High Energy Physics and Nuclear Physics

Volume 18, Number 3

Meteorological Effects on the Trigger Rate of Air Showers Observed with the Tibet Air Shower Array

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A possibility of monitoring a few TeV cosmic ray flux with China-Japan joint Tibet Air Shower Array is discussed. The meteorological effects are examined using the data obtained with this array, and a correction of these effects on the data is discussed.

Key words: Air shower array, TeV cosmic rays, trigger rate, meteorological effect.

1. INTRODUCTION

The monitoring of cosmic ray flux, with neutron monitor and μ detector, in the energy region from GeV to few tens GeV becomes a routine work in space physics and geophysics. It also plays an important role in the study on the production, acceleration and propagation of cosmic rays, on solar physics and atmospheric physics. Since the 1950s, the variations of cosmic ray flux caused by the meteorological effects, i.e., the variations of the barometric pressure, temperature and moisture of the atmosphere as well as the interferences between them, have been studied quantitatively. The measurement of cosmic ray flux with neutron monitors and μ detectors should be corrected with the meteorological effects, especially, the correction with the barometric pressure effect is an essential

Received on May 22, 1993. Supported by the National Natural Science Foundation of China and Chinese Academy of Sciences, Grants-in-Aid for Scientific Research of Japan and International Scientific Research from the Ministry of Education, Science and Culture of Japan.

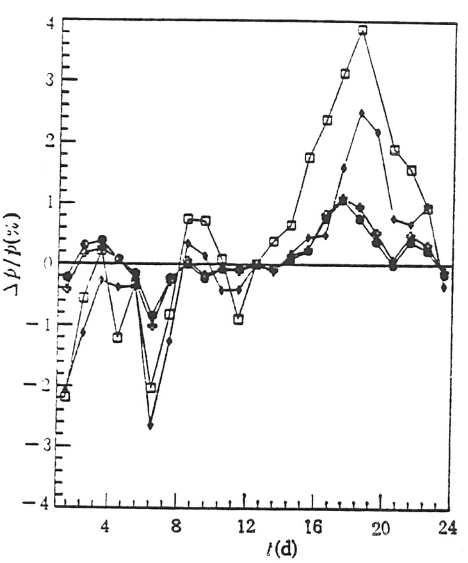

Fig. 1

A typical example of variation of barometric pressure at various depth in the atmosphere, observed at Lhasa Meteorological Observatory in March 1991 (with balloons). The dots, crosses, diamonds and squares show the corresponding changes of barometric pressures on 658 mbar, 600 mbar, 300 mbar and 100 mbar isobaric surfaces, respectively.

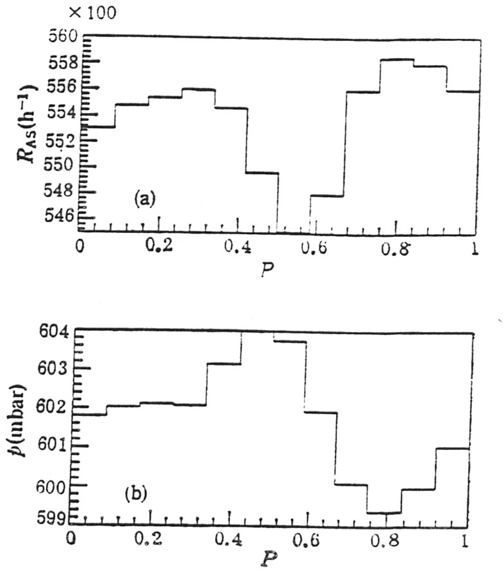

Fig. 2

The periodic variation with a period of 0.998 day of the EAS trigger rate (a) and the barometric pressure detected on the surface (b). The horizontal axes are the relative phase.

