

Effects of the atmospheric electric field on the HAWC scaler rate.

Angel Ricardo Jara Jimenez*

Universidad Veracruzana, México.

E-mail: rt_jaja@outlook.com

Alejandro Lara

Instituto de Geofísica-UNAM, México

The Catholic University of America, Washington DC, USA.

E-mail: alara@igeofisica.unam.mx

Arun Babu Kollamparambil Paul

Instituto de Geofísica-UNAM, México.

E-mail: arun@igeofisica.unam.mx

James Ryan

University of New Hampshire, USA.

E-mail: jimunhryan@me.com

for the HAWC collaboration[†]

Strong electric fields in thunderclouds have long been known to accelerate secondary charged particles. We investigate this effect using three years (2015-2017) of data from the scalar system of the High Altitude Water Cherenkov (HAWC) observatory, which is an air shower array deployed 4100 m a.s.l. in central Mexico. The experimental site is frequently affected by strong thunderstorms, and the detector's high altitude, large area, and high sensitivity to cosmic-ray air showers make it ideal for investigating particle acceleration due to the electric fields present inside the thunder storm clouds. In particular, the scaler system of HAWC records the output of each one of the 1200 PMTs as well as the 2, 3, and 4-fold multiplicities (logic AND in a time window of 30 ns) of each water Cherenkov detectors (WCD) with a sampling rate of 40 Hz. Using data from this scaler system, we identify approximately 100 increases in the scaler rate which is in time coincidence with thunderstorms. These events show high cross correlation between the scaler rate and the electric field, hence can be produced by the acceleration of secondary particle by the thunderstorm electric fields. In this work we present the method of identification of these events and their general characteristics.

36th International Cosmic Ray Conference -ICRC2019-

July 24th - August 1st, 2019

Madison, WI, U.S.A.

*Speaker.

[†]for collaboration list see PoS(ICRC2019)1177

1. Introduction

It is well known that strong electric field generates large enough forces on electrons to overcome the drag forces and also can remove secondary electrons from these atoms, these are the so called run-away electrons. ([1], [2]). A secondary electron, produced by cosmic-rays or radioactive decay (the seed particle) with enough energy (hundreds of keV) accelerated by a strong electric field may be able to produce at least one run-away electron in the range of tens to hundreds keV, which in turn can create additional run-away electrons, producing an avalanche multiplication. In this way, each energetic seed electron injected into a high electric field region will result in a large number of relativistic run-away electrons. This mechanism is known as Relativistic Runaway Electron Avalanche (RREA). The flux of relativistic run-away electrons experiences a deceleration due to the interaction with atoms and ions, producing high energy photons by bremsstrahlung emission, ([3], [4]).

These events have been detected by satellite gamma ray detectors and are known as terrestrial gamma ray flashes, ([6]). At ground level , high altitude cosmic ray detectors have reported ground enhancements during thunderstorm, ([7], [5],[8]). The HAWC observatory has also report this kind of enhancements, [9]. We report on a new method to find increases in the count rate in HAWC dataset, and select those that are due to cloud electric fields by finding the correlation with the electric field intensity. We show the results corresponding to the years of 2015-2017.

2. HAWC scaler system

The High Altitude Water Cherenkov (HAWC) observatory is located on a relatively flat piece of land near the saddle region between the Sierra Negra and Pico de Orizaba, with latitude $18^{\circ}59'41''$ N, longitude $97^{\circ}18'30.6''$ W and altitude at 4100 m above sea level. HAWC consist of 300 water Cherenkov detectors (WCD), each of them are of 7.3 m in diameter and 5.0 m in depth. They are spread over an area of $20,000 m^2$. Each of these WCDs is filled with filtered water and instrumented with 4 photomultiplier tubes (PMTs) a 10 inch PMT at the center of the WCD at positions 'C' and three 8-inch PMTs being arranged around the central one, C, making an equilateral triangle of side 3.2 m at positions A, B and D.

