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# TRAJECTORY ANALYSIS OF POLAR PATROL BALLOON (PPB) FLIGHTS IN THE STRATOSPHERE OVER ANTARCTICA IN SUMMER AND SPRING: A PRELIMINARY RESULT

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## ABSTRACT

Actual trajectories of two PPBs which flew in the Antarctic stratosphere in austral summer and spring are compared with those calculated based on objective analysis data of Japan Meteorological Agency (JMA). The differences between the actual and calculated trajectories are discussed to check reliability of the JMA objective analysis data for the stratosphere, and to detect sub-synoptic scale variability due to gravity waves and others.

## 1. INTRODUCTION

The Polar Patrol Balloon (PPB) project is to execute a long duration circumpolar balloon experiment in the Antarctic using a zero-pressure balloon with an auto-ballast control to keep it at an almost constant pressure level in the stratosphere. The PPB project has been developed under cooperation between the Institute of Space and Astronautical Science (ISAS) and the National Institute of Polar Research (NIPR): See, e.g., Nagata *et al.* (1985), Nishimura *et al.* (1985), Yamanaka *et al.* (1988), Fujii *et al.* (1989), Kadokura *et al.* (1991), and Ejiri *et al.* (1993). The planning of the observation using the PPB has been concretely discussed by the PPB Working Group chaired by N. Yajima (ISAS) and co-chaired by M. Ejiri (NIPR), whose members include H.K., R.F., and M.D.Y.

Actual trajectories of two PPBs launched from Syowa Station (69.01°S, 39.59°E), having flown in the Antarctic stratosphere in austral summer and spring, are compared with those calculated from objective analysis data of the Japan Meteorological Agency. The motivation is to check reliability of the JMA objective analysis data, being intended to describe planetary and synoptic scale phenomena, for the stratosphere, and/or to detect sub-synoptic scale variability due to gravity waves and others.

## 2. DATA AND METHOD OF ANALYSIS

The horizontal positions of the balloon are obtained using the ARGOS location system about 20 times a day with accuracy of 10-20 km. The vertical positions of the balloon are obtained from a pressure sensor data on board the PPB using the ARGOS data collection system about every a few minutes over a period of about 10-15 minutes, 25-30 times a day.

The calculated trajectory is obtained from wind data on the basis of objective analysis of JMA with time resolution of 12 hours and with horizontal resolution of 1.875 degrees for both latitude and longitude on the stratospheric levels of 100, 70, 50, 30, 20, 10 hPa. The objective analysis scheme is described, e.g., by JMA (1990): Geopotential height and temperature above 70 hPa level are analyzed from observational data using two-dimensional least squares fitting method, with zonal wavenumber truncation at wavenumbers 6 to 8 and with latitude resolutions of 10 degrees. The JMA stratospheric analysis, thus, represents scales larger than synoptic scale.

The winds are calculated from geopotential height data of JMA objective analysis on the assumption of "balance winds", which gives better estimate for winds than that of geostrophic winds by taking account of local wind curvature effects (Randel, 1987). The "balance winds" adopted in the present study are found to estimate the actual trajectory better than the conventionally used geostrophic winds. The winds are linearly interpolated in space to the position of the PPB, and in time at the time interval of 0.5 hours (30 minutes). The calculated trajectory is obtained by advection of the winds from an initial position of the actual PPB, following the method described in Yamazaki (1987) and Yamazaki *et al.* (1989). The dependence of the trajectory on the initial positions is not so strong according to the trajectory calculations.

