PRECIPITATING ELECTRONS OBSERVED ON BOARD THE JAPANESE ANTARCTIC SOUNDING ROCKETS S-310JA-1 AND S-310JA-2

Haruya KUBO, Tomizo ITOH, Setsuo MURATA,

Institute of Space and Aeronautical Science, University of Tokyo, Komaba 4-chome, Meguro-ku, Tokyo 153

Susumu KOKUBUN

Geophysics Research Laboratory, University of Tokyo, Yayoi 2-chome, Bunkyo-ku, Tokyo 113

and

Takeo HIRASAWA

National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173

Abstract: Cylindrical electrostatic analyzers on board the Japanese Antarctic sounding rockets S-310JA-1 and S-310JA-2 launched on February 13, 1976 and on February 10, 1977, respectively, at Syowa Station, obtained the energy spectra of energetic electrons in the Antarctic polar ionosphere. At the time of the former flight, the geomagnetic activity was low, and the electron flux of about 10^3 electrons/cm^2·sec·ster·eV was obtained at an energy of 5 keV. The altitude dependence of the flux of 2 keV electrons showed the maximum flux near 150 km altitude of the descending path. This implies that there was a local electron precipitation region. At the time of the latter flight, the geomagnetic activity was high, and the electron flux of about 1.8×10^3 electrons/cm^2·sec·ster·eV was obtained at the energy of 4.2 keV. The field aligned electron flux of about 2.3×10^4 electrons/cm^2·sec·ster·eV was also observed at the energy of 740 eV.

1. Introduction

In recent years there have been many auroral electron observations using rockets. However, the results of experiments differ according to the auroral and geomagnetic conditions. Moreover, the particle experiment in the polar ionosphere when aurora does not exist, have little been attempted by rocket until now.

This paper describes the results of measurements of energy spectra of electrons made on board the two Japanese Antarctic sounding rockets S-310JA-1 and S-310JA-2. Hereafter, the experiments of S-310JA-1 and S-310JA-2 are denoted by experiment I and experiment II, respectively. The purpose of the experiment

I is to obtain information on the precipitating electron flux in the polar ionosphere when the aurora is absent. Therefore, the experiment I was made when the geomagnetic activity was low. By contrast, the experiment II was performed during the expansion phase of the moderate polar magnetic substorm. The solar zenith angles at the launch time were 55° and 89.97°, respectively. Therefore auroras were not visible even if they existed.

2. Instrumentation

The detector system of the experiment I is shown in Fig. 1. The detector consisted of a cylindrical collimator, a cylindrical electrostatic analyzer, the center angle of which was 60°, and a continuous channel electron multiplier. The collimator was set in parallel with the rocket axis. The cylindrical electrostatic analyzer was used with balanced voltages; that is, a positive potential, +V volts, and simultaneously a negative one, −V volts were applied to the inner and outer

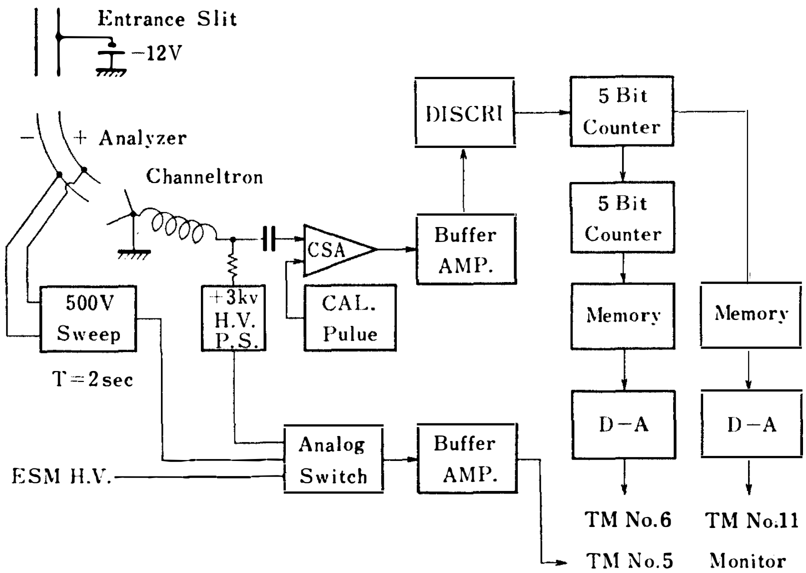

Fig. 1. Block diagram of the detector system of S-310JA-1.

