Magnetospheric transmissivity for cosmic rays during selected recent events with interplanetary/geomagnetic disturbances

2015 J. Phys.: Conf. Ser. 632 012064

(http://iopscience.iop.org/1742-6596/632/1/012064)

Magnetospheric transmissivity for cosmic rays during selected recent events with interplanetary/geomagnetic disturbances

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Abstract. The variability of cosmic rays (CRs) observed at selected European neutron monitors (NMs) around moderate geomagnetic disturbances, namely during the intervals (a) DOY 49-51 in 2014, (b) DOY 58-59 in 2014, (c) DOY 238-240 in 2014 and (d) DOY 6-8 in 2015 is discussed. Assuming the primary spectra of the CREME96 model, the yield function and geomagnetic transmissivity changes provided by the Tsyganenko96 model, the expected increases at the mid-latitude station Lomnický štít are compared with the observed ones. The examples stress the importance of including anisotropy of the CR flux in interplanetary space, the use of other geomagnetic field models and other yield functions to the computations in future analysis.

1. Introduction

During geomagnetic field disturbances the transmissivity of the magnetosphere for the cosmic rays is changing (e.g. [1,2] and references therein). The structure of forbidden and allowed trajectories as well as the asymptotic directions for the allowed ones obtained by numerical tracing of CR particle trajectories differ for different geomagnetic field models. There exist various geomagnetic field models with external current systems (e.g. [3]). Checking the transmissivity improvement during geomagnetic storms is not easy, since in many cases (not in all, e.g. [4]) such events are accompanied by Forbush decreases (FD, studied long time since paper [5]) which mask the geomagnetic effect.

The recent period is characterized by not many irregular changes in CR intensity observed by NMs. Four events with increases in the CR flux observed by selected European NMs (data from PIs and/or from http://nmdb.eu) during the Dst depressions not accompanied by FDs are used to compare the expected effects of the magnetospheric transmissivity change with that observed by NM measurements. The Dst index represents the axially symmetric disturbed magnetic field at the dipole equator on the Earth's surface [12]. During strong magnetic storms the Dst is reaching several hundreds of nT (negative values). For that we use simplified assumptions: neglected anisotropy; vertical geomagnetic cut-off rigidities only; primary CR spectra approximated by the CREME96 model [6]; Tsyganenko96 and 05 geomagnetic field models [7,8] and the yield function given by [9]. CREME96 is a code providing (among other components of near-Earth ionizing radiation) the primary CR energy spectra for various elements and various phases of the solar cycle activity. There are several studies of changes of cut-offs during geomagnetic and interplanetary disturbances (e.g. [1,2]). Review of geomagnetic models for CR trajectory computations is in paper [10] or in monograph [11].

2. Description of events

Figures 1a - 1d show four intervals with variations of CR records at selected european NMs with different vertical geomagnetic cut-offs: Rome, R_{eff} = 6.27 GV; Jungfraujoch 1, R_{eff} = 4.5 GV; Lomnický štít, R_{eff} = 3.84 GV and Oulu, R_{eff} = 0.8 GV. Here the lowest Dst values were around < - 60 nT whereas the IMF was directed southward. The hourly values of the count rates of each NM station are normalized to the mean of the first twelve hours of the event. Along with the Dst index (available at http://wdc.kugi.kyoto-u.ac.jp/) the hourly values of the solar wind pressure (p), the solar wind density and velocity (NSW, VSW) as well as the magnitude of the IMF (B) and its latitude in GMS coordinates are plotted (data downloaded from http://omniweb.gsfc.nasa.gov NASA site).