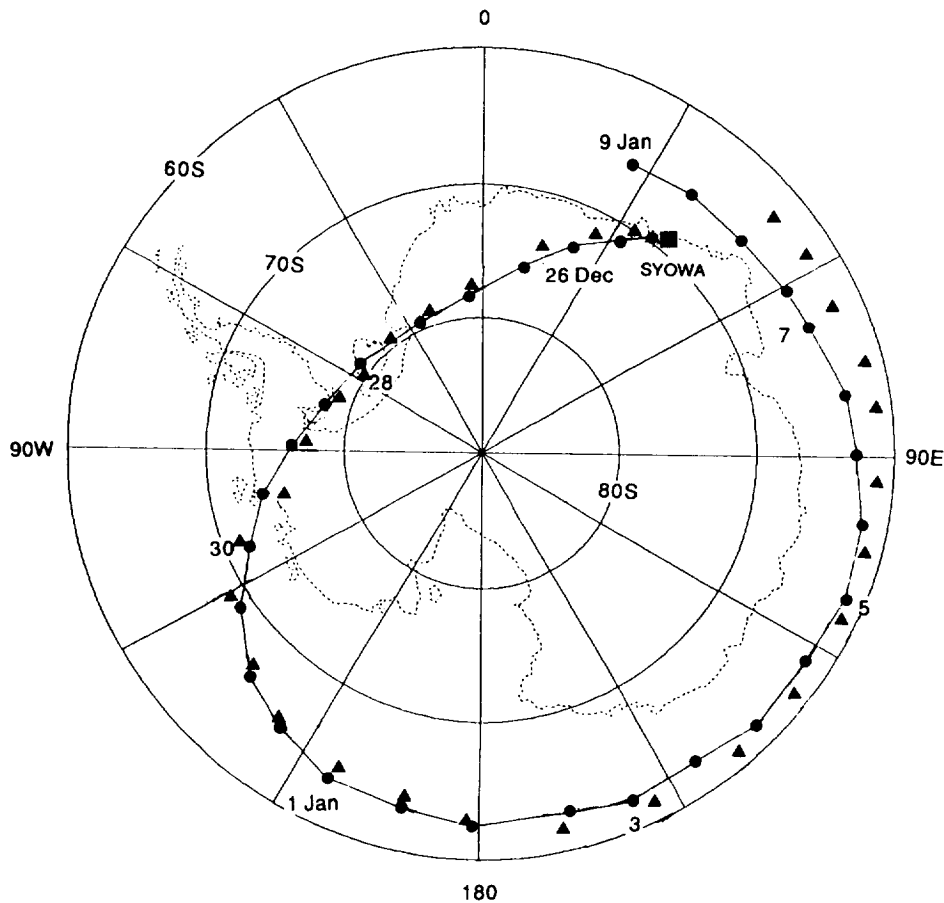


Fig. 1. Actual trajectory of the PPB (●) versus calculated trajectory (▲) in the middle stratosphere in austral summer. Stereographic projection. The data are plotted twice daily (00 UT, 12 UT). The dates assigned to the notation ● means respectively the data of the PPB position at 12 UT on the dates. The calculated trajectory starts from the initial position of the PPB at 12 UT on 25 December 1990 (69.47°S, 38.00°E, 14.0 hPa). It is obtained on the assumption that the air parcel moves by the balance winds from the JMA objective analysis, taking account of the change of the pressure level of the PPB as shown in Fig. 2.

### 3. SUMMER FLIGHT IN DECEMBER 1990 JANUARY 1991 IN THE MIDDLE STRATOSPHERE

As shown in Fig. 1, a balloon for observation of magnetic field was launched at 08:25 UT on 25 December 1990, and directed westward around the 10-20 hPa level (~31 km) to come back to Syowa Station on 9 January 1991 about 15 days after the launch. It moved more westward in the stratosphere to reach about 65°S, 135°W on 19 January after about one and a half round flight, and at last dropped to the Indian Ocean around 31 January.

Figure 2 shows time variation of pressure level of the PPB at the time interval of 0.5 days (12 hours). The PPB flew between 10 hPa and 18 hPa levels in the middle stratosphere until about day 20 in Fig. 2 (12 UT 14 January 1991). The up and down motion of the PPB is due to using the zero-pressure balloon: It releases helium gas during sunshine, and its level is kept by an auto-ballast system. Around day 25 (19 January 1991), the balloon dropped into the troposphere after consuming the ballast.

The actual trajectory of the PPB in the stratosphere for the round flight till 9 January 1991 is compared with the calculated trajectory in Fig. 1. The initial position for the calculation is the actual position of the PPB at 12 UT on 25 December 1990; 69.47°S, 38.00°E, 14.0 hPa. The wind data being interpolated on the actual pressure level of the PPB at each time step of 0.5-hour interval are used for the calculation: The calculated trajectory for this case considers the variation of pressure level of the PPB shown in Fig. 2.

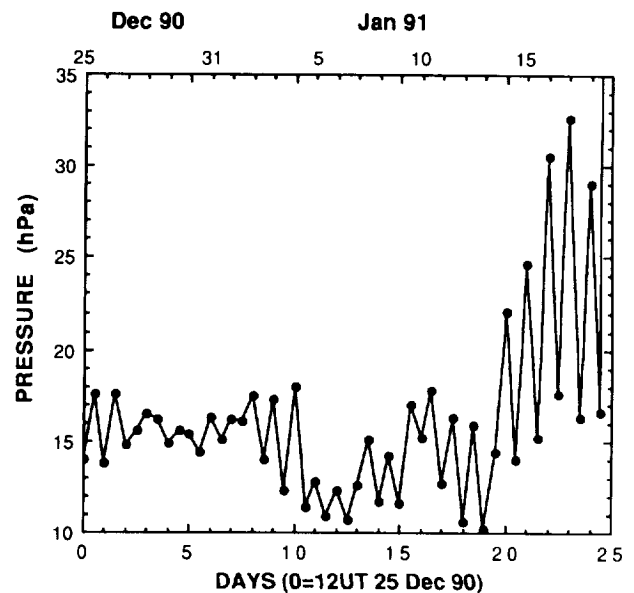


Fig. 2. Time variation of pressure level of the PPB for the summer flight. Time in abscissa is in unit of day after 12 UT on 25 December 1990. The data are plotted at an interval of half a day. Calendar dates of December 1990 and January 1991 are assigned at the top abscissa.

