PROCEEDINGS OF SCIENCE

Computation of ionization effect due to cosmic rays in polar middle atmosphere during GLE 70 on 13 December 2006

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At recent one of the modern topics in solar-terrestrial physics is the study of the possible effect of solar variability, respectively cosmic rays variation on atmospheric physics and chemistry. An important feature in most of the proposed mechanisms and models is the key role of the induced by cosmic rays ionization. At recent is observed an apparent effect on minor constituents and aerosols over polar regions during major solar proton events. Therefore the ground level enhancement 70 on 13 December 2006 deserves a special attention. In this work we compute the ion production on 13 December 2006 on the basis on a previously applied model based on detailed Monte Carlo simulations of cosmic ray induced atmospheric cascade. The ion production rate during the event is considered as superposition of cosmic rays with galactic and solar origin. The time evolution of ion production is computed in a realistic manner. The spectral and angular characteristics of the solar protons are explicitly considered throughout the event as well their time evolution. The ionization effect during the event is computed at several altitudes above the sea level in a region with $R_c \leq 1$ GV. The 24^h ionization effect is estimated in the region of the Pfotzer maximum.

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1. Introduction

Our planet is constantly hit by high-energy particles Galactic cosmic rays (GCRs). The majority are protons and $\alpha-$particles. They penetrate deep into the atmosphere producing large amount of secondaries. They are the main source of ionization in the troposphere and stratosphere [1, 2, 3]. The intensity of GCRs is modulated by the solar wind and follows the 11-year solar cycle. It responds to transient phenomena such as Forbush decreases [4]. Another important sporadic source of ionization is related to eruptive solar processes as solar flares and coronal mass ejections (CMEs), which produce solar energetic particles (SEPs) (see [5, 6] and references therein). Occasionally the SEPs initiate an atmospheric cascade leading to an enhancement of count rate of ground based neutron monitors (NMs), the so-called ground level enhancements (GLEs). They could significantly increase the ion production in the atmosphere, specifically in polar regions [7, 8, 9, 10].

2. Ion production rate and ionization effect during GLE 70

In this work we assume a model similar to [11]. The detailed description of the model as well several features related to computations are given in [12, 13, 14].

$$Q(h,\lambda_m) = \frac{1}{E_{ion}} \sum_i \int_E^\infty \int_\Omega D_i(E) \frac{\triangle E(h,E)}{\triangle h} \rho(h) dE d\Omega \tag{2.1}$$

where $\triangle E$ is the deposited energy in an atmospheric layer $\triangle h$, h is the air overburden (air mass) above a given altitude in the atmosphere expressed in g/cm^2 subsequently converted to altitude a.s.l., $D_i(E)$ is the differential cosmic ray spectrum for a given nuclei of primary CR, ρ is the atmospheric density in $g.cm^{-3}$, λ_m is the geomagnetic latitude, E is the initial energy of the incoming primary nuclei on the top of the atmosphere, Ω is the geometry factor - a solid angle and E_{ion} = 35 eV is the energy necessary for creation of an ion pair in air. The ion production rate during the GLE 70 is a superpose of the contribution of GCRs and SEPs. For the GCR spectrum we assume the force field approximation [15]. The SEPs rigidity spectra and angular distributions are considered according to reconstructions using NM data [16]. The computed ion production rate is presented in Fig.1a for $R_c \leq 1$ GV cut-off, accordingly Fig.1b for $R_c \leq 2$ GV.

The derived ion production rate profiles allow us to estimate the time evolution of ion production (ion production [ion pairs cm^{-3}] - integration of ion production rate over the phase of the event) throughout the event [17, 18]. The ion production at 12 km above the sea level (a.s.l.) during the initial phase Fig.2a, main phase Fig.2b and late phase Fig.2c are shown.

The corresponding ionization effect is shown in Fig.3. Accordingly the computed 24^h ionization effect in the region of the Pfotzer maximum is shown in Fig.4. As it was recently shown [18] the maximal ionization effect is observed on higher altitudes than the produced by the average of GCR. As example, during the event the ionization effect is $\approx$ 200 % (at altitude of 18 km a.s.l.) in the region of 60-180° E in the Southern hemisphere and diminish to about 150-160 % at the altitude of 15 km a.s.l. The 24^h is about 20 % in the region of Pfotzer maximum. In the troposphere the ionization effect sharply diminish. At altitudes below some 10 km a.s.l. the 24^h ionization effect is marginal or even negative in some regions due to significant Forbush decrease leading to reduce of a GCR flux.

