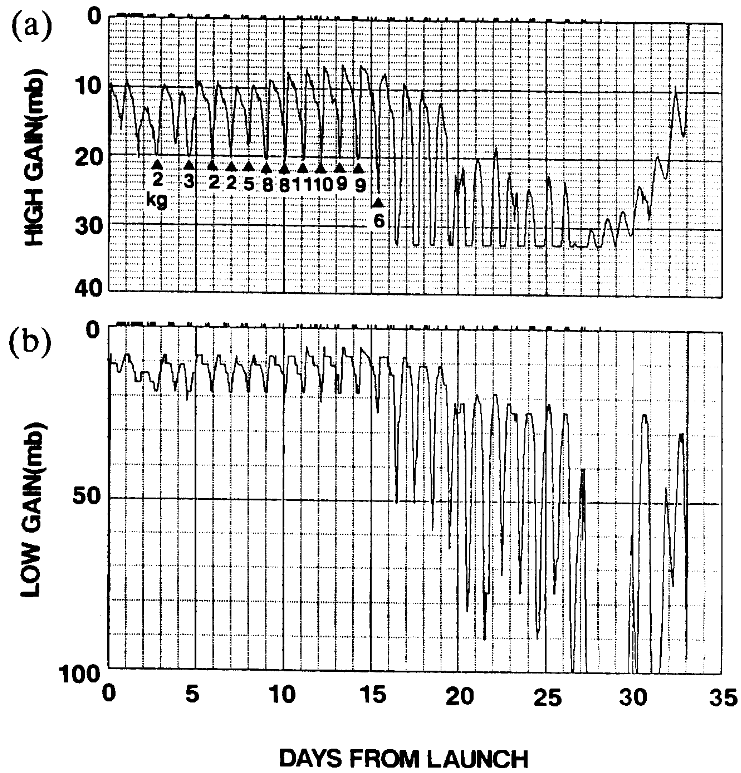

Fig. 8. Pressure gauge output in high gain mode (a) and low gain mode (b). Abscissas are time from launch, and ordinates are pressure in mb. The filled triangles and numbers below them in (a) show time and amount of ballast casting, respectively. Tip marks at the top of each panel show the time of position data acquisition.

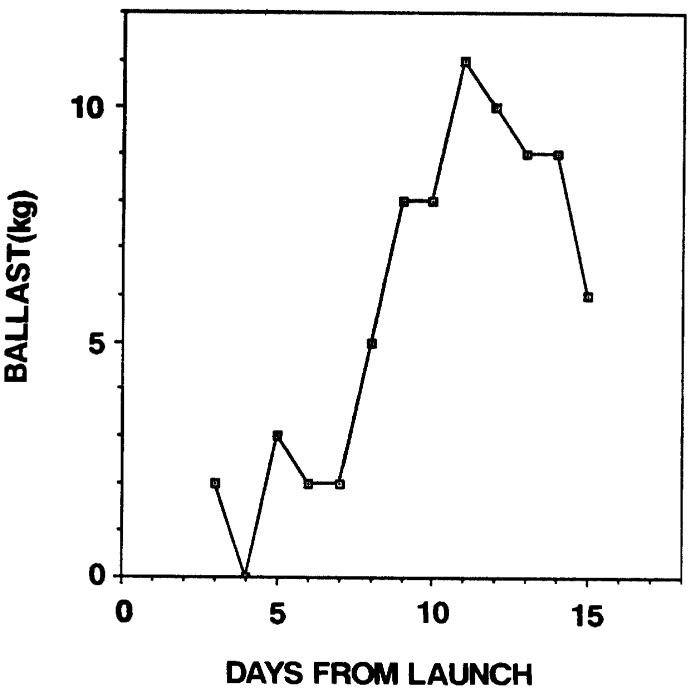

Fig. 9. Time history of the casting ballast amount.

