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Catalogue of electron precipitation events as observed in the long-duration cosmic ray balloon experiment

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ABSTRACT

Since the International Geophysical Year (1957), the Lebedev Physical Institute performs the regular measurements of charged particle fluxes in the Earth's atmosphere (from the ground level up to 30–35 km) at several latitudes. The unique experimental data base obtained during 58 years of cosmic rays observations in the atmosphere allows to investigate temporal, spatial and energetic characteristics of galactic and solar cosmic rays as well as the role of charged particles in the atmospheric processes. Analysis of this data base also revealed a special class of numerous events caused by energetic electron precipitation recorded in the atmosphere at polar latitudes. In this paper we present Catalogue of electron precipitation events observed in the polar atmosphere during 1961–2014 and briefly outline the previous results of this data set analysis.

1. Introduction

From the middle of 1957 till present the P.N. Lebedev Physical Institute of the Russian Academy of Sciences (Laboratory of Solar and Cosmic ray physics-Dolgoprudny Scientific Station) has carried out the regular balloon measurements of charged particle fluxes in the atmosphere from the ground level up to 30–35 km above the sea level. The measurements are performed at polar (northern and southern) and middle latitudes (including six latitude surveys in1962–1987; Bazilevskaya and Svirzhevskaya (1998)). More than 85,000 measurements of cosmic ray fluxes in the atmosphere have been performed using the Geiger counters. The main goals of observations are the investigations of galactic cosmic ray modulation in the heliosphere, solar cosmic ray generation and propagation, precipitation of energetic electrons from the Earth's magnetosphere and the role of charged particles in the atmospheric processes (Charakhch'yan, 1964; Bazilevskaya et al., 1991; Bazilevskaya and Svirzhevskaya, 1998; Stozhkov et al., 2001, 2009).

In this paper we focus on the magnetospheric electron precipitation into the atmosphere which is important process of the outer radiation belt depletion (e.g., Horne and Thorne, 2003). In the stratospheric experiment we deal with $E > 200$ keV electron flux. The magnetosphere reacts to the disturbed solar wind with changes of its configuration and violation of the magnetopause. The outer radiation belt populated by energetic electrons gets additional electrons both from the solar wind and the ionosphere. The electrons are then subject of two competing processes-betatron or stochastic acceleration and losses via escaping back to space or into the atmosphere (Reeves et al., 2003). Currently accepted rapid loss mechanisms include magnetopause shadowing and/or outward diffusion, and precipitation to the atmosphere due to wave-particle interactions (Ukhorskiy et al., 2015).

Satellites situated in the magnetosphere observe an enhanced variability of high-energy electron fluxes not only because of real particle acceleration and loss but also because of particle spatial and energy redistribution. Therefore from the satellite observations it is not always easy to assess real electron precipitation. In the atmosphere we avoid this ambiguity. It should be noted that solar wind-magnetosphere coupling leading to electron precipitation remains still an open area for research (Blum et al., 2015; Clilverd et al., 2010; Sandanger et al., 2009).

Precipitation is a consequence of the electron scattering into the loss cone which results from the nonlinear wave-particle interaction. ULF and VLF waves are generated in the magnetosphere by interplanetary disturbances (Reeves et al., 2003). Whistler mode chorus, hiss and electromagnetic ion cyclotron waves (EMIC) can both accelerate electrons to higher energies and scatter electrons into the loss cone through resonant pitch angle interaction. In the course of the bounce and drift motions an electron passes to various regions and can be accelerated or lost. Numerous works are devoted to modeling and observation of such effects, to mention just a few: Carson et al., 2013; Clilverd et al., 2015; Kersten et al., 2011; Kubota et al., 2015; Li et al., 2013; Lorentzen et al., 2000; Meredith et al., 2002; O'Brien et al., 2003, Wang et al., 2014.

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Even a brief outline shows extremely complicated dynamics of magnetospheric electrons.

Study of electron precipitations is important both for fundamental science and human practice activity. Large electron fluxes affect orbital satellites causing an electrostatic discharge (ESD) anomaly. Cumulative effect of radiation damages is one of the most important factors limiting the lifetime of a spacecraft. A single energetic electron can introduce errors into memory chips and other electronic devices, known as a single-event upset (SEU). SEUs can lead to corruption of data in memory chips and to phantom commands (Horne, 2002). Additional ionization created by the electron fluxes violates the radio wave propagation in the ionosphere (Clilverd et al., 2010). Electron precipitation contributes to the production of odd nitrogen NO_x and odd hydrogen HO_x through ion-molecular reactions in the upper atmosphere. Both NO_x and HO_x can destroy odd oxygen through catalytic reactions, and hence play an important role in the ozone balance of the middle atmosphere (Clilverd et al., 2009; Turunen et al., 2009; Krivolutsky and Repnev, 2012). During the last decades enormous efforts have been undertaken for understanding and forecasting of electron precipitation. Dynamics of energetic electrons in the magnetosphere has been observed at many spacecraft missions including GOES, POES, CRRES, SAMPEX, Polar, Cluster and others. A dedicated pair of satellites – Van Allen Probes – was launched in 2012 (Spence et al., 2013). Special balloon campaigns MAXIS, MINIS, BARREL have been organized with the aim of simultaneous observation of electron fluxes in space and in the atmosphere (Millan et al., 2002, 2007; Comess et al., 2013; Sample, 2013; Woodger et al., 2015). Observations proved that the electron flux can vary by several orders of magnitude on time scales as short as a few minutes (e.g., Blake et al., 1996; Nakamura et al., 2000; Blum et al., 2015).

