Magnetospheric cut-off rigidity variations recorded by neutron monitors in the events from 2001 to 2010

2013 J. Phys.: Conf. Ser. 409 012201

(http://iopscience.iop.org/1742-6596/409/1/012201)

Magnetospheric cut-off rigidity variations recorded by neutron monitors in the events from 2001 to 2010

H Mavromichalaki[1], E Eroshenko[2], A Belov[2], V Yanke[2], G Mariatos[1], A Laoutaris[1], A Kontiza[1]

[1]Nuclear and Particle Physics Section, Physics Department, National and Kapodistrian University of Athens, 15784 Athens Greece
[2]Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS (IZMIRAN), Troitsk, Moscow, Russia

E-mail: emavromi@phys.uoa.gr

Abstract. During a geomagnetic storm, many interesting variations in cosmic ray intensity recorded by the worldwide network of neutron monitor stations are observed. More specifically, a characteristic increase of cosmic ray intensity mainly in the middle latitude stations is observed, due to the geomagnetic cut-off rigidity changes. During the declining phase of the last solar cycle, many characteristic geomagnetic effects were observed with the most significant one on November of 2003, which is considered as the largest magnetic storm in the history of neutron monitors. In this work, the magnetic storms of 31 March 2001, 11 April 2001, 8 and 10 November 2004, 15 May 2005 and 24 August 2005 are analyzed using cosmic ray data from a number of neutron monitor stations located at different places worldwide.

1. Introduction

Disturbances in the Earth's magnetic field during magnetic storms can cause essential changes in the charged particle trajectories in the magnetosphere. These initiate two main consequences for ground-level observations: the effective cut-off thresholds and the effective asymptotic directions of the particles are changing. Both of these consequences are important for cosmic ray (CR) observations [1, 2].

In this work the relation between Dst-index, cosmic ray intensity variations and cut-off rigidity changes (dRc) during a number of geomagnetic storms occurred on the 31 March 2001, 11 April 2001, 8 and 10 November 2004, 15 May 2005 and 24 August 2005 is studied. All these events occurred in the declining phase of the solar cycle 23 that eventually coincides with the operational period of the Athens neutron monitor (NM). The results on the evolution of these events and their characteristics are presented below.

2. Data and Method

Hourly data of cosmic ray intensity from about thirty Neutron Monitor stations located around the world has been used (http://www.nmdb.eu). Dst index data are taken from http://swdcwww.kugi.kyoto-u.ac.jp/dstdir/ (WDC). The global survey method (GSM) which is conceptually a version of spherical analysis has been utilized for calculations of the rigidity changes dRc of each station. Different versions of this method have been evolved and improved at different stages of data processing [2, 3, 4].

The observed cosmic ray intensity I at i-th point, with rigidity Rc located at level h can be written as following:

$$\frac{\delta I^i}{I_0^i} = \delta^i{}_{mag} + \delta^i{}_{izot} + \delta^i{}_{anizot} + \delta^i{}_{err}$$

Where δ_{mag} is the magnetospheric component caused by particle propagation in the magnetosphere, δ_{isot} and δ_{anisot} are the mean isotropic and anisotropic cosmic ray variations out of the magnetosphere, and δ_{err} is the residual variations [2].

3. Results

The variations of the secondary CR component which is generated by the primary CRs in the Earth's atmosphere were obtained from the hourly data of each NM station relatively to the quiet base period. The time profiles of the CR intensity variations during two of the examined events (March 2001 and November 2004) are presented along with the Dst index variations in Fig.1. Middle latitude stations and polar stations are chosen for this presentation. It is noteworthy that the decrease of the CR intensity (called as a Forbush decrease) is happening simultaneously with the Dst decrease which is evidence of their common nature.

The latitudinal dependence of cut-off rigidity variations (dRc) during the examined events with respect to cut-off rigidity (Rc) in the quiet period of each station has been studied for each hour starting from the shock arrival until the final recovery of the magnetosphere [1], [5]. Cut-off rigidity variations dRc were calculated for each station throughout the storm by the mentioned above global survey method (GSM) applied to the data of the worldwide neutron monitor network. As typical examples, for certain representative hours of each geomagnetic storm, cut-off rigidity variations (dRc) versus the cut-off rigidities (Rc) for two of the studied events are presented in Figure 2, before the main phase of the storm, during the peak phase, and during the recovery period (Dst<100nT). Crosses indicate the points obtained by the global survey method applied to the data of the worldwide neutron monitor network [2], while the curve is a 3rd order polynomial fit, whose coefficients were calculated by a least-square technique.