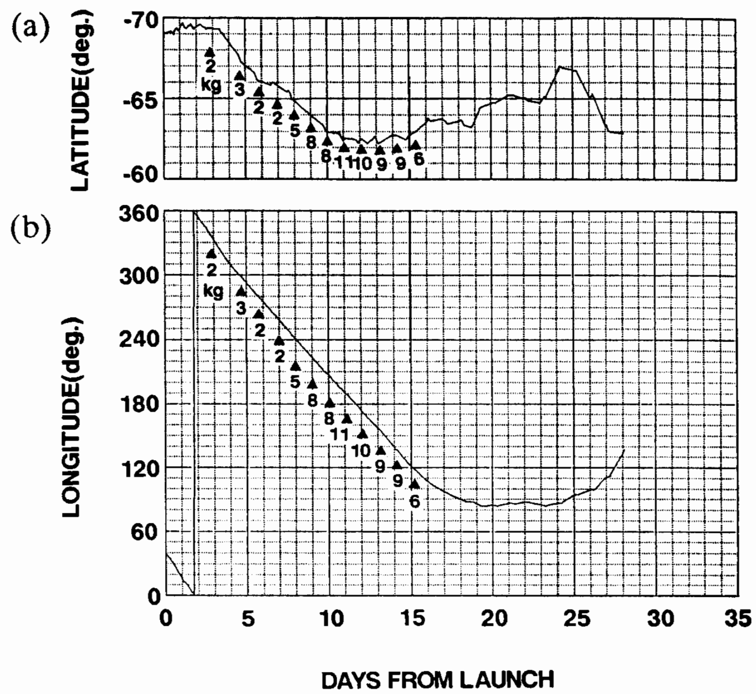

Fig. 10. Latitude (a) and longitude (b) time profile of the balloon. Ballast casting time and amount are also shown in the same manner as in Fig. 8a.

when the balloon reached at about 65° latitude. The westward (longitudinal) drifting speed was nearly constant, about 18.7° per day, until the day when total ballast was consumed. If this speed was maintained, we could expect that the balloon should return to the area around the launching site after about 20 days from launch.

5. Discussion

We have two questions. One is why the ballast has been perfectly consumed on the 15th day after launch in the halfway of circular motion, and the other is why the balloon changed its drifting direction on January 29th. To find an answer to the former question we calculated instantaneous solar zenith angle at the balloon height, which is shown in Fig. 11. In this figure solid inverse triangles and numbers above them are again the time and amount of casting ballast, and the line around 95° zenith angle is the geometrical sunset zenith angle at the balloon height. In local daytime the solar zenith angle becomes small and in nighttime large, so one cycle of wave form in this figure shows one local day. If this wave form is above the line of geometrical sunset angle, then there is no sunset at the balloon height. Now we concentrate on examination of the maximum angle of the daily change. After launch it gradually became closer to the sunset level because the balloon drifted to the lower latitudes as shown in Fig. 10 and from the 10th day it went below the sunset level, which means the balloon entered a sunset region. If the solar zenith angle becomes greater than 90°, an optical length of a solar radiation through the air becomes much larger and larger, and the weakened radiation results in falling down of the temperature inside the balloon, *i. e.* decrease in its buoyancy. Basically speaking, to stop its downward

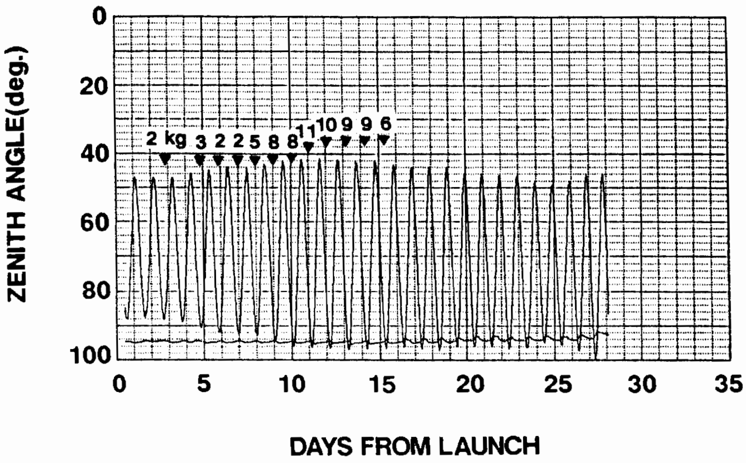

Fig. 11. Calculated instantaneous solar zenith angle at the balloon height. Filled inverse triangles and numbers above them are again the time and amount of casting ballast, and the full line around 95° zenith angle is the geometrical sunset zenith angle at the balloon height. The abscissa is time from launch.

motion a balloon must cast down so much ballast as comparable to the weight difference between its total weight and buoyancy, which is called "free buoyancy". This means that the smaller buoyancy for same total weight needs the greater amount of casting ballast. So that we can expect the reduced solar radiation is closely related with the casting ballast amount. To see this relation we calculated the duration in which the solar zenith angle was greater than 90° and than sunset angle in each local day. Figure 12 shows the result. The duration for 90° appeared from the 5th day after launch and for sunset angle from the 10th day; on the other hand, the increase

