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Identification of Solar Cosmic Ray Ground Level Enhancements at the Middle Latitudes

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Abstract: Ground Level Enhancements registered by means of neutron monitors were investigated using Student's criterion. Two events on November, 6th, 1997 and 24 August 1998 were analyzed. It is shown that using of Student's criterion allows to reveal effectively Ground Level Enhancements at the middle latitudes.

During powerful solar flares on the Sun relativistic protons - particles with energy > 1 GeV can be generated. They reach the Earth and are registered by means of ground detectors - neutron monitors and muon telescopes, therefore events in which these particles are observed, have been named ground level enhancements of solar cosmic rays (GLE - Ground Level Enhancements).

The registration of GLE is seldom enough: during 64 years (from the moment of registration of the first event on February, 28th, 1942) 69 events have been registered. For all period of the investigation of such events by means of high altitude Alma-Ata neutron monitor the maximal amplitude of effect was observed in event on September, 29th, 1989 - 151 %. Amplitudes of the majority of events are about 1-4 % for middle latitude Alma-Ata neutron monitor (latitude 43.1º) [1].

There is a question of detection of solar cosmic rays flux on a background of galactic particles. For unification of the approach to detection GLE for each event uniform base hour is entered.

The maximal effects on amplitude are observed by means of high-latitude neutron monitors. By means of middle-latitude monitors as well as the high-altitude station Alma-Ata, it is possible to find out these enhancements visually not always, but only during powerful events. Alma-Ata high mountain neutron monitor is located nearby of Alma-Ata city (3340 m above sea level, geomagnetic rigidity R_c = 6,7 GV).

With the purpose of detection GLE by means of high mountain neutron monitor Alma-Ata, we had been lead the statistical analysis of cosmic ray intensity. For everyone GLE, found out at any stations of a world network of neutron monitors, we investigated a ten-hour time interval, registered by means of Alma-Ata neutron monitor. The beginning of base hour of data GLE was accepted to the beginning of a time interval.

For everyone GLE average value of intensity of the particles registered by means of the monitor within base hour was defined

$$\mathcal{J}(t_{base}) = \frac{1}{n} \cdot \sum_{k=1}^{n} J_k(t_{base}), \qquad (1a)$$

Also average values of intensity of particles for each hourly interval of time outside of base hour were defined

$$\mathcal{J}(t) = \frac{1}{n} \cdot \sum_{k=1}^{n} J_k(t). \qquad (1b)$$

Here n - number of steps of registration on a hourly interval of time; $J_k(t_{base})$ - the quantity of particles registered by means of neutron monitor on that step of registration inside of base hour; $J_k(t)$ - the quantity of particles registered by means of neutron monitor on that *k*-th step of registration inside of an interval of time (t; $t + \Delta t$), where Δt=1 hour.

At each value t average value of intensity $\mathcal{J}(t)$ was compared to average value of intensity $\mathcal{J}(t_{base})$ by means of Student's criterion

$$K_S(t) = \frac{\mathcal{J}(t) - \mathcal{J}(t_{base})}{\sqrt{\tilde{D}(t) + \tilde{D}(t_{base})}}. \quad (2)$$

Estimations of dispersions for averages intensities $\mathcal{J}(t)$ also $\mathcal{J}(t)$ were defined, accordingly, under formulas

$$\tilde{D}(t) = \frac{1}{(n-1)\cdot n} \cdot \sum_{k=1}^{n} (J_k(t) - \mathcal{J}(t))^2, \quad (3a)$$

$$\tilde{D}(t_{base}) = \frac{1}{(n-1)\cdot n} \cdot \sum_{k=1}^{n} (J_k(t_{base}) - \mathcal{J}(t_{base}))^2. \quad (3b)$$

Student's criterion is a random variable which submits to Student's law with N=2·n - 2 degrees of freedom and is described by density of distribution

$$f(K_S) = B_N \cdot \left(1 + \frac{K_S^2}{N}\right)^{-\frac{N+1}{2}},$$

where B_N - a normalizing multiplier which depends only on number of degrees of freedom N.

