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OBSERVATIONS OF THE GEOMAGNETIC FIELD BY POLAR PATROL BALLOON (PPB) EXPERIMENT IN ANTARCTICA

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Abstract: Two scientific balloon experiments of the Polar Patrol Balloon (PPB) project were performed by the 32nd Japanese Antarctic Research Expedition in December 1990 and in January 1991. Proton precession magnetometers were used to measure the total intensity of the geomagnetic field for studying the underground magnetic structure by detecting magnetic anomalies and geomagnetic variations like pulsations. The first balloon (PPB-1) showed a trajectory through the center of the Magnetic South Pole with a circumpolar trajectory. The total intensity of the geomagnetic field as obtained by the ARGOS data transmission system every 30 s with an accuracy of 1 nT during the flight of 22 days. A new proton precession magnetometer system was developed that had a wide dynamical measurement range for the PPB observation. This brief paper reports magnetometry, data processing system and some preliminary results.

1. Introduction

Due to a stable stratospheric zonal wind in Antarctica, the experimental balloon is expected to show a circular trajectory around the Antarctica and to return to the launching site at Syowa Station (YAMANAKA *et al.*, 1988). This experimental project has been conducted and named as Polar Patrol Balloon (PPB) project by the National Institute of Polar Research (NIPR), the Institute of Space and Astronautical Science (ISAS) and collaborative scientists (FUJII *et al.*, 1989). The 28th Japanese Antarctic Research Expedition (JARE-28) performed two test PPB experiments in December 1987 and could obtain many technological and meteorological data (MIYAOKA *et al.*, 1988). In January 1990, JARE-30 has accomplished a PPB experiment with a long-term flight and a full circumpolar trajectory (KADOKURA *et al.*, 1991). JARE-32 has executed three scientific PPB experiments in 1990–1991 and two of them were to measure the geomagnetic field. The geomagnetic total intensity was observed by a new proton precession magnetometer and the data were stably obtained through ARGOS data-transmission system. We describe in this paper the new proton precession magnetometer system for PPB and some preliminary results.

2. Proton Precession Magnetometer for PPB

Proton precession magnetometer (called as proton magnetometer) is a scalar detector and measures a frequency signal proportional to the intensity of the ambient magnetic field. It can measure the absolute intensity of the geomagnetic field with a high accuracy and high resolution. The measurement can be made continuously regardless of sensor direction and the gondola motion. But an ordinary proton magnetometer has a narrow measuring range of 1000–2000 nT in the magnetic field. Assuming that the flight trajectory of PPB is circumpolar along the south latitude of 70°, theoretically expected total intensity of the geomagnetic field varies from 40000 to 65000 nT at the height of 30 km over the earth. We have developed a new type magnetometer with a wide measurement range and with an automatic range switching system.

Figure 1 shows a block diagram of the new type proton magnetometer. Frequency signal through multiple band-pass filters must be counted within a short time. CPU controls tuning switches that are composed of 20-step narrow band-pass filters. During the initial stage just after the launch or at the region where a large gradient of the magnetic field exists, automatic tuning system need to search a resonable frequency band rapidly. In this range searching mode, a measuring period becomes short automatically. The resolution of measurement is 1 nT and the dynamic range has a wide band from 40000 nT to 70000 nT. The sensor of proton magnetometer is composed of a 1000-turn ring core coil, kerosene menstruum and a pressure safety valve. Exciting drive current is 2.8 A for 3 s interval. Sampling rate is every 30 s during the flight and can also select 8 or 16 s or by an external trigger signal on ground test mode. The sensor was hung at 15 m below from the gondola in order to keep away from magnetic influence of the gondola. Output signal is converted to 16-bit digital format and transmitted to a telemetry system.

