

# Search for Solar Neutron Events in Alma-Ata NM Data

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## Abstract

The Alma-Ata high altitude neutron monitor has a favorable location and good data statistics for solar neutron observations, however, only one enhancement of June 15, 1991 has been attributed to primary solar neutrons during 1976-1998 years. This work presents our search for other possible solar neutron events in the Alma-Ata NM data. The catalog of major x-ray events registered by the GOES satellites and the available information on the hard x-ray and gamma solar emission obtained aboard the SMM and CGRO satellites were used in this search. For each event from the catalog we calculated an expected response of the Alma-Ata neutron monitor to the flux of solar neutrons like observed on June 3, 1982. Possible candidates were chosen by comparing expectations with real NM count rate. Some particular candidates and the statistics of NM count rate close to onset of energetic solar events are discussed.

## 1 Introduction:

The observation at the Earth of solar protons and neutrons, generated during powerful solar flares (in combination with X-ray and gamma-ray data) allows us to obtain unique information on the Sun's flare process and particle acceleration mechanisms. The first solar neutrons were observed near the Earth by the Gamma Ray Spectrometer on the Solar Maximum Mission (SMM) on June 21, 1980 (Chupp et al., 1982). The first simultaneous measurements of solar neutrons by space and ground based detectors were made during the prominent event on June 3, 1982 (Chupp et al., 1987; Debrunner et al., 1983). Solar neutron measurements provide more direct information about the source of acceleration, than proton and electron observations do, and may provide the crucial information to test the models of particle acceleration. For instance, solar neutron observations gave the decisive argument for multi-step acceleration mechanisms during the solar flare event on June 4, 1991 (Struminsky, Matsuoka and Takahashi, 1994). The identification of the solar neutron enhancement in NM data among other cosmic ray variations is a complex problem. Solar neutrons propagate straightly in the interplanetary space and are closely associated with solar gamma and x-ray radiation, so using some additional information we may try to identify the onset of ground-level neutron event.

The detection of solar neutrons is mostly probable near local noon at mid- and low-latitude mountain neutron monitors. There are only a few such cosmic ray stations in the world network (about 10), and high mountain (3340 m) neutron monitor at Alma-Ata (Institute of Ionosphere, MN-ANRK) is among them. It is the only station with such capability to detect solar neutrons in this longitudinal region. The combination of its geomagnetic cutoff rigidity (6.7 GV), altitude (3340 m) and high statistical accuracy (18NM-64) makes this station enable to record solar neutrons of the energy order of 300 MeV. However, only one enhancement registered on June 15, 1991 has been attributed to primary solar neutrons up to now (Usoskin et al., 1995). Belov et al. (1987) studied variations of high-altitude Alma-Ata and Lomnicky Stit NMs around onsets of x-ray events in order to find their response to solar neutrons. This work presents our search for other possible solar neutron events in the Alma-Ata NM data obtained during the period of 1976-1998 years.

## 2 Data and Method:

NM registers solar neutrons, if their intensity is sufficient at the Earth orbit and the NM looks in the right direction. We created two catalogues of events when the Alma-Ata NM might observe solar neutrons. The first is based on the GOES satellite data and accounts 776 events over the period of 1974-1999 when all flares >M1 importance and all proton flares followed by optical flare >2 class and/or with >1 hour duration. The second uses data of hard x-ray and gamma-ray solar emission obtained by the BATSE detector aboard the CGRO satellite (1991-1999) with magnitude >1000imp/s and accounts 341 events might be effective for detecting at Alma-Ata.

A complex database was created on the basis of these catalogues and corresponding data from the Alma-Ata neutron monitor. A special computer program was elaborated to work with this database. It allows sorting data by date, magnitude of expected or observed effect, amplitude of solar X-ray or gamma-ray event and so on. The program calculates possible response of the Alma-Ata neutron monitor (the parameter  $N_p$ ) in percents above background to the neutron flux of the prominent neutron event of June,3 1982, i.e. what should be observed if a flux of solar neutrons near the Earth would be like on June 3, 1982. Choosing, as a threshold, the response  $N_p$  equal to 0.03, more than 750 events in CR intensity mostly favorable for observation in Alma-Ata were selected. Therefore, we assume that the flux of solar neutrons can be about 100 times greater than that observed on June3, 1982. Analyzing variations of real NM count rate and comparing them with expectations we may select possible neutron enhancements among other cosmic ray effects of magnetosphere, interplanetary and solar origin. As additional information we used in our analysis data of other NM's, observations of hard x-ray and gamma-ray solar emission aboard the SMM and CGRO satellites.

## 3 Results and Discussion:

The considered effects, in general, are not clear and large; however, it looks very interesting and promising in some cases. To our opinion the most probable candidates for registration of solar neutrons are: 79.07.24 (Year.Month.Day) 07:59 (UT – onset of the x-ray event) ; 80.04.07 05:18 (UT); 82.08.09 06:37; 89.09.04 06:25; 04:37; 89.09.14 06:59; 89.10.02 08:41; 90.09.17 07:50; 91.06.01 04:00; 91.06.06 07:05; 91.06.12 07:00 91.06.15 06:33; 91.06.17 08:09; 91.07.11 08:35; 91.07.14 08:27; 91.07.22 09:36; 91.08.05 05:24; 91.10.27 05:36; 98.05.08 05:53.

