32ND INTERNATIONAL COSMIC RAY CONFERENCE, BEIJING 2011

Energetic electron precipitation events recorded in the Earth’s polar atmosphere

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DOI: 10.7529/ICRC2011/V06/0297

Abstract: There are three main populations of ionizing particles in the Earth’s atmosphere, namely, galactic and solar cosmic rays and energetic electrons precipitating from the magnetosphere during interplanetary and geomagnetic perturbations. All these particle populations were observed in the long term balloon cosmic ray measurements in the atmosphere at several geomagnetic locations including northern and southern polar regions and mid latitudes. The measurements are carried out by the Lebedev Physical Institute RAS from 1957 till now. We focus on energetic electron precipitation events observed in the Earth’s polar atmosphere in 1958-2010. We discuss (1) the origin of these events and their relation to the geomagnetic disturbances, and (2) the relationship between the solar activity level and the occurrence rate of electron precipitation events in the polar atmosphere.

Keywords: cosmic rays, electron precipitation, interplanetary and geomagnetic disturbance

1 Introduction

There are three main populations of ionizing particles in the Earth’s atmosphere, namely, galactic and solar cosmic rays and energetic electrons precipitating from the magnetosphere during geomagnetic perturbations. All these particle populations were observed in the long term balloon cosmic ray measurements in the atmosphere at several geomagnetic locations. The measurements by radiosound-detector in the atmosphere are carried out by the Lebedev Physical Institute RAS from 1957 till now [1, 2]. A detector consists of two Geiger tubes arranged as a telescope with a 7 mm (2 g·cm^{-2}) thick Al filter inserted between the counters. A single counter is sensitive to electrons (E>200 keV), protons (E>5 MeV), and X-rays (E>20 keV), and a telescope records electrons (E>5 MeV) and protons (E>30 MeV). Efficiency of the charged particles recording is close to 100%.

Precipitating electrons are absorbed at altitudes of ~70−100 km. However, the bremsstrahlung X-rays generated by these precipitating electrons may be detected at altitudes of ~20-35 km by a single counter, which is sensitive to X-rays, but not by a telescope. In view of very small efficiency (~1%) of X-ray recording by Geiger counter, we point out that only strong events characterized by large fluxes of precipitation electrons were recorded in our CR experiment. Furthermore we identified an Electron Precipitation Event (EPE) if the enhancement in the count rate of a single counter (but not of a telescope) >30 % was observed at altitude higher than 20 km at least during 10 minutes. In ~ 75% of EPEs recorded, X-rays penetrated down to ~25 km, the remainder being registered at altitudes above 30 km.

Thus, we mainly deal with time extended (several tens of minutes) precipitation of electrons with energies above several hundreds of keV [3, 4]. By comparing the balloon experimental data obtained during precipitation event in the atmosphere and the Monte Carlo simulation results on the electron flux transport through the Earth’s atmosphere we can evaluate primary spectrum of precipitating electrons at the top of the atmosphere [5, 6]

This paper considers numerous high-energy electron precipitation events recorded in 1958-2010 in the northern polar atmosphere at the Murmansk region (Olenya and Apatity stations; geomagnetic cutoff rigidity Rc=0.6 GV, McIlwain parameter L=5.6). We discuss the origin of these events in terms of their relationship to the interplanetary and geomagnetic disturbances as well as a relationship between solar activity level and the occurrence rate of electron precipitation events in the polar atmosphere.

2 Interplanetary and geomagnetic disturbances accompanying the energetic electrons precipitation into the Earth's polar atmosphere

To define the interplanetary and geomagnetic conditions accompanied the precipitation events in the Earth's polar atmosphere the following parameters were examined: interplanetary magnetic field (IMF) strength and its Bz component, solar wind velocity, geomagnetic Kp, AE, and Dst indices, and >2 MeV electron daily fluences recorded onboard GOES satellites at geostationary orbit, and database on the geomagnetic Sudden Storm Commencements (SSC) [7, 8]. The superposed epoch method was applied to this set of interplanetary and geomagnetic parameters. The date of selected EPE observation in the atmosphere was taken as a zero day and the mean values of an examined parameter were calculated during 10 days before and 10 days after this EPE. Obtained results based on such analysis allow us to conclude that (1) the electron precipitation mainly occurs next day after relative maximum in IMF strength and at the relative maximum of solar wind velocity, (2) the Bz component of IMF is southward at least 2 days before an EPE and (3) the electron daily fluence reaches its maximum value ~1 day after an EPE, (4) ~ 20% of EPEs occur 1– 2 days after SSC, (5) the Dst, Kp and AE indices reaches their extreme values on the EPE day. We note the temporal order of phenomena is in a qualitative agreement with results of Baker [9, 10].

