

THE COMPARATIVE ANALYSIS OF GLEs 1998-2001 ON DATA OF CLOSE NEUTRON MONITOR STATIONS IN APATITY AND OULU

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Abstract. Count rates of two closely located neutron monitors (NMs) in Oulu and Apatity showed unusually different behaviour during the onset phase of the GLE of 14 July 2000. A similar behaviour took place during the onset of the GLEs of 2 May 1998 and 15 April 2001. All three events took place after a strong Forbush decrease implying the significantly disturbed interplanetary and geomagnetic conditions. In all cases the NM with higher count rate (Oulu on 02.05.1998 and 15.04.2001 and Apatity on 14.07.2000) was located in the so-called "14 MLT" region (14-16 hours Magnetic Local Time) where the maximum of the dayside auroral intensity and other anomaly geophysical phenomena are located. Here we present the results of a comparative analysis of the events using also data of other NMs as well as their asymptotic cones calculated using Tsyganenko 1989 magnetospheric model. It is hypothesized that in the given sector of the midday magnetosphere there is an anomaly in its structure, facilitating penetration to the Earth of cosmic ray protons from the dayside magnetopause.

Introduction

The Ground-Level Enhancement (GLE) of 14 July 2000 was caused by parent flare 3B/X5.7 with heliocoordinates N22 W07. The start of the type II radioburst close to the relativistic proton acceleration (Cliver et al., 1982) was registered at 10:20 UT. The event occurred during the Forbush effect in progress

implying the significantly disturbed interplanetary and geomagnetic conditions. In particular, a bidirectional solar proton anisotropy observed in the event could be related with the loopelike IMF geomery in the magnetic cavity formed by CME produced Forbush effect. The interplanetary anisotropy of relativistic solar protons was studied with a help of asymptotic cones of neutron monitor stations calculated using Tsyganenko 89 magnetosphere model.

The main focus of the paper is made to the unusual increase of difference between the close neutron monitor stations in Apatity and Oulu during the onset phase of the GLE. The similar difference between Apatity and Oulu stations has been observed in the GLEs of 2 May 1998 and 15 April 2001 also occurred in disturbed conditions. In all three cases the NM station with higher count rate (Oulu on 2.05.1998, 15.05.2001 and Apatity on 14.07.2000) was located in the so called "14 MLT" region (14-16 hours Magnetic Local Time) where the maximum of the dayside auroral activity and other anomalies in the geophysical phenomena occur.

Neutron monitor observations

Fig.1 shows increase profiles for the 14 July 2000 GLE at a number of high-latitude neutron monitors. The profiles of Apatity and Oulu closely located stations are shown in Fig.1a. The remarkable detail here is the initial impulselike maximum visible in the data of Apatity and absent in the Oulu profile, although

