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INTRUSION OF ENERGETIC ELECTRONS INTO THE POLAR ATMOSPHERE DURING THE SOLAR PROTON EVENT OF 24 SEPTEMBER, 2001

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Abstract

Cosmic Ray Group of Lebedev Physical Institute (LPI) has been carrying out long-term cosmic ray measurements in the atmosphere by radiosounding since 1957. . During quiet periods, the radiation in the atmosphere is due to galactic cosmic rays. The enhanced radiation level is observed at altitudes above 20 km during solar proton events and electron precipitation events. Protons penetrate rather deep in the atmosphere while electrons are absorbed at altitudes ~70–100 km. However, the bremsstrahlung X-rays generated by electrons may be detected by the radiosounds at altitudes of ~20–35 km. Some powerful electron intrusions are observed during solar proton events mainly simultaneously with geomagnetic disturbances. This paper describes an electron precipitation event as observed at Mirny (Antarctica) during the solar proton event of September 24, 2001.

Introduction

Long-term measurement of charged particle fluxes in the Earth's atmosphere is conducted by Lebedev Physical Institute at Murmansk region (geomagnetic cutoff rigidity R_C=0.6 GV, invariant latitude ϕ=65°), Moscow region (R_C=2.4 GV, ϕ=52°), and Mirny observatory, Antarctica, (R_C=0.03 GV, ϕ=–77°), [1–3]. The radiosounds are launched several times a week (used to be launched daily till the late 90-ies) since 1957 till present at 5–8 UT (8–11 LT) in Murmansk region and Moscow, and 6–9 UT (13–16 LT) in Mirny. The long-term homogeneous data series are generally used for studying galactic cosmic ray variations. In the course of this program the intrusions of solar and magnetospheric particles are observed from time to time at polar latitudes against the background of galactic cosmic rays. Being of different origin, solar protons and magnetospheric electrons are usually not observed simultaneously.

Fig. 1 shows the yearly values of solar proton events (SPE), electron precipitation events (EPE), sunspot number, and corotating streams of solar wind [4]. The occurrence of solar proton events demonstrates an 11-year cycle in phase with solar activity, whereas the electron precipitation occurs more frequently at the descending branch of a solar cycle [5, 6] in accordance with the rate of corotating solar wind streams from solar coronal holes. During energetic solar particle events, the enhanced proton fluxes are observed both at the northern and southern polar latitudes, whereas the energetic electron precipitation events are not seen as a rule in Mirny situated in the region of the open magnetic field (*L*-parameter is about 20). In addition, the Mirny launching is performed in local day time. From electron precipitation events presented in Fig. 1 only 9 events were recorded in Mirny. However, during some solar proton events an additional radiation is observed in the atmosphere that appears to occur due to electron precipitation. In such cases the electron precipitation events may happen both in Apatity and Mirny, both simultaneously and not at the same time. This paper describes an electron precipitation event as observed in Mirny (Antarctica) during the solar proton event of September 24, 2001.

Observations

The detectors composed of two Geiger counters return the values of omnidirectional (single counter data) and vertical (telescope data) fluxes of charged particles versus atmospheric depth at altitudes from the ground level up to 30–35 km. A single counter is sensitive to electrons (*E*>300 keV, efficiency ~100%), protons (*E*>6 MeV, efficiency ~100%), and X-rays (*E*>20 keV, efficiency ~1%), and a telescope records electrons (*E*>5 MeV, efficiency ~100%), protons (*E*>30 MeV, efficiency ~100%), but no X-rays. The precipitating electrons while being absorbed at 50–70 km, generate the bremsstrahlung X-rays, which are detected by a single counter and not detected by a telescope.

Some examples of radiosound measurements are presented in Fig. 2. During the electron precipitation event of September 12, 2001, there is an increase just in the single counter count rate , because a telescope is not sensitive to X-rays (Fig. 2*a*). The observations on September 26, 2001 refer to solar proton event of September 24, 2001. They were performed at ~07–08 UT, simultaneously in Apatity, Murmansk region (Fig. 2*b*), and Mirny, Antarctica (Fig. 2*c*). There was a surplus flux against the background due to galactic cosmic rays at both sites. The solar protons penetrated into the atmosphere down to ~26 km (20 g/cm^2) as recorded in Apatity both by a single counter and a telescope. An energy spectrum of solar protons was in agreement with the spectrum observed simultaneously by GOES [http://spidr.ngdc.noaa.gov]. In Mirny, the telescope recorded a solar proton flux equal to that in Apatity, however, a single counter revealed an extra radiation in the atmosphere at significantly lower altitude than the telescope, namely, at ~20 km.