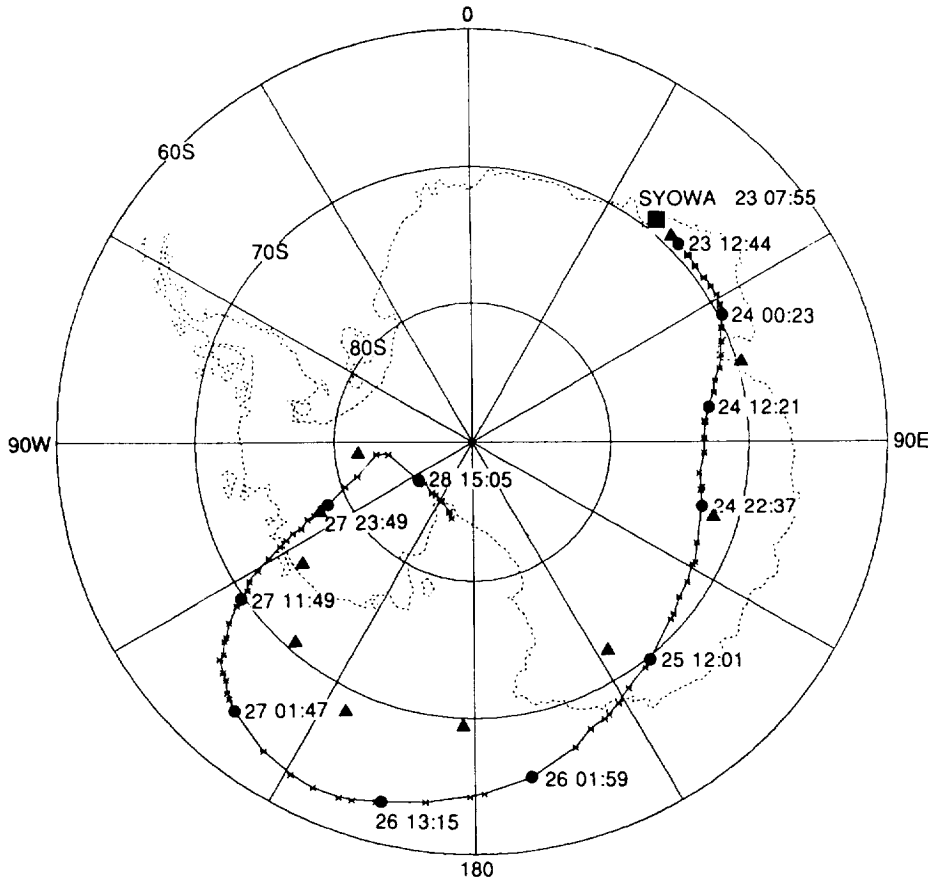


Fig. 3. Actual trajectory of the PPB (●) versus calculated trajectory (▲) in the lower stratosphere in austral spring. Stereographic projection. All of the obtained ARGOS positioning data of the PPB are plotted with asterisks. The data whose time are nearest to 00 UT and 12 UT on each day among the obtained data are plotted with the notation ● to which the dates and times are assigned. The calculated trajectory starts from the initial position of the PPB at 12 UT on 23 September 1991 (69.25°S, 45.15°E, 80 hPa). It is obtained on the tentative assumption that the air parcel moves by the balance winds at the 80 hPa level from the JMA objective analysis, *i.e.*, taking no account of the change of the pressure level of the PPB. The positions are plotted twice daily (00 UT, 12 UT).

The actual trajectory fairly well coincides with the calculated one. This confirms that the wind flow has little variability in time and space in the summer stratosphere over Antarctica, as has been anticipated from a lot of consideration on the basis of observation and theory of planetary and synoptic scale flow in the stratosphere. The smoothness of the actual trajectory of the PPB itself suggests that planetary scale flow is dominant in comparison with synoptic and sub-synoptic scale one. The situation of the stratosphere is different from that of the troposphere as shown in super-pressure balloon experiments in the southern hemisphere troposphere, *e.g.*, of GHOST (Lally and Lichfield, 1969) and EOLE (Morel and Bandede, 1973), in which synoptic scale motions are dominant in the trajectories. The close agreement between the observed and calculated trajectories indicates also that the JMA objective analysis is highly reliable for expressing the actual wind of planetary and synoptic scale in the Antarctic summer stratosphere: But note that the wind speeds of the JMA objective analysis are somewhat smaller than the actual wind speeds. The small difference is considered to come from small scale variability due to gravity waves and others or from inability for the JMA objective analysis to well express the synoptic scale flow.

