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MEASUREMENT OF COSMIC-RAY PROTONS DURING POLAR PATROL BALLOON EXPERIMENT IN ANTARCTICA

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Abstract: To study cosmic protons, helium and CNO components (E=100–500 MeV/n) together with Hard X-rays (E=30–120 keV) of auroral, solar and/or cosmic origins, the Polar Patrol Balloon no. 6 (PPB # 6) was launched from Syowa Station, Antarctica on January 5, 1993 by the 34th Japanese Antarctic Research Expedition. PPB # 6 moved westward by 1.5 circumpolar rounds over Antarctica covering 6–13 g/cm^2 atmosphereic depth and 63°–70° S geographic latitude. The cosmic radiation intensity was measured by detector system on PPB # 6. This paper shows the cosmic proton intensity as a function of the geomagnetic rigidty and the proton spectra at invariant latitude of 55°, 80°, and at the cusp latitude.

1. Introduction

Since 1984, the National Institute of Polar Research and the Institute of Space and Astronautical Science studied the feasibility of a long-term circumpolar balloon experiment over Antarctica using a zero-pressure balloon with an auto-ballast controlling system, which was called as the Polar Patrol Balloon (PPB) project (NISHIMURA *et al.*, 1985; HIRASAWA *et al.*, 1990; EJIRI *et al.*, 1994). Three test flights in 1987 and 1990 at Syowa Station (69.0° S, 39.6° E) convinced us that the PPB experiment would have a high probability of returning to the launching area, if we utilize the advantage of having no sunset during the summer in Antarctica. Six PPB experiments were planned and carry out as an Antarctic STEP (Solar Terrestrial Energy Program) project. The 2nd half of six PPBs were launched in December 1992–January 1993 by the 34th Japanese Antarctic Research Expedition members. This flight (hereafter referred to as PPB # 6) continued to fly from January 5 to the end of January. During the long-flight operation, the whole PPB # 6 data have been received by the multi-ID ARGOS system via NOAA satellites.

In this paper we present the results from the analysis of the PPB # 6 data for cosmic protons.

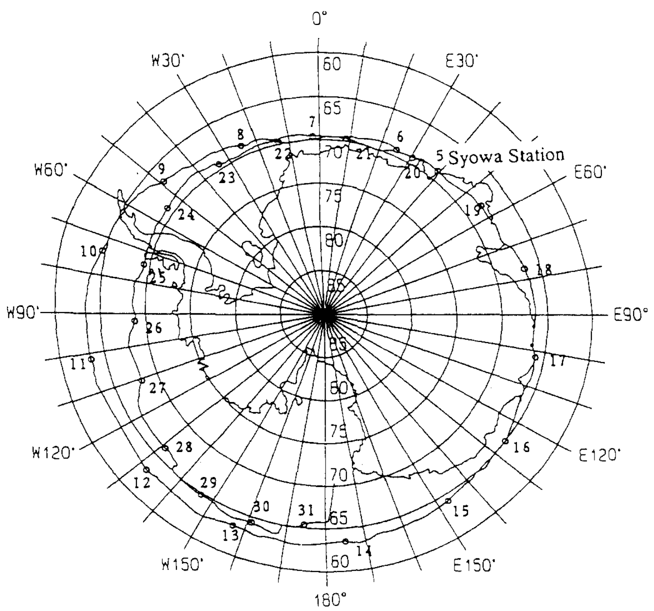
2. Experimental Procedure

2.1. *Flight trajectory of PPB # 6*

PPB # 6 (B60: 59467 m^3 in volume) was launched at 0855 UT on January 5, 1993, from Syowa Station and drifted westward 1.5 circumpolar rounds in 27 days at a ceiling altitude between 31 km and 36 km. As shown in Fig. 1, this balloon took about 16 days for one round covering the narrow geographic latitude range from 63° S to 69° S. Nevertheless, PPB # 6 moved to a wider geomagnetic latitude ranging from 43° to 81°. So, it is expected that the intensities of cosmic particles were observed with their rigidity value. With the auto-ballast controlling system, a seiling altitude of PPB # 6 was kept over the preset level of about 31 km until January 29, by that time all the ballast amounting to 150 kg were spent out.

2.2. *The PPB # 6 instruments*

The payload of PPB # 6 consisted of observing equipment, housekeeping (HK) and telemetry system. In order to measure cosmic ray components and hard X-rays, three detection systems (D1, D2 and D3) were used (YAMAGAMI *et al.*, 1994).



Launch on 08^h55^mUT/5/Jan./1993

Landing on 22^h45^mUT/31/Jan./1993

Fig. 1. Trajectory of Polar Patrol Balloon No. 6 (PPB # 6) launched from Syowa Station on January 5, 1993, on the geographical coordinates is presented by a solid line. Numerical figures attached indicate the date at 0 h UT.

Figure 2 shows a cosmic ray telescope named as D2. This instrument detected protons coming from vertical direction with a cone angle of 20°. Since the effective SΩ of D2 detector was 0.088 cm·sr, the expected value for protons was about 1×10^4 cts/20 days at an energy range of 100–500 MeV/n, estimated from the cosmic-ray spectrum in a literature (LONGAIR, 1992) under the condition of successive collection.

