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INVESTIGATION OF MIDDLE ATMOSPHERE IONIZATION DURING GLE 70 EVENT FROM DECEMBER 2006 BY MEANS OF CORIMIA MODEL AND NORMALIZED CR SPECTRA

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Abstract

The ground level enhancement (GLE) of cosmic rays (CRs) on December of 13, 2006 is one of the biggest GLEs in 23rd cycle (behind GLE 69 from 20 January 2005 only) in minimum phase of solar cycle. The greatest maximum was recorded at Oulu Neutron Monitor Station (92.1 %), i.e. the maximum of GLE70 was recorded at sub-polar stations, which shows that the anisotropy source was located near the equator.

Here we compute in details the ionization effects in the terrestrial middle atmosphere and ionosphere (30-120 km) for various latitudes. The computation of electron production rate profiles q(h) is according the operational model CORIMIA (COsmic Ray Ionization Model for Ionosphere and Atmosphere). This improved CR ionization model is important for investigation of the different space weather effects. The influence of galactic and solar CR is computed with the new version of CORIMIA code, which is with fully operational implementations. The solar CR spectra are taken from recent reconstructions from ground based measurements with neutron monitors. Hence we compute the time evolution of the electron production rates q(h) in the ionosphere and middle atmosphere.

The cosmic rays determine to a great extent the chemistry and electrical parameters in the ionosphere and atmosphere. They create ozonosphere and influence actively the stratosphere ozone processes. But the ozonosphere controls the meteorological solar constant and the thermal regime and dynamics of the lower atmosphere, i.e. the weather and climate processes.

1.Introduction

The relativistic solar energetic particles (SEP) cause an excess of ionization, specifically over the polar caps and sub-polar latitudes, but also over the high middle, respectively low middle latitudes, i.e. the SEP influence has global and planetary character. The cosmic ray induced ionization rate will be estimated from the particle flux using the basic physics of ionization in air, an appropriate atmospheric model and realistic modeling of cascade process in the atmosphere [1, 2]. The detailed study of ion production in the ionosphere and atmosphere is important, because it is related to various environmental processes in the space weather and atmospheric physics and chemistry [3].

The solar cycle 23 (May 1996 - January 2008) have provided altogether 16 GLEs (Ground Level Enhancements) (http://cosmicrays.oulu.fi/ GLE.html), which are some of the largest SEP events in the history of CRs, namely the Bastille day event on 14 July 2000 (GLE 59), Easter event on 15 April 2001 (GLE 60), October-November 2003 Halloween events (GLEs 65, 66 & 67), the enormous GLE 69 on January 20, 2005 and the last event from the cycle on 13 December 2006 (GLE 70). This event occurred during the decline phase of solar cycle 23 in conditions on the Sun and in interplanetary medium appropriate to a solar minimum, however it refers to large events. This event was related to X3.4/2B flare with the coordinates at the Sun S06 W24. The flare was accompanied by radio bursts of types II and IV and by a halo type coronal mass ejection (CME). The GLE 70 on 13.12.2006 during the initial phase showed a large anisotropy [4] and the duration of the event of neutron monitor energies was approximately 5 hours.

The present paper shows the results from CORIMIA (COsmic Ray Ionization Model for Ionosphere and Atmosphere) programme [3, 5, 6] with application to the GLE 70 on December of 13, 2006.

2. Determination of differential spectra of Solar Energetic Particles

The SCR spectra at different moments from the event onset, namely 03:00 UT(initial phase), 04:00 UT (main phase) and 06:00 UT (late phase) are assumed as power law:

$$D(E) = J_0 E^{-\gamma}$$

They are reconstructed on the basis of ground based neutron monitor measurements (www.nmdb.eu) according [7] (see Table 1).

