PROCEEDINGS OF SCIENCE

Atmospheric Electric Field Effect on the Count Rate of Charged Particles Detected at Chacaltaya Mountain

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From the moment of their formation all particles produced by a primary cosmic ray are influenced by atmospheric conditions, such as pressure, temperature, air density, and others. Atmospheric Electric Field (AEF) is one of these factors. There is evidence of a considerable increase of the counting rate of particles during electrical storms. In the present work at the Chacaltaya Cosmic Rays Physics Laboratory (5220 m a.s.l.), the existent relation between AEF and secondary particles produced by primary cosmic rays under two different weather conditions is searched, during fair weather days and disturbed weather days.

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1. Introduction

All of particles produced by a primary cosmic ray have three components: hadronic, electromagnetic and muonic; this set of particles are embedded inside a series of meteorological conditions, such as electric field modulation [1], pressure and temperature [2] among others. These effects are present from the moment of the formation of the particles but not all them will be affected in the same way.

The idea of a possible influence on charged particles by the Atmospheric Electric Field (AEF) during electrical storms, being these particles electrons at first, was considered for the first time during the 1920's [3]; in the next decades there were many attempts to find out an acceleration of charged particles before and/or during electrical storms, but the acquired results were contradictory and not clear. In 1985 Aleexenko et al. [4] were the first to make a detailed inspection between measurements of AEF and variations of the count counting rate of cosmic rays, finding correlations of short duration (around 8 to 16 minutes) showing an increase of 0.2 to 0.3 %; later works like the one by Aglietta et al. [5], Brunetti et al. [6], and Vernetto et al. [8], among many others, showed that the AEF influences muons with charge as much as electrons, besides of showing an increase of X- and γ radiation. Vernetto reports an increase of the counting rate in the Extensive Air Shower (EAS) from 10 to 15% in a period from 10 to 20 minutes. Alexeenko et al. [4] also report an increase of up to 20% before an electrical discharge.

The generation of AEF is produced by the potential difference between the Earth and the electrosphere, and there are also other atmospheric influences like electric charged clouds that are able to produce strong electric fields. The classic model of the charge distribution inside clouds can have even three charge centers: the first one located at the top of the cloud, with a charge of +40 *coulombs*, around of 10 to 12 *Km* from the Earth's surface, a second concentration with -40 *coulombs*, located around of 5 to 7 *Km* from the Earth's surface too, and the last charge concentration, not that important, which is not always present, with +3 *coulombs*, located at the bottom of the cloud, around 2 *Km* above. These are only reference values, and they will depend of the type of the cloud, its development, topology of land, and so on.

The particles inside a AEF are accelerated by the Runaway Breakdown mechanism suggested by Gurevich [7]; this mechanism allows the particles accelerated inside a AEF to endure an increase of their energy and can produce new particles due to the collisions with atmospheric molecules so that they can generate more electrons able to exponentially produce new electrons and so on until the energy is not enough to continue with the process.

This work's goal is to research the influence of the AEF on the counting rate of secondary particles generated from cosmic rays detected at the Laboratorio de Física Cósmica de Chacaltaya (5230 m a.s.l.) on plastic scintillators, during two different climate settings: fair weather days and disturbed weather days, during a period of three months.

2. Particle detectors at Chacaltaya

There are several experimental array layouts at the Laboratorio de Física Cósmica de Chacaltaya in order to detect secondary particles, which, like anywhere else, are affected by atmospheric factors. The counting rates are always corrected by pressure and temperature because there are the necessary devices to make these measurements. Variations of the counting rate during electric storms are continually observed; some of them are reported by Huaygua et al. [11]; they arranged offhand several devices to measure electric discharges in the atmosphere. It was not until September, 2008, that this laboratory began to record measurements of the AEF with a device designed for this aim, and for the first time, in Chacaltaya, we accomplished a study of the variations on charged counting rate accompanied by AEF measurements.

3. Data and methodology

The two detectors used for this work are installed at the Laboratorio de Física Cósmica de Chacaltaya. The first one is a sensor of atmospheric electric field, *Boltek EFM - 100*, response time of 0.1 seconds, resolution digital output of 0.01 kV/m and electric field measurement range from -20 kV/m to +20 kV/m. In order to reduce the sensitivity of the sensor it is possible to plug a sensitivity device. In the preliminary tests we found high values of AEF, and then we reduced the sensitivity of the sensor up to 25% of the original value.