cylindrical plates, respectively. The mean energy E of the transmitted electrons was related to V by E=20 V. The geometrical factors of the detectors used in experiment I and experiment II were 1.54×10^{-3} cm^2·ster and 5.3×10^{-3} cm^2·ster, respectively. In experiment I, the electron energy was scanned from 100 eV to 10 keV by 0.5 Hz triangular wave voltage. The time base of the data acquisition was 10 msec. In experiment II, the energy was scanned stepwise. One sweep was completed in 1.2 seconds and data acquisition time base was 100 msec.

3. Experimental Results and Discussions

3.1. Experiment I

The trajectory of S-310JA-1 is shown in Fig. 2. The window of detector was opened at 120 sec after launch (159 km) and high voltages were applied at 150 sec (185 km), but due to a malfunction of the power supply, data were obtained only from 180 sec after launch (204 km). The rocket reached the

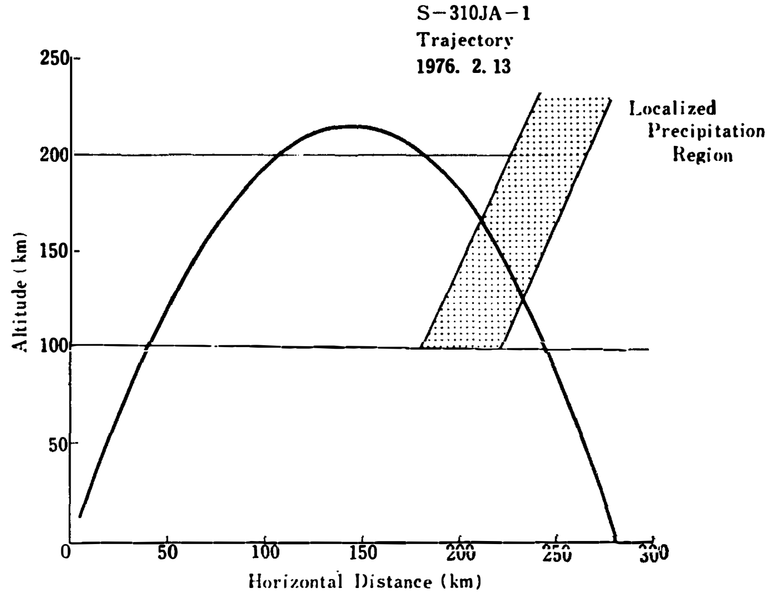

Fig. 2. Trajectory of S-310JA-1.

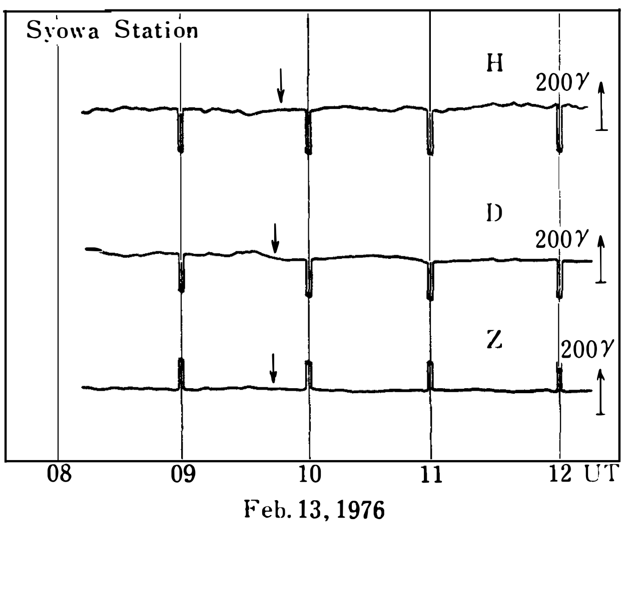

Fig. 3. Magnetic record for the period around the flght time of S-310JA-1. Arrows show the time of launch.

highest altitude (216 km) at 226 sec after launch. The localized precipitation region inferred from the observed data is also indicated in Fig. 2.