Finally, selected correlation diagrams of the dRc changes together with Dst-index values for the events of March 2001 and November 2004 are shown in Figure 3. Note that the variations of these two parameters seem to be simultaneous and that they both present a minimum at about the same time. In some cases however, such as the one of May 2005, this correlation is not observed because other current systems (for example, magnetopause currents, currents in the tail of magnetosphere) are likely to make the main contribution to Rc variations [6]

Certain characteristics of the examined events, concerning both the CR variations and the geomagnetic behavior, are given in Table I. The information on the events such as the start and end time of the magnetic storm, the maximum amplitude of the indices, as well as the calculated variations of the cut-off rigidities are presented in this table, in order to define the behavior of each event and reveal the NM stations which recorded the maximum variations in each case.

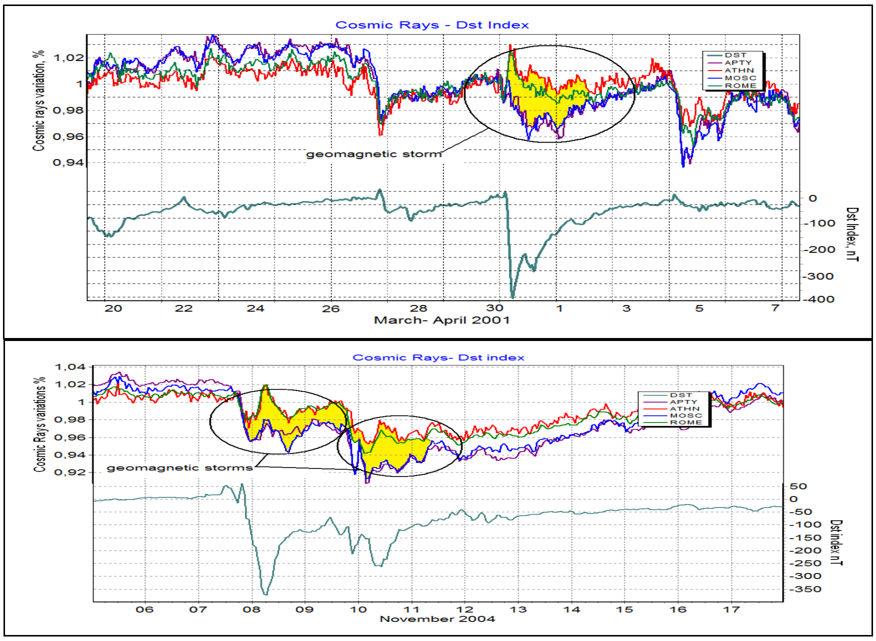

Figure 1: Time profiles of the cosmic ray intensity at the middle latitude (Athens, Rome) and polar (Moscow, Apatity) stations (upper curve) together with the geomagnetic index Dst (lower curve) for the time period of 20 March-7 April 2001 (upper diagram) and for 6-17 November 2004 (lower diagram).

DD/MM/YYYY	**31/03/2001**	**11/04/2001**	**08/11/2004**	**10/11/2004**	**15/05/2005**	**24/08/2005**
Magnetic storm Tstart	31/03/2001 2:00 UT	12/04/2001 1:00 UT	07/11/2004, 22:00 UT	10/11/2004, 4:00 UT	15/05/2005 8:00 UT	24/08/2005 12:00 UT
Magnetic storm Tmax	31/03/2001 06:00 UT	12/04/2001 4:00 UT	08/11/2004 6:00UT	10/11/2004 9:00UT	15/05/2005 12:00 UT	24/08/2005 19:00UT
Cosmic Ray intensity ΔImax (%)	4.7±0.5	4.0±0.5	4.9±0.5	2.8±0.5	4.0±0.5	6.0±0.5
Dst-index Tmin	31/03/2001 9:00 UT	12/04/2001 0:00 UT	08/11/2004 6:00 UT	10/11/2004 11:00 UT	15/05/2005 9:00 UT	24/08/2005 12:00 UT
Dst-index max	-387.00 nT	-271.00 nT	-374.00 nT	-263.00 nT	-247.00 nT	-184.00 nT
Kp index	9^-	3	8^-	8^-	8^-	9
Cut-off rigidity changes Δ(dRc max)	0.57 GV	0.23 GV	0.71 GV	0.65 GV	0.25 GV	0.65 GV
Stations with dRc max	ATHN (8.53 GV)	PTFM (6.85 GV)	PTFM (6.85 GV)	ERVN (7.30 GV)	PTFM (6.85 GV)	ROME (6.32 GV)

Table I: Main characteristics of the magnetospheric events analyzed in this work.

