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Effects of environmental factors on the LHAASO-ED array

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KM2A is a sub-array of the Large High Altitude Air Shower Observatory (LHAASO) which comprising 5195 electromagnetic detectors (EDs) and 1188 muon detectors (MDs). The array is affected by various environmental factors, such as temperature, atmospheric pressure, and precipitation, particularly for the EDs which are installed in an open-air configuration. In this study, we analyse and compare the KM2A data of the full array with meteorological records to investigate the variations in the trigger rate array. The temperature and pressure coefficients are found to be stable over a year and half. After applying temperature and atmospheric pressure corrections, sudden changes in trigger related to atmospheric electric fields during thunderstorms are examined.

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1. Introduction

As a sub-array of the Large High Altitude Air Shower Observatory (LHAASO), the 1 km^2 array (KM2A) consists of 5195 electromagnetic particle detectors (EDs) and 1188 muon detectors (MDs)[1]. EDs are scintillation detectors with effective detection areas of 1 m^2, each comprising four plastic scintillator plates with a dimension of $25 \times 100 \times 1$ cm^3, wavelength shifting (WLS) fibers, and a photomultiplier tube (PMT). These components are housed in a steel shell. ED is designed to detect electromagnetic particles in the extensive air showers (EAS) including electrons, positrons, muons and gamma rays. EDs are installed in varies terrains, such as grass land, stones, marshes and waters (Figure 1). These detectors are designed to operate in this high-altitude region for 20 years, characterized by thin air, intense ultraviolet radiation, and significant temperature variations between day and night. Environmental factors can have diverse impacts on the detectors. On one hand, the harsh environment can accelerate the aging of detector components or increase the failure rate, posing challenges to the detectors' long-term operation. On the other hand, environmental changes can alter the performance of the detectors, which should be taken into consideration in the data analysis. Some of these effects have been reported by various groups, including ARGO-YBJ[2], Pierre Auger[3], and GRAPES-3[4]. This paper will primarily focus on analyzing the influence of temperature, air pressure, and precipitation on the trigger rate of LHAASO-KM2A.

Figure 1: Photograph of one installed ED

In the current operation of KM2A, the trigger condition is set as 20 or more EDs or MDs fired in a time window of 400 ns. The trigger rate of array is defined as the total number of triggered events per second. In practical calculations, the value is typically obtained by fitting the time difference (dT) between adjacent events with an exponential function. At the altitude of 4400 m a.s.l., the electromagnetic component of the EAS secondary particles far exceeds the muon component. Therefore, the vast majority (~99%) of events are triggered by EDs, and the trigger rate of KM2A is mainly determined by EDs.

The experimental trigger rate over time exhibits a clear daily modulation[5]. Since the flux of primary cosmic rays above KM2A's energy threshold is quite stable, this modulation can only be attributed to environmental factors. Firstly, the density of the air, determined by its pressure (P) and temperature (T), affects the development of EAS, resulting in changes in the energy and quantity of secondary particles reaching the ground. Secondly, since each component of the detector has a certain temperature coefficient, variations in temperature can lead to changes in the detector's gain and noise level, causing fluctuations in the detector's single channel counting rate. The variations of the single-channel counting rates, in turn, lead to changes in the trigger rate through accidental coincidences. Finally, weather process such as precipitation and thunderstorms can also have an impact on the counting rate of the array.

2. Method

Performance data of the array and detectors analyzed in this study are taken from the daily monitoring of the ED array operation. They are extracted by the monitoring program from the decoded experimental data and are saved to a database at regular intervals automatically. Array-level monitoring includes the trigger rate, the number of running detectors, et al. Unit detector-level monitoring includes single-channel counting rate, charge MPV (most probable value), AD (anode and dynode) ratio, as well as slow control data. Meteorological data of the external environment are primarily collected and recorded by a 20-meter meteorological tower located at the southwest edge of the array. This data includes temperature, relative humidity at heights of 1m, 2m, 4m, 8m, 16m, and 20m, as well as wind speed, wind direction, atmospheric pressure, precipitation, and other parameters. Additionally, an atmospheric electric field meter has been installed at the center region of the array, near the WCDA pool, which continuously records atmospheric electric field values at a sampling rate of 0.5 s. The measurement range of the instrument is ±27 kV/m. All the data are aligned by time and downsampled by averaging in a 10 min's interval. Abnormal data is excluded before further analysis, such as data from test runs and during significant fluctuations in number of detectors. Multivariable least square regression is applied to the data. The corrected trigger rate can be written as