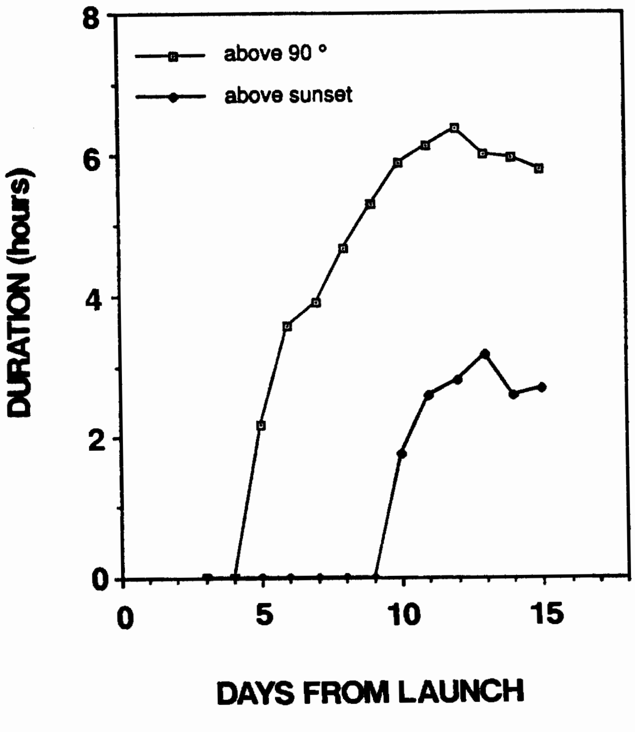

Fig. 12. Duration in which the solar zenith angle was greater than 90° and than sunset angle in each local day.

of the casting ballast amount began from the 8th day as shown in Fig. 9. From this result we can expect that there should be some "critical" angle to the ballast casting between 90° and sunset angle, and the duration for the angle should be zero until the 7th day and first appear on the 8th day. If we assume this angle is the maximum value on the 7th day, then the critical angle is 92.4°. To compare the duration for 92.4° with the casting ballast amount, we calculated a ratio to the value on the 8th day for each case. Figure 13 shows the result. We can see both time changes from the 8th

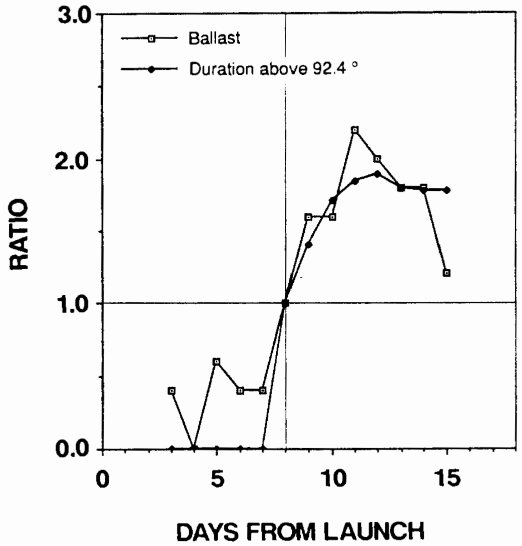

Fig. 13. Duration in which the solar zenith angle was greater than 92.4° and casting ballast amount. We plot a ratio to the value on 8 days after launch for each case.

day look very much alike except on the 15th day when the ballast has been perfectly consumed before we cast down enough amount to stop downward motion of the balloon. Figure 13 shows there may be some linear relation between the duration and the casting ballast amount, but we cannot go further to a quantitative discussion without a strict consideration about heat process which determines a temperature inside balloon. That is a future problem. Now we present a qualitative answer to our first question. After launch the balloon drifted to the lower latitudes and went closer to a sunset existing region, and finally it entered a "critical region" on the 8th day after launch where the solar zenith angle at the balloon height became greater than a "critical angle" between 90° and sunset angle. From that day the casting ballast amount was proportional to the duration of the balloon's stay in the critical region. To summarize our story, the duration in the critical region becomes longer, the solar radiation reaching the balloon weaker, the temperature inside the balloon lower, its buoyancy smaller, its free buoyancy larger, and then the casting ballast amount becomes larger. We can say that a cause of the increase of casting ballast amount was the drifting motion of the balloon to the lower latitudes.