HAWC has two different kinds of Data Acquisition System(DAQ).The main DAQ measures arrival times and time over thresholds of PMT pulses. It also has a TDC scaler system which counts the hits within a time window of 30 ns of each PMT and the coincidences of 2, 3 and 4 in each water Cherenkov detector. These coincidences are called multiplicity 2, 3 and 4, respectively. The secondary DAQ consists of a counting system that registers each time the PMT is hit by 1/4 photoelectron charge and it is called hardware (HW) scaler system. The secondary DAQ is sensitive to gamma-rays, cosmic-rays, solar activity and transitive events that increase or decrease the count of rates.

The response of each PMT is sent to a control room where is digitized by time to digital converters (TDC) so it can be read by a computer ([11], [10], [13]).

3. Data Selection

3.1 HAWC Data

The time period covered by this work corresponds to 2015-2017 and the data recording has a time cadence of one minute to improve the statistical accuracy of the measurements. In our study, we analyze the information of each multiplicity (2,3 and 4) of the 300 detectors. The electric field data used for the study was measured in kV/m and have in general a resolution of 1 minute. During the three years there are some exceptions that will be explained in section 3.2.2

The data selection was made using three-step algorithm that we call filters. This filters only select the data that fulfill the specified requirements. To have a better and clear idea of how the study was made, we will use as example a event where the electric field was not saturated and was observed by the two scaler systems, the event of 2015 May 26. In Fig. 1 the data for multiplicity 2 are shown.

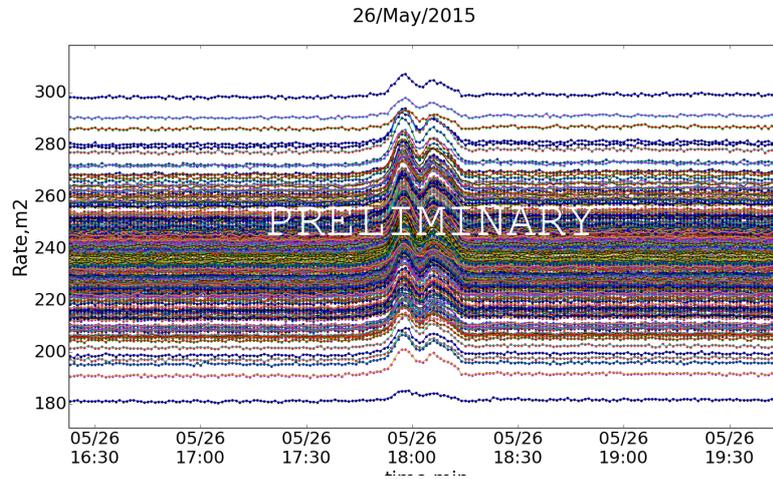


Figure 1: 26/May/2015, multiplicity 2, each curve correspond to a detector.

3.2 First Filter

As mention above and shown in the example (Fig. 1) each detector have his own average rate, so the first step was to obtain a standard average value for all the detectors. The standard average value was obtained by doing a selfnormalization of each detector i with a mean p_i . The normalized values, $nv_{i,t}$, were calculated as:

$$nv_{i,t} = \frac{Sd_{i,t}}{p_i}, \quad (3.1)$$

where $Sd_{i,t}$ is the original value of the data at time t corresponding to detector i . Fig. 2 shows what happens after selfnormalization.

Once the selfnormalization is done, the standard average value will be approximately 1, as seen in Fig. 2. This will then be used to calculate a threshold which is then used to define the increments. With the standard deviation for each minute t , σ_t , the threshold is calculated according to Eq. 3.2. For an increment to be deemed an event $nv_{i,t} > th_i$ must be true for at least 5 continuous minutes