Table 1. Rigidity spectra of SEP assumed for ion rate production during GLE 70 [7]

Time UT	J_0 [m^{-2} s^{-1} sr^{-1} GV^{-1}]	γ
03:00	78550	3.77
04:00	203100	6.75
05:00	181750	7.76

We take experimental spectra from the GLE 70 event on 13 December 2006 [7, 2]. We transform the spectrum $D(R)=KR^{-\gamma}$ in its new form $D(E_k)=K'(E_k)R^{-\gamma}$.The latter is suitable for calculations with CORIMIA model [3]. The measurement units are transformed in the new form as follows: particles/(m^2.s.st.GV) become particles/(cm^2.s.MeV) by multiplication with normalizing factor $2\pi/(10^4)$ and application of the formula $E_k=f(R)$[MeV] [8] where E_k is kinetic energy of the penetrating cosmic rays. For two characteristic points $E_{k1}(R_1)$ and $E_{k2}(R_2)$ at lower and higher energies we calculate spectrum values $D(R_1)$ and $D(R_2)$. Then the following nonlinear system of equations is solved towards K' and gamma':

$D(R_1)= K'E_{k1}(R_1)^{-\gamma'}$
$D(R_2)= K'E_{k2}(R_1)^{-\gamma'}$

On this way we obtain the new transformed spectrum $D(E_k)=K'(E_k)^{-\gamma}$. The calculated CR spectra for the case under consideration are presented in Fig. 1.

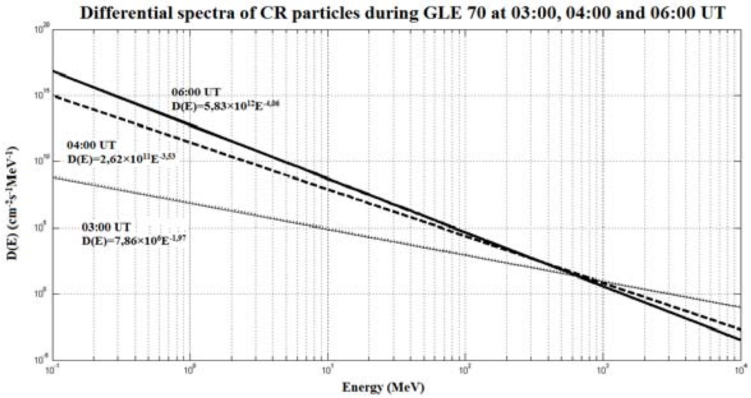

Fig. 1

3. Electron production rate profiles during GLE 70

The ionization production rate during GLE 70 on 13 December 2006 is calculated as a superposition of ion rate due to SEP and to the permanent flux of GCR. The ionization rate due to GCR is computed considering parameterization based on force field model [9, 10]. The atmospheric simulations are fulfilled considering winter atmospheric profile, which allows a detailed and realistic description of ionization profiles in specific conditions. We apply our operational programme CORIMIA (COsmic Ray Ionization Model for Ionosphere and Atmosphere). In the final version of the applied model an approximation in 5 characteristic energy intervals of the Bohr–Bethe–Bethe function including charge decrease interval is used. For the first time we present these quantitative and qualitative appreciations of the SCR fluxes impact from these Solar Particle Events (SPE) on the ionosphere and middle atmosphere (30–120 km). Unlike the cases of galactic cosmic rays (GCR), SCR differential spectra vary essentially in time during the course of the investigated event. Also SCR fluxes differ from one another for different events. The profiles behavior is explained taking into account the structure of the CORIMIA programme.

The production rate is computed for different rigidity cut-offs, namely 1 GV, 3 GV and 5 GV corresponding to sub-polar and polar latitude, high middle, and respectively low middle latitudes. The obtained production rate at 1 GV rigidity cut-off is presented on Fig. 2. Accordingly, the ion production rate is plotted on Fig. 3 for 3 GV rigidity cutoff and Fig. 4 for 5 GV rigidity cut-off. As was expected the maximal effect is observed at polar and sub-polar regions (Fig. 2).