The second one is a plastic scintillator with an area of 0.25 m^2 and a thickness of 0.1 m. As we know, the scintillators only detect charged particles, mainly electrons and muons, hence it results suitable for our goal.

3.1 Data selection

The data used for this work were recorded from September to November, 2008; first of all, we select and separate the daily records of the AEF with a soft modulation and low intensity; next we choose daily records in which the intensity of the AEF shows sudden disturbance and saturation on the sensor. The first case is called *fair weather days* because they feature a sky with low or absent cloudiness which is corroborated by satellite imagery obtained at [9]. The second group is called *disturbed weather days* because they feature electrical disturbances in the atmosphere due to the presence of electrical charged clouds, rainfall, lighting, etc. The first group has 14 cases and the second one has 24 cases.

3.2 Methodology

3.2.1 Fair weather days

The data obtained by both detectors are registered each second and in total we have 86400 values per day for each detector. The figures 1 (a) and (c) show that record for the scintillator and the AEF respectively (data recorded on October 06). In the case of the scintillator (1(a)) we only see a bar, without modulation, however, if we take the average of the values over a minute we can reduce the number of the values to 1440; next we smooth the curve with a moving average and now we see a modulation. The figure 1(b) shows the result of this process, where the black curve is the smoothing of the averaged record. An identical process is performed for the AEF counting rate; the figure 1(d) shows the result for this case.

Once we obtain the smooth curves of both records for the 14 cases, we graph an average plotting for both modulations (2). We see that both modulations begin at the same time approximately, between 7 and 8 in the morning, local time.

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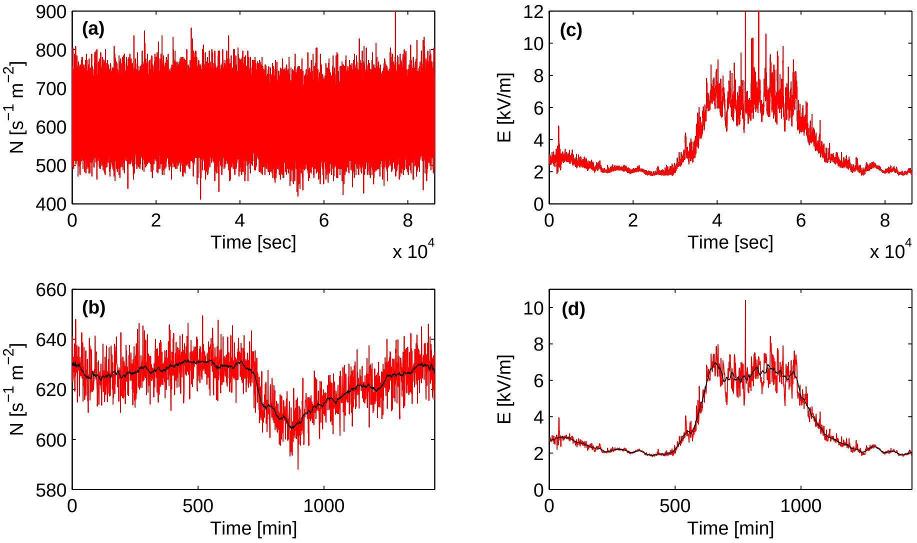

Figure 1: Records made on October 06. (a) Record per second of one day for the scintillator detector. (b) Average record of the scintillator detector per minute, the black curve corresponds to the smoothing. (c) Record per second of one day for AEF. (d) Average record of the AEF per minute, the black curve corresponds to the smoothing.