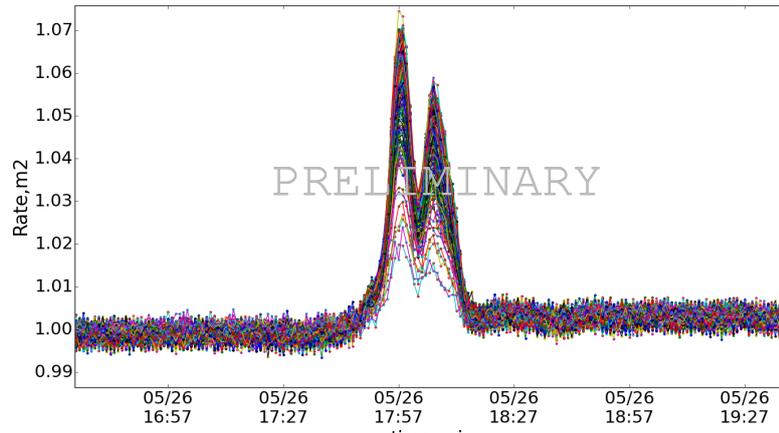


Figure 2: Example of the dataset, each color line represent a detector. The dataset correspond to the count of rate in multiplicity 2 for 2015 May 26. The y-axis shows the count rate as a function of time.

and registered in at least 30 detectors. These conditions were chosen so as to not select electronic malfunctions of a PMT. In Fig. 3 is graphic representation of the count rate and the threshold. In this filter 202 events were found.

$$th_i = 1 + 5\sigma_i. \quad (3.2)$$

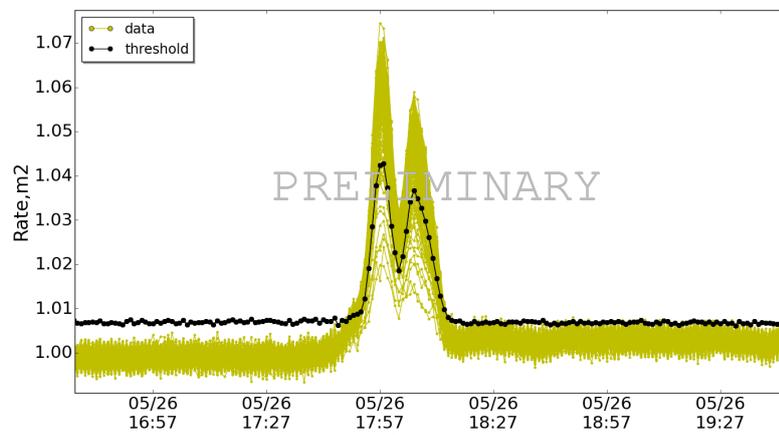


Figure 3: 2015 May 26, multiplicity 2 data(yellow) and threshold(black)

3.2.1 Second filter

The duration of a thunderstorm cell is around 30 to 60 minutes [12]. For that reason we choose the increments with a significant duration ($5 < t < 120$ minutes). The intervals longer than 2 hours are more likely to be due solar or atmospheric modulation, no the objective of this study. Only 100 intervals have the specified duration.

3.2.2 Third filter

The electric field detector, Boltek EFM-100, was installed on 2015 May, so the intervals before that date have not corresponding electric field data. There are also gaps because the detector could stop functioning from a nearby electric discharge or maintenance. Thus, in the 100 events only 79 had corresponding electric field data.

4. Analysis

For the subsequent steps in the analysis of the 79 events, we again use the event of 2015 May 26 as an example.

4.1 Pressure correction

A pressure correction was made to the selected events. In the method proposed by K.P. Arun Babu, the data are transformed as percentages, with the pressure data and the pressure coefficients for each multiplicity. Then the data are smoothed by using a moving central average with a window of 5 minutes, finally a linear transformation is made by setting the minimum value of the data equal to zero.

