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

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Abstract

There are three main populations of ionizing particles in the Earth’s atmosphere, namely,

* Galactic Cosmic Rays (GCRs)
* Solar Cosmic Rays and
* Energetic Electrons precipitating into the atmosphere 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.

The measurements are carried out by the Lebedev Physical Institute RAS from 1957 till now.
Lebedev Physical Institute RAS (1957–up to now);
polar regions: Murmansk region, 68°57′N, 33°03′E, and 
Mirny obs., Antarctic, 66°34′S, 92°55′E

The main goals of the experiment are the investigation of
- Galactic Cosmic Rays
- Solar Cosmic Rays
- Radioactivity
- Electron Precipitation Events – (~ 490 in Murmansk reg., 11 at Mirny obs. !)

Cosmic Ray Measurements with Standard Radiosound
by Meteorological Balloon

INSTRUMENTS
a) Two geiger counters (Aluminium filter inserted)
b) Electronic plate with high-frequency transmitter
c) Altitude sensor
d) Power supply

CHARACTERISTIC FEATURES
- Maximum altitude about 35 km
- Electron records for E > 0.2 MeV
- Proton records for E > 5 MeV
- Bremsstrahlung photons for E > 20 keV
<table>
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<th>Geograph.</th>
<th>CGM</th>
<th>IGRF</th>
<th>Magnet. Field</th>
<th>Dipole</th>
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<th>Geog.</th>
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<th>Merd.</th>
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<td>Long.</td>
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+ sea expeditions (survey)! 

- MIRNY
- MOSCOW
- APATITY
CR Pfotzer maxima
Monthly averaged charged particle fluxes in the atmosphere vs. time in the Murmansk region (1957-2011 (May)).

Graph showing the variation in charged particle fluxes measured in the Murmansk region from 1955 to 2015. The x-axis represents years from 1955 to 2015, and the y-axis represents the flux in Nmax/cm²*s. The graph includes lines for different flux ranges, indicated by various colors and styles.
2 New Results related to the last CRs maximum ...
For details: Stozhkov et al., 2011; ID: 0844
Proton Energy Spectra of the additional CR flux recorded at Murmansk region during Nov 2008 — July 2009 (Bazilevskaya et al., 2011 in press).
Now we focus on energetic Electron Precipitation Events observed in the Earth’s polar atmosphere in 1958-2010

- How to determine the primary energy spectrum of precipitating electrons from balloon measurements?

- Interplanetary and Geomagnetic Conditions related to the EPE in the atmosphere

- EPEs distribution over the 11-year Solar Cycle
Few notes ...

• During such events a major flux of bremsstrahlung photons is generated by precipitating electrons at the top of the atmosphere (H~ 50-100 km).

• In contrast to electrons these photons (X-ray) can penetrate down to altitudes of 15-20 km depending on their initial energy and can be registered by balloon-borne radiosonde
Examples of electron precipitation events observed in the stratosphere

Three minute averages of count rates of single counters during (1) EPEs and (2) quiet conditions, and (3) telescopes versus residual atmospheric depth. Count rates of telescopes are multiplied by 5. On the left panel is EPE of September 26, 1997; on the right panel is EPE of October 9, 1998.
(a): The count rate of the omnidirectional counter in the atmosphere during the electron precipitation events on 28 and 29 Sep 1999, and 5 May 2000 as observed at Olenya (68.57 N, 33.03 E). The pre-EPE quiet time background count rate due to galactic CRs on 27 Sep 1999 is shown by thick line (curve 4). The vertical arrows denote altitude levels for the selected atmospheric depths $X$. (b): The count rate of the counter due to the bremsstrahlung photons vs. atmospheric depth during these events (see text).
How to determine the energy spectrum of precipitating electrons at the top of atmosphere from balloon measurements?
Previous interesting papers: Berger et al., 1972, 1974; Lazutin, 1979; Kalinina et al., 1988; and others