$$R = \overline{R} + \alpha_T \left(T - \overline{T}\right) + \alpha_P \left(P - \overline{P}\right),$$

where $\overline{R}$, $\overline{T}$, $\overline{P}$ are mean values of the trigger rate, temperature and atmospherically pressure, respectively. α_T and α_P are correlation coefficients. The coefficient of determination (R squared) is

$$\mathcal{R}^2 = 1 - \frac{\sum_{i=1}^{n} (R_i - \widehat{R}_i)}{\sum_{i=1}^{n} (R_i - \overline{R})},$$

where $\widehat{R}_i$ is the predicted value of trigger rate.

3. Results

3.1 Coefficients in short-term

One example of the results of correction is shown in Figure 2 and Figure 3. Data from January 2nd to 9th, 2021 are used. Scatter plots of trigger rate with temperature or atmospheric pressure are shown in Figure 2. It can be seen that in the case where only one of temperature or air pressure is corrected (Figure 2(a) and (b)), there is a clear correlation between the trigger rate and the other variable. However, when both temperature and air pressure are corrected, the trigger rate becomes almost independent of either variable (Figure 2(c) and (d)).

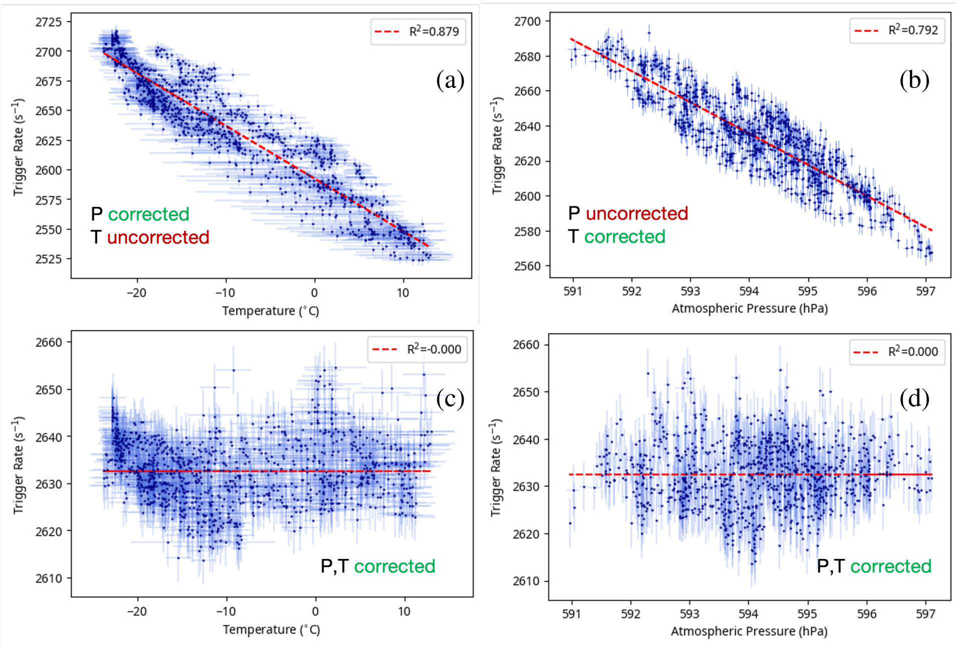

Figure 2: Correlations between trigger rate and temperature (T) (a,c) or atmospheric pressure (P) (b,d). The data are corrected with only P in (a), with only T in (b), and with P and T in (c) and (d).

In Figure 3(a) the raw trigger rate is shown in blue line and the corrected trigger rate shown in red line, using atmospheric pressure (Figure 3(d)) and temperature data recorded by the meteorological tower. In Figure 3(b) similar results are shown but using the internal temperature collected by the slow control of EDs. These two sets of temperature data are very close at most of the time, except for significant difference in the afternoons. This is because the solar radiation heats the detectors and make their internal temperature significantly higher than the outside. The number of running EDs during this period is shown in Figure 3(e), which is quite stable and has almost no impact on the trigger rate.

By comparing corrected trigger rates from Figure 3(a) and (b) one can conclude that correction using internal temperature is better than that using external temperature. This can be confirmed in Figure 4, in which the distributions of raw trigger rate, corrected with internal temperature and external temperature. Data corrected with internal temperature has a much lower standard deviation of 0.26% compared to the one corrected with external temperature (0.49%), while the raw data has a standard deviation of 1.87%. It is worth noting that the change in internal temperature lags behind the external one by about 1 h, which can also lead to difference in the fitting results.