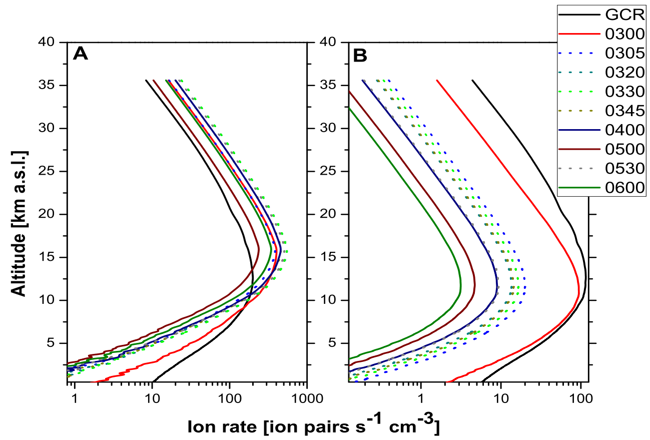

Figure 1: Ion production rate due to GCRs and GLE particles the GLE 70 on 13^{th} of December 2006. a) 1 GV rigidity cut-off; b) 2 GV rigidity cut-off.).

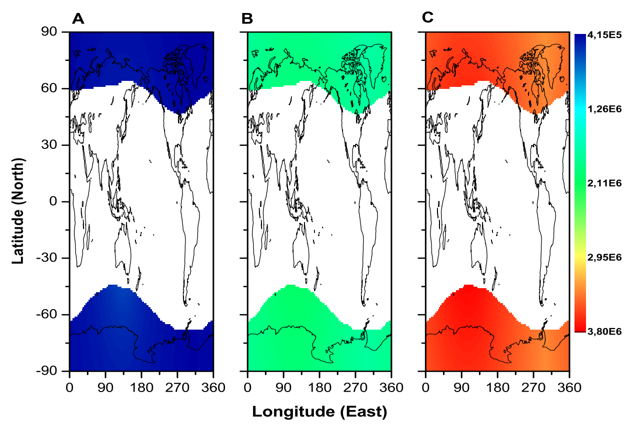

Figure 2: Ion production [ion pairs cm^{-3}] at 12 km a.s.l. throughout GLE 70. a) 0300-0330 UT; b) 0330-0430 UT; c) 0430-0700 UT;

3. Conclusion

Here we present an assessment of ionization effect due to CRs of galactic and solar origin throughout the GLE 70. The ion production rate and ion production as well as the corresponding ionization effect varies throughout the event. This is due mainly on variation of apparent source position (movement to a North-West direction) as well as variation of spectral (SEP spectrum soften during the event) and angular characteristics (the pitch angle distribution broaden out). The ion production is maximal in the sub-polar and polar regions of Southern hemisphere, while it is minimal near to the anti-sunward direction. The ionization effect is important in a limited atmospheric region (range of altitudes a.s.l.), because of the rapidly falling and soft SEPs spectra. The anisotropy of SEPs considerably reflects on the magnitude of ionization effect in a given geographic region.

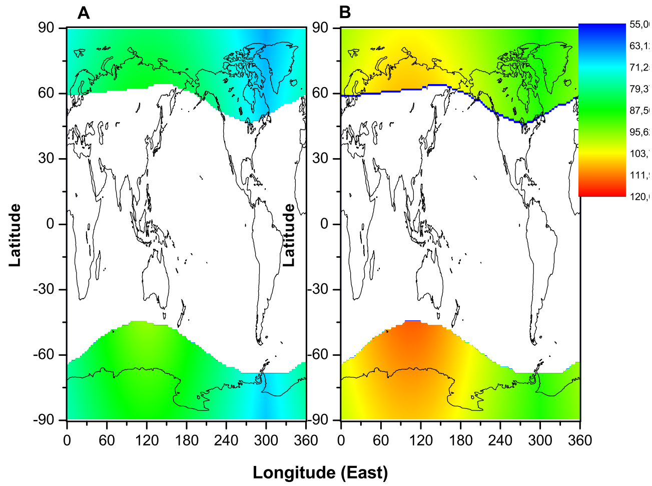

Figure 3: Ionization effect relative to average due to GCR during GLE 70. a) initial phase 0300-0330 UT; b) late phase 0430-0700 UT;

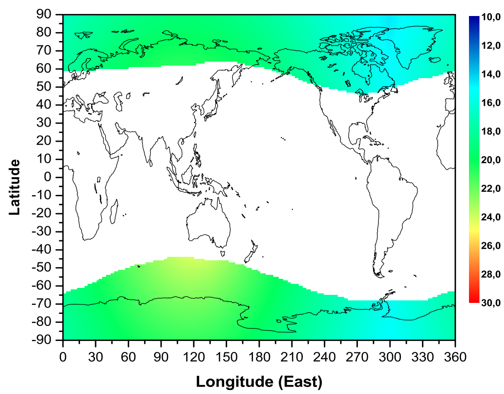

Figure 4: 24^h ionization effect in the region of the Pfotzer maximum

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