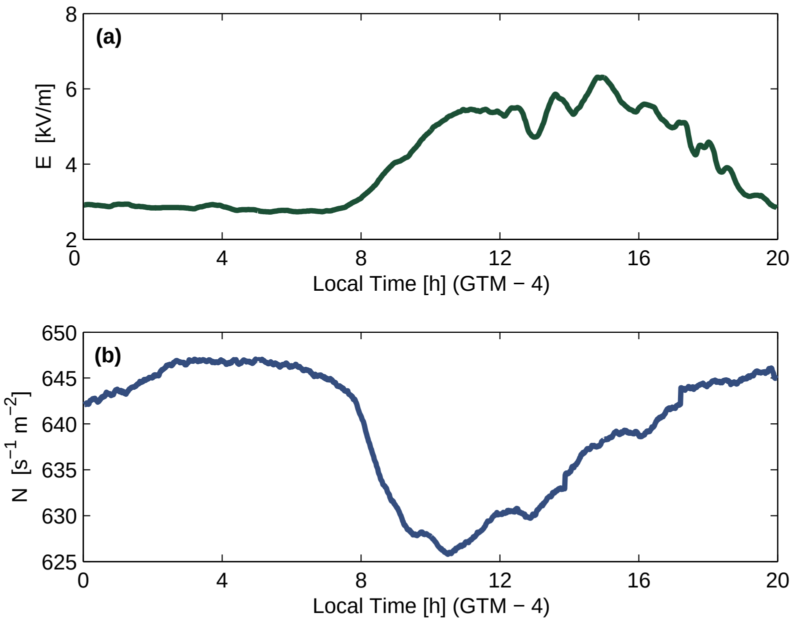

Figure 2: Average modulations. (a) AEF. (b) Particles counting rate.

Next, we perform a correlation between both modulations, the figure 3(a) shows the result, where it is possible to realize a cycle because both modulations are opposite; while one is increasing the other is decreasing, and viceversa. When the values of the scintillator become smaller it is possible to make a square fit (3(b)). We obtain a correlation coefficient of 0.99; this correlation between both records is kept for 7 hours approximately.

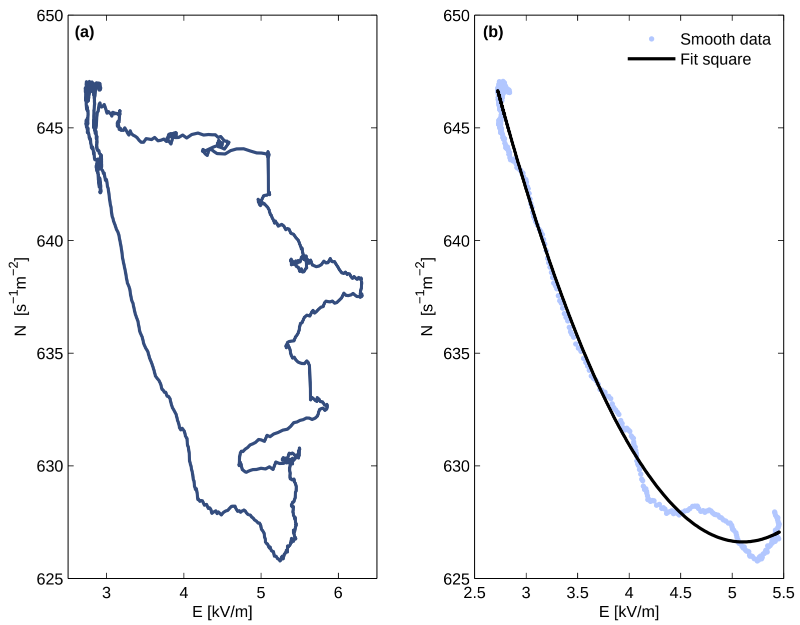

Figure 3: (a) Average correlation between both smooth data. (b) Square fit on the fall in the particle data.

3.2.2 Disturbed weather days

First of all, we perform an identical analysis to the previous one. After that we subtract the daily modulations that we obtained for the previous case from the present one, thus we obtain the records free of modulations. We find three cases in which we notice considerable increases of long duration on the record of particles with strong and sudden changes in the AEF counting rate. However, the process previously described does not allow observing short variations on both records, specially on the particle record, hence in order to observe these short variations we use the primary records (the records with 86400 values). We analyze percentage variations of the particle record that temporarily match extended saturations and sudden changes in the intensity of AEF. Analyzing the percentage variations is not enough to identify these short duration increases and for that reason we smooth the particle record which helps minimize the fluctuations of the record which allows us to see the short duration increases. The corresponding graphics are showed in the next section.

4. Results

4.1 Fair weather days

In order to verify the variations of the particle counting rate we substract the daily modulations in both records and now we can analyze the maximum percentage variation. The figure 4 shows the result of that analysis. Besides it we can notice the independency of both modulations, in other words, it does not matter how much the intensity of AEF might increase because it can even be almost 200% with respect to the daily minimum since the particles do not endure an important increase of the counting rate; it always oscillates between 2 to 5 %. It could be because, in fair weather days, the intensity of the AEF is not enough to trigger the Runaway process.