3.2 Coefficients in long-term

The long-term variation of temperature and pressure coefficients since the whole array's operation in September 2021 are shown Figure 5(a) and (b). Each data point in the figure is obtained by fitting a week's worth of data. They are considerably stable through one and half years, with several outlier points. After comparing these curves with the precipitation amount (Figure 5(c)), it can be inferred that these anomalies may be related to precipitation. It has been known that, during rain fall or snow fall, the presence of radioactive isotopes such as radon in the air can be brought

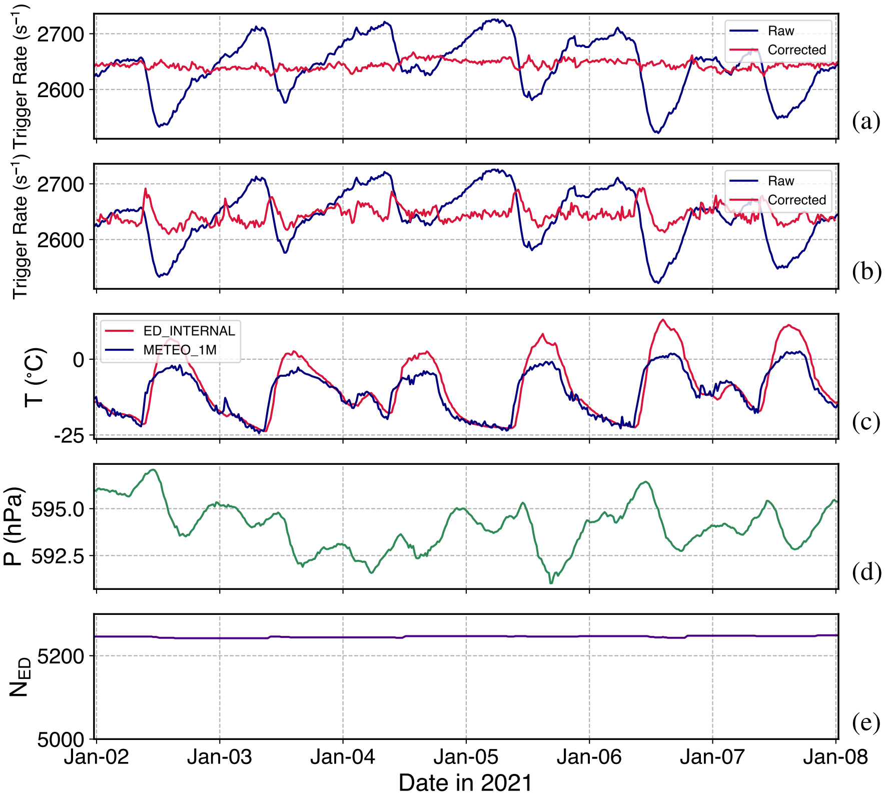

Figure 3: Example data and correction result of trigger rate. (a,b) Raw trigger rate (blue lines) and corrected trigger rates with external T and internal T (red lines), respectively. (c) comparison of external T (red line) and internal T (blue line). (d) The atmospheric pressure. (e) The number of running EDs.

down to the ground, leading to an increase in the background noise level of the detectors[6]. This has been confirmed by KM2A observation (see Figure 6(d)). Note that only single-channel rate of ED is influenced, since the main structure of an MD is buried underground.

3.3 Thunderstorms

Acting as a typical climate on the eastern Tibetan Plateau, thunderstorms at the LHAASO site are as frequent as rainfalls during the rainy season, which lasts from June to September every year. Lightning strikes occurring within the observatory have caused malfunctions in the detectors, as well as in the power or network equipment. In addition to these direct damages, we notice some other indirect effects. For example, sudden changes in the trigger rate during thunderstorm clouds gather and when ground lighting strikes occur.