step. Since the 1970s, the techniques of the observation of air showers induced by energetic cosmic rays have been developed to meet the requirements of studying ultra-high energy interaction of cosmic ray particles with air nuclei and searching for the extreme high energy (10^{18}-10^{20} eV) cosmic ray particles. After 1983, all air shower arrays are improved to rise their angular resolutions and are adapted to search for the possible ultra-high energy γ point sources. The China-Japan joint EAS array in Tibet is originally designed to search for 10 TeV gamma-ray sources. Due to its quite high altitude, low threshold energy and the application of advanced fast electronics for the data acquisition, the EAS event trigger rate of this array is so high that the statistical fluctuation of the recorded EAS event number in unit time interval is small enough (e.g., smaller than 0.5% h^{-1}). This provides a possibility to monitor the cosmic ray flux in the TeV energy region with this EAS array. In order to do this, however, all effects which will cause the variation of EAS trigger rate should be figured out and corrected for the measured cosmic ray flux. Among the known effects, the meteorological effects are the most distinct one at lower energies. However, to monitor the cosmic ray flux at such high energies, on such a high altitude and with such a large statistical significance, it is really the first attempt in the world. The conventional method of correction of the meteorological effects in GeV region cannot be directly applied. The observation of air shower might be influenced strongly by the variation of barometric pressure at different height above the array, so that the meteorological effects might depend strongly on the position, altitude, climate, environments of laboratory, trigger conditions of the array and so on. It is meaningful to figure out the explicit expressions of the meteorological effects and corresponding correction methods for individual detector array. In this paper, we will discuss all these

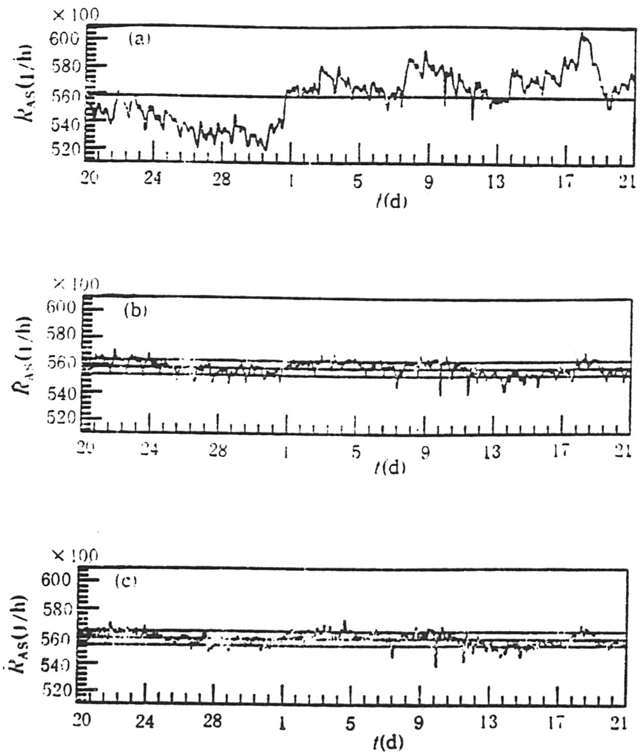

Fig. 3

The EAS trigger rate curve from 20 Jan. to 20 Feb. 1992 before correction (a), after the correction of barometric pressure and temperature (b) and after the correction with the periodic variation in Eq.(4).

questions specifically for the case of AS_γ array at Yang Ba Jing, Tibet and discuss the possibility of monitoring the cosmic ray flux in TeV region.

2. ANALYSIS

The Tibet EAS array consists of 56 scintillation counters with a lattice spacing of 15m, located at Yang Bajing (4310m a.s.l., 90°31′E, 30°06′N) in Tibet, China. The performance of the array was already described elsewhere [1,2]. The trigger condition for EAS events is set as any four-fold coincidence of the 49 FT detectors within a 300 ns time interval. The average trigger rate is about 20 Hz. The threshold energy for detected showers is estimated to be about 10 TeV for protons. A monitor for the barometric pressure, temperature indoor, temperature outdoor and moisture has been installed in September 1991, and all these data are recorded every two hours. Combining the meteorological data and the average trigger rate of EAS over the corresponding two hours, we get a effective record for the present analysis. 1286 effective records have been accumulated up to March 23, 1992. In addition, a bulk of meteorological data was obtained from Lhasa Meteorological Observatory (90°08′E, 29°41′N, 3650 m a.s.l.). One part of those data are collected on different heights with balloons at 23:30 (UT) and 11:30 (UT) every day and the others are collected on the surface at 0:00, 6:00, 12:00 and 18:00 (UT) every day. All these data are used in the present analysis.

