29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

Geomagnetic effects on cosmic rays during the very strong magnetic storms in November 2003 and November 2004

A. Belov[a], L. Baisultanova [a], R. Buetikofer[b], E. Eroshenko[a], E. O. Flueckiger[b],
G. Mariatos[c], H. Mavromichalaki[c], V. Pchelkin[d], V.Yanke[a]
(a) Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS (IZMIRAN), 142190, Troitsk, Moscow region, Russia
(b)Physikalisches Institut, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland
(c)Nuclear and Particle Physics Section, Physics Department, Athens University, Pan/polis-Zografos, 15771 Athens, Greece
(d) Polar Geophysical Institute, 183010 Murmansk, Russia
Presenter: E. Eroshenko (erosh@izmiran.rssi.ru), rus-eroshenko-E-abs1-sh35-oral

Cosmic ray variations due to changes in the magnetosphere are evaluated for the two severe geomagnetic storms on 2003 November 20 and 2004 November 08 using data from the worldwide neutron monitor network and the global survey method. From these results the changes in the planetary distribution of magnetic cutoff rigidities during the geomagnetic storms are evaluated in dependence of latitude and longitude. The latitudinal distribution shows a maximum change at geomagnetic cutoff rigidities around 7-8 GV in November 2003, and at 5-6 GV in November 2004. A comparative analysis of the cutoff rigidity changes derived from neutron monitor data and those calculated by using a state-of-the-art magnetospheric field model was performed. The results can be used to correct neutron monitor data for geomagnetic effects, as well as for validating magnetospheric field models during the severe geomagnetic storms.

1. Introduction

Cosmic ray (CR) variations due to cut-off rigidity changes (dRc) during a big magnetic storm, have already been studied in many papers [1-7]. Nevertheless, a several important problems still remain to be solved, in particular, definition a quantitative relation between Dst and possible dRc for each station after the analysis of a sufficient number of large magnetic storms (Dst<-100 nT). It would be also desirable to compare the current system models and experimentally derived changes in cut-off rigidities at different stages of the magnetic storm. In this analysis, direct incorporation of cosmic ray data is important in order to study the global effect of the current systems on particle trajectories. This is both during the initial phase of the magnetic storm, associated with currents in the magnetopause, and during the main phase, when cut-off rigidity is significantly reduced.

The biggest geomagnetic effect in CR seems to be observed in November 2003 [7] when the CR variation caused by the cut off rigidity changes during the severe magnetic storm (Dst=-472 nT) reached 6-7% at low latitude stations. The year after, the next burst of the solar activity in November 2004 - very close to the solar activity minimum -produced a series of the strong magnetic storms. In this paper we study and compare geomagnetic effects in cosmic rays during these two events.

2. Data and Method

Hourly data from 46 neutron monitors (NMs) of the worldwide network have been employed in a detailed analysis: 19 high latitude (Rc<1.2 GV), 22 mid and low latitude, and 5 sub equatorial (Rc>10 GV) stations.

Dst-index was taken from: http://swdcwww.kugi.kyoto-u.ac.jp/dstdir/ (WDC-C2). The global survey method (GSM) described in [6], has been utilized for calculations a set of parameters defining the galactic cosmic ray density and anisotropy from the ground level neutron monitor network, and then, for DRc evaluation. The method takes into account the cosmic ray transformation in the magnetosphere and atmosphere and uses trajectory calculations in the Earth's magnetic field and the neutron monitor response functions [8, 9].

3. Discussion and Conclusions

In Figure 1 the CR variations at different stations during the magnetic storm are presented for 2003 (a) and 2004 November (b) events. Geomagnetic effect for November 2003 is analyzed and described in details [7].

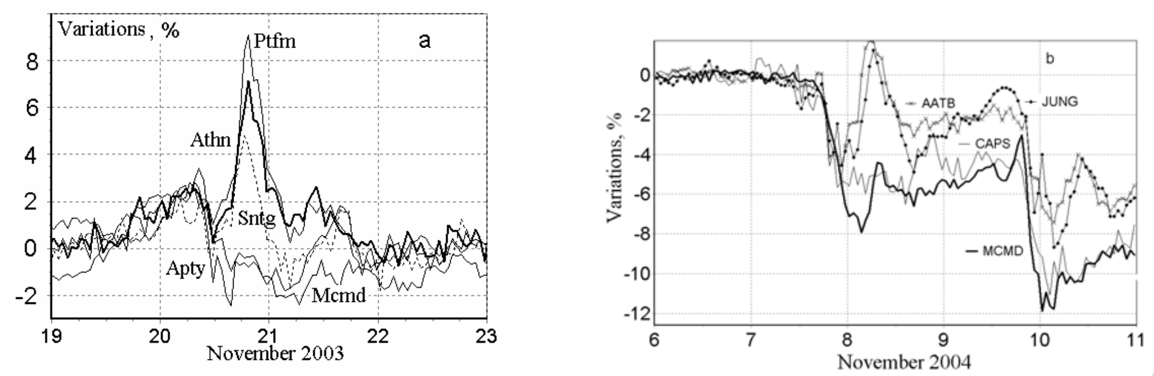

Figure1. Cosmic ray variations at different stations during the severe magnetic storms in November 2003 (a) and November 2004 (b). The station notifications are the following: AATB-Almaty (6.7GV), APTY (Apatity, 0.65GV), ATHN-Athens (8.7GV), JUNG-Jungfraujoch (4,5GV), MCMD-McMurdo (0.01GV), PTFM-Potchefstroom (7.3GV), SNTG- Santjago (11GV).

