Transmissivity of low energy cosmic rays in the disturbed magnetosphere.

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Abstract—**Cosmic rays of low energies access the atmosphere above a given position on the Earth depending upon the state of the magnetosphere. Its anisotropy, deduced from the neutron monitor network, must assume the variability of the magnetosphere. Results of computations of transmissivity function and asymptotic directions for selected points on the ground and at low altitude polar orbiting satellite are presented and discussed. The computations, based on different available models of geomagnetic field of external sources are performed for quiet time periods and for strong geomagnetic disturbances occurred in 2003 and 2004.**

I. Introduction

Geomagnetic field is a filter for cosmic ray (CR) access to the Earth. Most commonly this effect is estimated by particle trajectory tracing from the point of observation in the model geomagnetic field (e.g. [1]) and compared with the measurements (e.g. [2-6]). The enhanced geomagnetic activity leads to the changes of cutoffs and asymptotic directions (e.g. [7]).

Here we study the changes of transmissivity of magnetosphere for intervals October - November 2003 and November 2004 with strong geomagnetic disturbances using different models of geomagnetic field. Computations are done using backtracing of particle trajectory from the point of observations. The details of the computation method can be found in [9-11]. Cutoff terminology used is adopted from [13]. For **B** we use the modified 'Geopack 2003' subroutines http://nssdc.gsfc.nasa.gov/space/model/magnetos/data-based/modeling.html based on International Geomagnetic Reference Field (IGRF) model http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html.

The computations using three approaches, namely (1) Tsyganenko Ts89 model [13]; (2) extension of Ts89 with Dst [14] and (3) the new Tsyganenko Ts04 model [8] are done. As the first two models are parameterized by Kp and by instant Dst value, the inputs to the third model are derived from prehistory of solar wind and IMF parameters.

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II. Transmissivity In Different intervals

A. *Interval 1 (Oct.28-Nov.1, 2003)*

CR intensity at neutron monitors (NM) decreased during the first Dst depression on October 29-30. On the background of that Forbush decrease an increase around time of Dst minimum was observed, especially at low latitude NMs. It was slightly seen also at middle latitudes (Fig. 1). Time of minimum cutoff rigidity according to model (2) corresponds to that increase. However, the second Dst depression (around midnight 30/31 October) was not accompanied by any CR increase expected.

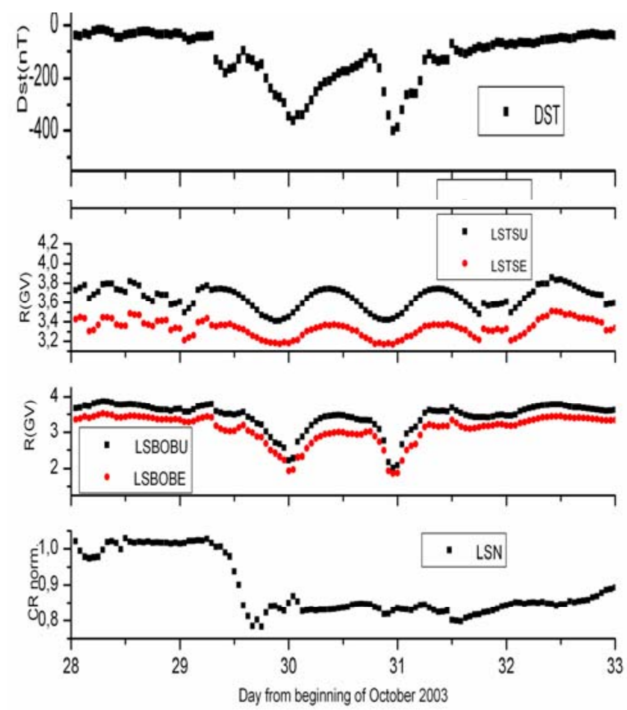

Fig.1. From top to bottom: Dst; computed upper and effective vertical cutoffs for Lomnicky Stit position using model (1); cutoffs by model (2); CR NM time profile of Lomnicky Stit (49.20 N, 20.22 E, 2634 m a.s.l).

During that interval the improvement of magnetospheric transmissivity was computed also for a low altitude polar orbiting satellite CORONAS-F and compared with measurements indicating shift of outer boundary penetration of protons with energy above 50 MeV [18].

B. Interval 2 (November 20-23, 2003)

The largest decrease of Dst during the years of 2002-2005 was observed on November 20, 2003 (Dst=-471nT). This disturbance affected strongly the transmissivity of the magnetosphere and, similarly to other earlier events [e.g. 2, 17] led to the increase of CR intensity at NMs with relatively high nominal cutoff rigidity as shown in Fig. 2.