#### 4. SPRING FLIGHT IN SEPTEMBER 1991 IN THE LOWER STRATOSPHERE

As shown in Fig. 3, another balloon for observation of

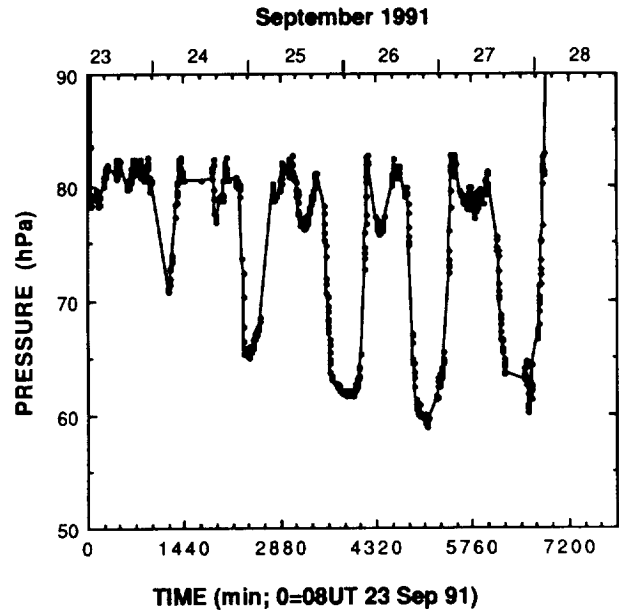


Fig. 4. Time variation of pressure level of the PPB for the spring flight. Time in abscissa is in unit of minutes after 08 UT on 23 September 1991; note that 1440 minutes is a day, and intervals of 240 minutes (4 hours) are marked. Calendar dates of September 1991 are assigned at the top abscissa.

ozone and aerosol was launched from Syowa Station at 07:55 UT on 23 September 1991, directed eastward around the 80 hPa level (~16 km) in the lower stratosphere in the inside of the polar vortex, *i.e.*, inside of the ozone hole, for about 5 days to reach around 80°S, 250°E (110°W) around 02 UT on 28 September after about three-fourth round flight in the stratosphere, and dropped to the Ross Ice Shelf at the earth's surface around 85°S, 200°E (160°W) around 20 UT on 28 September. The plan of the experiment is described in Kanzawa and Kondo (1991), and the results of the ozone and aerosol measurements are presented by Hayashi *et al.* (1992) in the present issue.

Figure 4 shows time variation of pressure level of the PPB at the time interval of 4 minutes. The PPB flew between 60 hPa and 83 hPa levels in the lower stratosphere until 6960 minutes in the time axis (=04 UT on 28 September 1992).

The actual trajectory of the PPB in the stratosphere is compared with the calculated trajectory in Fig. 3. The initial position for the calculation is the actual position of the PPB at 12 UT on 23 September 1991; 69.25°S, 45.15°E, 80 hPa. The balloon is assumed to be on the constant pressure level of 80 hPa. The calculated trajectory for this case does not consider the variation of pressure level of the PPB shown in Fig. 4. We will try the same way as the summer case in near future, *i.e.*, taking account of the variation of pressure level of the PPB. The result may not, however, change so much although the vertical gradients of horizontal winds are considered to give some effects.

Latitudinal difference of both trajectories is larger in spring than in summer: The calculated trajectory is, in general, poleward of the actual one. The JMA wind speed is somewhat larger than the actual one. For example, at the time of 12 UT on 24 September, the calculated position is about half a day forward of the actual one. The forwardness may bring about the poleward position in calculation.

## 5. CONCLUDING REMARKS

For summer case, the JMA objective analysis is highly reliable, and the JMA wind speed is somewhat smaller than the actual one. For spring case, the JMA objective analysis is reliable, and the JMA wind speed is larger than the actual one. Latitudinal difference of the trajectory is larger in spring than in summer. The differences for both cases are considered to be due to sub-synoptic scale motion (*e.g.*, gravity waves) or inability of the JMA analysis to well express synoptic scale motion. The next step to distinguish the cause for the differences is to calculate trajectories using the actual positioning data of the PPB at each time step as initial positions, and to compare the trajectories with the actual one at each time step.

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