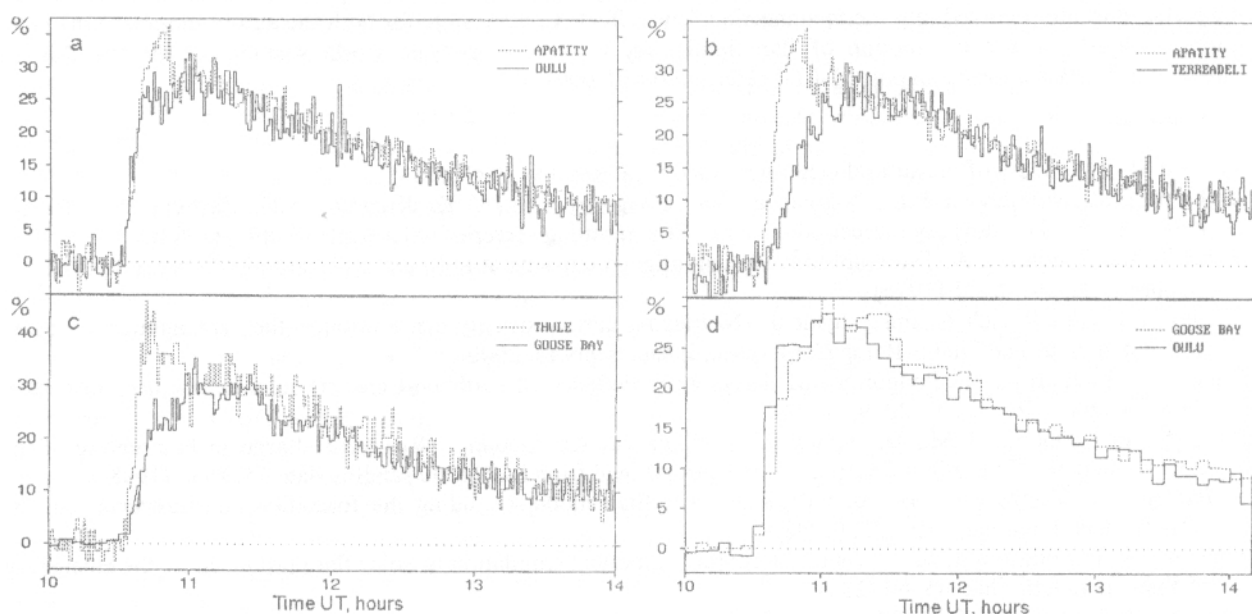


Fig.1. GLE 14 July 2000. Increase profiles at a number of NM station pairs. **a:** Apatity-Oulu; **b:** Apatity-Terre Adelie; **c:** Thule-Goose Bay; **d:** Goose Bay-Oulu. Note the prompt initial peak registered by Thule and Apatity NMs.

both profiles coincide for the rest of the event. In Fig.1b profiles of the Apatity and Terre Adelie NMs are shown. The gradual intensity rise at Terre Adelie contrasted with the fast Apatity profile and demonstrated the delayed population of solar protons. Note however the nearly simultaneous start of the prompt and delayed populations. Fig.1c shows in comparison the profiles of Thule and Goose Bay NMs and Fig.1d the Goose Bay and Oulu profiles. As can be seen the prompt solar proton peak was observed by only Thule and Apatity NMs. Profiles of all the stations are close together for later times (after 11:30 UT).

Anisotropy effects

Fig.2 shows the asymptotic cones for a number of NM stations used in this study calculated in GSE coordinates for the moment of time 11.00 UT, 14 July, 2000, Tsyganenko 89 model was used for these calculations. The IMF direction + (to the Sun) and $\times$ (from the Sun) as observed at the ACE spacecraft (the allowance of 30 min is made for solar wind propagation from ACE to the Earth) is shown. The equal pitch angle grid is drawn by steps of 10° from 0° (direct flux) to 180° (sunward reverse flux). The prompt impulse like increase was rather anisotropic as it was registered by Thule station whose asymptotic cone as a whole was inside the region of small ($<40^\circ$) pitch angles. On the other hand the asymptotic cone of Goose Bay NM was turned to the IMF by its high-rigidity end. That is why this station did not register the anisotropic but rather soft prompt fraction of relativistic solar protons (RSP). The low-rigidity end of the Goose Bay asymptotic cone is in a region of great pitch-angles of the direct flux and covers a common with Apatity and Oulu cones pitch angle domain. So increase profiles of these three stations nearly coincide for the late phase of event (Fig.1a, d).

The asymptotic cones of Apatity and Oulu stations are close to each other and as the Goose Bay cone are

turned sunward by their high-rigidity ends. So they, as the Goose Bay asymptotic cone, should have not accepted the soft anisotropic radiation of the initial impulse. It was really true for Oulu station. Nevertheless the prompt initial increase was registered by Apatity neutron monitor by absence of notable effect in Oulu (Fig.1a). After the initial impulse like increase in the direct flux the anisotropy had dropped and disappeared completely after 15 UT when an interplanetary shock arrived to the Earth (OMNI Web data).

