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Variations of geomagnetic cutoff rigidities during the series of geomagnetic storms in January 2005: observations and modeling

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Unexpected bursts of solar activity in January 2005, although much weaker than those in October 2003 and November 2004, led to a series of strong geomagnetic storms. Changes in the geomagnetic cutoff rigidities, dRc, during the geomagnetic storms on 17-22 January 2005 are evaluated from data of the worldwide neutron monitor network for middle and low latitude stations. The geomagnetic storm on 20-21 January occurred during the recovery phase of the large Forbush effect observed after the solar flare on 20 January, and it caused the most significant changes in the cosmic ray cutoff rigidities as compared to the other geomagnetic storms in January 2005. The values of dRc derived from neutron monitor data are compared with results of trajectory calculations using a state-of-the-art magnetospheric magnetic field model.

1. Introduction

The geomagnetic storm in January 2005 was chosen for analysis as the last among the large events in the series of the solar activity manifestations in the descending phase of cycle 23. An unexpected solar burst led to such a gigantic release of solar particles on 20 January 2005 that it was recorded at Earth as one of the largest Ground Level Enhancements (GLE) with up to 5000% at southern polar stations. This intense particle stream was followed by a powerful CME with a full halo and velocity of propagation of about 1000 km/s. A strong interaction with the geomagnetosphere was expected upon arrival of the shock at the Earth. Although this interplanetary disturbance created a large Forbush effect (~13% in 10 GV CR density), it produced only a relatively modest geomagnetic storm. The maximum Kp index was 8 and was reached only for one 3-hour value. The Dst parameter did not exceed -113 nT. This event was similar to the one in May 1978: during the recovery phase of the FE, the Dst amplitudes of the two events are very close, and in both events a large GLE occurred. The event in January 2005 is interesting because of the pronounced behavior of the Dst during the shock arrival, i.e. a very sharp increase of 60 nT caused by the currents on the magnetopause, which in turn are associated with magnetosphere pressing. This was an additional reason to study this interesting effect in a relatively weak magnetic storm.

2. Data and Method

Data from more than 40 neutron monitors (NM) have been used with the global survey method (GSM) [1, 2, 3] to derive parameters of 10 GV galactic CR density and anisotropy. After elimination of these variations from the initial data during the strong geomagnetic storms, the cutoff rigidity variations were calculated for each station and for every hour throughout the storm by the method described in [2, 3]. Dst data were taken from [http://swdcwww.kugi.kyoto-u.ac.jp/dstdir/ (WDC-C2)]. Theoretical evaluations of cutoff rigidity (Rc) were performed by the method of trajectory calculations in the model magnetosphere [7, 8, 9] for several most significant hours.

3. Discussion and Conclusions

In Figure 1 the two events in May 1978 and January 2005 are shown. In the following points the two events are similar: they occurred in the recovering phase after a FE, after a large GLE, and the Dst amplitude was of the same order (-132 and -113nT).

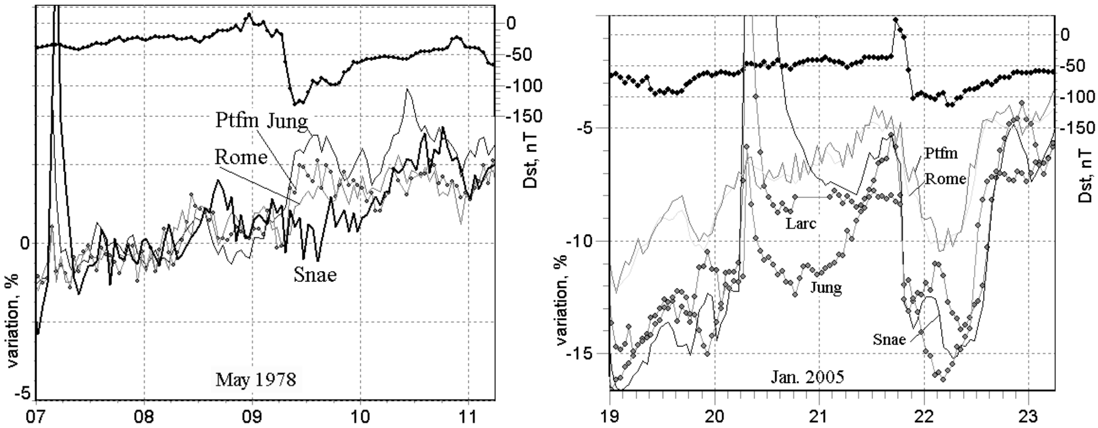

Figure 1. Dst index and relative counting rate of different NMs during the geomagnetic storms in May 1978 (left) and January 2005 (right).