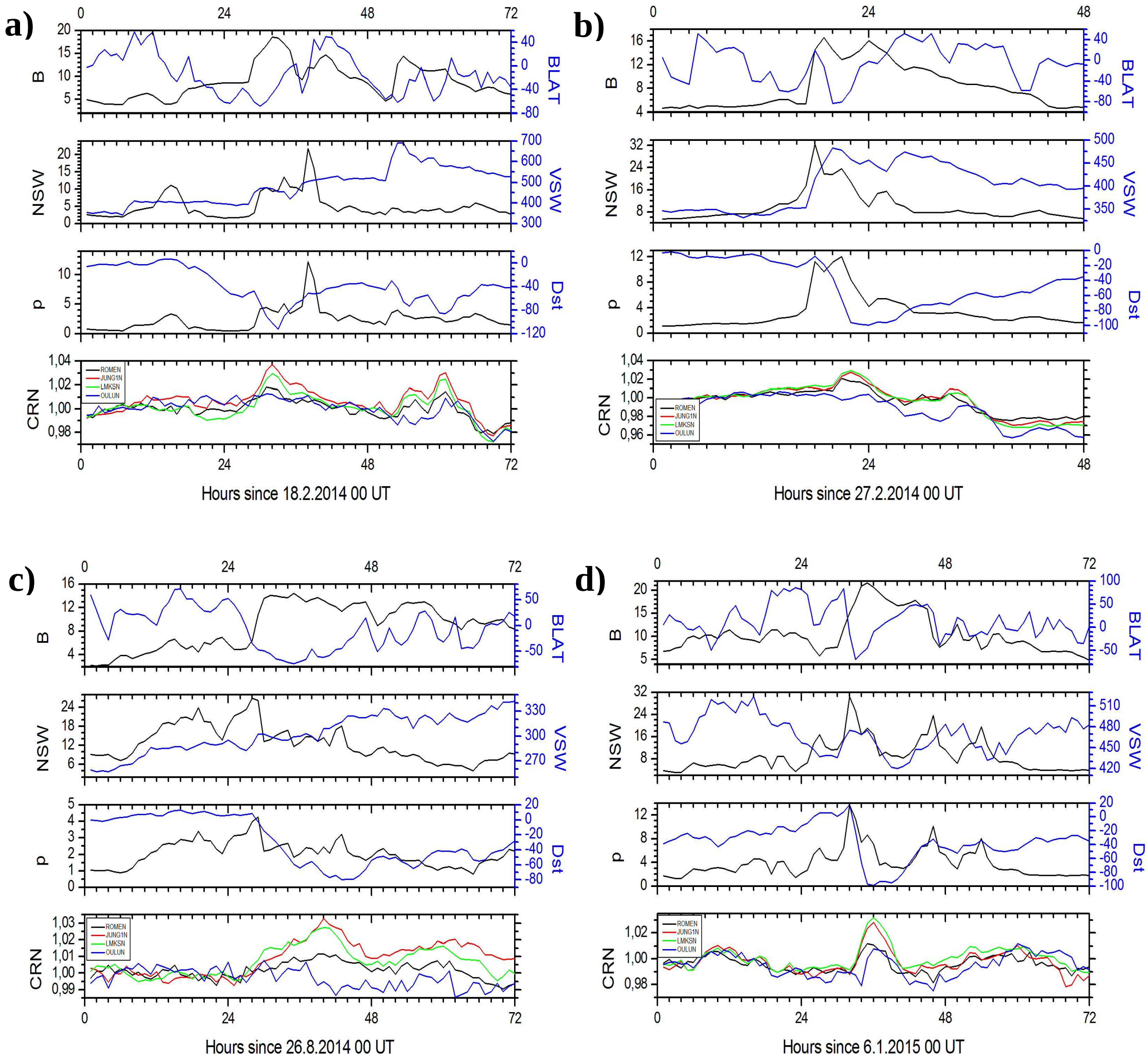

Figure 1. Four events with variations of CR (CRN) records at European NMs with different vertical geomagnetic cut-offs (Rome, Jungfraujoch 1, Lomnický štít, Oulu). Event 1 (upper left panel, a): DOY 49-51 in 2014; event 2 (upper right panel, b): DOY 58-59 in 2014; event 3 (lower left panel, c): DOY 238-240 in 2014; event 4 (lower right panel, d): DOY 6-8 in 2015. B is in nT, BLAT in degrees (GSM system), NSW in cm^{-3}, p in nPa, Dst in nT, VSW in $km.s^{-1}$. The values CRN are normalized to the mean of the first twelve hours of the event. Local peaks in time profile of high mountain stations count rate (red and green line in lowest parts of the panels) are supposed to correspond to Dst decreases.

3. Discussion

In all four events the CR increases during the Dst depression are most pronounced at the two mid-latitude high mountain stations, Jungfraujoch 1 and Lomnický štít. The smallest increases (in event 3 even a decrease) are observed at the low cut-off station Oulu. At Oulu the decrease of geomagnetic cut-off is not producing any strong increase in the CR flux due to an improvement of the geomagnetic transmissivity, since it is close to the atmospheric cut-off.

The expected/computed CRN profile was based on simplified assumptions: the energy spectra of primary CR is not changing during the event and it is estimated using the CREME96 model [6]; the yield function is taken from the recent paper [9]; the geomagnetic field model Tsyganenko96 [7] and for one event also Tsyganenko05 [8] is used. A basic description of the CREME96 code can be found at https://creme.isde.vanderbilt.edu/CREME-MC/help/what-is-creme96. We downloaded the differential energy spectra for protons for the period near solar activity maximum. The vertical geomagnetic cut-off rigidities have been computed by the tool available at http://www.geomagsphere.org/geomag/ [9]. The relative changes in the count rate profiles due to the variability in the geomagnetic cut-off values were estimated by integrating the product of primary CR flux and the yield function over the rigidity range > R_{eff} when R_{eff} is changing.