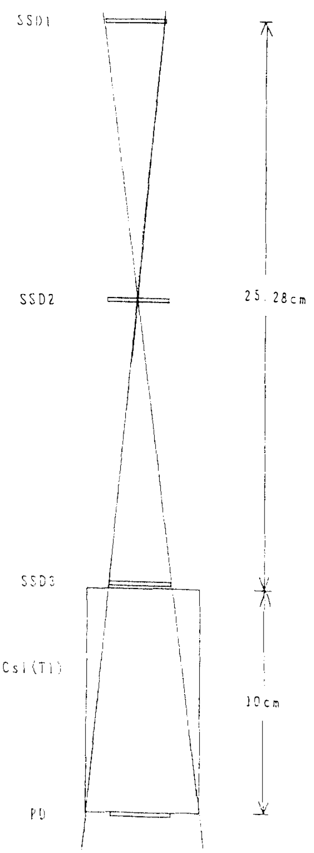


Fig. 2. The cosmic ray telescope consists of 3 SSDs and a CsI(Tl) viewed by a silicon photodiode triggered by coincidence with the 3 SSDs. This instrument named as D2 is one of three detectors on PPB #6.

2.3. *Data analysis*

Data transmission for PPB #6 was provided by the multiple-identify (multi-ID) ARGOS system that contained 40 ID channels. In this system, data were received at the ground station through NOAA satellites. So, the underlying premise of successful data was that PPB #6 had a chance of encounter at least once an hour with the ARGOS/NOAA satellites. As a result, the encounter was not regular, so that about 20% of the total observation were missed. Moreover, we checked an unusual event for daily data set. Figure 3 shows the observed daily variation on January 11, 1993, in the counting rate of proton marked as filled circles, and the balloon altitude in mb marked as open circles. As shown in this figure, from 0900 UT to 2400 UT the balloon altitude varied ranging from 9 mb to 6 mb, but the counting rate of proton remained

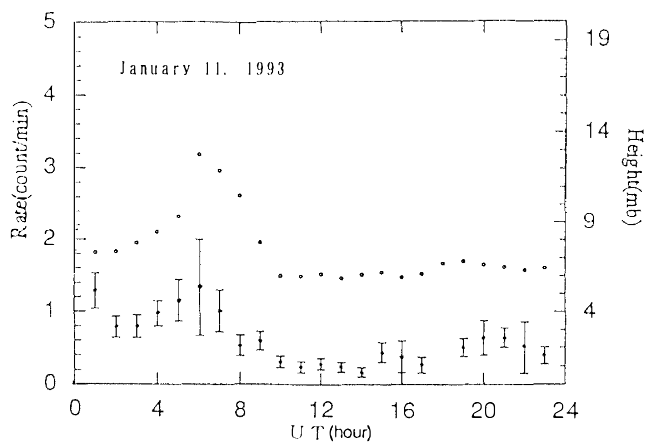


Fig. 3. One day variation of proton counting rate for January 11th marked as closed circles, and the balloon altitude in mb marked as open cicles.

constant within an error of one sigma. Therefore, in the data on January 11, 1993, we omit the data set from 0500 UT to 0900 UT. Then, all data sets were selected after eliminative the data obtained at altitudes lower than 9 mb. Finally, the usable data set became 48.8% of all data, and these data were analyzed to obtain the intensity and spectrum of observed protons.

3. Results and Discussions

Figure 4 shows the proton flux (counts/min) dependent on the Invariant latitude. For the trajectory of PPB # 6, the cutoff rigidity can be calculated as a function of invariant latitude, for example at the invariant latitudes of 70°, 60° and 55°, the cutoff rigidity is about 0.2 GV, 1.0 GV and 2.0 GV, respectively. As shown in this figure, we corrected the observed flux marked with diamond marks into the actual downward flux marked with open circles under the condition that the ratio of albedo protons to downward-moving protons varies with rigidity (R) approximately as R^{-4} (SEO *et al.*, 1991). The flux at high invariant latitude became to be roughly equal to that at low invariant latitude. So, the spectrum of cosmic protons at the top of the atmosphere is shown in Fig. 5 with three cases at invariant latitudes of 55° and 80° and at the cusp area (LEMAIRE and ROTH, 1991). As far as we know, this is the first observation of the cosmic proton spectrum at the cusp area. The broken curves in Fig. 5 represent the local interstellar and the modulated spectra with the modulation parameter ϕ: a, no modulation; b, $\phi=0.2$ GV; c, $\phi=0.4$ GV; d, $\phi=0.5$ GV; e, $\phi=0.6$ GV; f, $\phi=0.8$ GV; g, $\phi=1.0$ GV, and the local interstellar spectrum is the calculated one that is compared with the measurements at the 1987 solar minimum (SEO *et al.*, 1991). The spectrum measured at low invariant latitude is consistent with the previous balloon measurements (GLOECKLER and JOKIPII, 1967) within an error of one sigma. At high invariant latitude, however, the spectrum is clearly shifted upward as high as a factor of about two when compared with that at low latitude. According to SEO, the ratio of splash albedo protons to downward moving protons decreases with rigidity (R) as approximately R^{-4}. Then, we expected that observed proton spectrum just around 0.2 GV included the albedo component of about 66% of total flux.