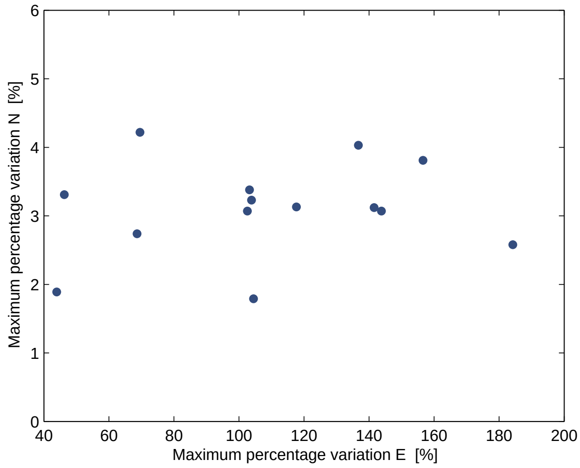

Figure 4: Maximum percentage variation between particle counting rate and AEF. Each point represents one day.

4.2 Disturbed weather days

As a result of the analysis of long duration variation we find three cases. In the first one (5) the particle record shows a jump from negative values to positive values respect to the average; this change matches a decrease in the AEF intensity from values higher than 80 kV/m to a minimum of 40 kV/m approximately with an approximate duration of 30 minutes beginning around 1 PM, local time.

The next case (6) shows two significant variations of the AEF that match two increases of the particle counting rate, too. The first variation reaches a little more than 20 kV/m during three hours approximately, also matching two little peaks in the particle counting rate but not matching at all, temporarily speaking, the peaks of the AEF. The second variation in the AEF is of about 33 kV/m; it lasts around 2 hours and matches certain increases of the particle counting rate, too. We can notice that the AEF does not endure saturations, that is to say, it does not reach its maximum value and even so there are noticeable increases of the particle counting rate.

The record made on November 11, 2008 (7) shows a very disturbed AEF, from variations with short duration, caused presumably by electric discharges, to long saturations, from which the longest one was of about two hours. In contrast to the two previous cases, the particle record variation is not matched temporarily, but after several hours after the perturbation of the AEF the particles start enduring the effect and it takes the particle counting rate around one hour more to go back to the average. The perturbation of the AEF takes about 10 hours; on the other hand, the increase of the particle takes about 11 hours.

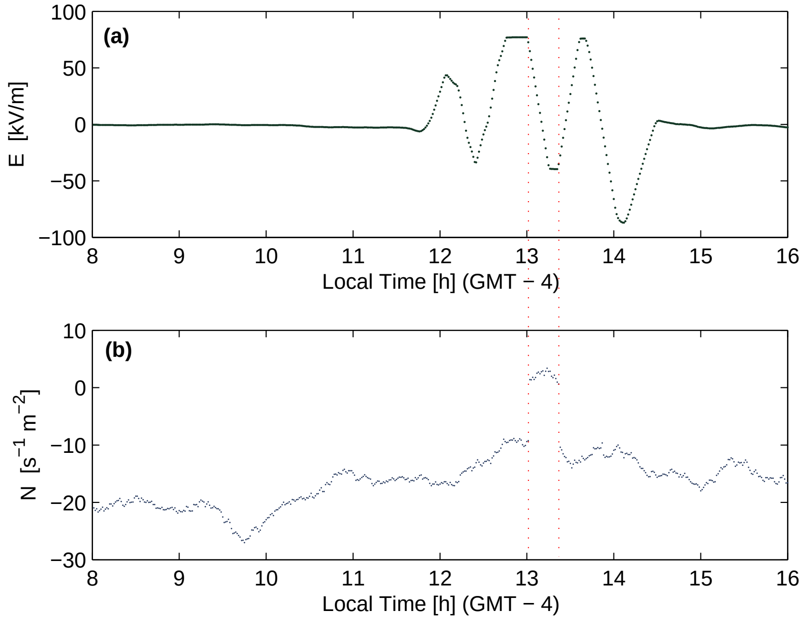

Figure 5: Increase of the particle counting rate recorded on October 07. The red lines show the temporarily matching between both rates: AEF (a) and N (b).