We used Monte Carlo simulations based on the PLANETOCOSMICS code (Geant4 toolkit by Desorgher et al. 2003, Desorgher 2004, Agostinelli et al. 2003)

This code simulates the electromagnetic and hadronic interactions of energetic particles (<100GeV) with the Earth's atmosphere.
We consider:

* the different primary spectra of precipitating electrons:
  
  \[ J_{e^-} \sim \exp(-E/E_0), \quad E_0 : 10 \text{ keV} - 5 \text{ MeV} \]

  angular distribution: \textit{vertical, isotropic}

* we compute the number of photons with $E > 10 \text{ keV}$ at different atmospheric depths: $X = 0, 0.05, 0.5, 1, \ldots, 60 \text{ g.cm}^{-2}$

* for each primary spectrum we obtained a photon absorption spectrum ($\text{#photon vs depth}$) as \[ J_{ph} \sim \exp(-X/X_0), \]

* $X_0$ is obtained as a function of the $E_0$ and of the angular distribution of the primary spectrum

By comparing the simulated and observed absorption spectra we can deduce electron spectrum at the top of the Earth’s atmosphere.
Solid lines show the results obtained for vertically incident electron flux at the top of atmosphere, dashed lines - that for isotropic angular distribution of electrons. The results presented are normalized to 1 primary electron with energy $E_e = 50$ keV, 500 keV and 5 MeV.
SIMULATION RESULTS

\[ J_{ph} = A \exp\left(-\frac{X}{X_0}\right) \]

\[ J_{e^-} = B \exp\left(-\frac{E}{E_0}\right) \]
Photon spectra in the atmosphere and precipitating electron spectra at the top of the atmosphere

<table>
<thead>
<tr>
<th>DATE</th>
<th>Aph,o (cm⁻²s⁻¹sr⁻¹)</th>
<th>Eph,o (keV)</th>
<th>Boe, (cm⁻²s⁻¹sr⁻¹)</th>
<th>Eoe (keV)</th>
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<td>3093</td>
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</table>

\[dN_{ph}/dE = A_{ph,o} \cdot \exp(-E/E_{ph,o})\]

\[dN_{e}/dE = B_{e} \cdot \exp(-E/E_{e})\]
Interplanetary and Geomagnetic Conditions related to the EPE in the atmosphere
The superposed epoch method of analysis

- IMF / Bz component
- Solar Wind Velocity
- Relativistic Electron flux at geostationary orbit (GOES data)
- Sudden Storm Commencements (SSC)
- Dst and AE indices
ELECTRONS, \(\text{cm}^{-2}\text{sr}^{-1}\text{day}^{-1}\)

SSC OCCURRENCE

ELECTRONS, \(\text{cm}^{-2}\text{sr}^{-1}\text{day}^{-1}\)

Dst, nT

AE, nT

DAY
“O” day is a date of Electron Precipitation Event. The error bars indicate rms errors of average meanings, N is number of events in analysis.
EPE occurrence rate and 11-year Solar Cycle
EPEs observed at Murmansk polar region in 1958-2010
Recent EPEs ...
POES auroral activity level charts

http://www.solen.info/solar/poes/poes.html
Conclusions - I

- More than 480 Electron Precipitation Events (EPEs) were observed at Olenya station (Murmansk region) during long-term balloon cosmic ray measurements performed by Lebedev Physical Institute in 1957-2010.

- The EPEs in the atmosphere at northern polar latitude (Olenya station) occurred 1-2 days after the SSC. During this time increased relativistic electron flux was observed onboard GOES at geostationary orbit.
There is a quasi-11-year cycle in precipitation event occurrence rate shifted with respect to solar activity cycle. The EPEs occur more frequently at descending phase of a solar cycle. This is in agreement with dual-peak solar cycle distribution of intense geomagnetic storms (Gonzales, et al., 1996; etc.)

We note that the new 11-year cycle of Energetic Electron Precipitation events at Northern Polar Atmosphere was started in 2010.
Thanks for your attention!