One of these thunderstorm events is shown in Figure 6. The variation of electric filed during this period is shown as red lines in Figure 6(a) and (b), with trigger rate of raw events and filtered events (NfiltE>=23) in green lines, respectively. Atmospheric pressure, temperature, and amount of rain (in half an hour), are shown in Figure 6(e)-(g). A major thunder strike is recorded near 20:00 with a steep surge of electric filed. The electric filed remains saturated until it falls back to a normal level after about 20 min. The relative slow increase of the trigger rate after the thunder strike from 20:00 to 22:00 is attributed to the rain fall, and can be eliminated by a higher noise

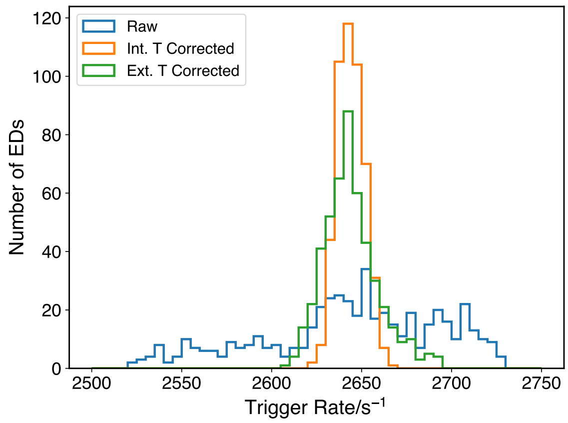

Figure 4: Standard deviations of raw and corrected trigger rate data

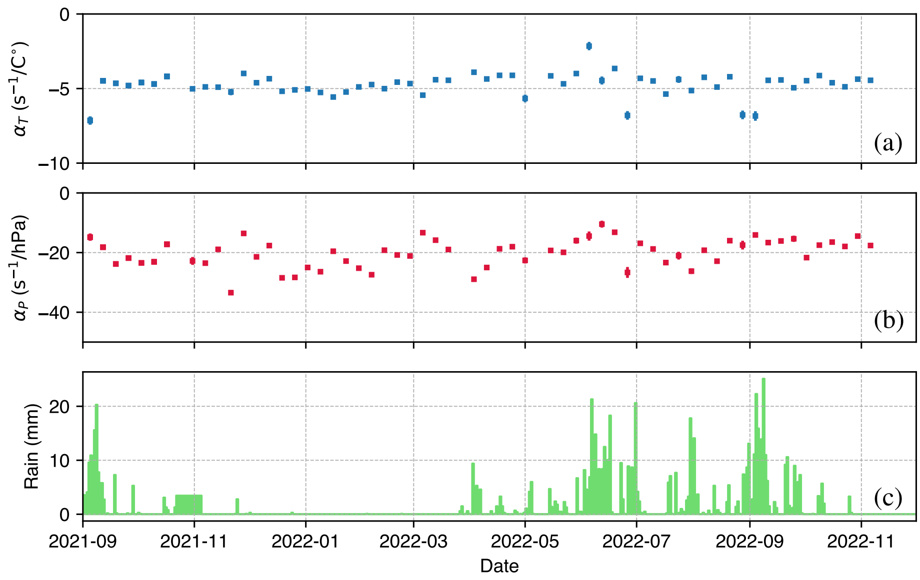

Figure 5: Long-term variation of temperature and pressure coefficients (a) Temperature coefficient (b) Pressure coefficient (c) Amount of rain

filtering threshold (Figure 6(b)). However, the decrease occurs almost at the same time with the thunder strike can only be explained by the charged particles in EAS accelerated or decelerated in strong electric fields. In other thunderstorm events, increases of the trigger rate are also observed. Recently, thunderstorm ground enhancements (TGEs) and terrestrial gamma-ray flashes (TGFs) are reported in ground based cosmic-ray experiments[7], while further examination is needed to find exact evidence of these phenomena from the experimental data of KM2A.

4. Conclusion

We examined the impact of environmental factors on the LHAASO-ED array, including temperature, air pressure, precipitation, and atmospheric electric field. The relation-ships among these