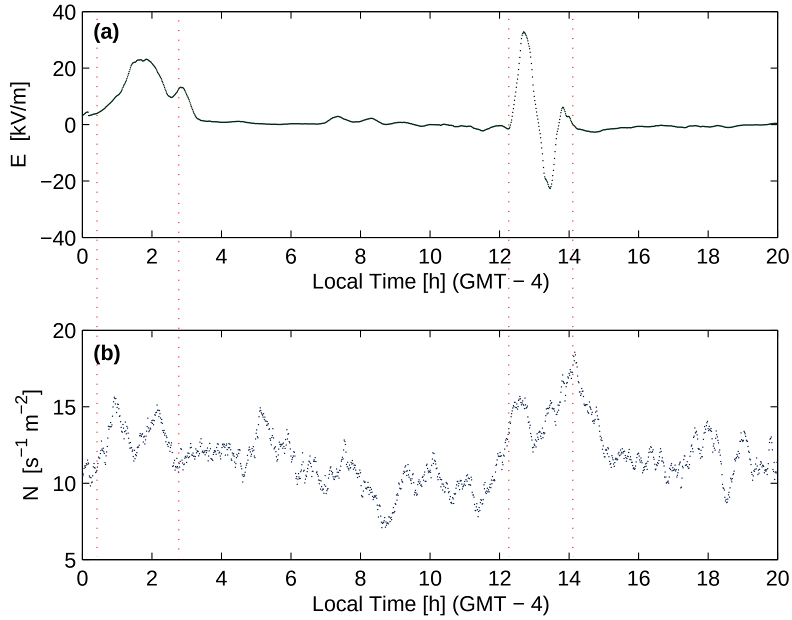

Figure 6: Two noticeable increases of the particle counting rate matching disturbances of the AEF rate recorded on October 13. The red lines show the temporarily matching between both rates: AEF (a) and N (b).

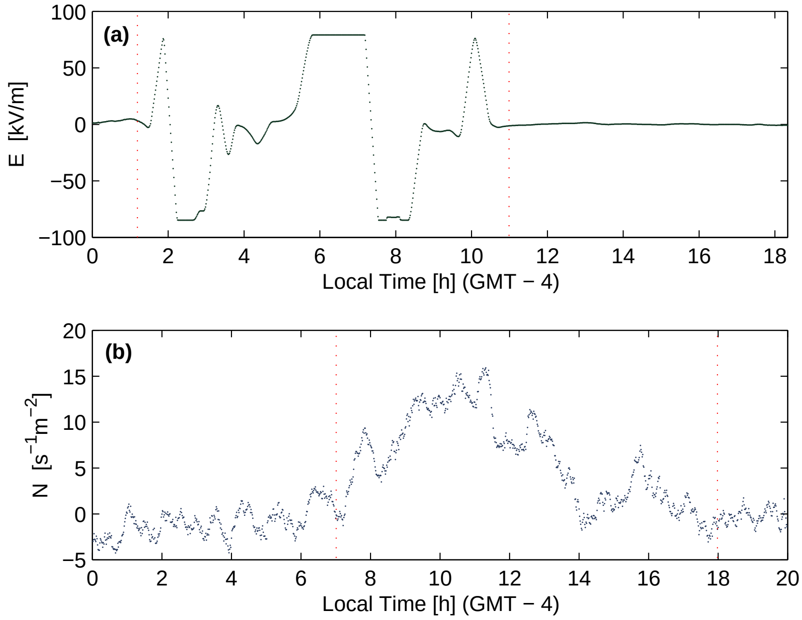

Figure 7: Variations of the particle counting rate, in this case the rates are not matching temporarily the perturbations of the AEF recorded on November 10. The difference is 7 hours approximately. The red lines show the close duration of each disturbance: AEF (a) and N (b).

Next, we show the cases with short duration. In these cases the smooth dark line over the particle counting rate only helps to find real increases. The first of these was recorded on October 18 (8) in which we notice strong variations and long saturations in the AEF rate (8(a)) and at the same time we find two increases in the particle counting rate (8(b)), the first of them with a duration of around 5 minutes (it has an increase of 28.9%), the second one with a duration of around 15 minutes (and an increase of 33.4%).

