Comparison of ionization effect in the atmosphere of the Earth due to GLE 65 and GLE 69

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Abstract. The study of the contribution of high energy particles of galactic and solar origin to cosmic ray induced ionization in the atmosphere of the Earth is of a big interest. The ion production rates in the atmosphere of the Earth due to a major solar energetic particle events on 28 October 2003 and 20 January 2005 produced by solar protons are obtained. The proton spectra are considered on the basis of GOES 11 satellite measurements and bibliographic data. The Forbush decrease during GLE 69 is taken into account. The cosmic ray induced atmospheric cascade simulation is carried out with CORSIKA 6.990 code using FLUKA 2011 and QGSJET II hadron interaction models. During the simulation a winter profile of the atmosphere is considered, which permits realistic description of the event. The ion production rate is compared for 40 N, 60 N and 80 N latitudes. The time evolution of obtained ion rates is presented. The 24h ionization effect is for various latitudes. It is demonstrated that the ionization effect is important on sub-polar and polar latitudes. The obtained results are discussed.

1. Introduction
The Earth is constantly hit by high energy cosmic particles. The galactic cosmic ray (GCR) are the main ionization source in the troposphere [1, 2]. In addition solar energetic particles (SEP) producing ground level enhancements (GLE) also contribute to the atmospheric ionization. The detailed study of ion production in the ionosphere and atmosphere is important, because it is related to various atmospheric processes. The cosmic ray induced electron-ion production rate could be estimated from the particle flux using the basic physics of ionization in air, an appropriate atmospheric model and realistic description of cascade process in the atmosphere [3, 4].

The GLE 65 on 28.10.2003 and GLE 69 on 20.01.2005 are among the largest SEP events. The extreme solar activity of October-November 2003 produced 3 GLEs, with onsets occurring on 28 October, 29 October, and 2 November. In this study we consider the first of these events, namely GLE65 on 28.10.2003. The GLE 69 on 20.01 2005 is the second largest event in the history of cosmic ray measurements. In this study the solar protons spectra are obtained on the basis of GOES 11 satellite measurements and additional data [5]. The spectra are expressed at various moments, the details given in [6, 7]. Since after the first fast impulsive phase of a SEP event, the bulk of solar particles arrives isotropically, we assume isotropic flux in this study.
2. Model and simulations
The estimation of cosmic ray induced ionization is carried out with full Monte Carlo simulation of the atmospheric cascade according Oulu model [8] using ionization yield function $Y$ formalism:

$$Y(x, E) = \frac{\Delta E(x, E)\Omega}{\Delta x E_{ion}}$$

where $\Delta E$ is the deposited energy in an atmospheric layer $\Delta x$, $\Omega$ is the geometry factor - a solid angle, $x$ in $g/cm^2$ is a residual atmospheric depth i.e. the amount of air overburden and $E_{ion} = 35$ eV is the ionization potential in air [1].

Hence the atmospheric ionization is obtained on the basis of equation (2) following the procedure [4, 9]

$$Q(x, \lambda_m) = \int_{\infty}^{E} D(E)Y(E, x)\rho(x)dE$$

where $D(E)$ is the differential cosmic ray spectrum for a given component of primary cosmic ray, $Y$ is the ionization yield function defined according to (1), $\rho$ is the atmospheric density, $\lambda_m$ is the geomagnetic latitude, $E$ is the initial energy of the incoming primary nuclei on the top of the atmosphere. The geomagnetic latitude $\lambda_m$ governs the rigidity, which is related to the integration (above $E$).

The simulation of atmospheric cascade is carried out with CORSIKA 6.990 code [10] with FLUKA 2011 [11] and QGSJET II [12] hadron generators. During the simulations a spherical atmospheric model is assumed with winter profile, which permits a detailed and realistic description of ion the rate production [13, 14]. The estimated ion pair production rates at various latitudes as a function of atmospheric depth and time are presented in figure 1 for GLE65, respectively figure 2 for GLE69. As was mentioned above the SEP spectra are expresses at 12:20 UT with a slope 3.58 and at 22:00 with a slope 2.33 for GLE65, respectively at 08:00 UT with a slope of 2.32 and at 23:00 UT with a slope of 3.43 for GLE 69.