Experiment I was carried out in quiet geomagnetic conditions. Fig. 3 is the geomagnetic record for the period around the time of the flight. The arrows show the time of launch.

Fig. 4 shows the energy spectra of the measured electrons. Flux of electrons near apogee was about 3–7×10^3 electrons/cm^2·sec·ster·eV at 1 keV. The energy distribution function of the measured flux follows a power law as $f(E) \propto E^{-1.1}$ up to 7 keV. Beyond this energy, the spectrum hardens. According to the calculations

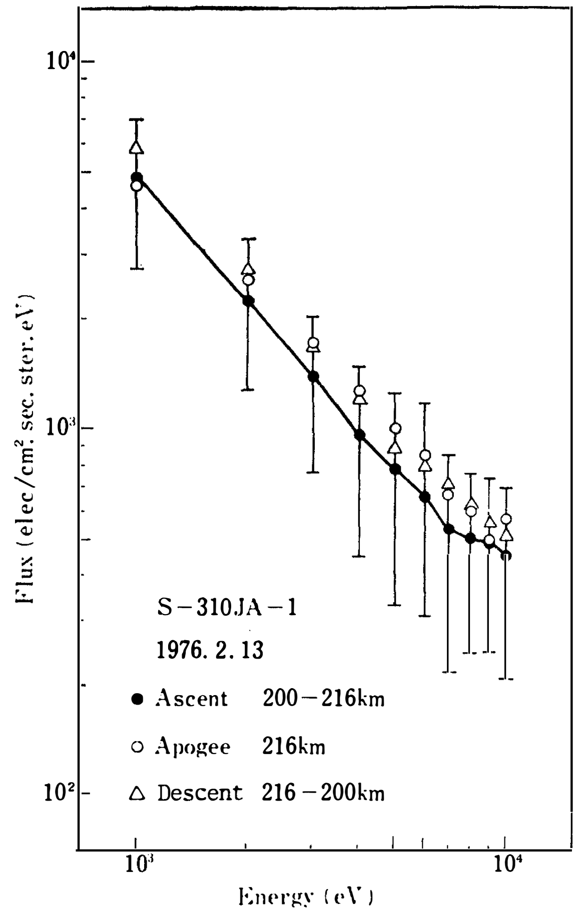

Fig. 4. Energy spectra of measured electrons.

of BANKS *et al.* (1974), the measured shape of the spectrum suggests that more energetic electrons which produce the harder part of the spectrum are precipitating at higher altitudes, as the incident electrons move into the atmosphere, their energy is diminished; *i. e.,* there is a production of lower-energy electrons that results in a net flux of low-energy particles.