4.2 Crosscorrelation

The electric field dependence of the 79 selected events was investigated first by comparing the count rate of the detectors and the corresponding electric field data, as in Fig. 4. Subsequent analysis is carried out using the average rate of all the detectors, Fig. 6a. The crosscorrelation is

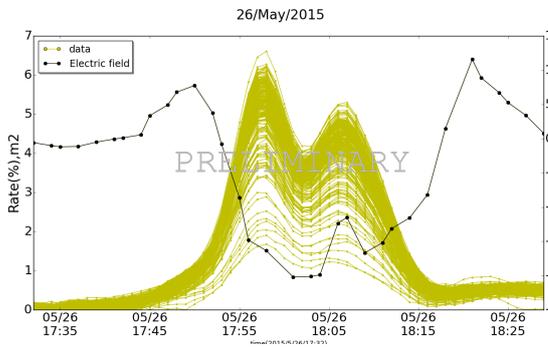


Figure 4: 26/May/2015, Comparison of the data with the electric field data.

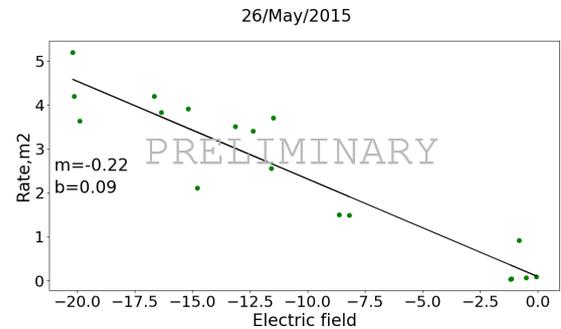


Figure 5: 26/May/2015, Linear fitting.

calculated by time shifting the electric field data by -15 to 15 minutes. The best shift for the electric field was obtained by calculating the crosscorrelation coefficient for each possible shift. In Fig. 6c we see correlation of the rates with the electric field for different offsets. In Fig. 6b we can see the comparison between the average data and the shifted electric field. Finally the dependency of the electric field on the measure rate was estimated by using a linear fit only considering the negative values of the electric field, as in Fig. 5. We can fit the dependency of the electric field on the measure rate with a linear fit, where, in Eq. 4.1, R is the scaler rate and E , electric field intensity.

$$R(E) = -0.22E + 0.09 \quad (4.1)$$

PRELIMINARY

26/May/2015

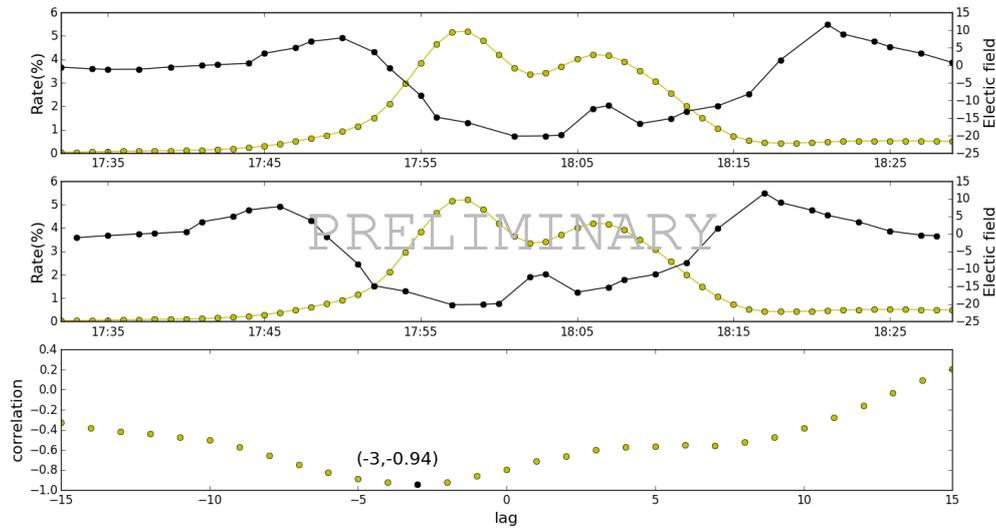


Figure 6: Up to down ,a)Comparison of the average rate with the electric field intensity.b) Comparison of the average rate with the shifted electric field. c)Cross correlation coefficient as a function of time lag.

