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Magnetospheric currents and variations of cutoff rigidities on October 20, 1989

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Abstract Changes in the cosmic ray cutoff rigidities for middle and low latitudes are evaluated for the Forbush decrease on October 20-22, 1989 from hourly values of the *Dst* index and the modified Dst_R index, which accounts only increasing of the ring current. The magnetostorm dynamical model using solar wind data available for the initial phase of the event obtains values of the modified *Dst* index. These results are compared with each other and with data of the balloon flights in Moscow on October 20, 1989, when solar protons of about atmospheric cutoff rigidity have been observed in the stratosphere.

1. Introduction

In practice of cosmic ray variation studies we need to know changes in the cutoff rigidity. The procedure of cutoff rigidity calculations was recently reviewed by Fluckiger et al. (2000). The trajectory calculations of particle propagation in the Earth magnetic field are only one way for estimating cutoff rigidities. However, the Earth's magnetosphere is dynamic and the most widely used magnetospheric models are quasi static. Apparently, the problem is far from its final solution, especially for periods of large geomagnetic activity.

Moreover, the trajectory calculations in the Earth magnetic field take a lot of time and it is difficult to apply them directly for a particular period of the geomagnetic activity to study a particular cosmic ray event. Simple models, which use some pre-calculated results, have been elaborated for this purpose.

In this work we apply the model of Fluckiger et al. (1986) to calculate changes of cutoff rigidities during the Forbush decrease on October 20-22, 1989. We develop this model and separate *Dst* into its contributions due to the ring and magnetopause currents for October 20, 1989 using the magnetostorm dynamical model of Olson and Pfitzer, (1982). Input parameters of the model are solar wind and geomagnetic field data. All data were taken from the SPIDR database *(http//spidr.ngdc.noaa.gov)*. Unfortunately the solar wind data are not available for the later period of the event on October 21-22, 1989.

The Forbush decrease on October 20-22, 1989 is one of the greatest and interesting events of the previous solar cycle. The decrease started on the background of the October 19 ground level enhancement and close to arrival of protons with energy >500 MeV associated with the shock front. This protons were observed during several hours after the shock passage in the stratosphere in Moscow, but the Moscow neutron monitor didn't show a clear effect at that time. The Forbush decrease was lasting about three days and during its recovery phase occurred the next large GLE on October 22, 1989. Estimates of cutoff rigidity changes are the first step to study cosmic ray variations of different origin during this complex event.

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2. Model calculations

2.1 Cutoff rigidity

Fluckiger et al. (1986) proposed a procedure to estimate changes of vertical cutoff rigidity and asymptotic directions during geomagnetically active time periods for any specific low-latitude or mid-latitude location (Λ_m, Φ_m). In this model the change of the rigidity of first discontinuity R_1 is presented as a weighted sum of the horizontal component of the equatorial surface magnetic field.

$$\Delta R_1(\Lambda_m, \Phi_m, t) \approx \sum_{n=0}^{7} g_n(\Lambda_m)\Delta H_{eq}\left[\Phi_m + n(15^0), t\right] \quad (1)$$

The major changes of the cutoff rigidity are the result of magnetic perturbations within ~60^0 E of the observation location and magnetic perturbations located more than ~120^0 E have practically no effect on the cutoff rigidity values. Therefore, values of the equatorial magnetic field are sampled in this model at interval of 1 hour in local time from 00:00 to 07:00 to the east of the specified location. Its values at one particular moment $t = t_0$ in the point with local time t_L are assumed to be equal

$$\Delta H_{eq}(t_L, t=t_0) = Dst(t=t_0) + 50\sin(2\pi \cdot t_L / 24) \quad (2)$$

The corresponding weighting factors $g_n(\Lambda_m)$ for effective cutoff rigidities within the interval of *3 < Rc < 13.5 GV* are presented in the paper of Fluckiger et al. (1986). Besides, it is mentioned there that the rigidity of first discontinuity, the upper cutoff rigidity and the effective cutoff rigidity change similarly, so one can easily estimate changes of the cutoff rigidities for desired periods of the geomagnetic activity.

We have applied the above method to get changes in the cutoff rigidities during the Forbush decrease on October 20-22, 1989. Figure 1 shows the results of our calculations for three European neutron monitors: Moscow *(N55.47 E37.32, Rc=2.43 GV)*, Kiev *(N50.72 E30.30, Rc=3.57 GV)* and Rome *(N41.9 E12.52, Rc=6.32 GV)*.