This paper presents the Catalogue of events of high-energy magnetospheric electron precipitation recorded by the cosmic ray group from the Lebedev Physical Institute during more than half century of cosmic ray observations in the stratosphere. Results of simulations of the energetic electron flux propagation through the Earth's atmosphere are described. These results were used for evaluation of characteristics of precipitating electron fluxes given in the Catalogue.

2. Balloon cosmic ray experiment in the Earth's atmosphere

Since the International Geophysical Year (1957), the Lebedev Physical Institute performs the regular measurements of cosmic rays in the atmosphere (Charakhch'yan, 1964; Bazilevskaya et al., 1991; Bazilevskaya and Svirzhevskaya, 1998; Stozhkov et al., 2001, 2009). Observations are taken with light balloons at several latitudes almost every day. In the frame of this program, the electron precipitation events (EPEs) are detected at polar latitudes. Information on polar stations of cosmic ray measurements in the stratosphere where these events were recorded is given in Table 1.

Balloon launching time during many year observations remained in the limits of 8–11 *LT* and ~13–18 *LT*. A typical flight lasts about 1.5 h and a balloon usually reaches altitudes where precipitation can be observed. The balloons do not remain long at high altitudes where EPEs may be observed, i.e., we usually do not record an EPE start and end as it would be possible during long-lasting balloon flights (e.g., Lazutin et al., 1982; Parks et al., 1993; Millan et al., 2002). In spite of the fact that observational time at Murmansk region and at Mirny observatory was close, almost all of EPEs were recorded at Murmansk region. This is because Mirny is located in the polar cap, mainly at ~~the~~ open geomagnetic field lines (Makhmutov et al., 2002).

Simultaneous observations of the EPEs at the different locations are very important from the point of view of estimation of longitudinal extension of energetic electron precipitation region. Such simultaneous balloons being at the same atmospheric altitude at any two stations during the EPE are rather rare occasion. Table 2 presents a comparative statistics of few electron precipitation events observed simultaneously at pair of stations Olenya-Norilsk and Olenya – Tixie Bay.

In spite of small statistics of events recorded at Norilsk and Tixie Bay, it is possible to conclude that (1) the events recorded at Norilsk in ~30% of cases were also recorded at Olenya, and contrary, the events observed at Olenya in ~23% cases were also recorded at Norilsk; (2) in ~50% of cases the events recorded at Tixie Bay also were observed at Olenya, but in ~20% of cases the electron precipitation events at Olenya were seen at Tixie Bay. The fact of simultaneous observations of EPEs at well separated locations means that the energetic electron precipitation region

Table 1
List of high-latitude stations of stratospheric cosmic ray monitoring (R_c – geomagnetic cutoff rigidity).

Station	Geograph. Coordinates	R_c (GV)	Start time of balloon launch (UT)	Period of measurements	Number of balloon launches	Number of EPEs recorded till 2014
Olenya, Murmansk region	68°57′N 33°03′E	0.6	5–8	07/1957–2002	~ 40,000	524
Apatity, Murmansk region	67°33′N 33°20′E	0.6	12–15	2002–present time		
Mirny, Antarctica	66°34′S 92°55′E	0.03	6–9	03/1963–present time	16,700	10
Norilsk	69°00′N 88°00′E	0.6	5–8	11/1974–06/1982	760	10
Tixie Bay	71°36′N 128°54′E	0.5	5–8	02/1978–10/1987	1190	17

Table 2
Comparative statistics of EPEs recorded at Olenya, Norilsk and Tixie Bay.

Pair of stations (*S1* and *S2*)		Period of measurements	Number of simultaneous launches at *S2*	Number of EPEs recorded at the *S1*	Number of EPEs recorded simultaneously at *S1* and *S2*
S1	*S2*				
Olenya	Norilsk	11/1974–06/1982	13	89	3
Norilsk	Olenya	11/1974–06/1982	10	11	3
Olenya	Tixie Bay	02/1978–10/1987	47	145	9
Tixie Bay	Olenya	02/1978–10/1987	16	17	9

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