Fig. 5 shows the energy spectra in the descending path. The fluxes of Fig. 5

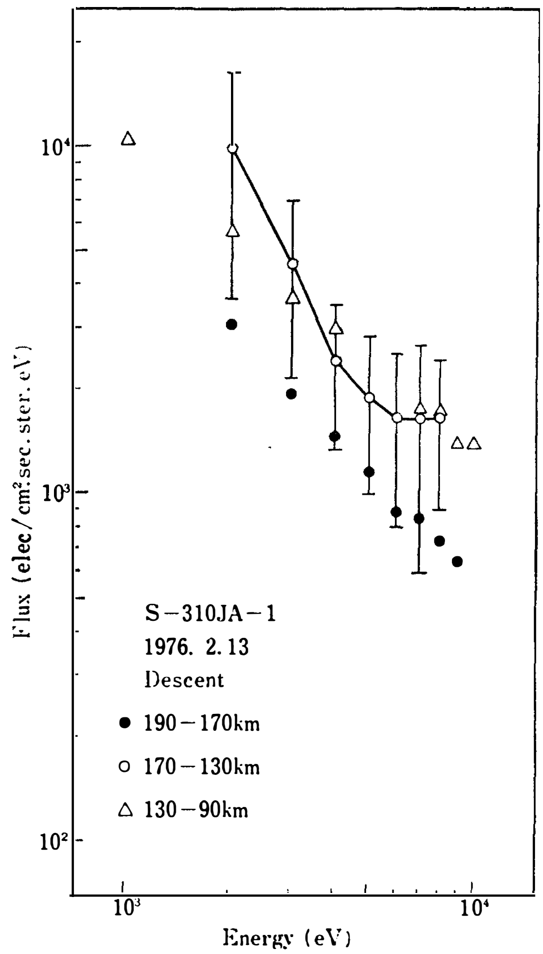

Fig. 5. Energy spectra of electrons measured when the rocket was descending.

are larger than those of Fig. 4. This suggests that the rocket penetrated into the localized electron precipitation region during the descent. The spectra of Fig. 5 also show the hardening in the high energy side.

The magnetic analyzer called ESM which measured the 3 keV electrons with a parmanent magnet was also on board the same rocket. The electron flux measured by ESM was about 2×10^2 electrons/$cm^2\cdot$sec$\cdot$ster$\cdot$eV at 3 keV, and this was about 5 times smaller than the results obtained by our electrostatic analyzer. This difference may be due to the difference in evaluation of the solar UV contamination.

The altitude dependences of the electron fluxes at two typical energies are shown in Fig. 6. These altitude dependences are peculiar because they show lower fluxes at higher altitudes, contrary to the results of HILL *et al.* (1970) and KUBO *et al.* (1976); That is, the higher the altitude, the higher fluxes. This implies that there existed a localized precipitation region. Plasma wave experi-

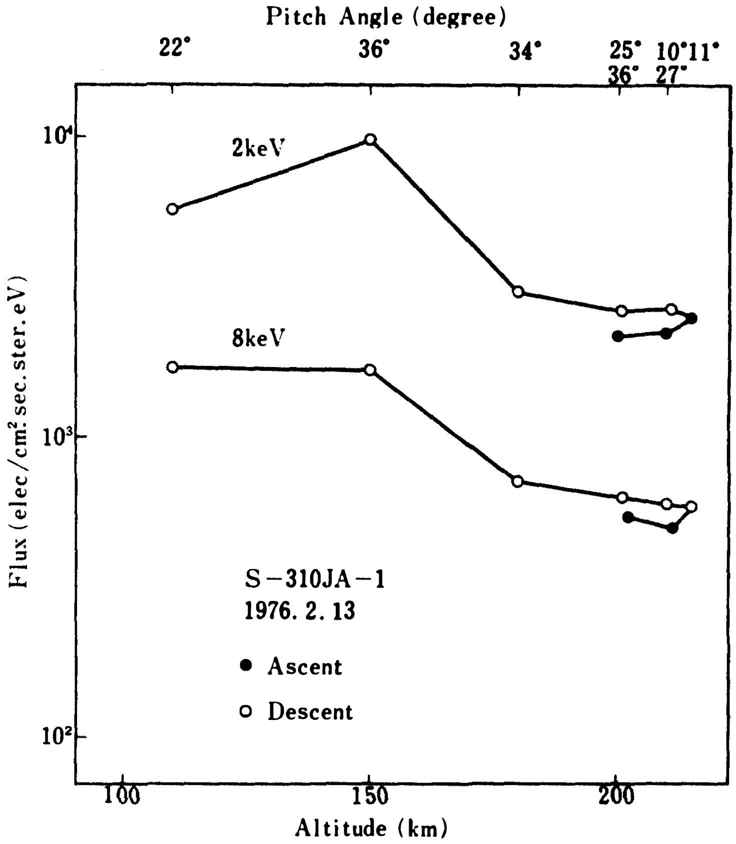

Fig. 6. Altitude dependences of electron fluxes.

ment made on board the same rocket detected the signals which suggested the local electron precipitation.