As the ground calibration, characteristics of sensitivity and S/N ratio were measured, and automatic tuning test and long-running operation were checked at Kakioka Magnetic Observatory. Temperature test, vacuous test and electric total system tests were carried out at ISAS. The power for drive current was supplied from lithium

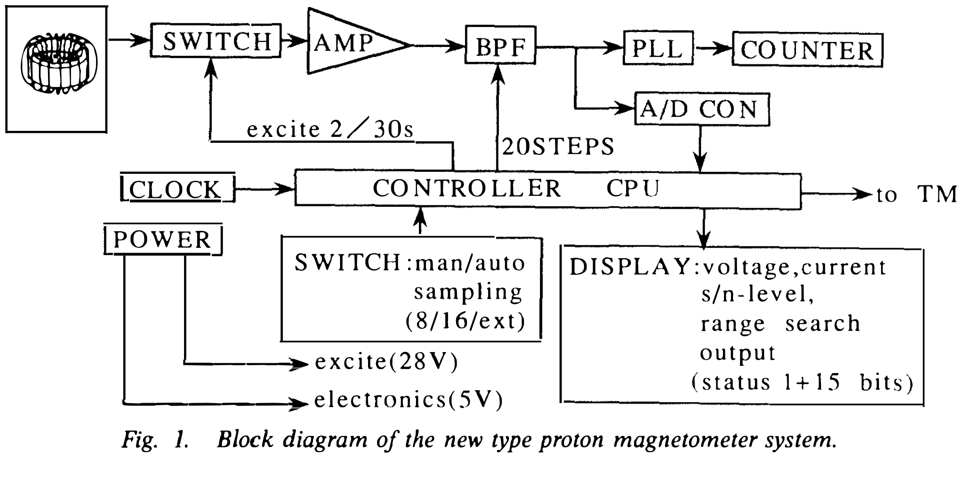

Fig. 1. Block diagram of the new type proton magnetometer system.

Table 1. Characteristics of the proton magnetometer.

Dynamic range	40000–70000 nT	
Resolution	1 nT	
Sampling period	32 s	
Exciting power	28 V×2.8 A×2 s	
Power supply	28 V×90 AH (22 days)	
Output format	digital 16 bits	
Size/Weight	electronics	180×300×150 mm/6.0 kg
	sensor	140ϕ×150 mm/4.5 kg
	battery	170×310×150 mm/7.5 kg

batteries that provided a voltage of 28 V and a capacity of 90 AH which is enough for continuous measurement for 3 weeks. The specification of proton magnetometer for PPB is shown in Table 1.

3. Balloon System and Launching

The constitution of the first balloon, PPB-1 and data acquisition system is shown in Fig. 2. Instruments were a proton magnetometer for scientific observation and a barometer, temperature sensors, data recorder, telemeter, CPU, command receiver and ARGOS transmitter as house keeping system. For the second balloon, PPB-2, an

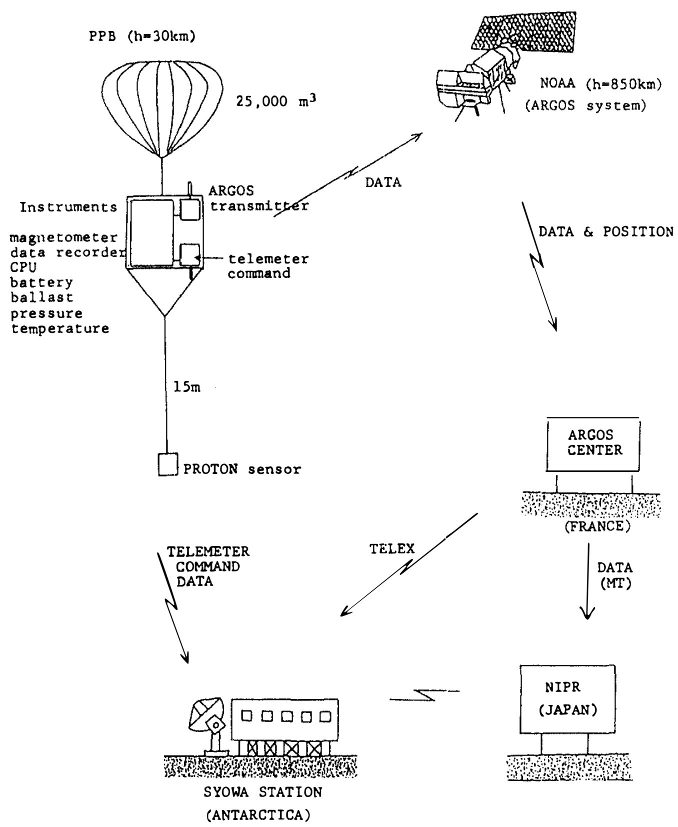

Fig. 2. Constitution of balloon (PPB-1) and data acquisition system. Observed data is obtained through NOAA satellites by ARGOS transmitter system.