It was caused by the strong interplanetary disturbance with Bz =-60nT after series of M class solar flares followed by the effective CMEs on 18 November. This event is distinguished by record value of the magnetospheric variations and their unusual latitudinal distribution with maximum at cut off rigidity 7-8 GV. Solar activity burst in November 2004 led again to the significant sporadic variation of CR, although less by the magnitude as compared to the events in 2003, or in March-April 2001. In Figure 2 some characteristics of the interplanetary medium as well as CR behavior and indices of geomagnetic activity are plotted for a period from 6 to 12 November 2004. By NOAA data (ftp://ares.nrl.navy.mil/pub/lasco/halo) in that time CMEs with partial or full halo occurred almost every day (mainly from AR10696), thus, 2-3 disturbances were permanently present and produced shocks in the interplanetary space. As one can see from Figure 2 during the five days 5 SSC were recorded near the Earth (mid panel) followed by abrupt increasing of the solar wind velocity (up to 700-800 km/s) and strengthening of the IMF up to 40-45 nT (upper panel). This led to a significant increase of geomagnetic activity (lower panel): Dst index fell down to -373 and – 289 nT, and Kp index got a value 9 during the storms on 8 and 10 November.

We emphasize also some unusual behavior of the CR density on 8 November in the minimum of Forbush effect (FE) when during almost 12 hours a density increase of about 2% was observed. Its peak coincides both with the jump of solar wind velocity and with a Dst minimum (-373 nT). This seemingly should be attributed to a magnetosphere effect in cosmic ray. However, additional analysis doesn't allow accept this simple explanation. Magnetosphere effect as a rule reveals at mid- and low latitude stations and is not seen at the stations with cut off rigidity less than 2-2.5 GV. In this case a CR density increase was recorded also at high latitude neutron monitors (except of the very eastern) and even at polar stations (South pole, McMurdo). Excluding from the processing stations with Rc>1.2 did not change a situation. Thus, this enhancement of CR density in the minimum of FE at least partly, may be a result of the galactic CR [10]

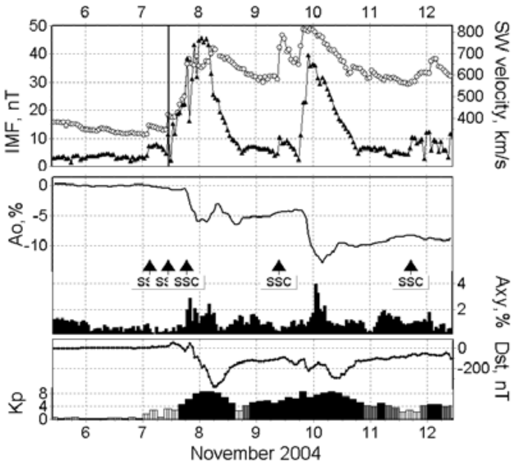

Figure 2. Variation of the parameters of interplanetary space, cosmic ray (CR) and geomagnetic activity in a disturbed period on November 2004: A0-density of 10GV CR derived from the NM network data, Axy-ecliptic component of the firs harmonic of CR anisotropy, Kp and Dst-indices of geomagnetic activity.

modulation by certain structures in the interplanetary space. At that time a succeeding part of a disturbance propagated with higher velocity than preceding one, and as result of interaction of the solar wind streams a compressed region was created , with higher CR density and rather complicated structure, which manifested in the sharp, although short duration, changes of CR anisotropy (Figure 2).

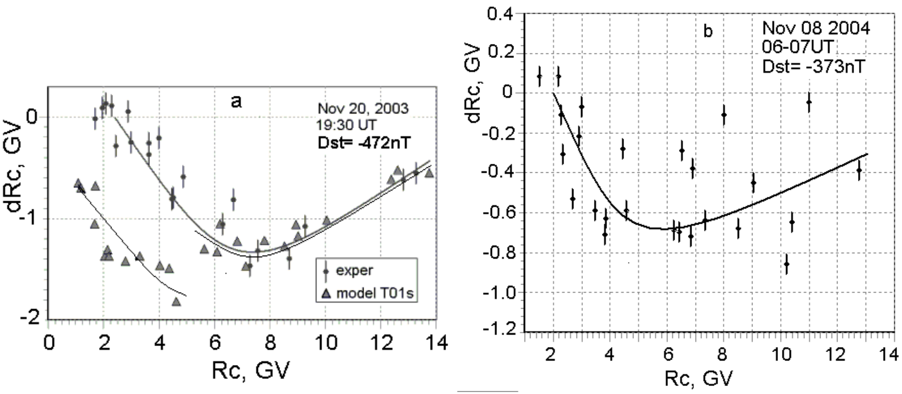

Figure 3. Cut-off rigidity changes (dRc) versus Rc in the quiescent magnetosphere at the maximum disturbed hours for the events in November 2003 and 2004. Points mark dRc derived from the NM data, triangles mean the values calculated by the "storm" model of Tsyganenko.