Other cases of the Apatity-Oulu GLE difference

As the longstanding observations show, the Apatity and Oulu neutron monitors demonstrate as a rule nearly equal increase effects during GLEs. Very few occasions of the marked differences were associated with a strong interplanetary anisotropy and discussed in the literature. In the 7.08.1978 GLE the computed anisotropy axis passed directly through the closely oriented asymptotic cones of the Apatity and Oulu stations. The supposed difference was due to shifted from each other asymptotic directions for equal rigidities at the Apatity and Oulu asymptotic cones (Shea and Smart, 1982). The similar reason of the difference between Apatity and Oulu was supposed to occur on the 29.09.1989 GLE (Vashenyuk et al., 1997). During the 16.02.1984 GLE the Apatity-Oulu difference was attributed to a possible quasidrift effects of high-energy solar protons in the magnetosphere (Shumilov et al., 1993).

The difference between Apatity and Oulu in the 14.07.2000 GLE as well as in cases considered below obviously has some other another physical cause. Fig.3 shows the other two cases of difference between Apatity and Oulu NMs observed during the GLEs 2.05.1998 (Belov et al., 2000; Danilova et al., 1999) and 15.04.2001. The initial impulsive increase observed in Oulu and nearly missed in Apatity (Fig.3a)

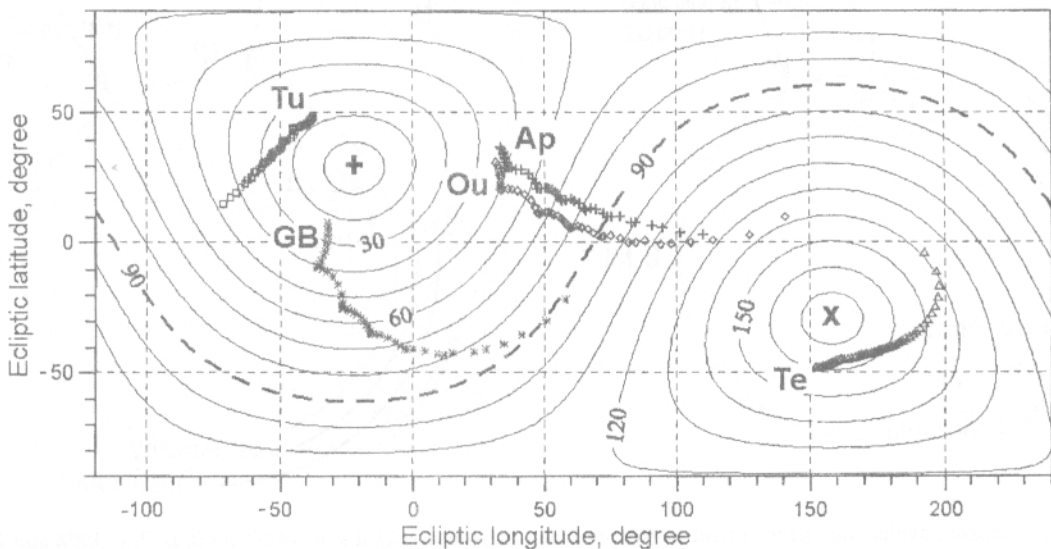


Fig.2. Asymptotic cone map for 11:00 UT, 14.07.2000. NM stations: Thule, Apatity, Oulu, Goose Bay, Terre Adelie. The rigidity range is 1-20 GV. Letter indexes are near the high-rigidity (20 GV) ends. The IMF direction: + (to the Sun) and $\times$ (from the Sun) and the pitch angle grid from 0° to 180° are shown.