3.2. *Experiment II*

S-310JA-2 was launched during the expansion phase of a moderate polar magnetic substorm. There might be diffuse aurora in that expansion phase, but it was invisible owing to the sunlight. Fig. 7 is the magnetic record at Syowa Station for the period around the time of flight and the arrows show the time of launch. The H component shows about 600 γ negative bay centered at 0030 UT. The Z component shows that the center of the current system was in the south of Syowa Station. Fig. 8 is the record of the 30 MHz cosmic noise absorption measured by a riometer at Syowa Station, in which the arrow shows the time of launch.

It shows about 3.0 dB absorption, indicating that there was a remarkable high energy electron precipitation into the polar D-region, and that disturbed conditions prevailed around the time of launch.

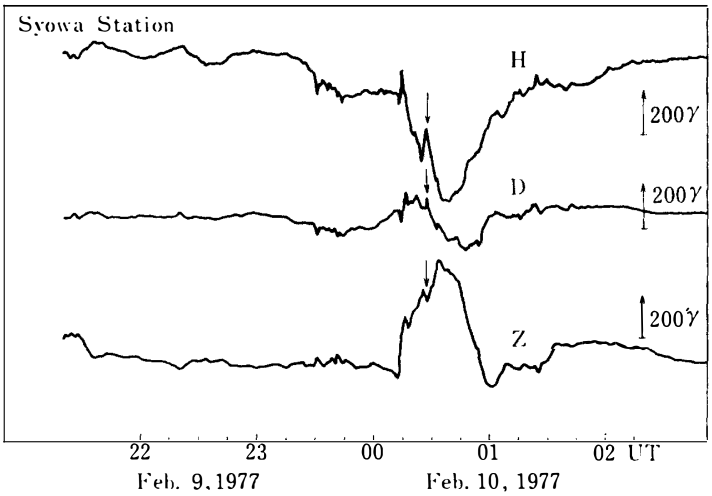

Fig. 7. Magnetic record for the period around flight time of S-310JA-2. Arrows shows the time of launch.

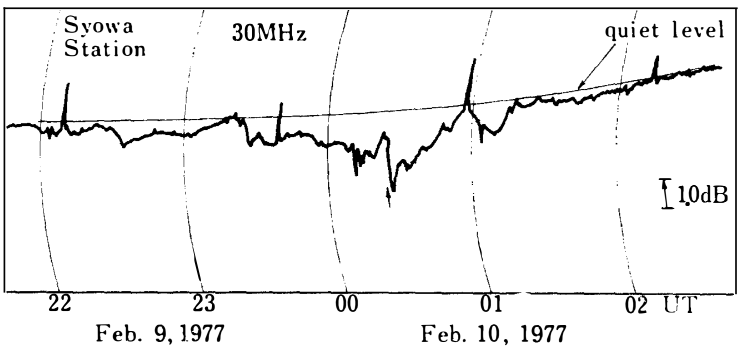

Fig. 8. Record of 30 MHz cosmic noise absorption. Arrow shows the time of launch.

The energy spectra of the measured electron fluxes at different altitudes and at different pitch angles are shown in Fig. 9. The angle between the magnetic field line and the rocket axis was about 10° at the apogee (212 km). As the detector was in parallel with the rocket axis, this angle is the pitch angle of the measured electrons. Intense field aligned fluxes of 480, 740 eV electrons were observed at the apogee. The field aligned fluxes of several keV electron reported by CHOY *et al.* (1971) was not observed here. This difference may be due to the fact that their experiment was carried out in the auroral arc whereas experiment II was in the diffuse aurora. The field aligned components of several hundred eV electrons were reported in auroral experiment by WHALEN and MCDIARMID (1972) and by WINNINGHAM *et al.* (1977) in the dayside cleft experiment. The energy flux of the several hundred eV electron was of the same

