First results on the spatiotemporal correlations of the remote Extensive Air Shower pairs

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Abstract The GELATICA experiment in Georgia (GEorgian Large-area Angle and TIme Coincidence Array) is devoted both to the Cosmic Ray (CR) energy spectrum investigation at very high energies and possible correlations in the arrival times and directions of separate Extensive Air Showers (EAS) over large distances. The timing distributions between the consecutive EAS events observed at the remote installations in the towns of Tbilisi and Telavi are considered. The expectation time for a consecutive pair of remote random EAS events at these two installations is estimated under the condition of their timing separation being less then a tolerable propagation time of shower front between the observation points.

There exists the special problem of investigation of High Energy CR by means of spatially separated detector systems timed by the Global Positioning System (GPS). Particularly, there exist some interactions of primary CR in near or deep space with interstellar and interplanetary matter that possibly would produce several particles or even a jet of particles propagating towards the Earth [1]. These particles could produce a set of detectable EAS within a short time interval, and besides separated by large distances. These effects are very rare, but during last years the problems of the type are widely researching. The projects for this purpose are running in North America and Europe [2] and in Japan [3]. Project named GELATICA (GEorgian Large-area Angle and TIme Coincidence Array) is devoted, inter alia, to creation and development of the network of tiny CR stations over the area of Georgia [4].

The task of investigation of spatiotemporal correlations of EAS events needs a simultaneous detection of time and detection of the EAS front arrival. That is why the CR stations of GELATICA system are constructed as EAS goniometers. The goniometer is an installation consisting of a detector system, registering the times of EAS particles passages through detectors. This information allows estimation of the EAS arrival direction by means of the relative delays of the signals mentioned. The UTC (Universal Time Coordinated) moment of EAS arrival is registered simultaneously by the GPS unit, allowing to investigate space-time correlations of EAS with energies > 10¹⁵ eV.

The GELATICA project has an educational component, so all prospected stations have to be allocated in sites of high schools and universities over Georgia [4]. It is during last four years that first two CR stations of the GELATICA network are operating in Andronikashvili Institute of Physics (Tbilisi State University) (“TBS”) and Gogebashvili University in Telavi (“TEL”). Some basic facts concerning properties of both installations have been published earlier [5]. Every installation in our case consists of only 4 detectors due to the standard equipment used [6]. That is why any direction estimations are forcibly constrained by the flat EAS front approximation. The flat goniometers (i.e. with all detectors in common plane; the goniometers of that sort possess some essential fault [7]) are used by the same reason. Main properties of both installations are shown in table 1.
Table 1. Some common parameters of CR stations in Tbilisi and Telavi.

|                         | TBS               | TEL               | Temporal Resolutions of the equipment used: |
|-------------------------|-------------------|-------------------|-------------------------------------------|
| Northern latitude       | 41.720500°(59)    | 41.910190°(64)    | TR of GPS device = 1 μs                   |
| Easterly longitude     | 44.743882°(7)     | 45.467853°(56)    | TR of detectors = 1.25 ns                 |
| Altitude                | 489 (4) m         | 820 (15) m        |                                           |
| Station spacing         | 0.5719°(1) ~ 63.633 (2) km | ~ 212.36 (1) μs |                                           |

The TBS installation is disposed in the roof space of second building of Andronikashvili Institute of Physics. The overlying concrete layer is relatively thin and the rate of events’ registration (table 2) is comparatively high: (13.4 ± 0.06) EAS/h. Detectors are placed symmetrically in the corners of square with the side of 10m length. This special arrangement results in the directions’ distributions observed – the average EAS direction only slightly differs in a sense from zenith direction (i.e. δθz = 0.45° ± 0.07°), though the deviation is statistically significant.

The values of standard deviations of zenith (θ) and azimuth (φ) angles of EAS arrival directions have been estimated for every event registered. They depend on the zenith angle [7, 8] value as

$$\sigma_\theta(\theta) = \sigma_\theta / \cos(\theta)$$

$$\sigma_\phi(\theta) = \sigma_\theta / \sin(\theta)$$

Here $\sigma_\theta = 3.261° ± 0.002°$ is the average value of the characteristic standard deviation of EAS direction estimation by TBS goniometer.