There are no clear indications of a new Forbush effect in association with the geomagnetic storm on 9 May 1978 because they are masked by the geomagnetic effect. Cutoff rigidity variations dRc are well defined by our method with maximum changes of 0.3 GV at ~3-4 GV (Figure 2). We checked 6 events with Dst amplitudes around -100 to -150 nT, and they all closely resemble the one in May 1978.

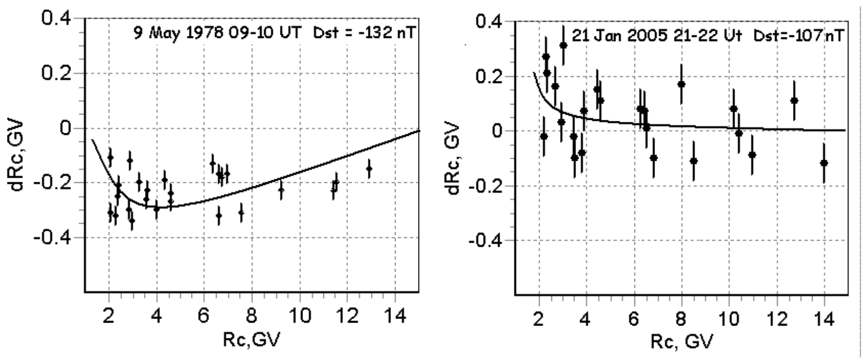

Figure 2. Distribution of the cutoff rigidity changes dRc versus cutoff rigidity in the quiescent magnetosphere in May 1978 and January 2005 for the hours with minimum Dst.

On the contrary CR variations recorded by different neutron monitors during the geomagnetic storm on 21-22 January 2005 are complex and seem to be caused not only by a disturbed magnetosphere but also by complex conditions in the interplanetary space. In Figure 2 the change in the cutoff rigidity calculated by our method as a function of Rc is presented for the hours with minimum Dst on 9 May 1978, 09-10 UT and on 21 January 2005, 21-22 UT. The result of the analysis is a small but clearly pronounced dRc with a maximum at Rc~3 GV in May 1978, whereas in January 2005 there is no clear indication of cutoff changes and the scatter of the results does not allow to deduce information on a possible dependence of dRc on Rc.

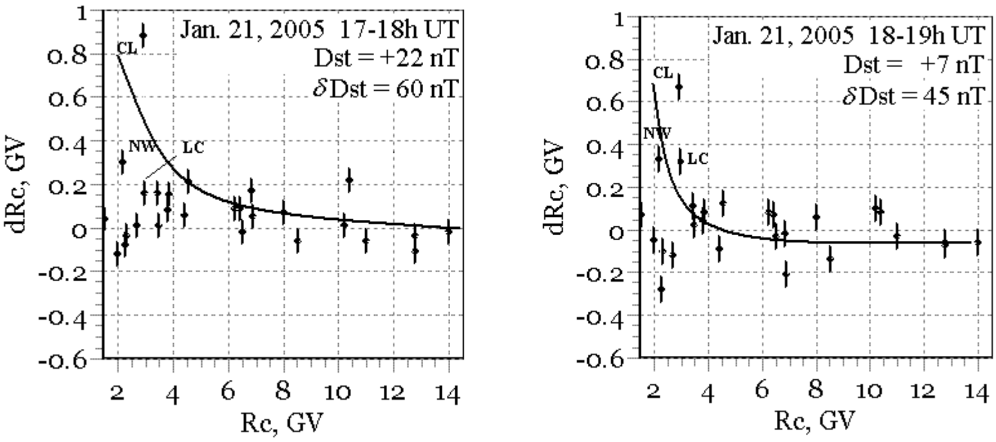

Figure 3. Distribution of the cutoff rigidity changes dRc versus cutoff rigidity for two hours during the storm on 21-22 January 2005. The following notations are used: CL-Climax, NW- Newark, LC- Larc.