![Figure 1](image1.png)  ![Figure 2](image2.png)

**Figure 1.** Ion rate during GLE 65 on 28.10.2003 for various latitude.  **Figure 2.** Ion rate during GLE 69 on 20.01.2005 for various latitude.

3. Results and discussion
The ionization in the atmosphere effect is a superpose of contribution of GCR and SEP during the event. The average ion rate due to GCR is also computed on the basis of (1) and (2) assuming the corresponding modulated spectrum. As was recently demonstrated [7] the ionization effect
Figure 3. Ionization effect for 40 N during GLE 65 and GLE 69.

Figure 4. Ionization effect for 80 N during GLE 65 and GLE 69.

Figure 5. Comparison of 24th ionization effect in the atmosphere due to GCR, GLE65 and GLE 69.

during GLE 65 at 40N at 12:20 UT is comparable with average ionization induced by GCR (figure 3A). It is more important at 22:00 UT, because the harder spectrum (figure 3B).

The event on 20.01 2005 occurred during the recovery phase of a large Forbush decrease. Moreover in the following days an additional suppression of the cosmic ray intensity was observed, which resulted on complicated time profile. Hence the ionization effect in the case of 40 N latitude at 08:00 UT is greater then the average of GCR (figure 3C), specifically in the region of Pfotzer maximum and upper atmosphere. However, the ion rates quickly decrease with altitude (below 5 km a.s.l.). In the troposphere the effect is comparable to the average of GCR, even it is slightly negative. The ionization effect at 23:00 UT is comparable to the average of GCR (figure 3D) and it is negative in the troposphere, because the Forbush decrease [15, 16].

The situation is quite different for polar region of the Earth, namely for 80 N. The ionization effect due to SEP is significant in all cases. The ion rate due to GLE 69 in the region of the Pfotzer maximum at 12:20 UT is greater than at 22:00 UT, because the low-energy flux of solar protons is greater than the high-energy flux. However in the troposphere it drops below to the average of GCR (figure 4A). At 22:00 UT the ion rate is greater than the average GCR in a whole atmosphere (figure 4B). In the case of GLE 69 for 80 N latitude a significant excess on
ionization rates in the atmosphere due to solar particles is observed. The effect at 08:00 UT is significant, specifically at altitudes above 10-12 km a.s.l (figure 4C). At 23:00 UT the effect due to solar nuclei decreases in the troposphere (figure 4D) and it is comparable to ionization effect due to GCR.

In general the ionization effect is maximal during the first 24h from the event onset [16]. The obtained ion rates at various latitudes permit to compute the 24h (figure 5) ionization effect. The 24h effect at 40 N during GLE 69 on 20.01.2005 is week, with excess in the region of Pfotzer maximum. Moreover the ionization effect is slightly negative in the troposphere, because the strong accompanying Forbush decrease. The 24h ionization effect during GLE 65 on 28.10.2003 is greater, specifically in the region of the Pfotzer maximum. This is due to the greater contribution of GCR in this case.

The situation is quite different at 60 N and at 80 N. The ionization effect due to SEP is significant in comparison to GCR effect. The ionization effect at 60 N is similar for both studied events. At polar latitudes in the upper atmosphere the ionization effect during GLE 65 is greater than GLE 69, because the reduced ionization from GCR for GLE69. In conclusion: the ionization effect is small for 40 N, specifically in the troposphere. The ionization effect is important only in the sub-polar and polar atmosphere during major ground level enhancement of 28 October 2003 and 20 January 2005 at high altitudes. Obviously a detailed studied of such events is necessary in attempt to make more general conclusion. In addition we have to pay attention to heavier nuclei contribution [17, 18], specifically Helium, which could significantly change the picture at mid latitudes [19, 20].

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