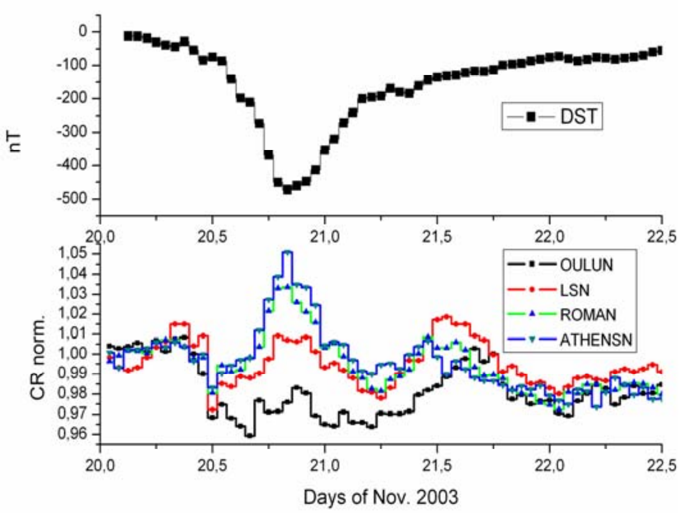

Fig.2. Upper panel: Dst profile. Lower panel: NM intensity at 4 European Observatories (Oulu, Lomnický Štít, Rome, Athens) during the interval on November 20-21, 2003, normalized to the mean 00-12 UT on November 20.

For interval 2 the data of solar wind and IMF are available (from http://nssdc.gsfc.nasa.gov/omniweb/). Also model (3) Ts04 is used for cutoff rigidity estimates. The input data for model (3) are shown in Fig. 3.

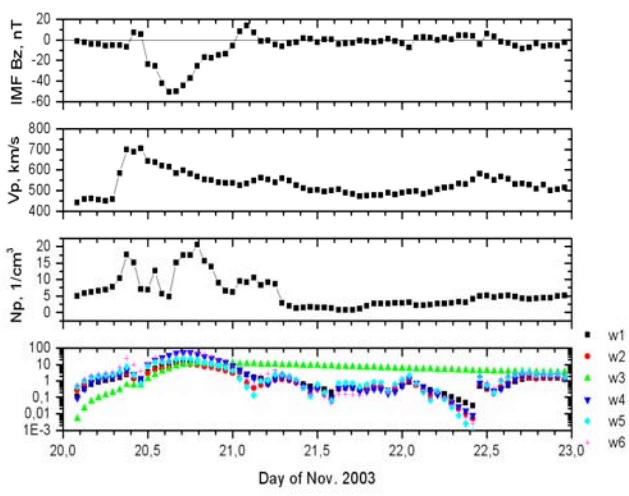

Fig.3. Input parameters W1(inner tail current), W2(outer tail current), W3(symmetrical ring current), W4(partial ring current), W5(field-aligned current-region 1), W6(field-aligned current-region 2) for Ts04 model - constructed from the time profiles of solar wind density Np, speed Vp, IMF Bz by formula (7) in [13] modified for hourly data).

Comparison of transmissivity function (TF) computed by the three models before the disturbance and during the Dst minimum is shown in Figure 4. TF is defined as the probability that a particle having rigidity (R, R+dR) will access the detector from zenith direction (vertical access). More details on TF are in [10, 11]. For dR we use here 0.1 GV.

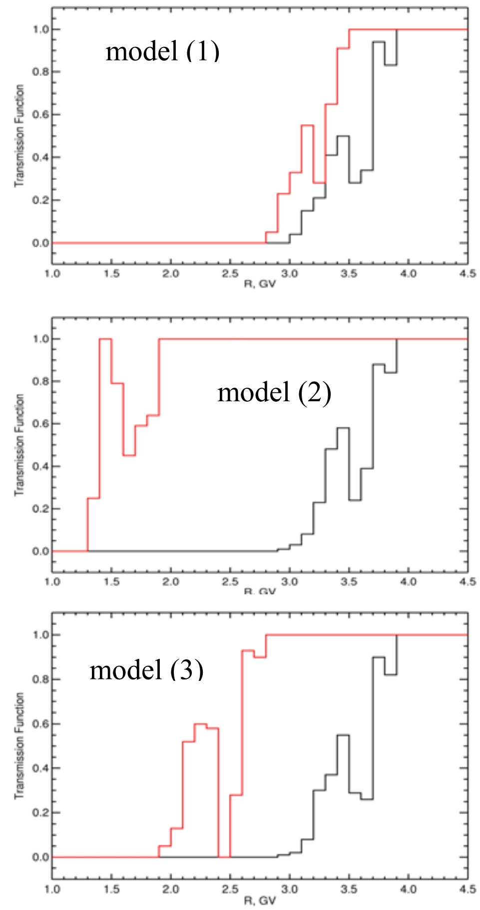

Fig.4. Transmissivity function TF (for vertical direction) for Lomnický Štít before the onset of the storm (Nov. 20, 2003, 02 UT, black) and during the Dst minimum (19 UT, red) for three models of disturbed magnetosphere.