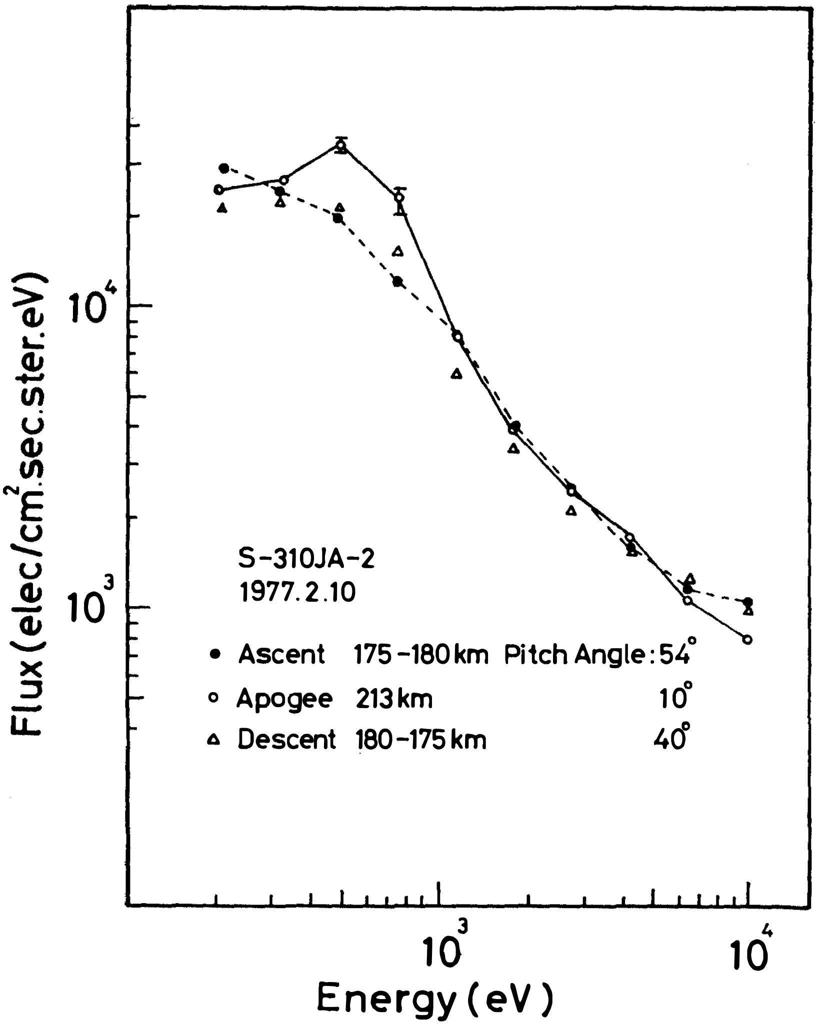

Fig. 9. Energy spectra of the measured electrons.

order in the diffuse aurora and in the cleft, but the energy flux of keV electron in the cleft was much lower than in the diffuse aurora. The measured electron flux was $7.3–8.3\times10^3$ electrons/cm^2·sec·ster·eV at 1140 eV and $1.55–1.90\times10^3$ electrons/cm^2·sec·ster·eV at 4.2 keV. The distribution function of the measured flux seems to be the sum of Maxwellian and power law.

The altitude dependences of electron fluxes are shown in Fig. 10, in which pitch angles corresponding to the rocket altitudes are also indicated. There was no remarkable altitude dependence except the field aligned component, but there were higher fluxes in the ascending path than in the descending path. Electron number density and electron temperature measurements made on board the same rocket showed the same tendencies.