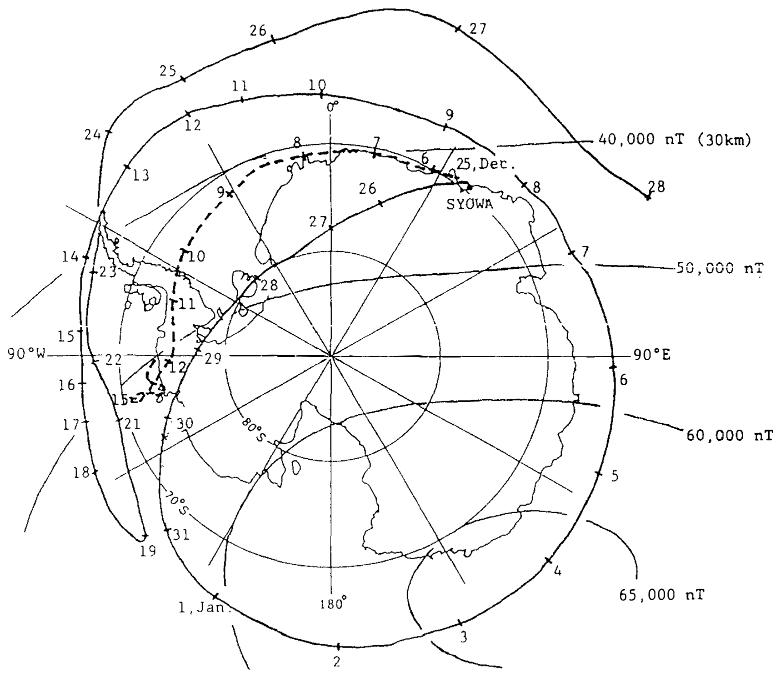

Fig. 3. Trajectories of PPB-1 (solid line: on December 25, 1990–January 28, 1991) and -2 (dotted line: on January 5–15, 1991). Numbers show the date of the balloon position. Contour lines show the equal geomagnetic total intensity lines at 30-km height computed with spherical harmonic coefficients of IGRF-90.

electric field detector and an auroral X-ray detector were added to those of PPB-1. Gas capacities of the balloons were 25000 m^3 for PPB-1 and 32000 m^3 for PPB-2. The weights of scientific instruments were 114.0 kg for PPB-1 and 191.5 kg for PPB-2. Ballast weights were the same (152.0 kg) for PPB-1 and PPB-2, and the total weights were 373.5 kg and 471.0 kg, respectively (AKIYAMA *et al.*, 1991). Observed data were transmitted to the NOAA satellites by ARGOS transmitter system and data was transmitted to the ground station from the satellites. Two PPBs had auto-ballast control systems that kept the balloon to the planned height by a barometer and ballast (KADOKURA *et al.*, 1991). The altitude of PPB was planned at the height of 28 km by the auto-ballast controller.

PPB-1 was launched at 0825 UT on December 25, 1990 and PPB-2 was launched at 1855 UT on January 5, 1991 from Syowa Station (geographic latitude: 69.0°S, longitude: 39.6°E, geomagnetic latitude: 70.0°S, longitude: 79.4°E) in the Antarctica. Figure 3 shows the trajectories of PPB-1 and -2. It also shows theoretically expected contour lines of total intensity at the hight of 30 km. The flight path of PPB-1 was inside the Antarctica and very close to the Magnetic South Pole on January 3 to 5. On January 8, PPB-1 returned to near the launching point with a perfect circumpolar trajectory. The height of PPB-1's flight varied from 32 to 28 km. The height of PPB-2 decreased to lower than 24 km on the fifth day after the launch and the balloon stopped.

The quality of data from the both magnetometers of PPB-1 and -2 was excellent for 22 days from the launch until the batteries exhausted.

4. Data Processing and Scientific Objects

The scientific aims of the magnetic observation are mainly the following subjects.

(1) Accumulation of geomagnetic field data in the Antarctica, especially in the region around the Magnetic South Pole.

(2) Evaluation of various geomagnetic field models after comparing with observed field.