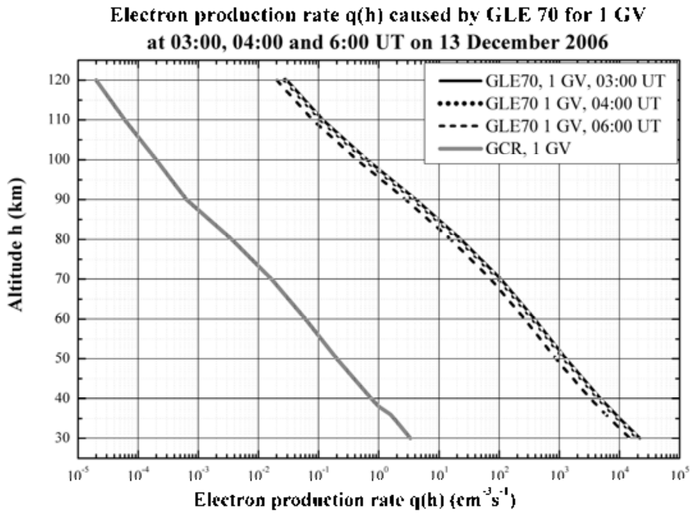

Fig. 2

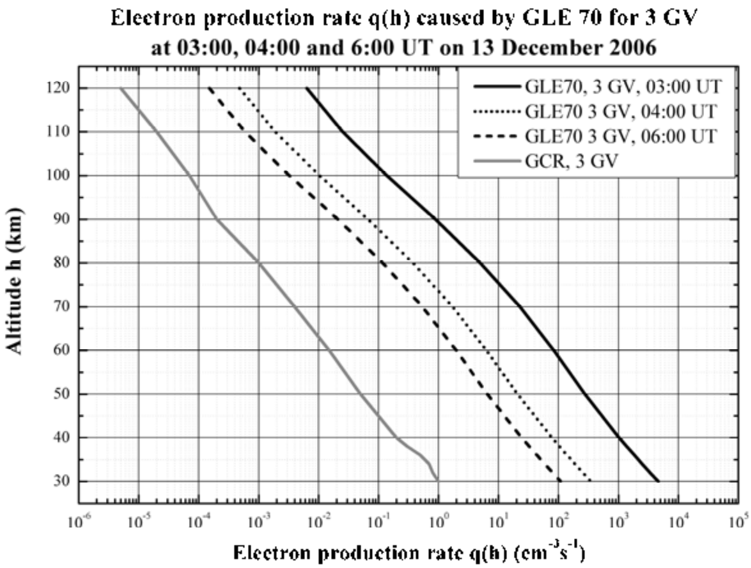
Electron production rate q(h) caused by GLE 70 for 3 GV
at 03:00, 04:00 and 6:00 UT on 13 December 2006
GLE70, 3 GV, 03:00 UT
GLE70 3 GV, 04:00 UT
GLE70 3 GV, 06:00 UT
GCR, 3 GV
Altitude h (km)
Electron production rate q(h) (cm-3s-1)