3 27-day periodicity in the electron precipitation event occurrence

One of the most important sources of large interplanetary and geomagnetic perturbations are high-speed solar wind streams originating from solar low latitude trans-equatorial coronal holes. Such "geo effective" coronal holes are very often during descending phase of solar activity cycle [11]. Interaction of high-speed solar wind streams (velocity V~ 700-1000 km·s^{-1}) and slow quiet solar wind (V~ 250-400 km·s^{-1}) create the so called Corotating Interaction Region (CIR) in the interplanetary space. The CIRs are characterized by strong magnetic fields B>20 nT and very fast variation of the strength and orientation of magnetic field B as well as the dynamic pressure [12, 13]. Such CIRs are very "geo effective" in producing the strong geomagnetic substorms and storms which significantly affect charged particle population of the inner and outer radiation belts of the Earth's magnetosphere.

Magnetospheric electron (>2 MeV) fluxes and strong geomagnetic storms demonstrate 27-day variation during descending phase of solar activity [14, 15]. To examine a possible presence of 27-day variation in the energetic electrons precipitation event occurrence rate in the polar atmosphere we choose balloon cosmic ray measurements in the atmosphere in December 1993 - June 1994. Very extended trans-equatorial coronal holes were observed at the Sun [7, 8; solar Bartels rotations nn. 2190-2196] during this time. The high-speed solar wind streams origi-

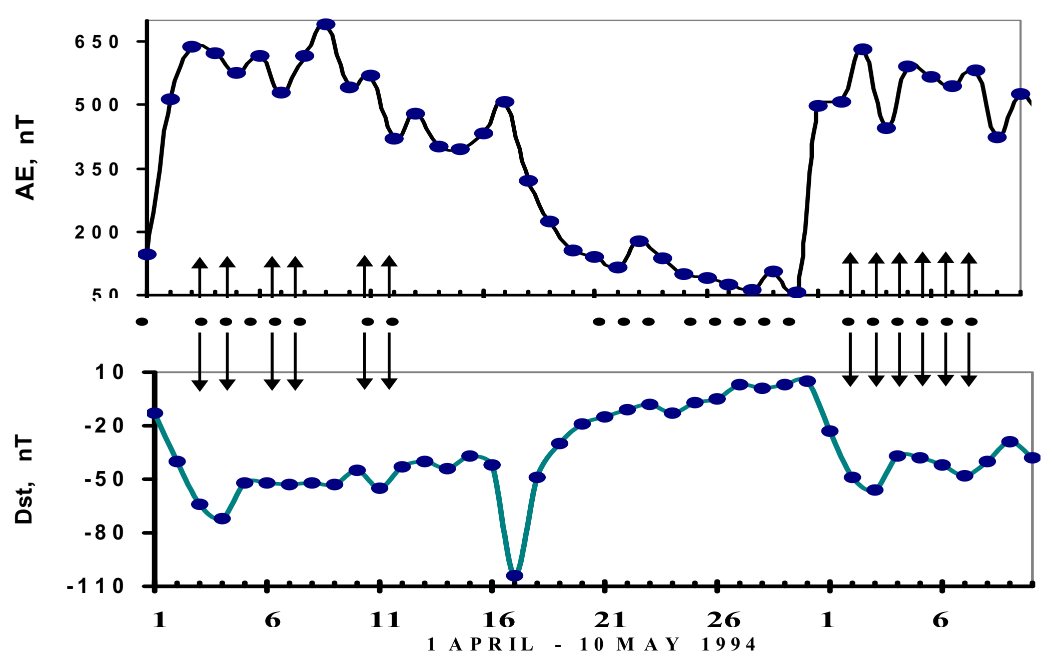

Figure 1. Geomagnetic auroral electrojet index (AE; upper panel)) and equatorial Dst index (bottom) time variations during April,1 – May, 10 1994. Dates of balloon flights at Murmansk region are noted by circles in middle panel, arrows indicate the days of EPE observation in the atmosphere.