(3) To infer some models of the underground geoelectro-magnetic structures by measuring magnetic anomalies.

(4) Detection of geomagnetic variation like a pulsation.

(5) Development of magnetometry and data analysis method for proton magnetometer.

The procedure of the data processing is shown in Fig. 4. At first, data are aligned in order with a time and impulsive noises are eliminated. Since the balloon locations were obtained at intervals from 30 min to 3 h by the *ARGOS positioning system*, the position at arbitary time was interpolated using the least square method. The height of the balloon is computed from the accurate barometer data using an atmospheric pressure model. The Earth's main magnetic field is computed theoretically using the International Geomagnetic Reference Field 1990.0-model (*IGRF-90*) (IAGA Division V, Working Group 8, 1991). The magnetic anomaly is defined as a difference between the observed value and the theoretical one. Observed magnetic field, theoretical field, position (latitude, longitude), height of the balloon, magnetic anomaly and observation time were filed as the PPB data base.

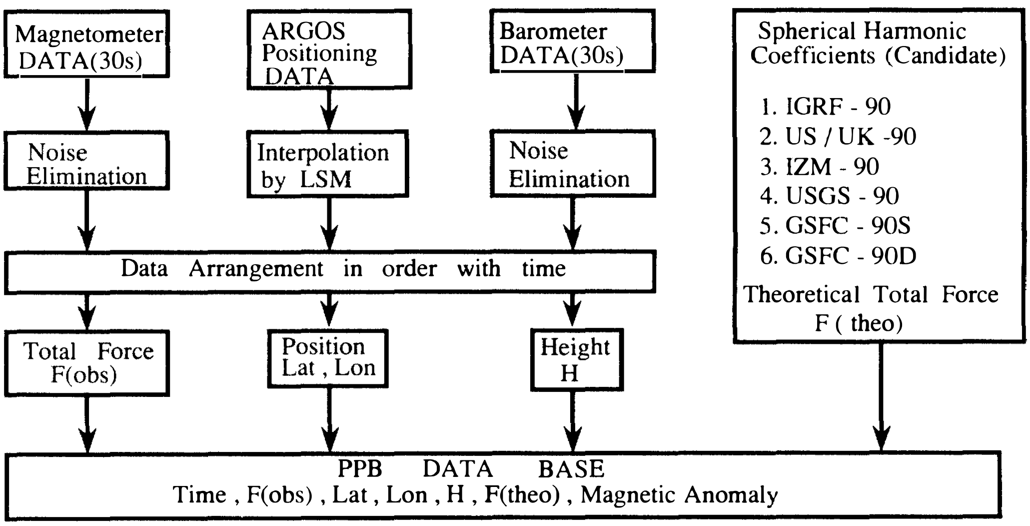

Fig. 4. Flow chart of the procedure of the data processing.

5. Preliminary Results

The observed magnetic total intensity and the height for the PPB-1 during the period of perfect circumpolar trajectory are shown in Fig. 5. It shows that the balloon