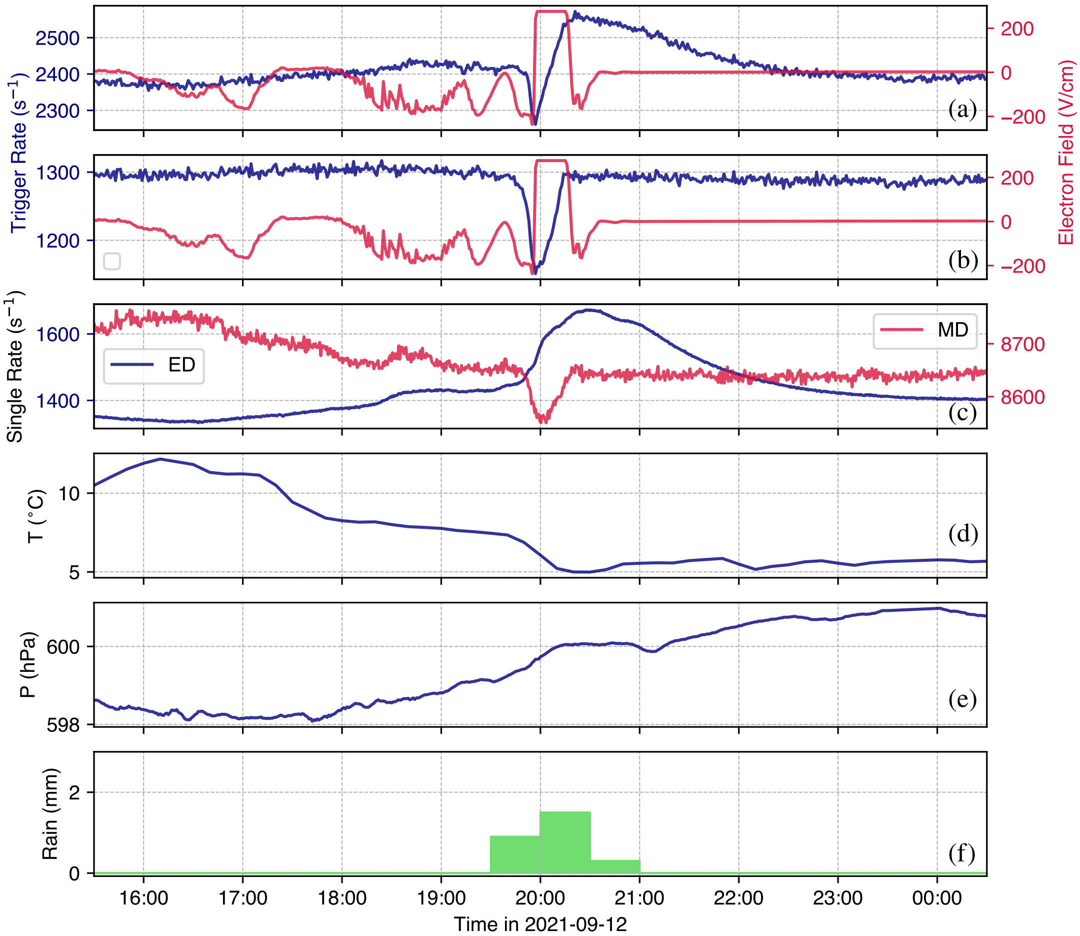

Figure 6: One of the thunderstorm events and its effect on the trigger rate. (a) Raw trigger rate (b) Filtered trigger rate of NfiltE>23 (c) Average single channel rate of MDs (d) Average single rate of EDs (e) Atmospheric pressure (f) Temperature (g) Amount of rain. In (a),(b) and (d) the electric field are shown in green lines.

factors are shown in Figure 7. Using the least squares method, the regression coefficients of the array's trigger rate between temperature and air pressure are calculated. The results show relative stability over a period of more than a year.

Compared to external air temperature, the temperature inside the detectors exhibits a stronger correlation with the trigger rate. This suggests that temperature mainly affects the trigger rate indirectly through detectors' single-channel rates by influencing the detector components. Same applies to the effect of precipitation, which increases the radioactive background within a short period. On the other hand, air pressure affects the development of EAS and thus modulates the trigger rate directly. The detailed mechanism of the atmospheric electric field on the secondary particles of EAS during thunderstorms is more complex and requires further investigation.

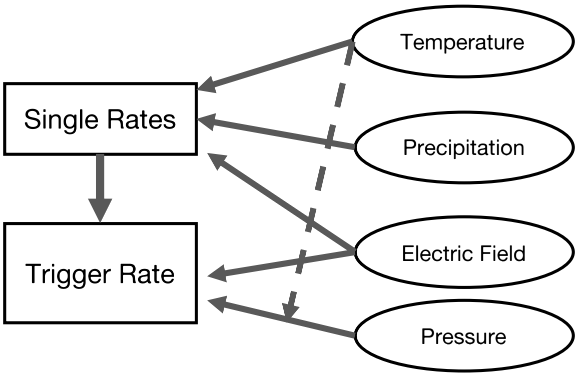

Figure 7: Chart of environmental factors and their interactions on the trigger rate

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