5. Discussion

In this work , we propose a new method to identify intervals in the HAWC scaler data affected by atmospheric electricity activity. Of the 79 events (Tables. 1a,1b and 1b), we see in Fig. 7 that the majority of events show a strong dependence of the electric field intensity. These results are evidence for the idea that particle acceleration due to the electric field of clouds is producing an enhancements of the scaler rate of HAWC. After correcting for barometric pressure variations we see in Fig. 7 that the majority of the events are inversely correlated with the electric field intensity. This implies that the enhancement in the scalar rates occurs almost concurrently with the decay in the electric field intensity.

If particle acceleration is occurring, it will possible to apply this method to other HAWC data to find more enhancements in all three multiplicities. From this, it will be possible to calculate the energy of the incidents particles initiating the runaway. By considering this possibility we have shown the great utility of HAWC in the study of the mechanisms of particle acceleration by the atmospheric electricity.

Further analysis is necessary accompanied by simulations of the spatial and temporal response of HAWC. This will allow us to quantify the magnitude of the effect and the underlying physics. We will also perform an inverse analysis to verify the method, in this case the decay in the electric field intensity will be determined first, from which we search for the corresponding enhancements in the rates.

2015			2016		
May,26	Jun,30b	Sept,18	Jan,05,a	Jun,01	Jul,30
May,30	Jul,09,10	Sept,25,a	Jan,05,b	Jun,05	Aug,02
Jun,20	Jul,20,21	Sept,25,b	Mar,03	Jun,08	Aug,09,a
Jun,21	Aug,07	Oct,28	Mar,04	Jun,17	Aug,09,b
Jun,23	Aug,12,a	Nov,02,a	Apr,20	Jun,17,18	Aug,19
Jun,30a	Aug,12,b	Nov,02,b	May,19	Jun,20	Aug,20
	Aug,30		May,24	Jun,27	Sept,12
			May,27,a	Jun,30	Sept,17
			May,27,b	Jul,01	Sept,24
			May,27,28	Jul,08	Sept,29
			May,28,a	Jul,12	Oct,01
			May,28,b	Jul,14	Oct,16

(a) 2015

(b) 2016

2017		
Mar,16	Jun,17	Aug,10
Apr,07	Jun,28	Aug,11
Apr,08	Jun,28	Aug,15
Apr,19	Jul,01	Sept,14
May,04	Jul,16,a	Oct,10
May,13	Jul,16,b	Oct,11,a
May,19,20	Aug,03	Oct,11,b
Jun,07	Aug,09	Oct,11,c

(c) 2017

Table 1: Tables with the dates of the events

Frequency of the correlation coefficients

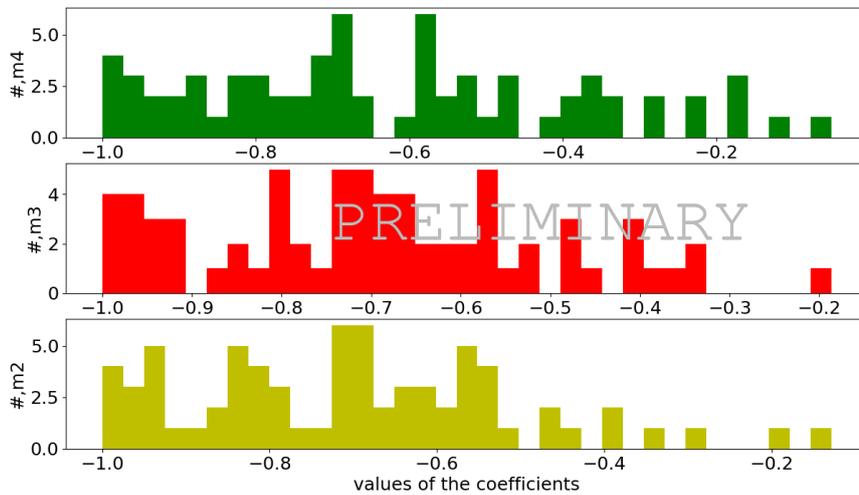


Figure 7: Histogram showing the frequency of the correlation coefficients.