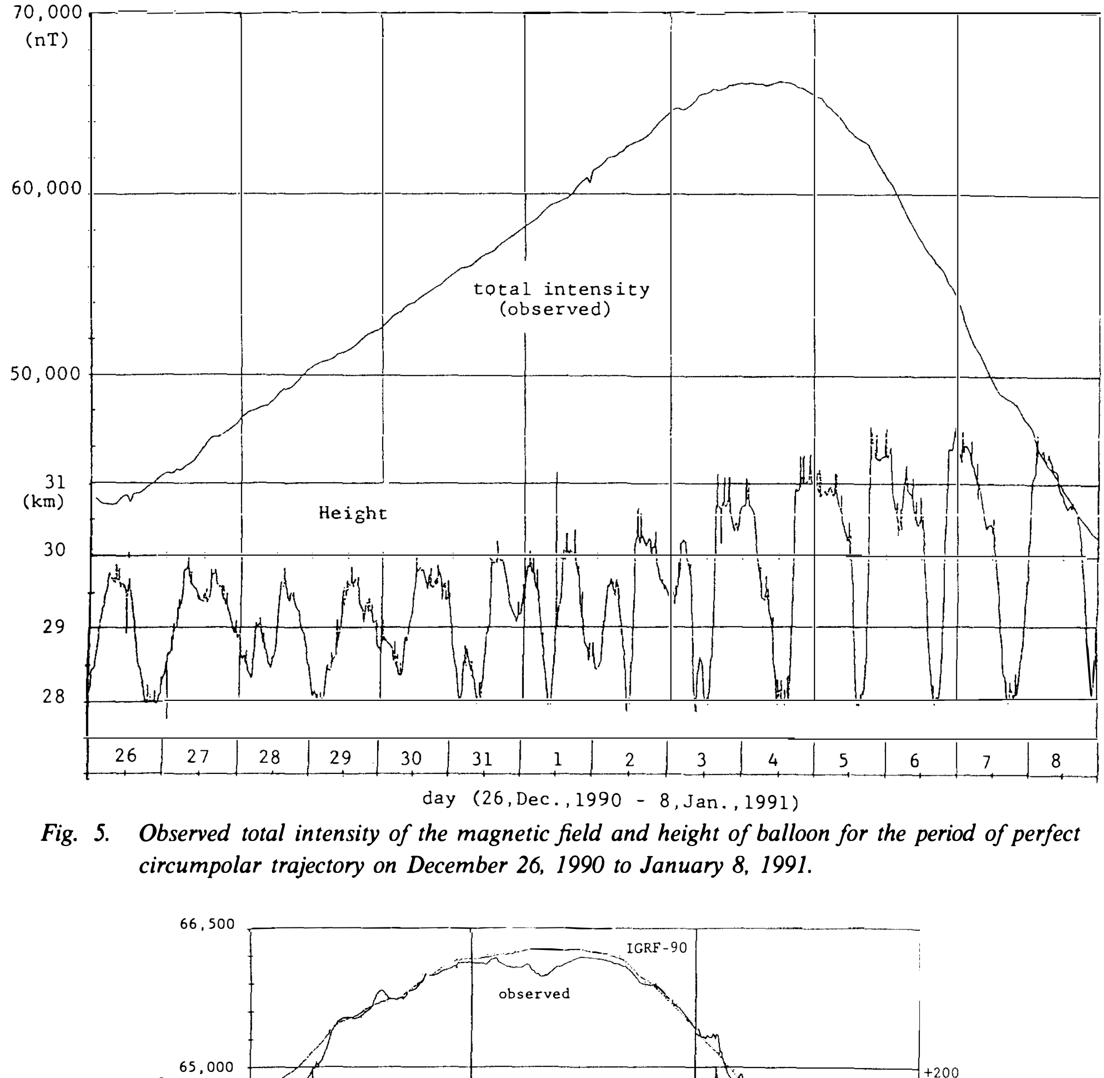

Fig. 5. Observed total intensity of the magnetic field and height of balloon for the period of perfect circumpolar trajectory on December 26, 1990 to January 8, 1991.