The differences in expectations of the transmissivity function, of the timing of minimum cutoff and of the asymptotic directions are discussed in [19]. Fig. 4 demonstrates that for Ts04 model (3) the transmissivity improvement is smaller than for Ts89+Dst extension (model 2) and larger than for model (1) based only on Kp.

The pattern indicating better correspondence in timing of minimum cutoff rigidity with the peak observed at NM Rome for Ts04 model (3) than for Ts89+Dst extension (2) for the interval 2 is shown in Fig.5. Similar timing correspondence was obtained for two low latitude CR NM, namely Mexico and Haleakala.

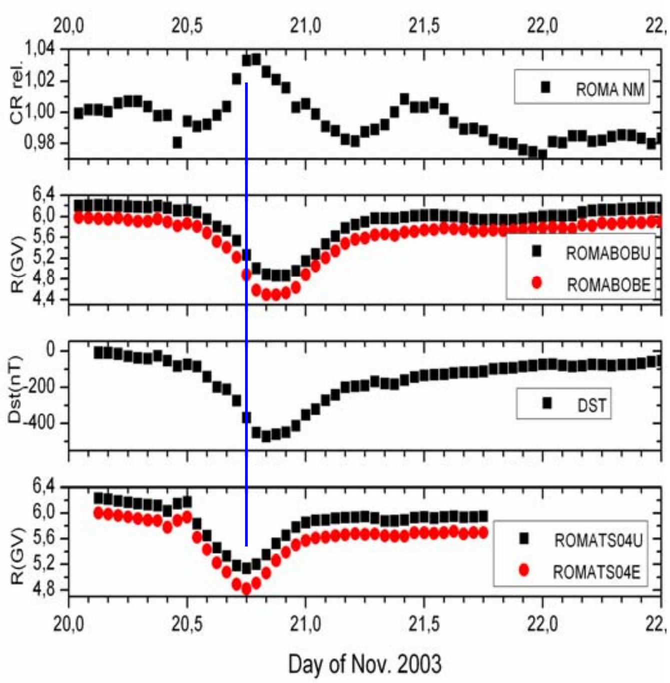

Fig.5. Rome NM normalized counting rate profile (upper panel) compared with the upper and effective cut-offs obtained from trajectory computations. Second and fourth panel show the vertical cutoffs computed for model (2) and model (3) respectively. Dst is in the third panel.

C. *Interval 3 (November 7-12, 2004)*

This is another strongly disturbed interval when the inputs into Ts04 model are found available. There is observed rather complex, long lasting decrease in cosmic rays with recovery to the pre-storm level reached close to the end of November (at Lomnicky Stit) discussed in more details in [19]. Contrary to the interval 2, the timing of CR increase during the Dst depression on November 8 is not matching better the time of minimum vertical cutoff using model (3) than model (2). This is shown in Fig.6 for a middle latitude station Rome. Similar profiles were obtained for a couple of middle and low latitude NMs. A very complicated structure of (a) allowed and forbidden cutoffs and (b) asymptotic directions during that interval was obtained for one low latitude station, namely Mexico [19]. This indicates that the concept of a single cutoff value (effective or upper one) is not good for strong disturbances. Strong differences were found in the fine structure of TF during that disturbance when different models of external magnetic field were used (2 and 3).