One feature in the Dst behavior on 21 January 2005 calls attention: it is very sharp, of short duration, and large with a peak of ~60 nT magnitude at 17-19 UT. It occurred as could be expected some hours after the large pre-increase in the CR intensity (Figure 1). This is evidence of their common nature and confirms the strong and effective shock that produced a strong magnetopause current system on the day-side of the Earth's magnetosphere. It revealed the CR variations recorded by some day-side (American) stations as a magnetosphere effect. In Figure 3 dRc distribution versus Rc is presented for two hours with maximum Dst. One can see an increase of Rc for the stations Climax, Newark, and Larc of about 0.3-0.8 GV. This distribution is characteristic for periods when the effect of the magnetopause is dominant [4, 10]. Analogous geomagnetic effects in the CR for NMs located on the day-side (on European longitudes) were observed e.g. on 4 August 1972 [2]. The shock in August 1972 was more effective and produced a severe magnetic storm, whereas the large shock in January 2005 did not cause a big storm because the Bz component of the IMF (Bz=-7 nT) was small. The Kp index reached only a value of 8 at the first moment of the magnetic storm and decreased quickly.

Nevertheless, the 21/22 January 2005 Forbush effect started simultaneously with the shock arrival and reached ~13% in density of 10GV CR. The count rates of different stations show an increase in the CR intensity at the maximum of the Forbush decrease that is simultaneous with a flat, long lasting minimum in the Dst (Figure 1). Usually such an effect is related to geomagnetic activity and may be caused by a disturbed magnetosphere as well as modulation processes in the interplanetary space [3-6]. A disturbed magnetosphere in the main phase of the storm may influence the CR flux both by varying cutoff rigidity and by changing the particle trajectories, which can create an anisotropy effect. Due to trajectory variations the CR effect may be observed even at high latitude stations as we can see during the magnetic storm on 21/22 January 2005. When the magnitude of the effect is not so large, it is impossible to discriminate between geomagnetic and interplanetary effects.

In Figure 4 the behavior of the CR density and of the three components of CR anisotropy (for 10 GV rigidity) are presented together with Dst variation for the period under consideration. One can see large variations of CR anisotropy during the initial phase of the storm. This may be an explanation for the scattered distribution

of dRc in Figure 2. We attempted to evaluate variation of the cutoff rigidity at 4 UT on 22 January when three components of anisotropy were closer to zero, but an increase in CR behavior was observed at different stations. The computed dRc as a function of Rc are presented in Figure 5. One can see a well-pronounced dependence of dRc with a maximum of ~0.3GV at rigidity around 5 GV.

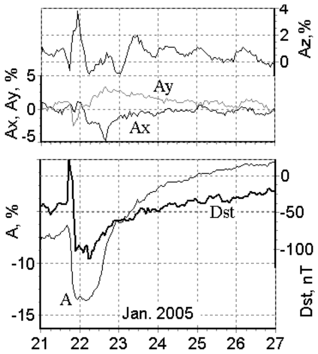

Figure 4. Behavior of CR anisotropy (Ax, Ay, Az), density A, and Dst variation in January 2005.

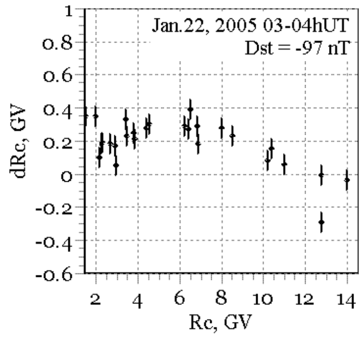

Figure 5. Distribution dRc versus Rc for 03-04UT on 22 January 2005

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