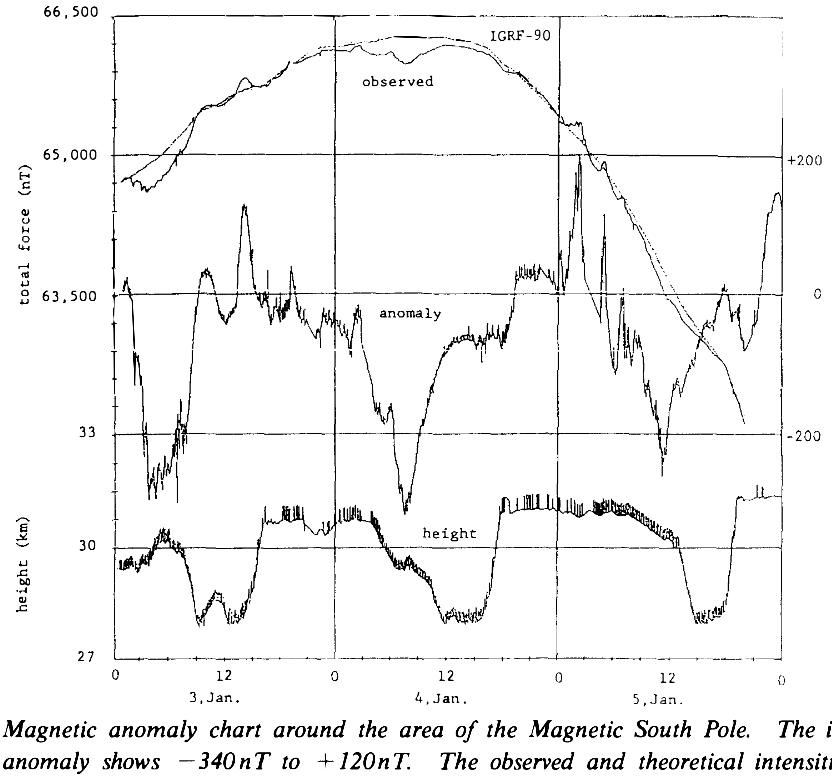

Fig. 6. Magnetic anomaly chart around the area of the Magnetic South Pole. The intensity of anomaly shows −340 nT to +120 nT. The observed and theoretical intensities (upper) and the height (bottom) are also shown.

repeatedly ascended by operating the auto-ballast control system when the altitude fell down to the height of 28 km. Figure 6 shows magnetic anomalies around the area of the Magnetic South Polar from January 3 to 5. It shows large anomalies more than −200 nT at 2–9 h on January 3, at 20–18 h on January 3–4 and at 3–18 h on January 5 in this figure. On the magnetogram at Syowa Station, the total intensity showed a small change with less than 50 nT and the geomagnetic planetary indices, *Kp* was from 1 to 3_0 and *Ap* was 8 from January 3–5. On the other hand, the anomalous gradient of the total intensity was estimated to decrease with −9 dB at the position of 40 km away from the edge of an underground magnetized body by a computed result. Since the velocity of balloon was about 40 km/h, a periodic variation shorter than a few hours is assumed to be caused by an upper atmospheric motion. After the upper atmospheric variations are eliminated from balloon data by referring to ground data and satellite data, some underground structural bodies are estimated. An example of a short period perturbation of magnetic field is shown in Fig. 7. The perturbation looks like a pulsation with a period of about 10 min with an amplitude of about 15 nT. It is independent of a change of balloon's height because the change rate of total intensity for height is estimated about 3 nT/100 m in this area.

Differences of anomalies between other geomagnetic reference field models at the Magnetic South Pole are shown in Fig. 8. Used models are IAGA (IGRF-90), Goddard Space Flight Center (GSFC-90) (LANGEL *et al.*, 1990), U.S. Geological Survey (USGS-90) (PEDDIE, 1990), USSR Academy of Sciences (IZM-90) (BONDAR and GOLOVKOV, 1990) and British Geological Survey and U.S. Naval Oceanografic Office Stennis Space Center (US/UK-90) (BARRACLOUGH and QUINN, 1990). The intensity of the IGRF-90 model shows the mean value of all the models. The largest differencial amplitude of the intensity is about 120 nT in this figure. An approach to underground structure study is

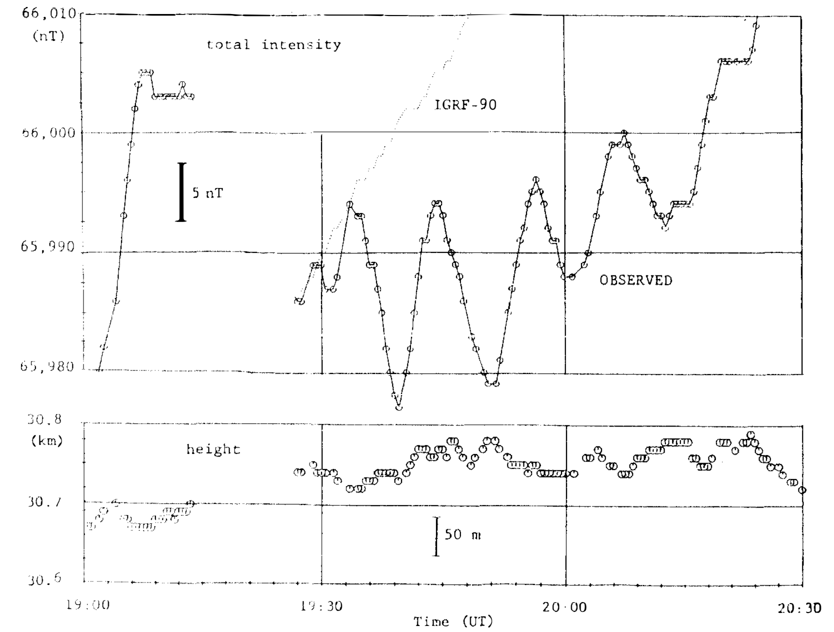

Fig. 7. Example of magnetic disturbances measured by PPB-1 at the region of the Magnetic South Pole on January 3, 1991.