We move on to the next question. Figure 14 shows the zonal wind profile above Syowa Station obtained by regular daily meteorological observation at 0000 UT from December 1989 to February 1990. Interval of each contour line in this figure is 5 m/s and shaded area shows westerly wind. Two dotted lines are traces of the maximum and minimum heights of the balloon, respectively. Until January 20th auto-ballast control maintained the flight level above about 27 km and the balloon floated in an easterly wind region. After that day when the ballast has been completely consumed the flight level went down, and on January 29th when the drifting direction changed reversely the balloon stayed in a westerly wind region for whole hours. If the auto-ballast control worked during the whole flight time, the balloon could float in an easterly wind region for almost whole hours even after January 29th, and we could expect a full circular trajectory.

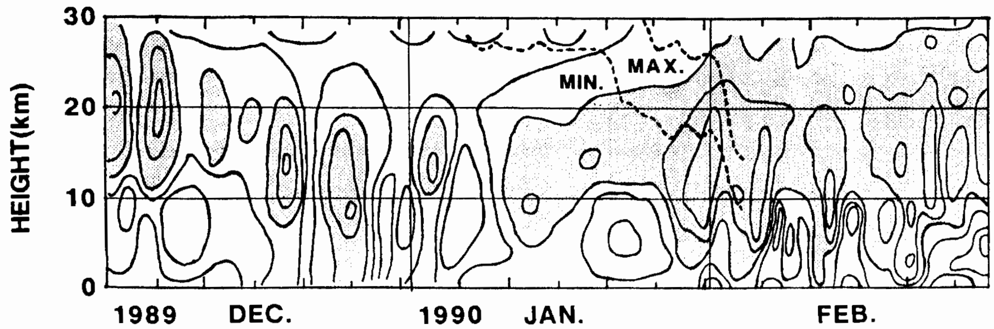

Fig. 14. Zonal wind profile above Syowa Station obtained by regular daily meteorological observation at 0000 UT from December 1989 to February 1990. Interval of each contour line in this figure is 5 m/s and shaded area shows westerly wind. Two dotted lines are traces of the maximum and minimum heights of the balloon, respectively.

6. Summary

We could not accomplish a circumpolar trajectory which was the main purpose of JARE-30's PPB. All the ballast has been consumed on the 15th day after launch and the balloon changed its drifting direction reversely on the 24th day. After launch the balloon drifted to the lower latitudes and went close to a sunset region. The increase of casting ballast amount started on the day when the solar zenith angle at the balloon height became greater than an critical angle, in our case 92.4°. After the total consumption of the ballast the flight level went down and the balloon entered a westerly wind region. We need a further study to explain what determines the casting ballast amount, why the flight level went down after the total ballast consumption, and when we should launch our balloon to accomplish a circumpolar trajectory.

Acknowledgments

We wish to express our cordial thanks to all members of JARE-30. Special thanks are due to meteorological members of JARE-30 and JARE-31 who kindly helped us with the use of the upper-air observation data at Syowa Station. The authors would like to thank Messrs. T. Ono and H. Nakazima who kindly shared their time to obtain the ARGOS telemetry telex data in February 1990 at Syowa Staion and to send the information to us. This PPB project have been done under the PPB working Group (Chairman: Prof. N. Yajima of Institute of Space and Astronautical Science). We are very grateful to all members of the Working Group.

References

FUJII, R., MIYAOKA, H., KADOKURA, A., ONO, T., YAMAGISHI, H., SATO, N., EJIRI, M., HIRASAWA, T., NISHIMURA, J., YAZIMA, N., YAMAGAMI, T., OHTA, S., AKIYAMA, H., TSURUDA, K., KODAMA, M., FUKUNISHI, H., YAMANAKA, M. D. and KOKUBUN, S. (1989): Nankyoku shûkai kikyû (PPB) shôrai keikaku 1991–1993 (Polar Patrol Balloon experiment during 1991–1993). Nankyoku Shiryô (Antarct. Rec.), **33**, 320–328.

MIYAOKA, H., MUKAI, H. and SAITO, H. (1988): Pôrâpatorôru kikyû jikken (Polar Patrol Balloon experiment). Nihon Nankyoku Chiiki Kansokutai Dai-28-ji Tai Hôkoku (1986–1988), ed. by Natl Inst. Polar Res. Tokyo, 165–174.

YAMANAKA, M. D., YAMAZAKI, K. and KANZAWA, H. (1988): Studies of middle atmosphere dynamics under the polar patrol balloon (PPB) project: Present status and future plans. Proc. NIPR Symp. Upper Atmos. Phys., **1**, 65–74.

(Received May 1, 1991; Revised manuscript received May 24, 1991)