In the energy region from GeV to few tens GeV, a complete expression of the meteorological effects of cosmic ray flux has been written [3] as following:

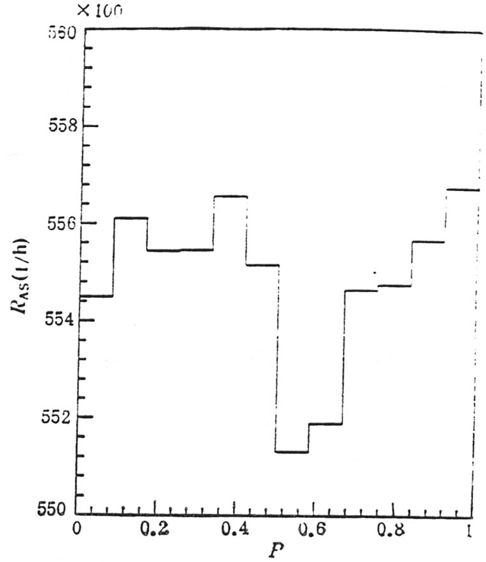

Fig. 4
The short periodic variation of corrected EAS trigger rate with the barometric pressure and temperature correction.

$$\frac{\Delta I(h)}{I(h)} = -\beta\Delta h + \int_0^h [W_T(h')\Delta T(h') + W_M(h')\Delta M(h')]dh'.$$

in which, h is the normal barometric pressure at the height where the observation is carried out; Δh, the variation of barometric pressure; $W_T(h')$ and $W_M(h')$, the densities of temperature and moisture coefficients at the isobaric surface h', respectively, which can be calculated, in principle, with the theory of the transportation of EAS particles in the atmosphere; $\Delta T(h')$ and $\Delta M(h')$, the variation of the temperature and moisture at the isobaric surface h', respectively, which can be detected by the meteorological balloon. If the temperature effect (for example, the largest effect is 0.03% for hadronic composition of cosmic rays) and moisture effect (0.001%) [4] were neglected, the cosmic ray flux would be expressed as a simple exponential function depending only on the variation of observation surface barometric pressure. In very high energy region, on the other hand, the cosmic ray flux measured with EAS array will be affected not only by the change of observation surface barometric pressure, but also by the change of pressure at different heights above the array which will affect the transverse development of the shower and then change the transverse distribution of the shower on the observing surface and finally affect the triggering efficiency of the EAS event. Obviously, this kind of effect will depend specifically on the altitude and the trigger condition of individual array. Hence, the meteorological effects of cosmic ray flux observed with EAS array cannot be described by a single meteorological variable or in an universal expression. Nevertheless, since the available data from balloon (twice daily) are not enough for the study of short periodic (typically one hour or ten minutes) behavior of cosmic ray flux, it is necessary to find our an approximate correction method, which depends on the meteorological variables detected on the observation surface and the technical parameters of the EAS array. For this purpose, we analyzed first the variations of barometric pressure at different atmospheric depths. A typical example with a strong change of barometric pressure is shown in Fig. 1. It is seen that there exists an approximate correlation between barometric pressure

Table 1
The results of the correlation analysis of EAS trigger rate and barometric pressure and temperature.