The procedure is valid in locations, where *Rc*>3 GV and its declared accuracy is about +/- 0.1 GV. In the case of Moscow the weight factors have been approximated to the region of *<3 GV*, so errors for Moscow might be higher.

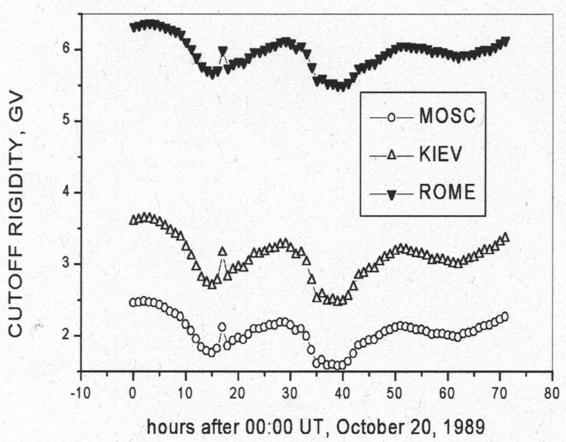

Fig.1 Effective cutoff rigidities for vertical incident particles on October 20-22, 1989.

2.2 Magnetospheric Currents

The changes of R_c are mainly attributed to variations of the ring current strength (Trieman , 1953). The close connection between changes in the geomagnetic cutoff rigidities and the ring current allows to estimate the relative strength of ring and magnetopause currents by knowing changes in the cosmic ray cutoff rigidity and values of the *Dst* index (Fluckiger et al. (1990). Below we solve the reverse problem and determine the changes in the cutoff rigidity using the *Dst* index and model values of magnetospheric current strengths.

The procedure to estimate changes in the vertical cutoff rigidity discussed in the previous section uses the *Dst* index to monitor variations of the equatorial geomagnetic field. Hence it accounts variations of all current systems in the magnetosphere not variations of the ring current alone. In general the *Dst* index rather well reflects variations of the ring current, and the effects of other current systems are negligible.

However, in some particular moments, when the magnetosphere is strongly compressed, the opposite effects of the ring current and the magnetopause current may be comparable. Therefore, in order to estimate changes in the cutoff rigidity it would be better to remove the contribution of the magnetopause current from the *Dst* index.

Following the paper of Olson and Pfitzer (1982) and using solar wind particle and magnetic field data we have separated *Dst* into two parts

$$Dst = Dst_R + Dst_{Mp} \quad (3)$$

due to the ring current Dst_R and the magnetopause current Dst_{Mp}. The magnetopause component of *Dst* is

$$Dst_M = 25 \cdot (S_M(t) - 1), \quad (4)$$

where

$$S_M(t) = \left(10.5 / R_s(t)\right)^3 \quad (5)$$

is the variation in the strength of the magnetopause current, R_s is a standard distance for the magnetopause in units of the Earth radius determined by the pressure balance formalism $R_S(t) = 98 / \left(\rho \cdot V^2\right)^{1/6}$.

The strength of the ring current relative to its quiet time strength is given by

$$S_R(t) = 1 - 0.025 Dst_R \quad (6)$$

The relative strength of the tail current is assumed to be proportional to the Pointing vector of the interplanetary electromagnetic field multiplied by a factor of 0.15 and by the cross section of the magnetosphere, i.e.

$$S_T(t) = 2 \cdot 10^{-7} \cdot V (R_S B)^2 \quad (7).$$

Using the expressions (5-7), we determine increasing of the magnetospheric currents relatively to their quite values of October 20, 1989 (Fig. 2). Substituting the relative strength of the magnetopause current into (4) we get the Dst_M component of *Dst*. The expression (3) gives the Dst_R component.

Figure 3 presents results of these calculations. One can see significant changes of the magnetopause current between 15:00 and 20:00 UT. The effect of the magnetopause current is really large and compensates about one third of the ring current effect.

We repeated calculations of cutoff rigidity changes described in the section 2.1 using the modified Dst_R index. Figure 4 shows a difference between vertical cutoff rigidities calculated using the *Dst* and Dst_R index for Moscow, Kiev and Rome. Clear that, when a relative strength of the magnetopause current is large, this difference is greater than the error of 0.1 GV declared above.