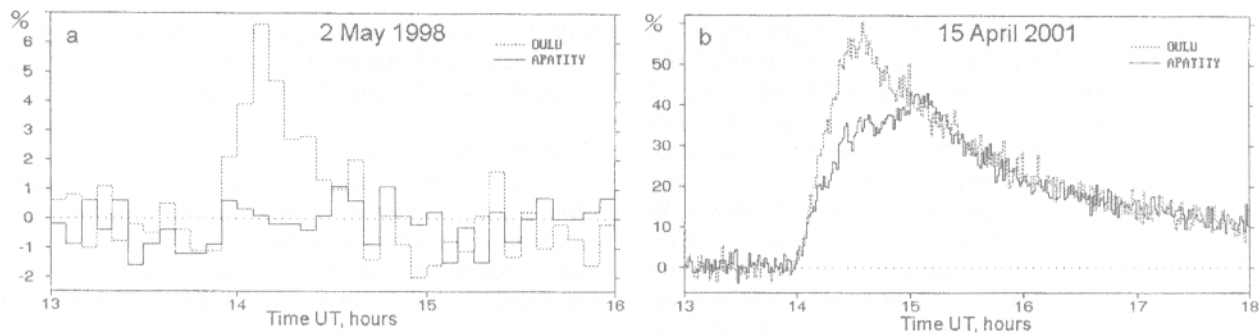


Fig.3. The difference between Apatity and Oulu GLE effect in the events of 2 May 1998 (a) and 15 April 2001(b)

was attributed by Danilova et al. (1999) to some magnetospheric effect under disturbed conditions. The GLE of April 15, 2001 (Fig.3b) was caused by a solar flare X14/2B, heliocoordinates S20 W85. The start of the type II radioburst was recorded at 13:48. The pronounced difference in the initial part of the increase effect between the Apatity and Oulu NMs can be seen to occur at the same time of day during both 2.05.1998 and 15.04.2001 events and in the season, for which the geomagnetic dipole tilt does not differ much. So appropriate magnetospheric conditions and positions of both Apatity and Oulu stations in the day sector of auroral zone were also similar.

Discussion

Considering the anisotropy effects in the 14.07.2000 GLE one should keep in mind a possible loop-like IMF structure related to the Forbush effect that was in progress. The bi-directional anisotropy could be created by injection of energetic solar protons into the two ends of the loop in the corona by an extended source: shock wave, CME, etc. (Richardson et al., 1991). It is hard to suggest the reverse flux as a reflected part of the direct one because both of them started to increase at the Earth orbit nearly

simultaneously, although this rise was slower from the antisunward direction (NM Terre Adelie, Fig.1c).

Considering the GLE difference between the Apatity and Oulu NMs we have to suggest some magnetospheric effect promoting the direct penetration of high energy solar protons to one of the stations and leaving out the calculated asymptotic cone. The common feature of the events of 14.07.2000, 2.05.1998 and 15.04.2001 was that the station pair Apatity-Oulu was in the dayside sector of local time. And in each case the station registered an enhanced increase effect was within the so called "14 MLT" region (statistically averaged position 14-16 hrs of Magnetic Local Time). This postnoon sector of the magnetosphere is characterized by the maximum of dayside aurora occurrences as well as other anomalies in geophysical phenomena (Kozlovsky and Kangas, 2001 and references herein). On the other hand, exactly in this local time domain the depression of magnetospheric field probably caused by magnetospheric current systems (Ostapenko and Maltsev, 2001) exists.

Fig.4a shows schematically in the geomagnetic equatorial projection the positions of the Apatity and Oulu stations compared to the "14 MLT" sector (darkened), their asymptotic cones, and the direction of