nated from them caused recurrent interplanetary disturbances and geomagnetic storms. Figure 1 show time profiles of the auroral electrojet (AE) and equatorial (Dst) indices for April 1994 - May 1994 (solar rotations nn. 2194 and 2195). Circles note dates of balloon CR measurements in the Northern polar atmosphere. Arrows indicate the days when the electron precipitation events were observed on balloons in the atmosphere. We evaluated energy spectra of precipitating electrons at the top of the atmosphere for some of these EPEs. We used a spectrum presentation in the form $J(>E)=B\cdot exp(-E/E_0)$, where E is electron energy. The characteristic energy, E_0, in the spectrum of precipitating electrons was estimated in the range 30-150 keV during these events [4].

It is seen that the EPEs were observed during significant geomagnetic storms 4-12 April and 2-8 May 1994. In contrast, the events were absent during quite time on 20 – 29 April 1994. Thus, there is an indication of the presence of ~ 27 day periodicity of the EPEs occurrence in the northern polar atmosphere during descending phase of 22nd solar activity cycle.

4 Electron precipitation events distribution over the 11-year solar activity cycle

We examined long-term behavior of EPE occurrence to search their origin. Yearly numbers of EPEs alongside with yearly sunspot numbers evolution as signature of solar activity cycle are presented in Figure 2. It should be noted that till the early 1970s not all balloons carried telescopes and some EPEs of that period may be omitted. We found that yearly number of EPEs in the stratosphere demonstrates an 11-year cycle with maximum values at the descending phase of the sunspot cycle in 1973, 1984, and 1994 [16] and in 2004. Similar temporal behavior has a number of geomagnetic disturbances associated with corotating solar wind structures discussed above. And contrary, the transient CME-related geomagnetic storms occur in phase with solar activity [17]. It should be noted that a certain amount of EPEs occurs during solar energetic particle intrusions into the stratosphere and are associated with CME-related disturbances [18]. However these EPEs are not numerous. Apparently, CME-related disturbances do not contribute significantly to the time profile of the EPE rate in the stratosphere and electron precipitation events are mostly associated with high-speed solar wind streams as discussed before. It is known that relativistic electron fluxes in the outer magnetosphere also correlate with high-speed solar wind streams from coronal holes [9]. We believe the EPEs observed in the stratosphere may be a result of electron acceleration in the magnetosphere and successive scattering into the particles loss cone during geomagnetic perturbations caused by the CIRs.

4.1 Recent electron precipitation events recorded at Murmansk region

Last time extended solar activity minimum in 2007-2010 was very quiet in terms of solar flares, interplanetary and geomagnetic storms [7, 8, 19, 20]. Practically no strong solar flares and geomagnetic disturbances were observed during this period. During long time an interplanetary magnetic field strength had a small variations around mean value estimated as ~3.5 nT.

Only four electron precipitations events were observed at Murmansk region during 2008-2010. Last two events were recorded on 13 and 17 December 2010, during

