# Study of the ground level enhancement of 13 December 2006

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**Abstract:** A new significant solar energetic particle event was recorded by the ground level neutron monitor network during the descending phase of the 23rd solar cycle. This ground level enhancement event (GLE 70) occurred on 13 December, 2006 during a magnetically disturbed period manifested by a series of Forbush decreases of the cosmic ray intensity at neutron monitors, starting from 6 December, 2006. In the same period a series of significant X-ray flares occurred. The flare X3.4/4B in the AR10930 resulted in a big proton flux increase in the energy range above 100MeV according to GOES-11 satellite recorded. The worldwide network of neutron monitors recorded GLE 70 on 13 December, 2006 starting from about 2:50 UT. Recorded data of the neutron monitor network showed this enhancement is one of the greatest GLEs of the 23rd solar cycle. In this work data of several neutron monitor stations were chose to analyze for the event of 13 December, 2006, and some preliminary results are presented.

## Introduction

A new significant solar energetic particle event was recorded by the ground level neutron monitor network during the descending phase of the 23rd solar cycle. This event was caused by an X3.4/4B flare at 13/0240 UT from Region 10930, heliocoordinates S06 W24. Solar activity increased to high levels on 13 December by this flare with an associated Type II (est. shock velocity 1534 km/sec) and Type IV radio sweeps, a 44000 sfu Tenflare, and a fast, full-halo CME (est. plane-of-sky velocity 1500 km/sec). A greater than 10 MeV and greater than 100 MeV events occurred on 13 December according to GOES-11 associated with this flare. The greater than 100 MeV event began at 13/0300 UT, and the greater than 10 MeV proton event began at 13/0310 UT. The ground based neutron monitors recorded the ground level enhancement as the No. 70 GLE. It also occurred during a magnetically disturbed period manifested by a series of Forbush decreases of the cosmic ray intensity at neutron monitors, starting from 6 December, 2006. The worldwide network of neutron monitors recorded GLE70 on 13 December, 2006 starting from about 2:50 UT, which was earlier than the time of proton events. Recorded data of the neutron monitor network showed this enhancement is one of the greatest GLEs of the 23rd solar cycle.

## Analysis

We chose 28 neutron monitors to analyse GLE70. The onset time of X3.4/4B flare was 13/0240UT, then the data from 0100UT to 0200UT was set to be the baseline to calculate the cosmic ray intensity(CRI) increase. After analysis, we found that the stations where cutoff rigidity above 5GeV couldn't show any obvious increase, and 24 neutron monitors of the chosen 28 neutron monitors with lower rigidity($<$4.5GV) demonstrated an increase profile to show the effect of this GLE70. The CRI increase of the 24 neutron monitors were listed in Table 1.

In Table 1 we could see that the time reaching maximum of CRI increase was within 1 hour after the flare onset time. Further more we cut the time into two parts as 0240-0310UT and 0310-0340UT to investigate the difference in responding to GLE70 of chosen neutron monitors. We found that mostly neutron monitors($\sim$71%) got the maximum increase in 0310-0340UT, Apatity and Oulu neutron monitors showed a rapid and significant response to GLE70.

Table 1: Cosmic ray intensity increase of different neutron monitors

| NM Station | Latitude,deg | Longitude,deg | Altitude,m | Pc,GV | Increase%(maximum) | |
|---|---|---|---|---|---|---|
| | | | | | 02:40-03:10UT | 03:10-03:40 |
| Mcmurdo | 77.95S | 166.60E | 48 | 0.01 | | 23.60% |
| Thule | 76.60N | 68.80W | 44 | 0.10 | | 20.67% |
| Inuvik | 68.35N | 133.72W | 21 | 0.18 | | 20.49% |
| Mawson | 67.60S | 62.88E | 0 | 0.22 | | 52.68% |
| Fort Smith | 60.00N | 112.00W | 203 | 0.30 | | 22.72% |
| Nain | 56.60N | 61.70W | 46 | 0.40 | | 22.40% |
| Cape Shmidt | 68.92N | 179.47W | 0 | 0.45 | | 18.47% |
| Peawanuck | 55.00N | 85.00W | 52 | 0.50 | | 22.81% |
| Tixie Bay | 71.60N | 128.90E | 0 | 0.53 | | 21.25% |
| Nroilsk | 69.26N | 88.05E | 0 | 0.63 | | 21.44% |
| Apatity | 67.55N | 33.33E | 173 | 0.65 | 83.40% | |
| Oulu | 65.02N | 25.50E | 0 | 0.81 | 92.10% | |
| Sanae | 70.30S | 2.35W | 52 | 1.06 | | 33.50% |
| Yakutsk | 62.02N | 129.72E | 105 | 1.70 | | 16.24% |
| Magadan | 60.10N | 151.00E | 0 | 2.10 | | 13.93% |
| Kiel | 54.30N | 10.10E | 54 | 2.29 | 32.06% | |
| Moscow | 55.47N | 37.32E | 200 | 2.46 | 23.26% | |
| Novoskbirsk | 54.80N | 83.00E | 163 | 2.91 | | 8.45% |
| Larc | 62.20S | 58.96W | 40 | 3.00 | 22.40% | |
| Irkutsk | 52.10N | 104.00E | 433 | 3.66 | | 4.61% |
| Irkutsk2 | 52.28N | 104.02E | 2000 | 3.66 | | 4.52% |
| Irkutsk3 | 52.28N | 104.02E | 3000 | 3.66 | | 4.92% |
| Lomnitski Stit | 49.11N | 20.13E | 26347 | 4.00 | 10.50% | |
| Jungfraujoch | 46.55N | 7.98E | 3550 | 4.48 | 8.26% | |