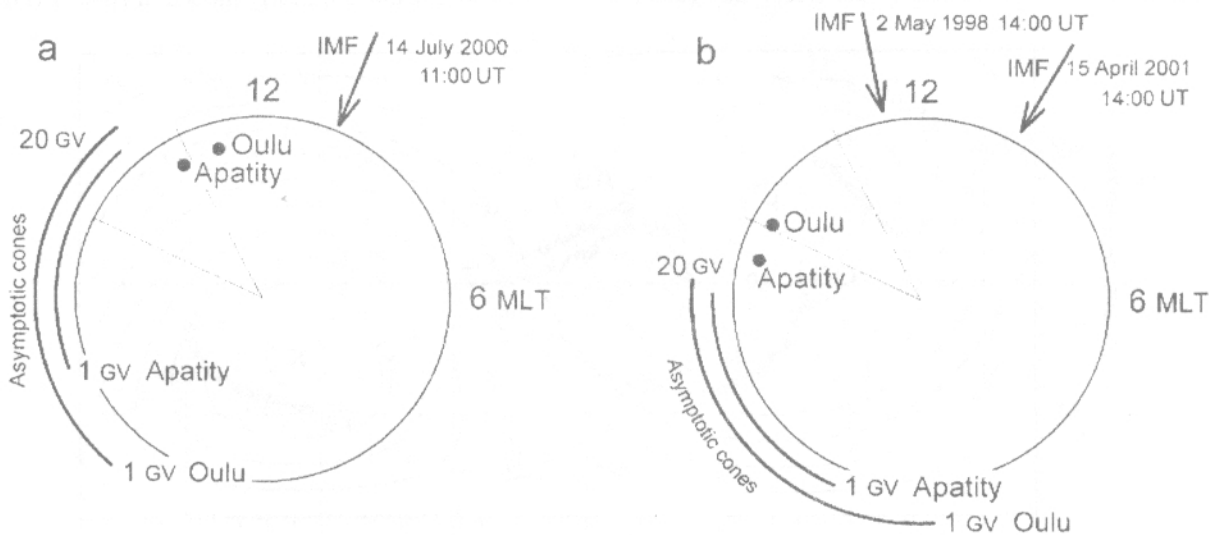


Fig.4. The schematic explanation of the effect of Apatity-Oulu difference in GLEs. a: 14.07.2000, b: 2.05.1998 and 15.04.2001 events. The magnetic local time projections of the "14 MLT" sector, NMs Apatity and Oulu locations, their asymptotic cones as well as IMF field line direction are shown.

IMF for GLE 14.07.2000. Fig. 4b shows the same for the events of 2.05.1998 and 15.04.2001. One can see that in all these cases the asymptotic cones of Apatity and Oulu stations are turned away from the sun along IMF direction and are incapable to accept an anisotropic particle flux from the Sun. The NM station Apatity registered the anisotropic peak in the event 14.07.2000 was in the "14 MLT" sector, whereas the Oulu station was outside it. In Fig.4b the close situation is shown for the events of 2.05.1998 and 15.04.2001. In these cases the Oulu NM registered an anisotropic solar proton flux was inside the "14 MLT" sector, and the Apatity station outside it. It should be noted that shown in Fig.4 the "14 MLT" sector (14-16 MLT) is only a statistically average of its location which may change within the limits in particular cases.

So one can suppose that in the "14 MLT" sector there is an easier way for solar protons penetration into the magnetosphere than the one expected from widely used magnetospheric models including Tsyganenko 89 model.

The analysis of magnetosphere response to different solar wind parameters using a vast number of satellite measurements Ostapenko and Maltsev (2001) revealed a depression up to 20 % of the geomagnetic field (within 3-10 R_E) in the postnoon sector observed during the periods with negative IMF B_z component. The physical reason for this magnetic field anomaly in the "14 MLT" sector may be the magnetopause and the inside magnetosphere currents induced by the IMF negative B_z component. The GLE difference between Oulu and Apatity in all three considered events coincided in time with negative B_z IMF. That allows us to assume, that an easier penetration of solar protons in of the "14 MLT" sector may be due to the weakening in that point of magnetospheric field caused by effects of interactions with the solar wind.

Summary

The unusual difference in the increase effect at two closely located neutron monitor stations in Apatity and Oulu during the GLE 14.07.2000, as well as during also in two other events 2.05.1998 and 15.04.2001 is investigated. All these cases correspond to the time when the pair of Apatity-Oulu stations was in proximity of local noon. And in all cases the NM with higher count rate (Apatity on 14.07.2000 and Oulu on 02.05.1998 and 15.04.2001) was located in the so-called "14 MLT" region (14-16 hours Magnetic Local Time) where the maximum of a dayside auroral intensity and other anomalous geophysical phenomena are situated.

It is suggested that in this part of postnoon magnetosphere exists an easier way for solar protons penetration exists than the one expected from widely used magnetospheric models.

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