It is reasonably explained by X-ray fluxes generated by precipitating electrons. We calculated the X-ray flux versus the atmospheric depth in assumption that the observed count rate of a single counter was composed of solar protons (which flux is known from the telescope records) and X-rays. Afterward we estimated the precipitating electron flux at a given time as

$J(>300\ \text{keV})=2.5\times10^4\ \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$.

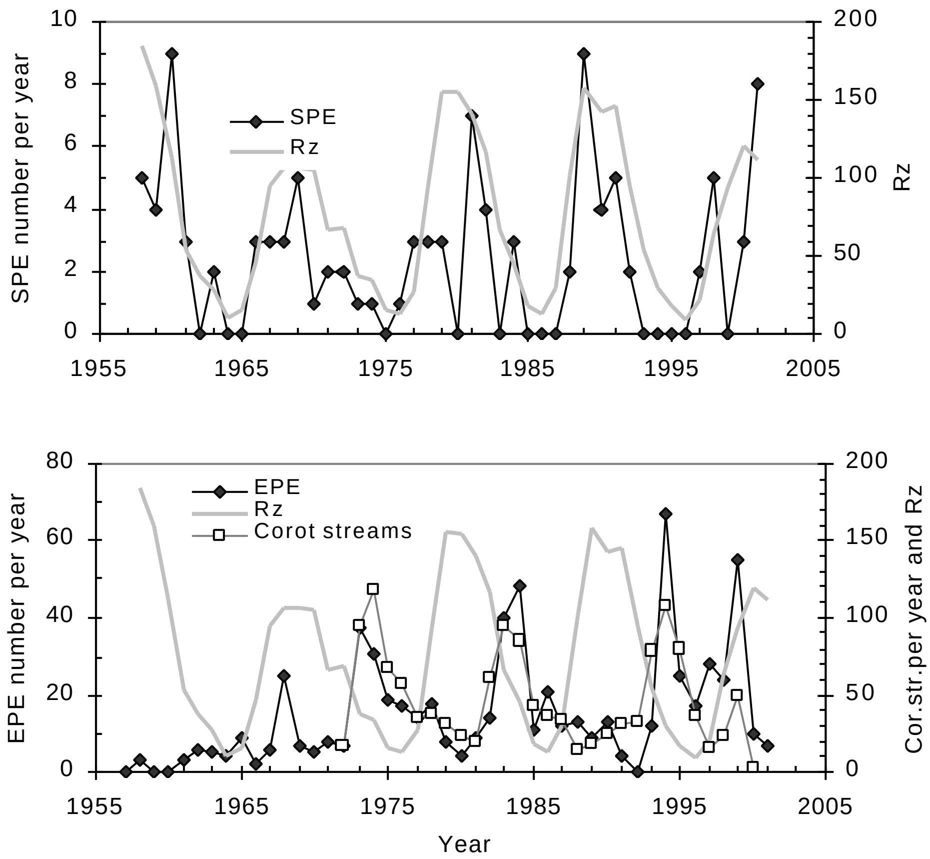

Fig. 1. Charged particle intrusion into the polar stratosphere. Top – yearly values of solar proton events (E_p>100 MeV) as observed in the stratosphere, bottom – yearly values of electron precipitation events in the Murmansk region and of solar wind co-rotating streams. Sunspot number is given to outline the 11-year solar activity cycles.

Fig. 3 demonstrates the time history of events during the solar proton event related to the flare X2/2B with coordinates of S16 E23 on September 24, 2001 at 1038 UT. A storm sudden commencement occurred on September 25 at 2025 UT. The intensity-time profile of >100 MeV solar proton intensity is given according to GOES data [7]. Solar protons were detected in Apatity during the radiosound flight on September 24 at ~18 UT (the onset of the solar proton event was missed in our observations). No electron precipitation was detected at that time. The further measurements in Apatity on September 26 at 0620–0820 UT (the time of surplus flux observation is given) and at 1130–1315 UT did not reveal X-rays either. In Mirny, the observations were performed on September 26 at 0710–0825 UT and September 27 at 0715–0830 UT, both times the X-rays being detected. The X-ray fluxes at the atmospheric depth of 20 g/cm^2 are indicated in Fig. 3 by the plus signs. An estimated flux of precipitating electrons during the second Apatity observation was found to be $J(>300\ \text{keV})=3.2\ \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$.