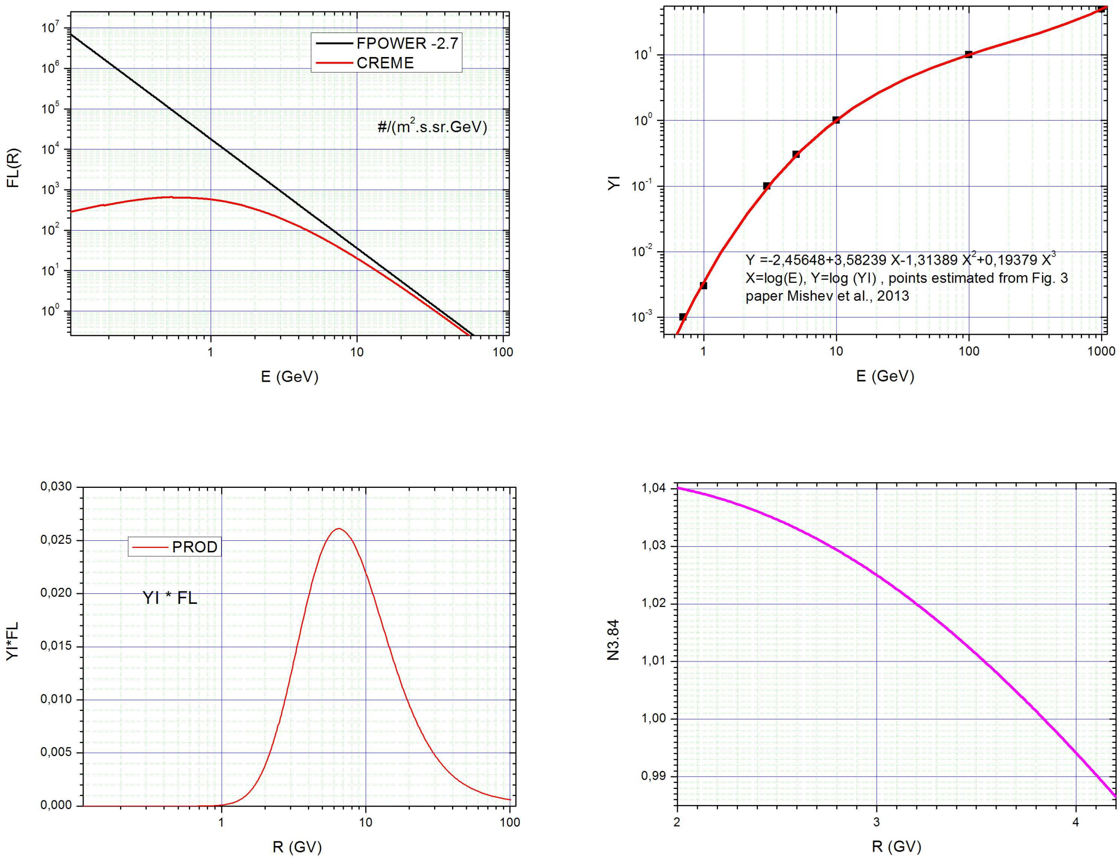

Figure 2. Upper left panel: FL (in #/(m^2.s.sr.GeV)) is differential energy spectra of protons from CREME 96 (for solar maximum) using [6]. Upper right panel: approximated yield function from figure 3 in paper [9] (in arbitrary units). Lower left panel: product of differential spectra and the yield function (both recalculated to rigidity scale). Lower right panel: integral of the function plotted in lower left panel (integration above the given rigidity R, and normalized to unity for Lomnický štít position with geomagnetic vertical nominal cut-off rigidity 3.84 GV).

Journal of Physics: Conference Series **632** (2015) 012064 doi:10.1088/1742-6596/632/1/012064

Using the procedure illustrated in Figure 2, a comparison of the estimated and measured CR profiles at NM Lomnický štít is shown in Figure 3 for all four events.