6. Acknowledgements

We acknowledge the support from: the US National Science Foundation (NSF); the US Department of Energy Office of High-Energy Physics; the Laboratory Directed Research and Development (LDRD) program of Los Alamos National Laboratory; Consejo Nacional de Ciencia

y Tecnología (CONACyT), México (grants 271051, 232656, 260378, 179588, 254964, 258865, 243290, 132197) (CÁtedras 873, 1563, 341), Laboratorio Nacional HAWC de rayos gamma; L'OREAL Fellowship for Women in Science 2014; Red HAWC, México; DGAPA-UNAM (grants AG100317, IN111315, IN111716-3, IA102715, IN111419, IA102019, IN112218), VIEP-BUAP; PIFI 2012, 2013, PROFOCIE 2014, 2015; the University of Wisconsin Alumni Research Foundation; the Institute of Geophysics, Planetary Physics, and Signatures at Los Alamos National Laboratory; Polish Science Centre grant DEC-2014/13/B/ST9/945, DEC-2017/27/B/ST9/02272; Coordinación de la Investigación Científica de la Universidad Michoacana; Royal Society - Newton Advanced Fellowship 180385. Thanks to Scott Delay, Luciano Díaz and Eduardo Murrieta for technical support.

References

- [1] C T R Wilson, *The electric field of a thundercloud and some of its effects*, in proceedings of *The Physical Society of London*,1924.
- [2] Coleman, L. M. and Dwyer, J. R., *Propagation speed of runaway electron avalanches*, *Geophysical Research Letters*,[2006].
- [3] Dwyer, Joseph and M. Smith, David and Cummer, Steven,*High-Energy Atmospheric Physics: Terrestrial Gamma-Ray Flashes and Related Phenomena*,*Space Science Reviews*,[2012].
- [4] Gurevich, A.V. and Milikh, G.M. and Roussel-Dupre, Robert *Runaway electron mechanism of air breakdown and preconditioning during a thunderstorm* *Physics Letters A*,[1992].
- [5] Shaw, Glenn E.,*Background cosmic count increase associated with thunderstorms*,*Journal of Geophysical Research*,[1997].
- [6] G. J. Fishman et al.,*Discovery of Intense Gamma-Ray Flashes of Atmospheric Origin*,*Science*,[1994].
- [7] Chilingarian, Ashot, *Thunderstorm Ground Enhancements (TGEs) - New High-Energy Phenomenon Originated in the Terrestrial Atmosphere*,*Journal of Physics Conference Series*,[2013].
- [8] Chilingarian, A. et al., *Ground-based observations of thunderstorm-correlated fluxes of high-energy electrons, gamma rays, and neutrons* *Phys. Rev. D*,[2010].
- [9] Lara, Alejandro and Raga, Graciela and Enríquez-Rivera for the HAWC collaboration, Olivia *HAWC response to atmospheric electricity activity*, in proceedings of *35th International Cosmic Ray Conference*,arXiv:1711.04202 [astro-ph.IM].
- [10] A.U. Abeysekara et al.,*On the sensitivity of the HAWC observatory to gamma-ray bursts*, *Astroparticle Physics*,[2012].
- [11] A.U. Abeysekara et al.,*Data acquisition architecture and online processing system for the HAWC gamma-ray observatory*, *Nuclear Instruments and Methods in Physics Research A*,[2018].
- [12] R. P. Feynman and R.B. Leighton and M. Sands,*The Feynman Lectures on Physics, Mainly Electromagnetism and Matter*, Addison-Wesley, 1963.
- [13] Ayala Solares,et al. of the HAWC Collaboration,*The Calibration System of the HAWC Gamma-Ray Observatory*,in proceedings of *The 34th International Cosmic Ray Conference*,[2016].