Fig. 3

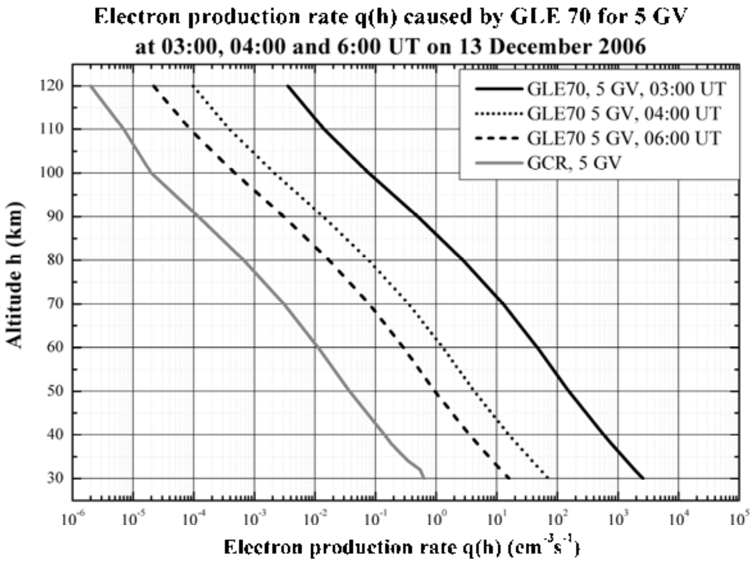
Electron production rate q(h) caused by GLE 70 for 5 GV
at 03:00, 04:00 and 6:00 UT on 13 December 2006
GLE70, 5 GV, 03:00 UT
GLE70 5 GV, 04:00 UT
GLE70 5 GV, 06:00 UT
GCR, 5 GV
Altitude h (km)
Electron production rate q(h) (cm-3s-1)

Fig. 4

4. Analysis and conclusion

Ground Level Enhancements are more likely to occur when the Sun is very active. The investigated GLE was a maverick. It occurred near solar minimum, but it was a large event by historical standards, with a peak increase exceeding 90% at some stations - f.e. the ground level neutron monitor Oulu, 5 min average, detected count rate increase by 92%.

The obtained results are important for improvement of recent models of cosmic ray induced ionization and the studies of solar-terrestrial influences and space weather. The cosmic rays determine to a great extent the chemistry and electrical parameters in the ionosphere and atmosphere. They create ozonosphere and influence actively the stratosphere ozone processes. But the ozonosphere controls the meteorological solar constant and the thermal regime and dynamics of the lower atmosphere, i.e. the weather and climate processes. This hypothesis of the solar- terrestrial relationships shows the way to a solution of the key problems of the solar-terrestrial influences.

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ИЗСЛЕДВАНЕ НА ЙОНИЗАЦИЯТА В СРЕДНАТА АТМОСФЕРА ПО ВРЕМЕ НА СЪБИТИЕТО GLE 70 ОТ ДЕКЕМВРИ 2006 ПОСРЕДСТВОМ МОДЕЛА CORIMIA И НОРМАЛИЗИРАНЕ НА СПЕКТЪРА НА КОСМИЧЕСКИТЕ ЛЪЧИ

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Резюме

Събитието GLE (Ground Level Enhancement) на Космическите лъчи (CRs) от 13 декември, 2006 год. е едно от най-мощните събития за изминалия 23-ти слънчев цикъл (единствено предходното събитие GLE 69 от 20 Януари, 2005 е по-мощно от него). Най-големият максимум (92.1 %) беше регистриран от неутронния монитор в Оулу (Oulu Neutron Monitor Station), тоест максимума на GLE 70 беше регистриран от суб-полярна станция, което показва, че анизотропният източник е локализиран в близост до екватора.

Тук ние детайлно изчисляваме йонизационните ефекти в средната атмосфера и йоносфера (30-120 км) за различни геомагнитни ширини, като въздействието на галактичните космически лъчи (GCR) и слънчевите енергетични частици (SEP) са представени отделно. Тези изчисления са направени посредством операционния моделCORIMIA (COsmic Ray Ionization Model for Ionosphere and Atmosphere), чрез

който значително се увеличават възможностите ни за изследване на различни проявления на космическото време. Спектрите на слънчевите енергетични частици са получени при реконструкции на експериментални данни от неутронни монитори. Чрез използване на различни спектри изместени във времето за потока от слънчеви енергетични частици, ние сме представили времевата еволюция на електронната продукция q(h).

Съвременните изследвания показват, че космическите лъчи (КЛ) са един от основните фактори в химичните и електрически процеси в атмосферата и йоносферата на Земята. КЛ влияят върху образуването на озона в атмосферата, което директно ги свързва с климатичните процеси.