The second case was recorded on November 13 (9). The AEF rate shows saturations that rapidly change of sign (plus to minus and viceversa), a clear example of electric discharge. There are three sections to identify: the first one happens around 11 AM, the second happens between 1 and 4 PM approximately, and the last one happens around 6 PM. On the other hand, the particle counting rate shows only two noticeable increases that correspond temporarily to the second perturbation of the AEF rate that happens between 1 and 4 PM, the first of them reaches a variation of 31.2% with a duration of around 10 minutes, the second one, a little more intense and long, reaches an increase of 36.1% for a period not less than 20 minutes.

Finally, the record made on November 19 shows a case similar to the previous one(10), the AEF rate shows two regions with strong changes, the first one between 10 AM and 1 PM, and the second one, less intense, between 4 and 5 PM, while the particle counting rate shows only one variation between 4 and 5 PM. In other words, this variation matches the variation of the less intense AEF rate. The variation of the particle counting rate has an increase of 29.4% and lasts for about 10 minutes.

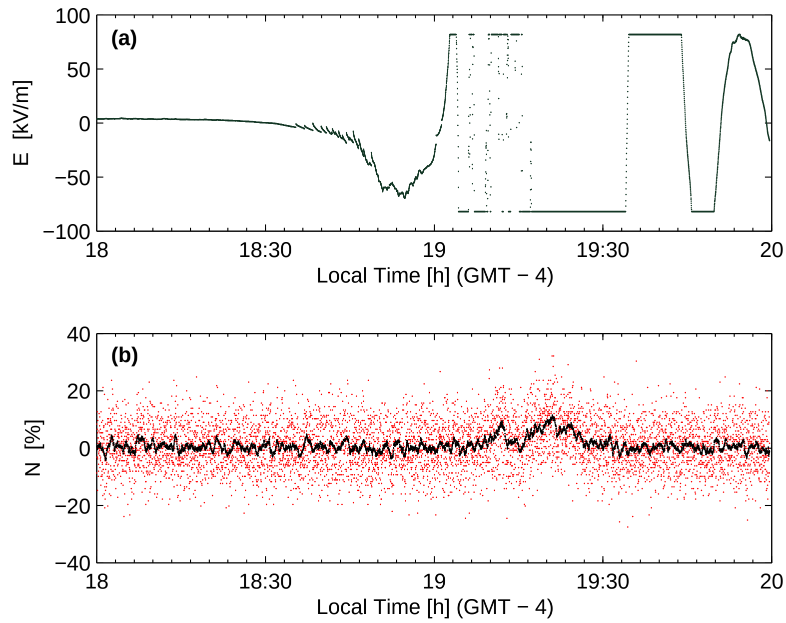

Figure 8: Short variation recorded on October 18. (a) Strong variations of the AEF rate. (b) Particle counting rate with two short variations.

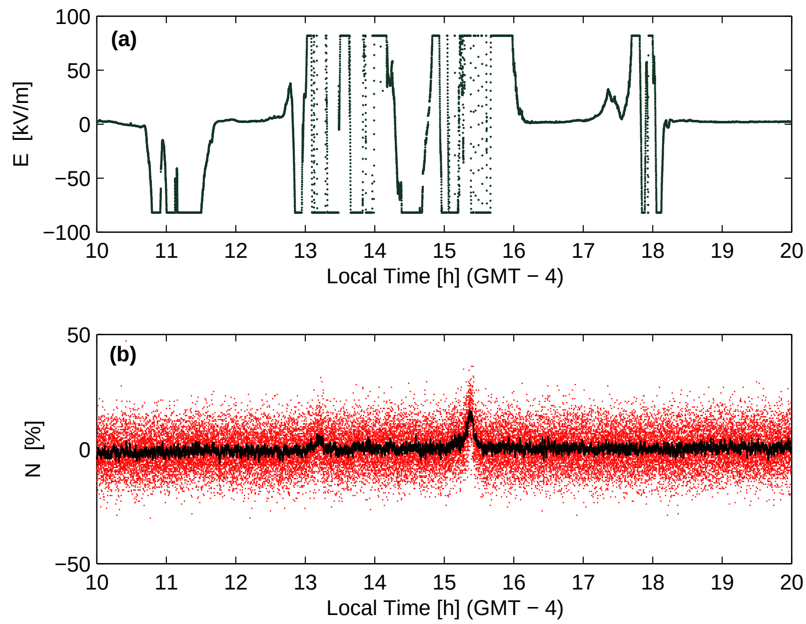

Figure 9: Short variation recorded on November 13. (a) Strong and suddenly variations of the AEF rate. (b) Particle counting rate with two sharp peaks.