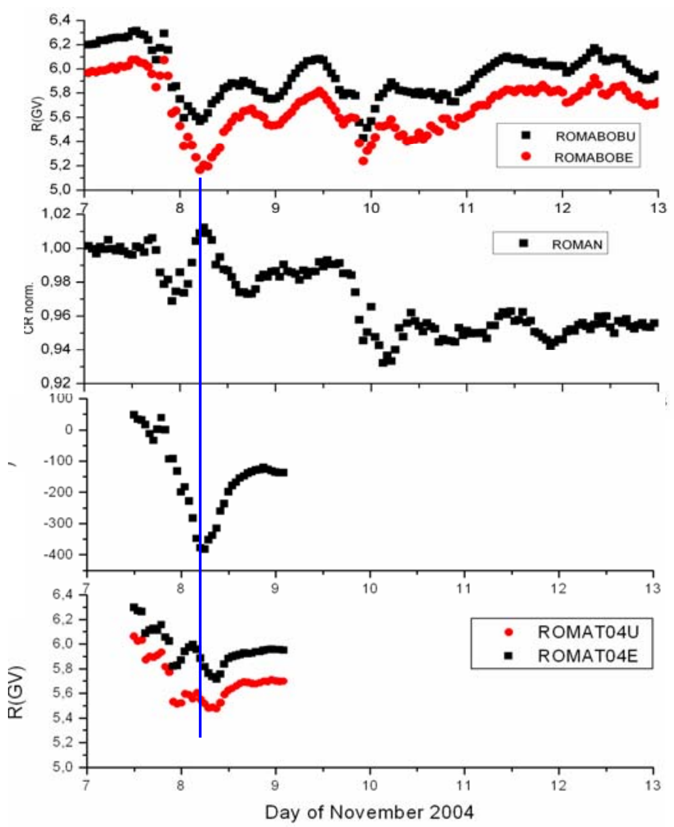

Fig.6. Comparison of time profile of upper and effective vertical cutoff rigidities expected using model (2) – upper panel and model (3) – lowest panel for position of Rome NM. Normalized counting rate of that NM is plotted in second panel. Third panel displays Dst profile.

III. Discussion and Summary.

Before the geomagnetic field models with external current systems were constructed, the local time (longitudinal) changes of cut-offs due to magnetospheric field perturbations were checked (e.g. [20]) and related to ring current effects. Changes of cut-offs and of asymptotic directions depending on longitude during enhanced geomagnetic activity were described [21]. In paper [22] the local time dependence of CR increase for 17 storms at various NMs was shown.

In the past two decades new geomagnetic field models assuming disturbed conditions in the magnetosphere were constructed. The question appears: can CR measurements by the NM network be helpful in checking their validity during geomagnetic storms? We illustrated that different models of magnetic field (external sources) during strong geomagnetic disturbances give different estimates of (a) time profile of cut-off rigidities at a particular ground station; (b) transmissivity function for particles coming from outside magnetosphere, and (c) asymptotic directions.

CR increases at middle and high nominal cut-off NMs are observed superposed on FD in many events observed during the past period. From our study it appears that model with prehistory (Ts04) and model with Dst give different results for two storms (intervals 2 and 3, comparison of CR peak time vs time of maximum cut-off depression). Thus, no general conclusion about validity of the models from this limited study can be deduced. Recently, the influence of different current systems in Ts04 model was studied in detail for one storm [23].

How to check the validity of field models using CR records during geomagnetic storms? Timing of maximum CR increase vs minimum predicted cut-off at many stations is one rough method. It is, however, very simplified: simultaneous change of CR anisotropy in interplanetary space (CME passing Earth's orbit) appears and combination of the two effects is causing variability of CR counting rate at a particular NM. Spaceship Earth [24] using a ring of NM at high latitudes provides CR anisotropy at low energies. The measurements are not strongly affected by magnetospheric disturbance because the asymptotic directions are in narrow interval of longitudes and the changes of TF and cutoffs are below the atmospheric cutoff. The anisotropy deduced from that installation can be used as a reference for interplanetary (IP) anisotropy of CR at low energies. Network of muon directional telescopes [25] can provide IP anisotropy reference of CR at energies above those to which NMs are mostly sensitive since this high energy range of CR is also not strongly affected by changes in magnetosphere. Thus, anisotropy estimate at "middle energies" can be probably obtained from interpolation between anisotropy in IP space by Spaceship Earth and by Muon Telescope Network. Using (1) the anisotropy in IP space at middle energies and (2) predictions of different models of the disturbed magnetospheric field for cutoffs, for TFs and for asymptotic directions, the comparison with NM measurements at low and middle latitudes can be used as a tool for checking the validity of geomagnetic field models used for the disturbed magnetosphere. However, such discrimination is not straightforward: the assumptions about the energy spectra of CR outside the magnetosphere must be used, oblique directions of CR access must be assumed too. At low energies for which ground based measurements have the limits because of the atmospheric cutoff, the measurements of energetic particles on high inclination satellites with high geometric factor as e.g. SKL on CORONAS-F, can be used for checking the consistency of transmissivity function at two altitudes which is also model dependent. For clarification of the relevance of CR NM measurements for geomagnetic field model discrimination, more systematic studies are needed: detailed trajectory computations using different methods; analysis during different geomagnetic storms; using network of NMs at middle and low latitudes and probably using better temporal resolution of NMs than hourly used here.

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