Time	N	$\sigma_{AS}(h^{-1})$	ρ	$\sigma_{cor}(h^{-1})$
91.10.12—11.19	431	930.8	0.8170	536.7
92.1.10—3.23	855	1603	0.9172	638.7
92.1.2—2.20	378	1837	0.9581	526.0

Time	$A_T(h^{-1}\cdot K^{-1})$	$B_p(h^{-2}\cdot mbar^{-2})$	$C_p(h^{-1}\cdot mbar^{-1})$	$D(h^{-1})$
91.10.12—11.19	−449.7	8.144	−414.0	−37.18
92.1.10—3.23	−234.0	2.245	−277.9	−32.56
92.1 2—2.20	−181.3	−3.627	−322.1	68.00

under different atmospheric depths and that on the observation surface, although the amplitudes of the variations are different. This correlation suggests that the dependence of the observed EAS trigger rate with the entire variation of the barometric pressure in the atmosphere can be replaced approximately by the dependence between the EAS trigger rate of the array and the variation of the barometric pressure on the observation surface. Therefore the correlation can be used for correcting the raw trigger rate of the array under some limited precision. We examined two kinds of systematic correlations between EAS trigger rate and the observation surface barometric pressure. One is on a short periodic scale, i.e., daily period, and the other on a long periodic scale, i.e., monthly. The EAS trigger rates and the barometric pressures are both folded up with a period of 0.998 day. Between the distributions of barometric pressure and of the EAS trigger rates, there exists a clear negative correlation as shown in Fig. 2. A similar negative correlation on longer periodic scale is also found.

We also found that the EAS trigger rate depends on the temperature in the electronics room, which is independent of those effects affecting the transportation of EAS particles in the atmosphere. The amplitude of a change of EAS trigger rate caused by unit temperature change (per degree centigrade) is almost as same as that caused by unit barometric pressure change (per mbar). The detector array, mainly aimed to search for the ultra high energy γ source, with quite large are, has to be installed out the door. This is distinct to that the neutron monitors or the μ detectors, specifically used for monitoring the variation of cosmic ray flux in GeV region, are usually installed in air conditioning rooms. In this work, the effects mentioned above will be analyzed then be used to correct the data.

3. CORRELATION AND CORRECTION

In order to describe the dependence of the trigger rate on the barometric pressure and temperature in laboratory simultaneously, a least-squares method with two variables is used for figuring out the correlative coefficient. By this way, the error in single variable fitting caused by the integral effect over the other one can be avoided. The extrapolate function is taken as,

$$\Delta R_{AS}(T,p) = A_T\Delta T + B_p(\Delta p)^2 + C_p(\Delta p) + D \qquad (1)$$

where $\Delta R_{AS}(T,p) = R_{AS}(T,p) - \bar{R}_{AS}(T,p)$, $R_{AS}(T,p)$ is the EAS trigger rate when temperature in laboratory is T and barometric pressure is p, $\bar{R}_{AS}(T, p)$ is the average EAS trigger rate per hour during the running period; $\Delta T = T - \bar{T}$, T and $\bar{T}$ are the temperature in laboratory and its average value in degrees centigrade, respectively; $\Delta p = p - \bar{p}$, p and $\bar{p}$ are the barometric pressure on observation surface and its average value in mbar, respectively; A_T, B_p, C_p and D are the temperature coefficient (per degree centigrade per hour), second order barometric pressure coefficient (mbar^{-2} per hour), first order barometric pressure coefficient (per mbar per hour), and a constant (per hour), respectively. Define

$$\sigma_{AS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\Delta R_{AS})_i^2},$$

$$\overline{\chi^2} = \frac{1}{N}\sum_{i=1}^{N}[\Delta R_{AS_i} - R_{AS}(T_i, P_i)]^2,$$

$$\rho = \sqrt{1 - \frac{\overline{\chi^2}}{\sigma_{AS}^2}},$$

$$\sigma_{cor} = \sqrt{\overline{\chi^2}},$$

as the standard deviation of EAS trigger rate, the average χ^2 value of the fit, the correlation coefficient and the square root of the average correction error, respectively, in which N is the number of effective records. Using 1286 effective records recorded during the period from Oct. 1991 to Mar. 1992, the correlation level and corresponding coefficients in Eq.(1) are obtained and summarized in Table 1.