5. Conclusions

We have accomplished a first study of the AEF at Chacaltaya Laboratory. We found an average

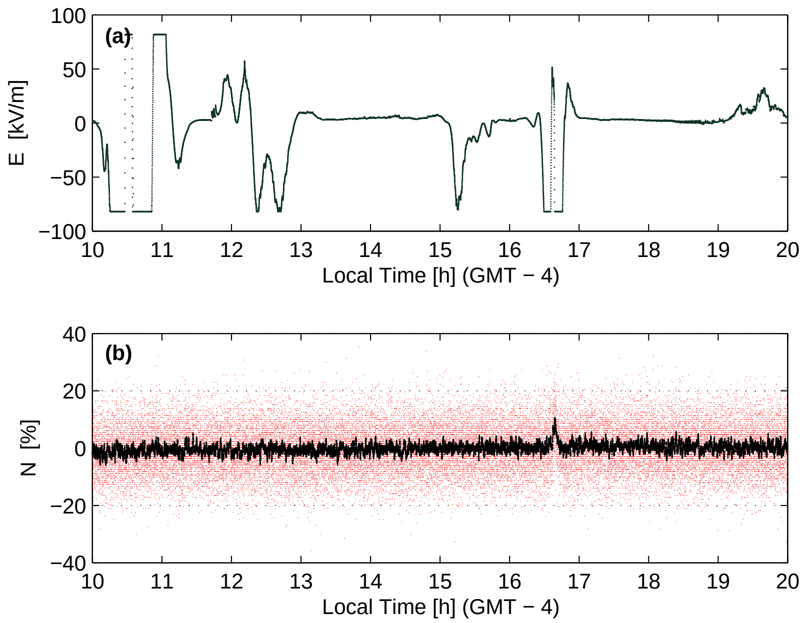

Figure 10: Short variation recorded on November 19. (a) Strong variations of the AEF rate with two clear regions. (b) Particle counting rate with only one peak.

profile for fair weather days (1). It shows a maximum value around 3 PM, local time. This result is in agreement with Feynman et al. (2000) which establishes that no matter the geographical location, the maximum variation in the atmospheric potential in fair weather days always happens at 7 PM, Greenwich Meridian Time. Bbesides it, Chacaltaya is a unique place in that sense because the minimum value recorded for these days is around 3 kV/m, in contrast with the 0.1 kV/m showed in the work by Ramachandran et al. (2007) and Feynman et al. (2000). This feature is mainly due to two peculiarities, the first one is due to the height of the Chacaltaya Laboratory (5230 m a.s.l.) and besides its topography, the second reason is the particular location of the sensor *EFM-100*: it is on a tower over a deposit of lead that increased the intensity of AEF which could be corroborated during the preliminary tests.

On the other hand, the analysis performed in order to find some correlation between the AEF rate and the particle counting rate during fair weather days shows that both daily modulations begin at the same time and keep a high correlation for several hours (the average correlation coefficient is 0.99 for 7 hours approximately). However, the final result, presented in 1, shows a complete independency between both modulations.

In the case of disturbed weather days we have two results, short and long variations of the particle counting rate; these results are in agreement with what was obtained by Aglietta et al. (1999). From 24 cases that we studied, only 4 show long variations of the particle counting rate but they have an inhomogeneous behavior, that is to say, the increases of the particle counting rate often happen without the AEF rate showing variations, this is the case of the record made on November 10 (1): the increases in both rates did not happen at the same time, the difference is of several hours.

The second case deals with short variations of the particle counting rate, we find 3 cases with this features; they show an increase on the particle counting rate between 29 and 36% with durations between 5 and 20 minutes approximately. Apparently, these variations always match strong variations and saturations on the AEF rate, temporarily speaking. However, when the AEF rate endures noticeable increases the particle counting rate can or not have increases, for example, in the records made on November 13 and 19 (1and 10), the AEF rate shows important variations but the particle counting rate only agrees with some of them.

In conclusion, we can say that the increases of the particle counting rate during perturbations of the AEF rate are not an effect that always takes place, not even having equal duration or intensities in all cases. One reason of this phenomenon not being constant might be the size of the scintillator detector because this detector has a small surface and the background of the counting rate is large (more than 4σ) and that is why the small variations of the particle counting rate are inside of the background and for this reason a next work should use an array for particle record.

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