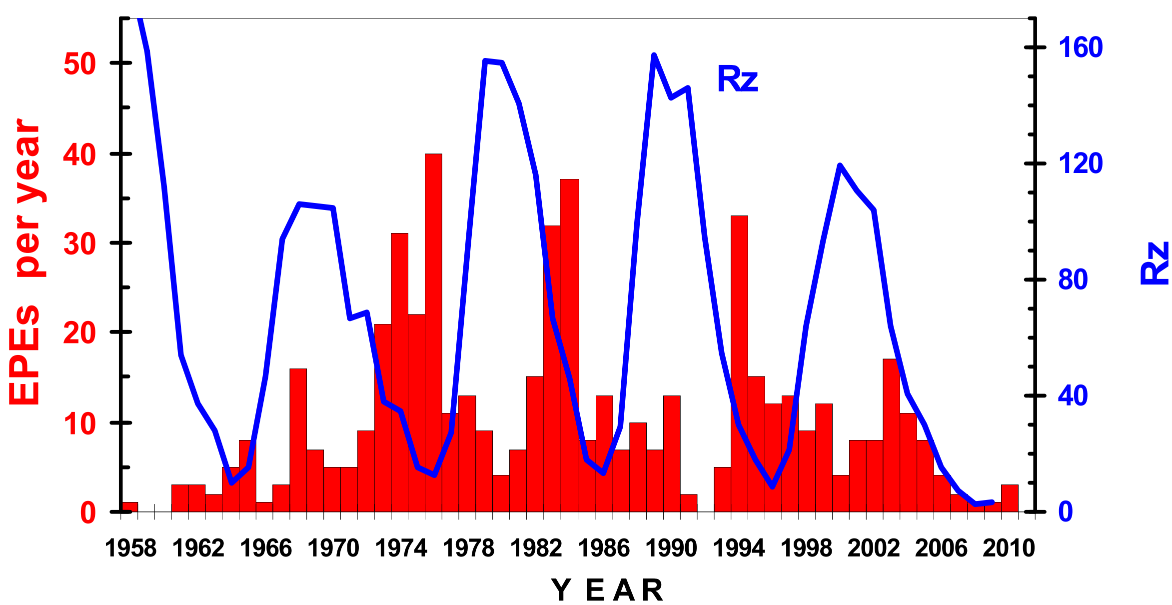

Figure 2. Yearly number of energetic electron precipitation events (EPEs) observed at Northern polar atmosphere (Murmansk region; histogram) and yearly sunspot number Rz (thick line; right Y-axis)

small geomagnetic storm and associated moderate cosmic ray Forbush decrease in 13-22 December ([7, 8], see the NM Apatity records as example [19]). We note, that during last year number of balloon flights was reduced a little bit, nevertheless, we conclude that an increase of geomagnetic activity at northern polar region was started in 2010.

As mentioned before, last two events were recorded on 13 and 17 December 2010. They happened during time interval when trans-equatorial coronal holes CH429 and CH430 existed at the Sun. Solar wind velocity varied in the range of ~380-750 $km \cdot s^{-1}$. During this time the POES auroral activity level was above 4 indicating significant changes of auroral conditions [20]. Also, > 2 MeV electron daily fluence measurements onboard GOES show about two orders increase of this fluence up to $7 \cdot 10^{7}$ $cm^{-2} \cdot sr^{-1} \cdot day^{-1}$ during ~13-18 December 2010 [7, 8].

Summary

We studied the energetic electron precipitation events recorded in the cosmic ray measurements in the Earth's polar atmosphere (Murmansk region; geomagnetic cutoff rigidity Rc=0.6 GV, McIlwain parameter L=5.6). These measurements are carried out by the Lebedev Physical Institute RAS from 1957 till now. Obtained results of analysis allow to conclude that the electron precipitation event mainly occurs (1) on the day when Dst, Kp and AE indices reaches their extreme values and (2) the next day after relative maximum in IMF strength and at the relative maximum of solar wind velocity. (3) The Bz component of Interplanetary magnetic field is southward at least 2 days before an EPE. (4) The daily > 2 MeV electron fluence measured onboard GOES reaches its maximum value ~1 day after precipitation event in the atmosphere. Also, about 20% of EPEs occur 1– 2 days after Sudden Storm Commencements (SSC).

The energetic electron precipitation events are very often during descending phase of solar activity cycle when a number of interplanetary and geomagnetic perturbations increases significantly. These perturbations are mainly producing by the high-speed solar wind streams originating from solar low latitude trans-equatorial coronal holes. Also these long-lived coronal holes are the sources of corotating solar wind streams causing a ~ 27-day repetition rate of the geomagnetic disturbances as well as of the EPEs occurrence in the Earth's polar atmosphere.

Acknowledgments. This work was partially supported by the Russian Foundation for Basic Research (grants 10-02-00326a, 11-02-00095a, 11-02-10018k) and by the program "Neutrino Physics and Astrophysics" of the Presidium of the Russian Academy of Sciences.

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