The location of Apatity and Oulu neutron monitor station is close. Many paper studied the difference between these two near-by neutron monitors by analysing specific events. As long-term observations have revealed, Apatity and Oulu neutron monitors generally show almost equal increase profiles during GLEs. But they would get significant differences for some events. Such as the 7 May 1978 GLE[1], the 29 September 1989 GlE[2], the 16 February 1984[3], the 2 May 1998[4, 5] and the 15 April 2001[6]. For the 13 December 2006 GLE, no obviously different increase profile was showed in Fig.1. The two stations demonstrated nearly the same increase profile. This event, GLE70, was not a special one for Apatity and Oulu neutron monitors.

After analysis, we also found that the GLE onset time was earlier than that of proton events which GOES-11 satellite recorded. Fig.2(top) was the proton integral flux. The solid line showed the flux

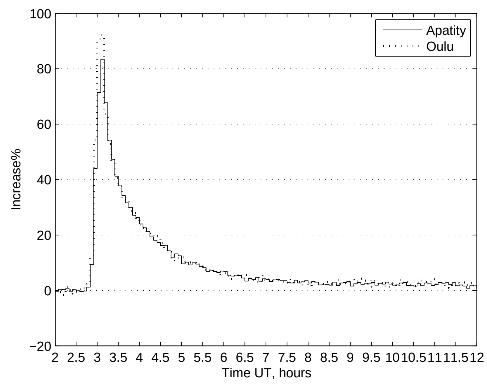


Figure 1: The increase profile of Apatity and Oulu in the 13 December 2006 GLE

of proton with energy greater than 100MeV, and the dotted one was the flux of proton with energy greater than 10MeV. According to the data, the onset time of greater than 100MeV proton event and greater than 10MeV proton event were 0300UT and 0310UT respectively. And Fig.2(bottom) was 5-min average data of 5 neutron monitors(Apatity, Oulu, Mawson, Larc and Lomnitski Stit).

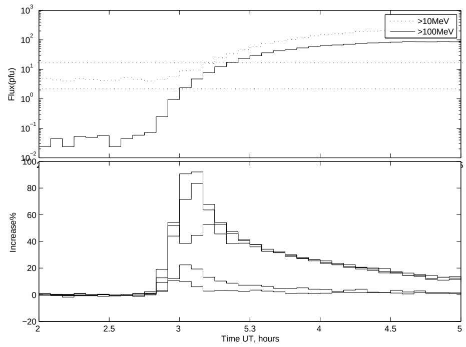


Figure 2: (top)proton integral flux recorded by the GOES-11 satellite(dotted line, >100MeV; solid line, >10MeV) and (bottom)5-min average data of several neutron monitors.

It is obvious that the onset time of GLE recorded by neutron monitors was earlier than 0300UT. GLE onset time is defined as the time when one of the stations intensity increase exceeds 3%. For the 24 neutron monitors, the GLE70 onset time was 0250UT. And the alert issued by SEC/NOAA on the basis of GOES data was 0312UT for proton with energy greater than 100MeV and 0324UT for proton with energy greater than 10MeV. If we produced the alarm or alert based on the neutron monitors data, it should precede compared with GOES proton data. This result was a positive supplement to that of [7]. [7] would set a GLE alarm system based on neutron monitors.

## Conclusions

To study the GLE of 13 December 2006, which is one of the greatest GLEs of the 23rd solar cycle, 24 neutron monitors which recorded this GLE70 were chosen for analysing. The response to the GLE was mainly investigated. After analysis, we found that all of the chosen neutron monitors got maximum intensity increase within 1 hour after the flare onset time 13/0240UT. Most of them(71%) reached the increase peak in 0310-0340UT. Apatity and Oulu neutron monitors were ones that got increase peak in 0240-0310UT. They showed a rapid and significant response to the GLE70, and they showed a nearly equal increase profile to this event. GLE70 onset time based on the neutron monitors was 0250UT. The time preceded the onset time of greater than 100MeV and 10MeV proton events. Also it is earlier than the alert time based on the GOES proton data. If we develop an alarm system based on the worldwide neutron monitors network, it is surely useful for avoiding or lightening loss when the disastrous events occurred.

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