Let us discuss some particular events from the list. Figures 1 and 2 present their time profiles.

**98.05.08.** The effect observed on May 8, 1998 is very interesting from many points of view. Counting rate increase occurred on Alma-Ata NM at the moment coinciding with the x-ray flare onset (05:53 UT) . It had not great amplitude (~1.5%) and was detected only due to the high statistics (~1200 imp/s) and good time resolution (1 min data) of the Alma-Ata neutron monitor. This event appears to be originated from the same active region that had produced on May, 2 the small and very anisotropic GLE. On May, 8 this region was on the western limb. At the moment of X-ray flare a significant brightening in UV and radio emission (the Nobeyama observatory) was observed on

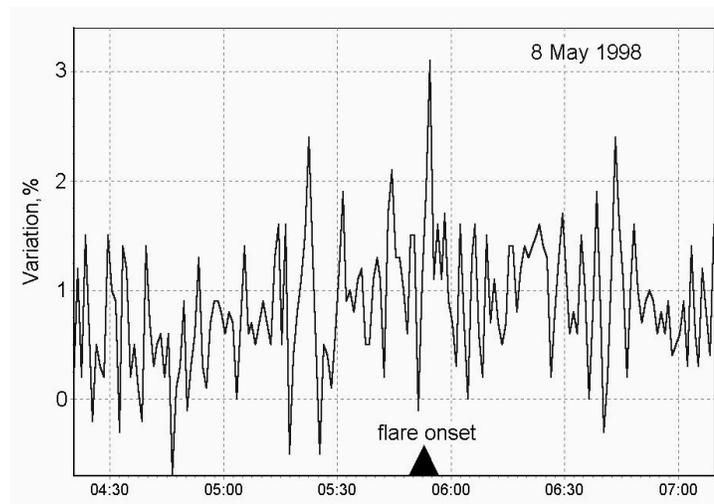
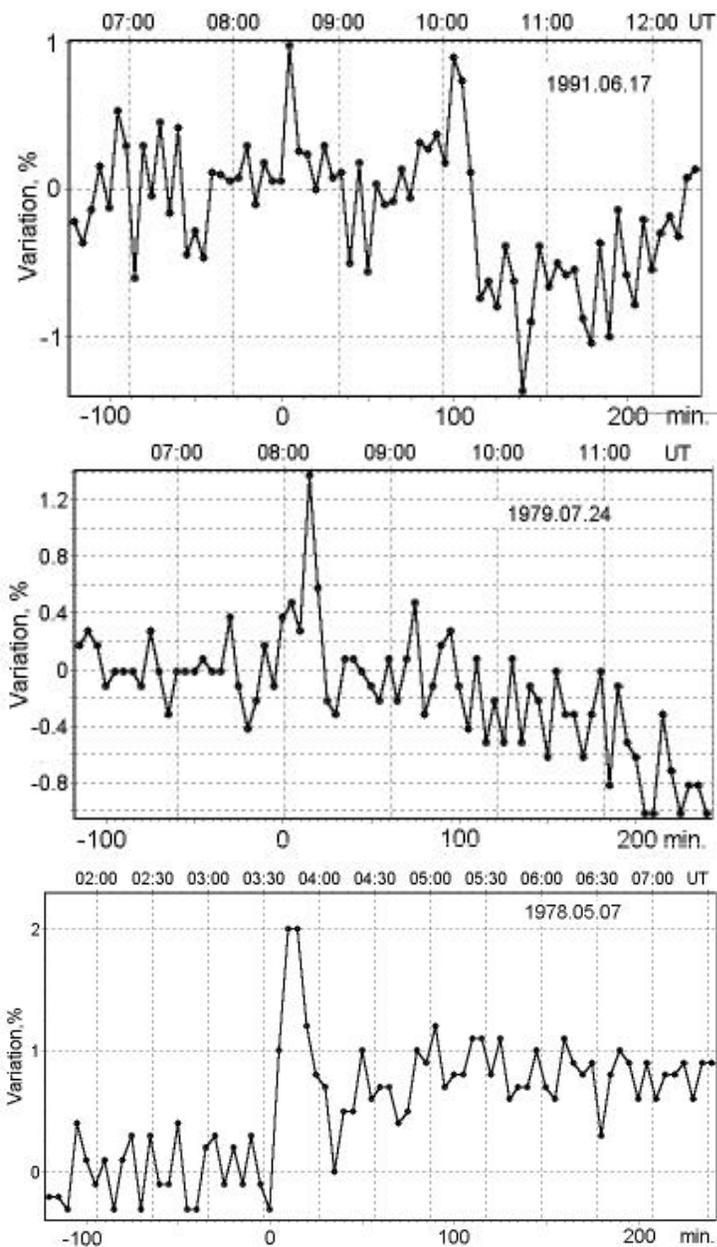


Figure 1: Variations of the Alma-Ata NM 1-min count rate.