Cosmic ray intensity were registered during 1978-1990 by means of neutron monitor Alma-Ata B with five-minute time interval, and during 1991-2005 - with one-minute interval. On a hourly interval of time (t; t+Δt) it is necessary n=12 five-minute and n=60 one-minute interval of registration. Therefore at use of data with five-minute interval of registration it is necessary to take Student's distribution with N=22 degrees of freedom, and for data with one-minute step of registration to take Student distribution with N=118 degrees of freedom.

Let's assume: 1) within base hour only galactic cosmic rays are registered; 2) in any interval of time considered after base hour (t; t+Δt) intensity of galactic particles which are registered by means of the monitor, remains the same, as well as at base time interval. Then size $K_s(t)$ serves as confidential border, which allows to calculate probability $P(t)$ that in an interval of time (t; t+Δt) the intensity of particles of solar cosmic rays, in the form of surplus above a background of particles of a galactic origin under the formula is found out

$$P(t) = \int_{-\infty}^{K_s(t)} f(x)\cdot dx.$$

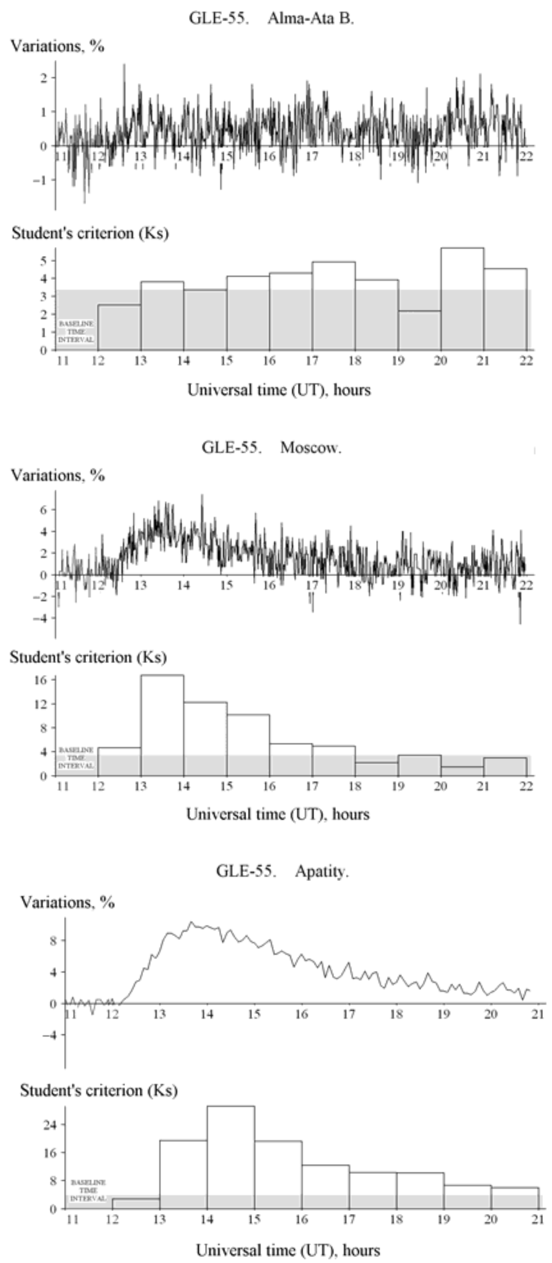

Figure 1:

In Figure 1 cosmic ray intensity registered on November, 6th, 1997 by means of neutron monitors Alma-Ata B (latitude 43.1°), Moscow (latitude 55.5°) and Apatity (latitude 67.5°) are shown. In the same place the behavior of Student's criterion $K_s(t)$, showing excess of average intensity of particles on hourly intervals after base hour above average intensity within base hour is shown.

In Figure 1 we can see that on the time interval reaching after base hour registered on the neutron monitor Alma-Ata B, "visually" GLE it is not found out. Student criterion $K_s(t)$ finds out on seven intervals surplus of an intensity of particles above an intensity at base hour. Statistically validated surplus exceeds a level 0.9995. It means that the probability of random occurrence of surplus on each of these intervals is less than 0.05 %. Probability of random occurrence of surplus on seven intervals simultaneously it will be essential less.