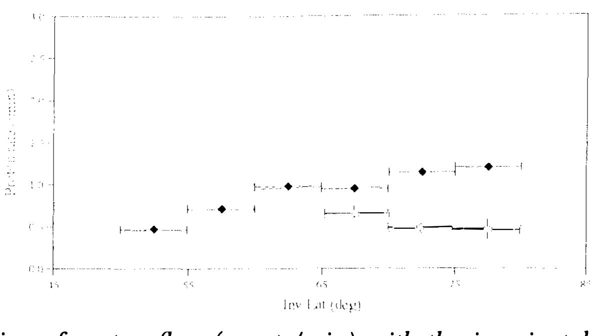


Fig. 4. The variation of proton flux (counts/min) with the invariant latitude ranging from 50° to 80°. Under the assumption, the flux marked with open circles is corrected from the observed flux marked with closed diamonds.

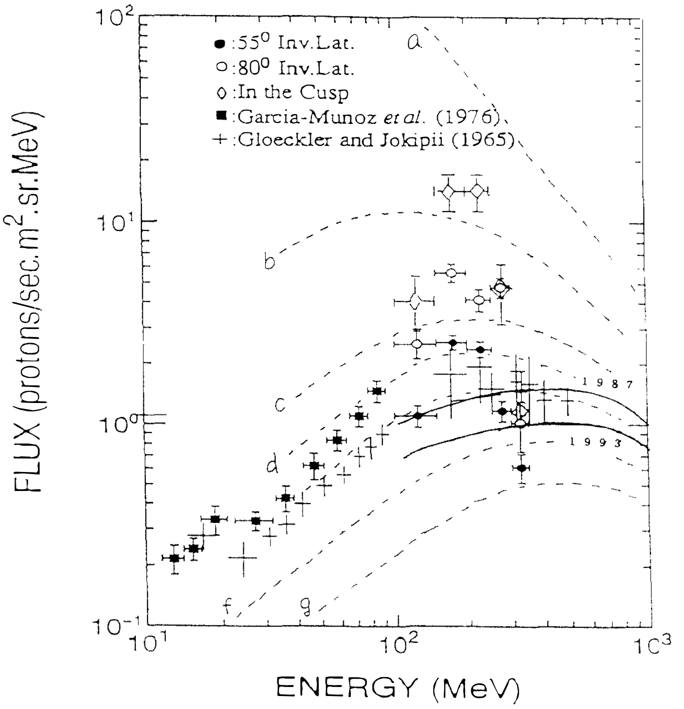


Fig. 5. The spectra of cosmic proton at the top of the atmosphere for three invariant latitudes of 55°, 80° and the cusp area. The dashed curves represent the local interstellar spectrum with the modulation parameters $\phi=0.0$ GV(a); $\phi=0.2$ GV(b); $\phi=0.4$ GV (c); $\phi=0.5$ GV(d); $\phi=0.6$ GV(e); $\phi=0.8$ GV(f); $\phi=1.0$ GV(g). The solid lines show the modulated spectra for the case of solar minimum in 1987 and intermediate level of modulation in 1993 (Labrador and Mewaldt, 1995).

4. Summary

The balloon (PPB # 6) floated for 21 days at 6–13 g/cm^2 atmospheric depth before the total ballast was exhausted. The coverage ballasting for each day was around 2% during the flight. This means that the flight from Syowa Station is slightly affected by the low inclination of the sun or the short-time sunsets, because the geographic latitude of Syowa Station is about 70° S and the temperature change of the lifting gas is relatively small in Antarctic flights. If we further develop a balloon of 2–3% over pressure for the zero pressure balloon, we will be able to reduce the amount of the ballast and the fluctuation of the ceiling altitude will become smaller than the ordinary one of the zero pressure balloon.

As shown in Fig. 5, the proton spectra increase with latitude even up to the cusp region. It is very important to study the spectral difference between the near cusp region and the higher cut-off rigidity area. At 55° invariant latitude, the spectrum of cosmic proton observed by PPB # 6 is fairly consistent with the previous balloon measurement (Gloeckler and Jokipii, 1967), the modulated spectrum with the parameter $\phi=0.5$ GV (Seo *et al.*, 1991), and with the expected one observed at 1993 derived from the solar activity periods (Labrador and Mewaldt, 1995) within an error of one sigma. However, the spectrum at 80° is clearly shifted upward relative to that at 55°. The ratio of albedo protons to downward-moving protons varies with rigidity approximately in proportion to R^{-4} (SEO *et al.*, 1991). Then, the expected ratio at 0.2 GV becomes about 2.1. So, the spectrum at 80° will shift downward by about 33% and become to be the same as the value at 55°. However, the enhanced proton flux observed at the cusp area must be investigated further in connection with the re-entrant proton and helium.

Acknowledgments

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