Several points can be noted from Fig. 3: (1) The observed effect is of magnetospheric origin because the direct arrival of electrons from the interplanetary space would generate X-rays both in Apatity and Mirny. Although the geomagnetic rigidity cut-off is lower in Mirny than in Apatity, the depth of X-ray penetration into the atmosphere (see Fig. 2*c*) argues that the electrons with energies at least above 500 keV were present. The energy spectrum of solar protons measured in Apatity was extended down to ~60 MeV which is indicative of decreasing R_c down to

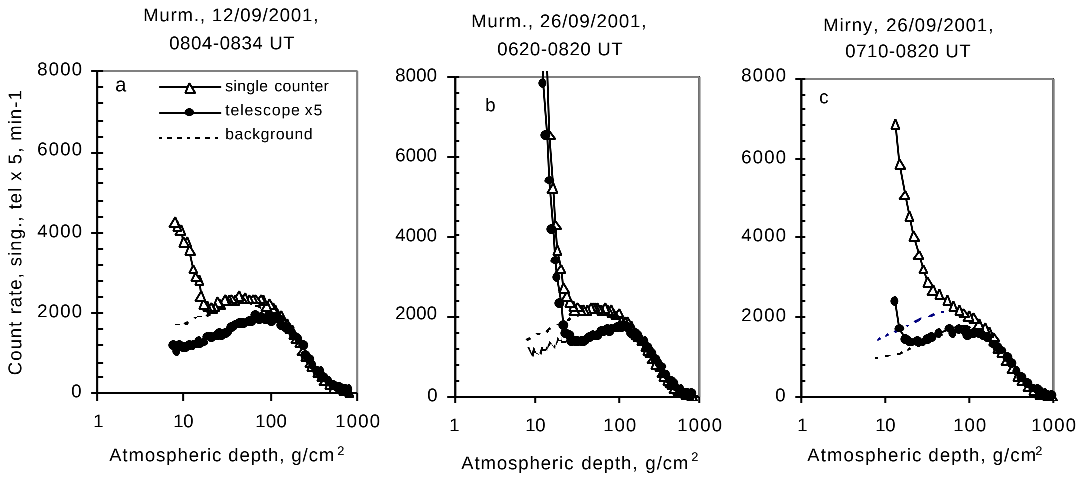

Fig. 2. Results of radiation measurement in the atmosphere: *a* – during electron precipitation, *b* – during solar proton event without electron precipitation, *c* – during solar proton event with simultaneous electron precipitation. Time indicated refers to observation of surplus particle fluxes (not to the whole radiosound flight). Count rate of telescopes is multiplied by 5. Dashed lines stand for the background due to galactic cosmic rays.

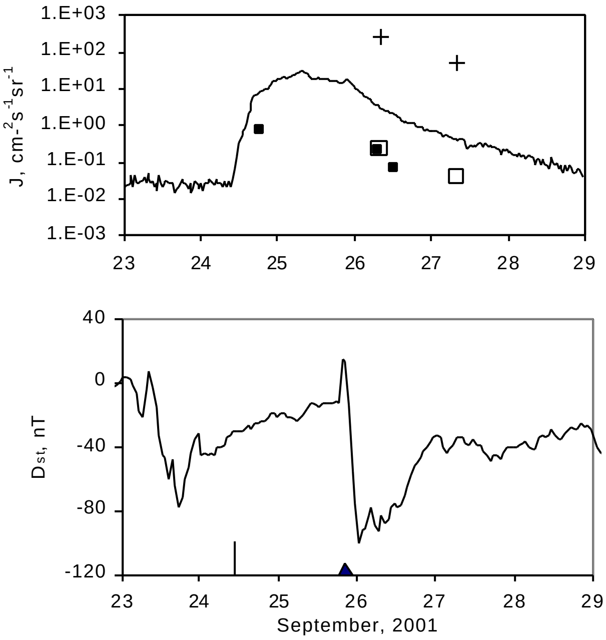

Fig. 3. Time history of the solar proton event of September 24, 2001. Top: solar proton intensity as measured by GOES [7] (>100 MeV, thin line) and by radiosounds in Apatity (>150 MeV, black squares) and Mirny (>150 MeV, white squares), >20 keV X-ray intensity at 20 g/cm^2 of atmospheric depth in Mirny (plus signs). Bottom: D_{st}-index (thin line), solar flare (vertical bar), and storm sudden commencement (black triangle).

0.35 GV. Such a change in R_c is a common situation during solar proton events [7]. (2) The electron precipitation was observed in Mirny during local day time which is unusual for the quiet time. Therefore, the position of precipitation zone was shifted compared to its usual position in the quiet time. (3) It is seen at the bottom panel of Fig. 3 that the electron precipitation was detected before the storm sudden commencement (September 25 at 2025 UT) but the geomagnetic field was rather disturbed (D_{st}=–23 nT).

The solar proton event of September 24, 2001, is rather typical with regard to electron precipitation. To understand the underlying physical processes other events have to be considered in detail.

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