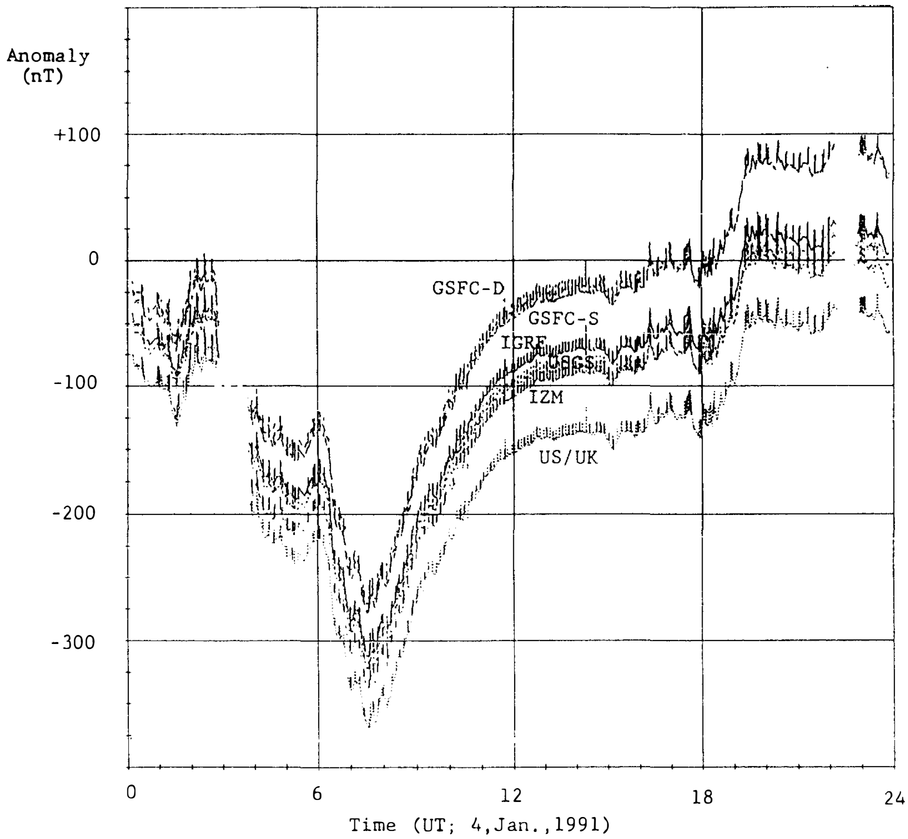

Fig. 8. Geomagnetic anomalies observed on January 4, from 6 different magnetic field models.

under way by using *Talwani method* (TALWANI, 1965).

6. Discussion and Future Plan for Magnetometry by PPB

It was evident that the auto-tuning system of the proton magnetometer was useful for a long-term measurement by PPB. In this PPB experiments, some problems are studied as listed below.

(1) Deviation of the measuring range in a part of PPB's trajectory.

(2) The error of the position and the altitude determination.

(3) Vector measurement of the magnetic field by a fluxgate magnetometer.

A wide dynamic range for the measurement could be achieved by an improvement of electronic circuit. It is supposed that the use of GPS positioning system is better than the use of *ARGOS positioning system* and barometer. Vector measurement of the geomagnetic field by a balloon is very difficult because it requires a very accurate attitude of the sensor direction. We are preparing a magnetometry by a proton magnetometer and a fluxgate magnetometer in the next PPB experiment project planned to be performed by JARE-34 in 1992–1993. Two PPBs are planned to be launched within a week from Syowa Station and the observation will be continued for 28 days. The fluxgate sensor is mounted on a rigid boom installed above the gondola. Attitude sensors are two orthogonal component clinometers and two sun-crossing sensors located in opposite direction. The gondola is rotated at 1 rpm by a spin motor and a sun-crossing

Table 2. Characteristics of the fluxgate magnetometer for planned PPB.