The TEL goniometer has been disposed in Telavi on the ground floor of rather heavy construction. Respective rate of events’ registration (table 2) has proved to be (2.06 ± 0.03) EAS/h. Detectors have been disposed in the corners of rectangle with sides dimensions 2.7 m × 5.2 m approximately. The overall disposition of detectors is oblong, consequent to the room form. The average position of all directions recorded is reliably distinguishable with the zenith direction: $\delta \theta_z = 14.4° ± 0.4°$. This shift can be explained by the asymmetric location of installation – absorbing material depth is strongly dependent on direction. That is why this installation is under reconstruction at present. It will be displaced into the roof space of the same building. More symmetric disposition of EAS arrival direction is expected as well as an essential growth of events’ rate.

Table 2. Parameters of distributions of temporal interval durations between the consequent EAS events detected by TBS and TEL installations independently.

|                         | TBS               | TEL               |
|-------------------------|-------------------|-------------------|
| Intervals number        | 56418             | 3686              |
| Events’ rate, 1 / hr    | 13.40 ± 0.06      | 2.09 ± 0.04       |
| Histograms’ number of degrees of freedom | 20                | 12                |
| Estimated $\chi^2$      | 20.0              | 15.3              |
| Confidence level        | 45.8%             | 22.6%             |

The UTC time markers of every EAS arrival moments, got by the GPS units, have been used for investigation of distributions of temporal interval durations between the consequent shower events detected by both installations. These plain distributions have to be of the exponential type for independent EAS events. It is evident from the table 2 that the sets of temporal intervals observed are in good agreement with regular statistical hypothesis of exponential type of distribution.

The UTC time markers precision of 1 μs (table 1) makes it possible to investigate the distribution of temporal cross-intervals between the consequent EAS observations by different installations, i.e. the intervals between the events observed by different installations, which is void for both ones. In this case the temporal intervals are derived from data observed in the periods of simultaneous exposition of both installations. There are temporal intervals histograms for both separate installations (from the time markers sets of simultaneous exposition periods) shown on figure 1, as well as the histogram of temporal cross-intervals from the same sets.
Figure 1. The histograms of temporal interval durations between the consequent EAS events detected in the course of 703 hr of simultaneous exposition.

a) observed by TBS and TEL installations independently
b) the histogram of cross-interval durations TBS × TEL.

The distributions of temporal interval durations have appeared to be of exponential type for both installations with high confidence level. It has appeared that the cross-interval durations distribution belongs to the same type. Moreover, as is evident from table 3, the last distribution with high confidence level is an exponential one with average rate equal to the sum of individual rates of the remote installations. This feature testifies to the mutual independence of EAS fluxes observed by both installations.

Table 3. Parameters of distributions of temporal interval durations between the consequent EAS events detected by TBS and TEL installations during the concurrent exposition of installation.

|                      | TBS only | TEL only | TBS × TEL$^a$ |
|----------------------|----------|----------|---------------|
| Intervals number     | 8582     | 1506     | 2652          |
| Intervals’ rate, 1 / hr | $13.11 \pm 0.14$ | $2.34 \pm 0.06$ | $15.45 \pm 0.16$ |
| Histograms’ number of degrees of freedom | 40       | 19       | 24            |
| Estimated $\chi^2$   | 40.5     | 24.8     | 28.8          |
| Confidence level     | 44.7%    | 16.6%    | 22.7%         |

$^a$ The rate of cross-interval events have been evaluated as the sum of the corresponding TBS and TEL rates.

The cross-interval average rate mentioned above reaches the value of 15.5 per hour. Therefore, to find at least one occasional crisscross pair of independent EAS events by the installations under discussion, with the corresponding cross-interval duration less than the time of light propagation between there positions (i.e. approximately 212 μs, see table 1), it would be expected to achieve the necessary duration of common exposition transcending the 90 000 hr term.

Thus, so close temporal agreement of two EAS observations by goniometers in Tbilisi and Telavi, if only it would occur, has to be considered as highly unusual event for being treated with the utmost thoroughness. For instance, it would become necessary to compare the measured directions of both EAS events to verify for possible common origin of the primary cosmic ray particles originating both showers.
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