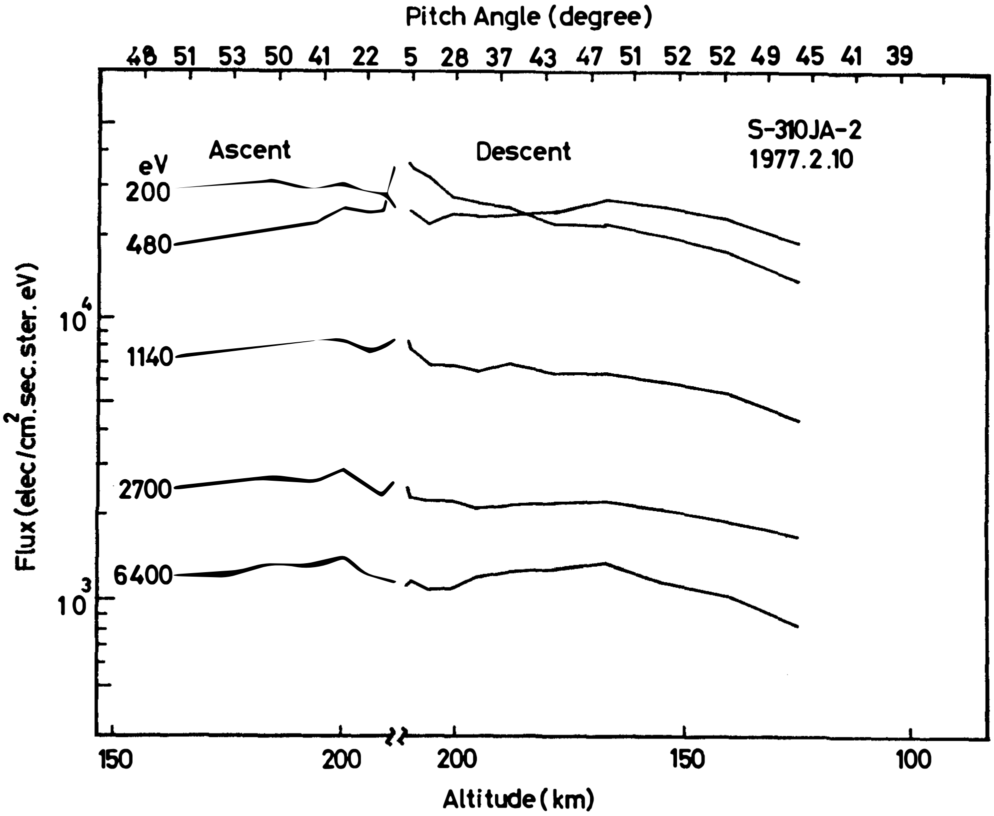

Fig. 10. Altitude dependences of electron fluxes.

4. Conclusions

In experiment I, the energy spectra of the precipitating electrons were obtained in a quiet condition. There was a localized electron precipitation region even in such a geomagnetically quiet condition. The energy spectra had the power law shape, and hardened in the high energy side.

In experiment II, the energy spectra of the precipitating electrons were obtained in the disturbed condition. Field aligned electron flux was observed at several hundred eV in the diffuse aurora. This energy was of the same order as those found in the field aligned precipitation in the cleft.

Acknowledgments

These rocket experiments were carried out by the parties of the 17th and the 18th Japanese Antarctic Research Expedition. The authors wish to express their sincere thanks to the members of the JARE parties for their efforts on carrying out these experiments, and to the staff of the National Institute of Polar Research for their kindness in giving them the chances of the rocket experiment at Antarctica.

References

BANKS, P. M., CHAPPEL, C. R. and NAGY, A. F. (1974): A new model for the interaction of auroral electrons with the atmosphere: Spectral degradation, back scatter, optical emission, and ionization. J. Geophys. Res., **79**, 1459–1470.

CHOY, L. W., ARNOLDY, R. L., POTTER, W., KINTER, P. and CAHILL, L. J., Jr. (1971): Field-aligned particle currents near an auroral arc. J. Geophys. Res., **76**, 8279–8298.

HILL, R. W., GRADER, R. J., SEWARD, F. D. and STOERING, J. P. (1970): Soft particle flux above 130 km at midlatitude. J. Geophys. Res., **75**, 7267–7271.

KUBO, H., MUKAI, T., ITOH, T. and HIRAO, K. (1976): Rocket observation of low-energy electrons in the mid-latitude night-time ionosphere. Space Res., **16**, 497–501.

WHALEN, B. A. and MCDIARMID, J. B. (1972): Observations of magnetic-field-aligned auroral-electron precipitation. J. Geophys. Res., **77**, 191–202.

WINNINGHAM, J. D., SPEISER, T. W., HONES, E. W. Jr., JEFFRIES, R. A., ROACH, W. H., EVANS, D. S. and STENBAEK-NIELSEN, H. C. (1977): Rocket-borne measurements of the dayside cleft plasma: The tordo experiments. J. Geophys. Res., **82**, 1876–1888.

(Received May 16, 1978)