**Figure 2:** Variations of the Alma-Ata NM 5-min count rate. Zero time on the bottom corresponds to the onset of solar x-ray event.

than 1 % contains 286 events. Data of all events within of each data set were centered on the x-ray onset of parent solar event and then were averaged. Results obtained for both groups are similar, but the effect is better pronounced for the second group (Fig. 3). Corridor around the main curve corresponds to two standard statistical errors. One can see the clear enhancement close to the x-ray event onset, although its magnitude is not large about 0.07%. It is interesting and gives some reasons for speculations that maximums of averaged variations are observed at the x-ray onset and about 30 minutes later. However, we should mention that GLEs and small Forbush effects were not removed from the data used to plot this

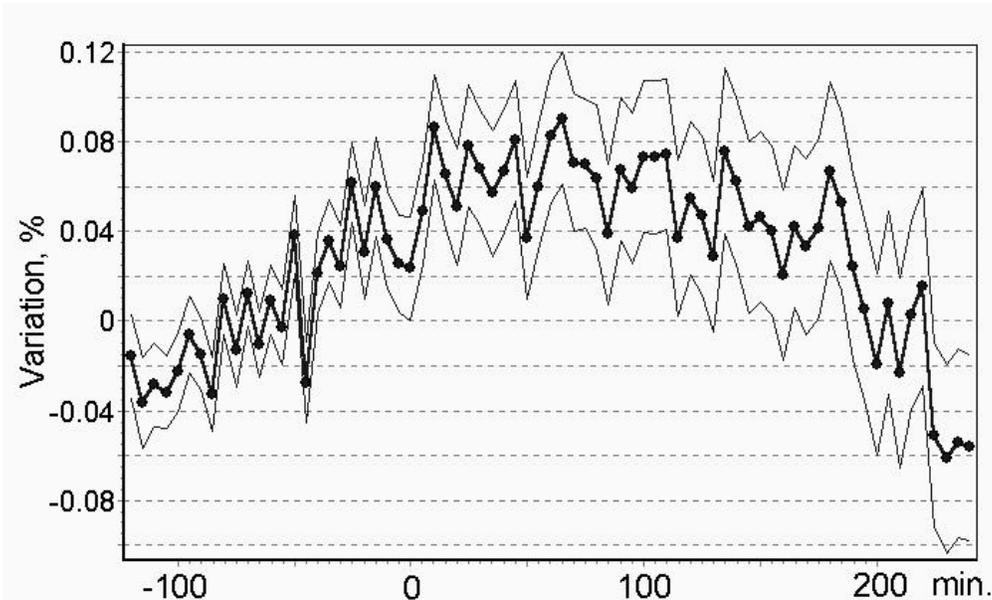
the western limb. At the same time BATSE recorded a long-duration gamma-event with complex time profile. This set of measurements shows that the great solar energetic event has occurred on the Sun, but only its top has been observed in X-rays.

**91.06.17.** Here we see two effects. First increase in the time of solar flare onset (8:27 UT) is possible solar neutron effect and second increase followed by decrease is shock wave effect (SSC was in 10: UT ) and beginning of Forbush-decrease.

**79.07.24.** Another example of possible neutron enhancement, which amplitude is much more than statistical variations, is the event on July 7, 1979.

**78.05.07.** We show as an example of the event caused by solar protons but not neutrons the relatively large enhancement observed on May 7, 1978. The Np parameter for this event was small and GLE 31, occurred at that time, was recorded by the NM network. Although it was not big (about 2%), but in 5-minute data both isotropic and anisotropic stages are pronounced very clearly.

**Mean effect.** Our database allows calculating an average enhancement for any data set. We did the preliminary statistical analysis by the epoch lay on method. Data without instrument variations and well-pronounced trends (more than 2%) were used. We applied this method for two data sets: one contains all events from the list (739), another group with expected effect more



**Figure 3:** Mean variation of the Alma-Ata neutron monitor count rate for different sets of possible neutron events, details see in the text. Zero time on the bottom corresponds to onset of x-ray events.

picture and 5-minute data of the 89-91 years were not corrected for pressure variations, although it can not change the result significantly.

#### 4 Conclusion:

We analyzed data of the Alma-Ata NM obtained during 1976-98 years, one of the best instrument for ground based observations of solar neutron events. Unfortunately no one powerful solar event with large x-ray and gamma-emission was favorable for solar neutron detection by the Alma-Ata NM during the considered period. We did not find any new large enhancement might be attributed to solar neutrons. However, we found several small enhancements with amplitude greater than statistical variations just in time for neutron observations in Alma-Ata, so solar neutrons might cause them. The expected effect for other high altitude NMs is much less in these cases. The statistical analysis by the epoch lay on method was applied to different sets of Alma-Ata NM data centered around the x-ray onset and provided another evidence for solar neutron arrival, small variation maximums appear close to the x-ray onset and about 30 minutes later. Therefore, an observation of direct solar neutrons by neutron monitors is still very rare event, any new solar neutron ground level enhancement would be a great luck.

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