Cosmic ray intensity on November, 6th, 1997 during GLE-55 is well visible by means of neutron monitor Moscow. Student's criterion $K_s(t)$ reaches great values equal 10 and above. It is visible, that dependence $K_s(t)$ from time approximately reflects the form of a curve of a trend time of some and shows, that duration GLE was not less than 6 hours.

Cosmic ray intensity during GLE-55 by means of Apatity neutron monitor has proved essentially more strongly, than by means of Moscow neutron monitor. Student's criterion $K_s(t)$ reaches values exceeding 20, i.e. Moscow reveals GLE on a time number of this monitor with security of much greater, than on the monitor. Dependence $K_s(t)$, from time reflects the form of a trend time of some and shows, that duration GLE was not less than 8 hours.

On Figure 2 the cosmic ray intensity registered by means of Alma-Ata, Moscow and Apatity monitors during time since the base hour chosen for GLE-58 on 24 August 1998 are shown. These intensity are interesting to that GLE-58 has visually proved by means of Alma-Ata neutron monitor stronger, than by mans of Moscow and Apatity monitors. The same has shown Student's criterion. Student's criterion for Alma-Ata monitor data is equal to 10, for Moscow monitor data the value of criterion is equal to 5, and for Apatity monitor is equal to 6. Thus, the strongest GLE-58 has been registered by means Alma-Ata neutron monitor. GLE-58 has proved essentially more weakly on Moscow and Apatity neutron monitor data.

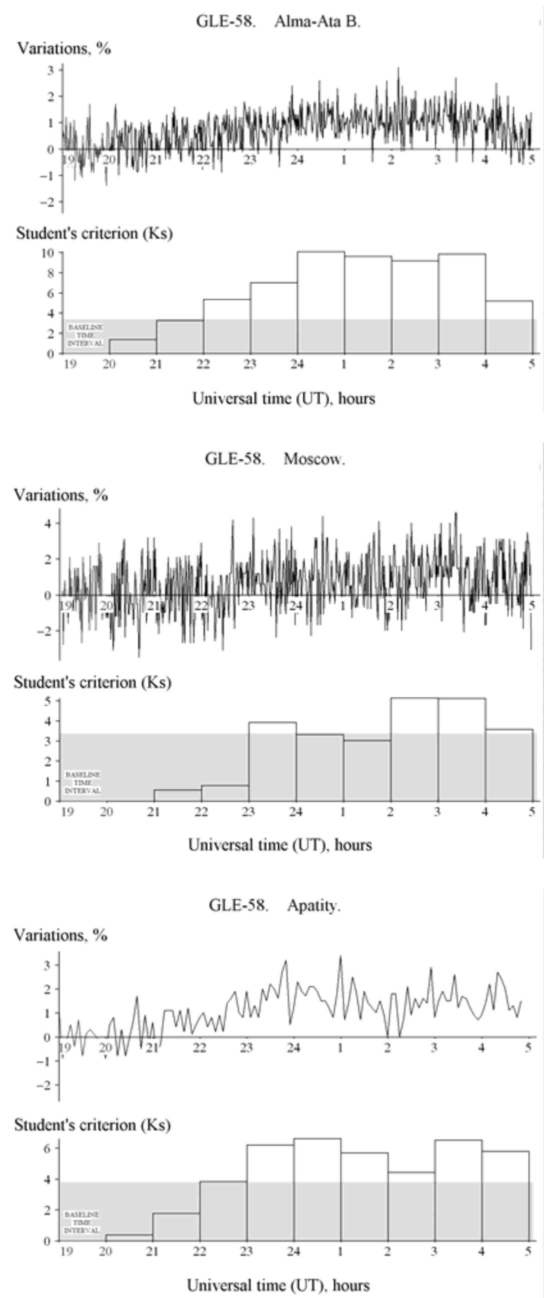

Figure 2:

Conclusion

This work allows righting the following conclusions.
1. Alma-Ata high altitude cosmic ray station is one of the most suitable station for investigation Ground Level Enhancements.
2. Using of Student's criterion allows to reveal effectively Ground Level Enhancements at the middle latitudes.

References

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