Nevertheless, counting rate at mid and low latitude NMs shows much bigger enhancement than at high latitude stations, that is may be really related to magnetosphere effect at these stations. Residual dispersion in calculations by GSM method, is large during these hours that indicates unaccounted magnetospheric effect. Thus, in this event the effects both of interplanetary and geomagnetic origin seem to be revealed simultaneously.

The variations DRc at different stations were calculated by the method described in [5, 7] during the effects in November 2003 and 2004. The distributions of rigidity variations dRc in these two events versus cut off rigidities for the quiescent magnetosphere [11] are presented in Figure 3a, b for the moments corresponded to the minimum Dst. As one can see, the maximal changes of Rc in the first event (nearly 1.4 GV) occurred at latitude corresponded to Rc= 7-9 GV. In the second event maximum changes of Rc were observed about 0.7 GV at the cut off rigidity 5-6 GV, that confirms more weak disturbance of the magnetosphere in this period as compared to the storm in November 2003.

In Figure 3a dRc calculated from the last "storm" magnetosphere model of Tsyganenko [12] are also plotted (triangles). The particle trajectories were calculated from the main cone to the Stormer cone adding all allowed intervals (i.e. for the flat spectrum of CR) with the step of calculations 0.002 GV. The model was tested for the rather quiet period at 6:30 UT on November 20. For this point the classical package T89 and the new T01S give very close values. Cut-off rigidity variations dRc were determined relative to this moment of the quiescent magnetosphere. One can see that there is a good agreement between experimental and calculated values for rigidities >6 GV, moreover, without any normalization. But we see a sharp discrepancy at rigidities less than 6 GV. Possibly, the model T01S still is not adequate for the greatest magnetosphere disturbances and this causes a discrepancy at lower rigidities.

5. Acknowledgements

This work is partly supported by Russian FBR grants 03-07-90389, 04-02-16763, by Program BR of the Presidium RAS "Neutrino Physics", by the Swiss National Science Foundation, grant 200020-105435/1and by PYTHAGORAS project in Greece.
We thank the collaborators from all CR stations which data were taken for analysis: Apatity, Barenzburg, Norilsk, Irkutsk, Irkutsk2, Irkutsk3, Tixie Bay, Yakutsk, Cape Shmidt, Magadan, Moscow, Novosibirsk, Alma-Ata, Tbilisi, Erevan,, Climax, Haleakala, Hermanus, Potchefstrom, Sanae, Tsumeb, McMurdo, Inuvik, Newark, Fort Smith, South Pole, Thule, Peawanuk, Nain, Mawson, Kingston, Santiago, Larc, Rome, Calgary, Jungfraujoch, Kiel, Lomnitsky Stit, Oulu, ESOI, Mexico, Kergelen, Terra Adelie, Beijing, Tibet.

References

[1] H. Debrunner et al., Planet. and Space Sci., **27**, 577-581, 1979.
[2] E. O. Flueckiger et al., Proc. 17-th ICRC, Paris. 4, 244-247, 1981.
[3] E. O. Flueckiger et al, J. Geophys. Res., 91, 7925, 1986.
[4] E. O. Flueckiger et al., Proc. 20-th ICRC, Moscow, **4,** 216-219, 1987.
[5] L. Baisultanova et al., Proc 24-th ICRC. **4,**1090-1094, 1995.
[6] V. M. Dvornikov and V. E. Sdobnov, Intern. JGA., 3**,** 1-11, 2002.
[7] A. Belov et al., J. Geophys. Res., 2005, accepted
[8] L. I. Dorman, Progress in Elementary Particle and Cosmic Ray Physics . (ed. By J. G. Wilson and S.A. Wouthuysen, North-Holland Publ. Co., Amsterdam, 1963
[9] S. Yasue et al., Coupling coefficients of Cosmic Ray Daily Variations for Neutron Monitor Stations, Report of Cosmic Ray Research Laboratory, N7,1982.
[10] M.Y. Hofer and E. O. Flueckiger, J. Geophys. Res., 105 (A10), 23,085-23,097, 2000.
[11] M. A. Shea and D. F. Smart, *Proc. 27th ICRC, Contributed Papers,* 10, 4063-4066, 2001.
[12] N. A. Tsyganenko et al., J. Geophys. Res., 108(A5), 1209, doi:10.1029/2002JA009808, 2003.