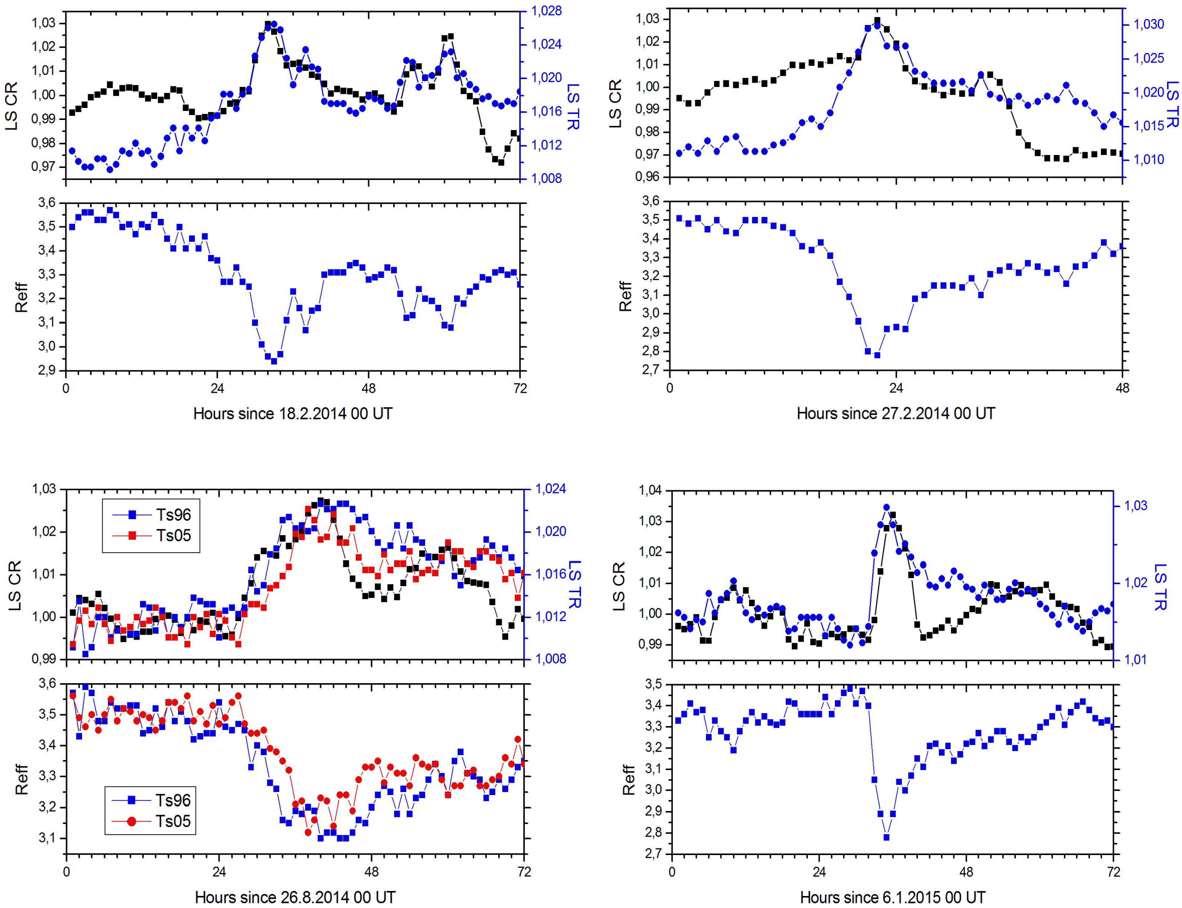

Figure 3. Effective cut-off rigidity Reff computed on hourly basis and comparison of measured (LSCR) and expected (LSTR, different scale, on the right hand side) normalized count rate at Lomnický štít NM for events 1 to 4 of Figure 1. In all cases the Tsyganenko96 model is used. For one event (3) in addition a comparison with model Tsyganenko05 is given.

In all four events the time profile of the NM count rate at Lomnický štít is similar to that estimated due to the geomagnetic transmissivity change characterized by the effective cut-off rigidity. The main CR increases observed in the events 1, 2 and 4 correspond to times of improved geomagnetic transmissivity (depression of Reff). Event 3 is more complicated and corresponds to a slower decrease of the Dst index in comparison with the other three events. For that event the use of the Tsyganenko05 model is matching slightly better the measured count rate during the recovery phase of the geomagnetic disturbance than model Tsyganenko96.

Although the measured profiles (LSCR) correspond qualitatively to the expected (LSTR) ones based on Tsyganenko96 model and the yield function used, the amplitudes of the observed increases is usually higher than those expected due to the simplifications used here.

4. Summary

Four events during the past two years when geomagnetic disturbances were not accompanied by Forbush decreases, observed at four stations with different geomagnetic cut-off, have been checked for the effect of geomagnetic transmissivity changes. The time profiles of NM count rates around the time of the minimum Dst for the positions where the geomagnetic cut-off is clearly above the atmospheric one, shows *qualitative agreement* with the profiles obtained from computations of the changing effective cut-off rigidity. Around the time of the minimum Dst, rather strong increases are observed at two mid-latitude high mountain stations. The values of the observed increases at one of them (Lomnický štít) are usually higher than those expected by computations based on simplified assumptions of primary spectra, yield function and one geomagnetic field model.

The examples stress the importance of including anisotropy of CR flux in interplanetary space, other geomagnetic field models and various yield functions to the computations in future analysis.

Acknowledgement
We acknowledge CREME96 project; Ch. Steigies and colleagues for keeping and updating http://nmdb.eu data base; PIs of NM Oulu, Jungfraujoch and Rome for the preliminary data. VEGA grant agency project 2/0040/13 and VVGS-PF-2014-445 are acknowledged for support. The authors acknowledge two anonymous reviewers for their comments and corrections.

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