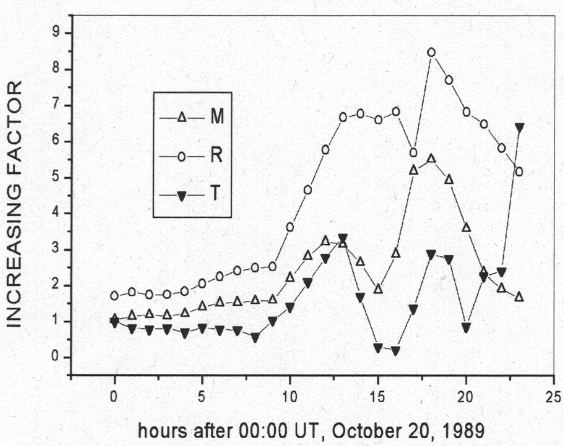

Fig.2. Increasing of the M – magnetopause, R – ring and T – tail magnetospheric currents relatively to their quite values.

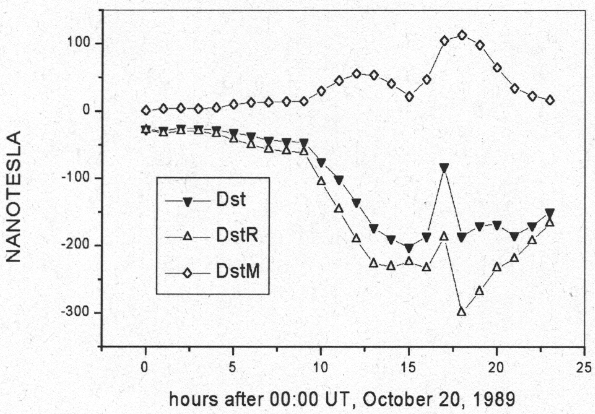

Fig.3. Time variations of the *Dst* index and its contributions due to the ring current Dst_R and the magnetopause current Dst_M.

The results of our model calculations we are compared with the changes in the cutoff rigidity in Moscow estimated by using data of the stratospheric experiment on October 20, 1989 (Struminsky, 1992).

The shapes of the cosmic ray absorption curves in the stratosphere strongly depends on the spectrum of primary particles and their minimum rigidity. During three balloon flights between 13:00 and 19:00 UT on October 20, 1989 the obtained absorption curves revealed a presence of additional protons with rigidity >1+/-0.25 GV. Therefore, the cutoff rigidity in Moscow dropped by about 1.5 GV. These protons apparently had the same origin as the second hump clearly seen in the GOES-7 proton data (see Struminsky, 2001 and references therein). Changes of the

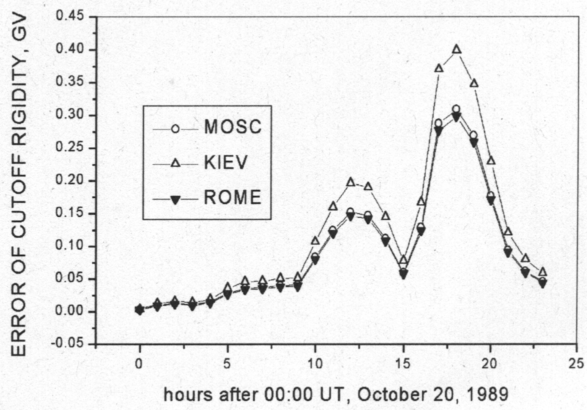

Fig.4. Difference between vertical cutoff rigidities calculated using the *Dst* index and the Dst_R index.

cutoff rigidities obtained with the modified Dst_R index show better agreement with this experimental result

3. Summary

Changes in the cutoff rigidities were evaluated from hourly values of the *Dst* index for different locations on October 20-22, 1989 using the procedure proposed by Fluckiger et al. (1986).

In order to account effects of the ring current only, hourly values of the *Dst* index were modified according to the dynamical model of the magnetostorm (Olson and Pfitzer, 1982) by removing the contribution of the magnetopause current.

Solar protons of about atmospheric cutoff energy were measured in Moscow in the stratospheric balloon experiment on October 20, 1989 (Struminsky, 1992). The changes in the cutoff rigidities obtained for Moscow with the modified Dst_R index show better agreement with this experimental results.

During the periods, when the magnetosphere is highly compressed, a difference between vertical cutoff rigidities calculated using the *Dst* index and the Dst_R index appeared to be greater by a factor of 4.5 than the error of the procedure 0.1 GV declared by Fluckiger et al. (1986).

The results of this work are used by Struminsky (2001) to separate cosmic ray variations of different origin during the Forbush decrease on October 20-22, 1989.

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