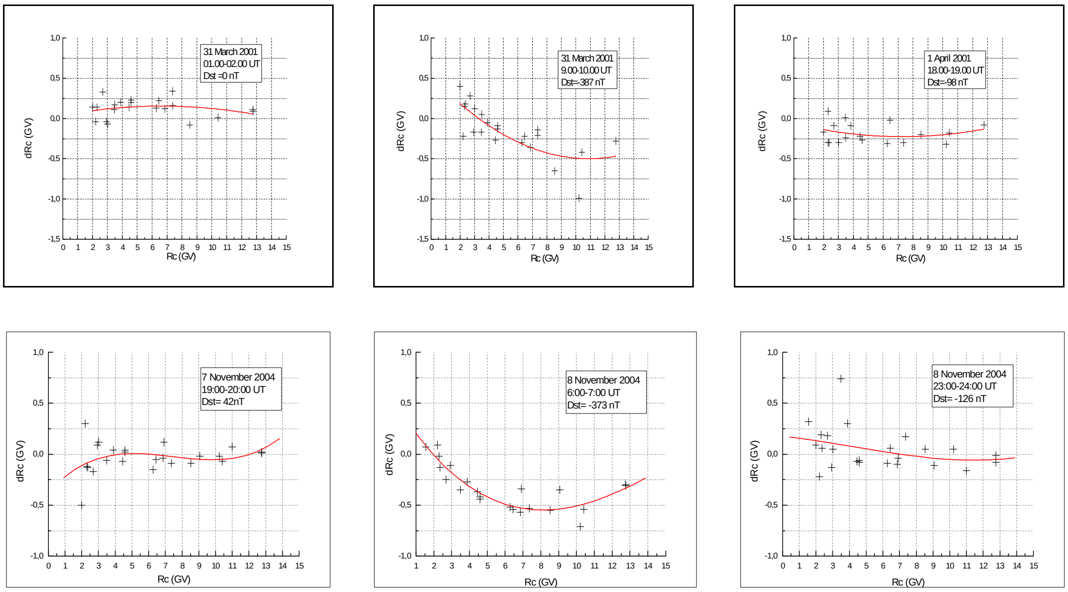

Figure 2: Diagrams of the cut-off rigidity variations (dRc) versus cut-off rigidities (Rc) that indicate the latitudinal dependence of the Rc during the different phases of the storm.

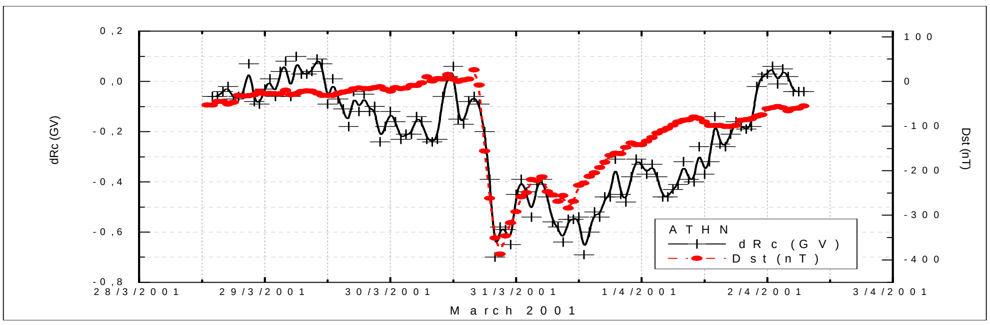

Figure 3: Time profiles of the Dst index and the cut-off rigidity variations dRc during the event of March 2001.

4. Conclusions

From the analysis of these six events, it is concluded that neutron monitors with Rc ranging from 6 to 9 GV are the most effective for recording major geomagnetic storms and definition of the maximum dRc changes. The magnetospheric effects of the cosmic rays caused by the longitudinal current system are well described by the proposed method. The analysis of more events accumulated over the history of the CR observations will contribute to obtain more reliable statistically results.

Acknowledgements: The authors thank the collaborators from the Neutron Monitor Stations for kindly providing CR data and the Kyoto Geomagnetic Center for the Dst-index data.

References

[1] Flueckiger E O, Smart D F, Shea M A 1987 *Proc 20th ICRC* **4** 216
[2] Belov A, Baisultanova L, Eroshenko E, Mavromichalaki H et al. 2005 *J Geophys Res* **110** A09S20
[3] Baisultanova L M, Belov A, Yanke V G 1995 *Proc 24th ICRC* **4** 1090
[4] Asipenka A, Belov A, Eroshenko E, et al 2009 *Proc 31st ICRC (Lodz)* icrc1106
[5] Flueckiger E O, Smart D F, Shea M A 1981 *Proc 17th ICRC* **4** 244
[6] Dvornikov V M, Kravtsova M V, Sdobnov V E 2009 *Bull. Russian Acad. Sciences: Physics* **73** 370