From these results, We conclude that the Eq.(1) can describe the correlation between EAS trigger rate, the barometric pressure and the temperature of the electronics room with the correlation coefficient from 0.82 to 0.96. Therefore, the EAS trigger rate will be corrected as

$$R_{AS}(t) = R_{AS}(T, p, t) - \Delta R_{AS}(T(t), P(t)) \tag{2}$$

and the normal fluctuation of corrected EAS trigger rates of the array should be estimated by including the correction error σ_{cor}.

As an example, the EAS trigger rate curves from 20 Jan. to 20 Feb. 1992 are shown in Fig. 3. Figure 3(a) indicates the trigger rate before correction with the line showing the average value. The largest deviation reaches to 8.7% on 18 and 19 Feb. Figure 3(b) shows the trigger rate after the correction according to Eq.(3) and the parameters listed in the last row of Table 1. The three lines in the figure give the average value of the trigger rate, and $\pm\sigma_{cor}$, respectively. It is seen that the most part of the fluctuations of corrected EAS trigger rates are less than σ_{cor} and the deviation drops to 1.3% on 18 and 19 Feb.

4. DISCUSSION

The analysis of the correlation between EAS trigger rate and barometric pressure and temperature described above as well as the correction of the EAS trigger rate with the correlation is based on a correlation coefficient larger than 0.82, this ensured the reliability of the correction. However, the behaviors of the trigger rate on both the longer and short periodic scalar seem to retain partially after the correction, seeing Figs. 3(b) and 4. Although, for the case on the short periodic scale, the period and the phase distribution changed from the original one. In face, the period seems more close to half a day and the amplitude of the fluctuation is decreased by only 60% after the correction. As mentioned in Sec. 2, the barometric pressure affects the EAS trigger rate not only by the change on the observation surface but also more strongly by the change on the different isobarometric surfaces above the array. It is clearly seen in the Fig. 1 that the relative amplitudes of the fluctuations of the barometric pressures are larger at 300 mbar and 100 mbar than that on the observation surface in a same event. Therefore, the fluctuations of corrected EAS trigger rate shown in Figs. 3(b) and 4 probably are partially the remainder effect of barometric pressure variation, because the correction is based on the variation of the barometric pressure on the observation surface. Of course, the remainder fluctuation is partially caused by other effects not considered in the current analysis, e.g., the windy effect. However, in practice, the further correction from other effects seems to be meaningless because the most fluctuations of the EAS trigger rates are smaller than the standard deviation. As an examination of this argument, we can do a further correction of EAS trigger rate with the periodic variation shown in Fig. 4. Although the mechanism of this periodic fluctuation is unknown, it can be expressed in terms of a expansion with Fourier series,

$$\Delta R_{AS}(t) = \sum_{k=1}^{N} \left[A_k \cos\left(\frac{2\pi k t}{T_p}\right) + B_k \sin\left(\frac{2\pi k}{T_p}\right)\right] \tag{3}$$

and has been used for the correction of EAS trigger rates recorded from 20 Jan. to 20 Feb. 1992. The results of Fourier analysis are as follows,

$T_p = 0.999$ day;

$A_k(k = 1,2,3,4,5,6) = 232.7, -154.7, 74.86, -32.09, -24.61, -1.800;$

$B_k(k = 1,2,3,4,5,6) = -5.349, -47.43, 65.96, -56.57, 14.51, -75.26.$

The results after the correction is shown in Fig. 3(c). Comparing with that in Fig. 3(b), one can see the EAS trigger rate curve becomes indeed more smooth, however the change is not so significant.

ACKNOWLEDGMENT

The authors thank Prof. Huo Anxiang who led a successful discussion with them.

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