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Distribution of EAS arrival times according to data of the EAS 1000 prototype array

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Abstract. We have analysed arrival times of extensive air showers (EAS) registered with the EAS–1000 prototype array during the period from August 1997 till February 1999. Our analysis has revealed that though the vast majority of samples of consecutive time intervals between EAS arrival times obey the exponential distribution, there are sequences of showers that have another distribution and thus violate the homogeneity hypothesis. The search for correlation between such events and clusters of showers and events with big delays between arrival times was also carried out.

1 Introduction

Distribution of arrival times of extensive air showers (EAS) has been studied by methods of classical statistics by different research groups (see, e.g., Chikawa et al. (1991) and Tsuji et al. (1993)). In this paper, we present some of the results of a similar investigation performed with the experimental data obtained with the EAS–1000 prototype array. This installation operates at the Institute of Nuclear Physics of Moscow State University (Fomin et al., 1999).

The EAS–1000 prototype array consists of eight detector units (DU) placed in the central part of the EAS MSU array and covers the area of 67×22 m. The array is designed for registration of extensive air showers produced by cosmic rays with energy more than 10^{14} eV.

When an EAS arrives, the corresponding signals from DU are transmitted to a PC for the preliminary program analysis of information quality and for EAS event verification. The shower selection criterion is the triggering of any four adjacent detectors in the course of time gate less than 3.2 ns.

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2 Analysis of experimental data

203 days of twenty-four hour regular operation during the period from August 1997 to February 1999 were selected for the analysis. The total number of showers in this data set is about 1.7×10^6. The average time interval between successive showers is 10.5 s. The discreteness of EAS arrival times is about 0.055 s (one tic of computer clock).

The first step of verification of the hypothesis that a certain data sample obeys some definite distribution law is a test of homogeneity of the given sample (see, e.g., Bendat and Piersol (1986)). There are numerous non-parametric criteria of homogeneity hypothesis. To begin, we have chosen the series criterion, which is based on the analysis of the number of groups (series) of successive time intervals in the sample under consideration that have lengths greater than the median value and less than median value (Bol'shev and Smirnov, 1983; Bendat and Piersol, 1986).

Using this criterion, we have verified a hypothesis about homogeneity of data grouped into samples of 100, 200, 500, and 1000 showers, into samples of 24 hour duration, into samples of all continuous intervals of the array running (duration from 2 to 21 days) and a sample formed for the total data set. The analysis was performed in two ways: with the barometric effect taken into account, and without considering this effect (see Fomin et al. (1999) for the details). The homogeneity hypothesis was checked for confidence levels equal to 0.1, 0.05, 0.02, and 0.01.

It was found that among samples of 100 and 200 showers there exist several samples for which the homogeneity assumption cannot be accepted even for the smallest confidence level. It is interesting to mention that we have found certain groups of days (e.g., in May 1998) such that the number of non-homogeneous samples grows at the beginning of the period and then decreases. We did not manage to reveal any methodical reasons of this behavior. Moreover, we have not found any correlation between non-homogeneous data samples and EAS clusters; no correlation has also been revealed between non-homogeneous samples and sequences
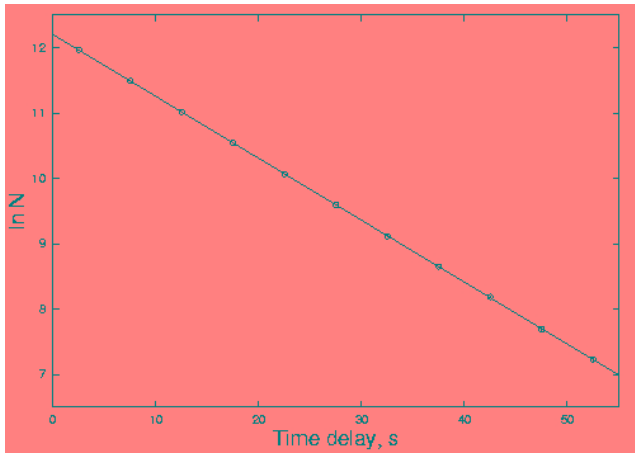
Fig. 1. Distribution of time delays between 416998 showers (see the text); N is the number of delays within a 5-seconds bin.

of showers with large delays (more that 1.5 min) (see Fomin et al., (2001a)). This allows us to conjecture that this effect reflects some astrophysical phenomena.

Next, it was found out that the homogeneity assumption cannot be accepted (with the confidence level 0.01) for certain samples of 3 and more days of regular observation and also for the sample constructed of total data. In particular, the series number for the total data set is equal to 829841, while the upper and low boundaries of series number that allow one to accept the homogeneity hypothesis with the given confidence level are 832580 and 835910 respectively. But if we study the same data sample taking into account the barometric effect, then we may accept the homogeneity assumption with the confidence level equal to 0.05.

For homogeneous samples, we have studied whether intervals between successive arrival times obey the exponential distribution. This was performed by means of the χ^2–test. We have studied separately time intervals with lengths ≤ 30, 40, 50, 60, 90, and 120 s. Data samples were grouped into bins of lengths 1, 2, 5, and 10 s. It was found that for all homogeneous data sets there exists a time scale (as a rule, $\leq$ 90 s) such that the hypothesis under consideration may be accepted at least at the confidence level 0.005. In particular, we have analysed a set of EAS obtained during 51 days of the array running for which the average atmospheric pressure was within 740–745 mm Hg, and daily variation did not exceed 10 mm. It was obtained that this sample (416998 showers) agrees with the homogeneity assumption at the confidence level 0.05, and the distribution of time intervals that are not longer than 55 s is exponential with the confidence level 0.9 (see Fig. 1).

In addition, we have studied EAS arrival times by methods of cluster analysis. This investigation has revealed that there are definite sequences of EAS that can be identified as clusters. The results will be reported in details elsewhere (Fomin et al., 2001a). We have also applied certain methods of non-linear time series analysis to the data sets that contain clusters. It was found out that the time series under consideration

demonstrate chaotic dynamics (Fomin et al., 2001b). Finally, we have begun to study a more complete set of experimental data, which covers the period up to November 1999 and contains 3.5×10^6 EAS.

3 Conclusion

It should be noted that our results do not contradict the conclusions of other research groups (Chikawa et al., 1991; Tsuji et al., 1993). However, it is necessary to increase shower statistics and to use other non-parametric methods of hypothesis verification since different criteria may give different results for the homogeneity assumption test (Bendat and Piersol, 1986).

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