Fluxgate magnetometer		
Dynamic range	x- and y-axis ±32700 nT, z-axis 0–65500 nT	
Resolution	1 nT/axis	
Sampling period	30 s	
Output format	digital 16 bits/axis	
	analogue 0–5 V	
Attitude sensor		
Sun sensor	sun-meridian zero-crossing type	
Field range of view	60° (elevational)	
Resolution	0.1°	
Clinometer	2-axial accelerometer	
Inclination range	−15° to +15°	
Angle resolution	0.02°	
Total power supply	10.5 V×270 AH (28 days)	
Size/Weight	electronics	230×300×160 mm/4 kg
	sensor system	60ϕ×800 mm/7 kg
	battery	180×210×150 mm/6 kg

signal is obtained each 30 s. Tri-axial components of the magnetic field are measured at the moment that the Sun instaneously crosses on a narrow slit. At the same time, two orthogonal component inclinations from the horizontal plane are measured by clinometers. From the balloon position, the direction of the Sun are computed and tri-axial sensor coordinate system is determined. The characteristics of a planned fluxgate magnetometer system is shown in Table 2.

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References

AKIYAMA, H., FUJII, R., ONO, T., EJIRI, M., OHTA, S., YAMAGAMI, T., YAJIMA, N. and NISHIMURA, J. (1991): Nankyoku syûkai kikyû jikken (Polar Patrol Balloon Experiment). Daikikyû Shinpojiumu (Proc. Balloon Symp.), ed. by Inst. Space Astro. Sci., 114–123.

BARRACLOUGH, D. R., WILLIAMS, L. D. and QUINN, J. M. (1992): US/UK candidates for the definitive geomagnetic reference field model DGRF-85 and the predictive international geomagnetic reference field model IGRF-90. J. Geomagn. Geoelectr., **44**, 719–734.

BONDAR, T. N. and GOLOVKOV, V. P. (1992): IZMIRAN candidate models for DGRF 1985, IGRF 1990 and a secular variation forecast model for the 1990–1995 period. J. Geomagn. Geoelectr., **44**, 709–717.

FUJII, R., MIYAOKA, H., KADOKURA, A., ONO, T., YAMAGISHI, H. *et al.* (1989): Nankyoku Shûkai Kikyû (PPB) shôrai keikaku 1991–1993 (Polar Patrol Balloon experiment during 1991–1993). Nankyoku Shiryô (Antarct. Rec.), **33**, 320–328.

IAGA DIVISION V, WORKING GROUP 8 (1991): International Geomagnetic Reference Field, 1991 Revision. J. Geomagn. Geoelectr., **43**, 1007–1012.

KADOKURA, A., EJIRI, M., OHTA, S. and AKIYAMA, H. (1991): Polar Patrol Balloon (PPB) experiment of the 30th Japanese Antarctic Research Expedition (1989–1990). Nankyoku Shiryô (Antarct. Rec.), **35**, 143–154.

LANGEL, R. A., SABAKA, T. J. and BALDWIN, R. T. (1992): The geomagnetic field: 1970–1990 and the NASA candidate models for DGRF1985 and IGRF1990. J. Geomagn. Geoelectr., **44**, 745–767.

MIYAOKA, H., MUKAI, H. and SAITO, H. (1988): Pôrâpatorôru kikyû jikken (Polar Patrol experiment). Nihon Nankyoku Chiiki Kansokutai Dai-28-ji-tai Hôkoku (1986–1988) (Report of the 28th Japanese Antarctic Research Expedision, 1986–1988), ed. by Natl. Inst. Polar Res. Tokyo, 165–174.

PEDDIE, N. W. (1992): Analysis of geomagnetic secular variation during 1980–1985 and 1985–1990, and geomagnetic models proposal for the 1991 revision of the International Geomagnetic Reference Field. J. Geomagn. Geoelectr., **44**, 735–743.

TALWANI, M. (1965): Computation with the help of a digital computer of magnetic anomalies caused by bodies of arbitrary shape. Geophysics, **30**, 797–817.

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.

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