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# Electric Storm Effects on the Soft and Hard Cosmic Ray Components Observed in Mexico City

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**Abstract:** The effects of thunderstorms (TS) on the electromagnetic and muon components of the cosmic ray secondary flux were studied during severe storms obtained in 2004, analyzing the variations of the counting rates shown in the upper and lower scintillators of the muon telescope installed in Mexico City and considering the data of storms report from the international airport of Mexico City.

## Introduction

The acceleration of electrons by a charged thundercloud was first discussed for C.T.R. Wilson in 1925 [1]. Since then, many experiments were made to find the predicted beams of accelerated particles during thunderstorm.

In the early 1980s experiments with the air shower array at Baksan demonstrated correlations of variations of short duration in the intensity of secondary cosmic rays with the electric field of the atmosphere during thunderstorms [2, 3]; the new version of this experiment was published in 2002. Pre-lightning enhancements of the intensity of the soft component of secondary cosmic rays were observed in the experiment. It was also demonstrated that these enhancements apparently are of two different types [4]. One type has longer duration (several minutes) and is most frequent, while the other is shorter and very rare.

In [5] and [6] the authors presented the results of a correlation between the hard and soft components of secondary cosmic rays and the atmospheric electric field during thunderstorm periods. They demonstrated that there is a quadratic effect changing the intensity of secondary cosmic rays in an electric field of any sign. They also studied the statistical effect of lightning on the cosmic ray intensity [7]. At the 29th ICRC, the same group studied the effect of thunderstorms electric field on the muon intensity observed at ground level. The resulting effect is predominantly negative (decrease intensity) and its amplitude increases with the decreasing energy threshold of muons [8].

## Classification of Cosmic Rays Variations

Cosmic ray intensity variations may be expressed as due to three causes:

$$\frac{\delta N^i(R_c,x)}{N^i(R_c,x)} = \underbrace{-W^i_{R_c}(R,x)\delta R_c}_{\text{I}} + \underbrace{\int_{R_c}^{\infty}\frac{\delta S^i(R,x)}{S^i(R,x)}W^i_{R_c}(R,x)dR}_{\text{II}} + \underbrace{\int_{R_c}^{\infty}\frac{\delta I(R)}{I(R)}W^i_{R_c}(R,x)dR}_{\text{III}}$$

Where:

$$W^i_{R_c}(R,x) = \frac{S^i(R,x)I(R)}{N^i(R_c,x)}$$

I. Variations of the geomagnetic cut-off that may occur as a result of any geomagnetic perturbation.

II. Variations in the integral multiplicity of generating secondary particles that may result from any type of variable conditions in the terrestrial atmosphere (Pressure, temperature, etc.).

III. Variations in the primary cosmic rays due to interplanetary variable conditions.

In this work we are interested in group II type variations.

## Data Selection

Muon counting rates were obtained from the coincident pulses of the upper and lower scintillators of the Mexico City muon telescope. We use 5 minutes data of the vertical direction for the electromagnetic (EM) and muon component corresponding to the year 2004.

An estimate of the EM intensity may be obtained subtracting the counting rates of the lower scintillator to the upper scintillator, the upper scintillator counts all the secondary cosmic rays. Figure 1 shows the scintillator array, each plastic has an effective area of 0.44 $m^2$. The geomagnetic cutoff of the detector is 8.2 GeV [9].

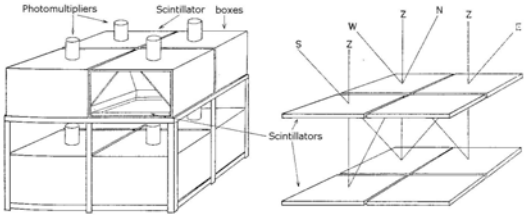


Figure 1: Schematic view of the Muon Telescope.

Quiet time data periods were selected. To eliminate the possible influence of geomagnetic disturbances, we choose days for which the daily sum of geomagnetic index $K_p < 20$. Finally the data were corrected for atmospheric pressure and temperature variations.

The thunderstorm data were obtained from the International Airport of Mexico City. The meteorological station is less than 10 km from the muon telescope location.

We found 107 thunderstorms (TS), of which only 88 correspond to quiet days, of those we selected 25 events that were longer than two hours.

## Study Design

To find high frequency signals produced in the muon telescope due to variable electric fields we use a high pass filter to eliminate data trends. Figures 2 (EM) and 3 (muon) show the filtering process, we plot the 2σ level as horizontal lines in the lower panel.

The filtering was made for the 25 events longer than two hours. The resultant series were analyzed with a wavelet transform [10] with the data normalized with $1/\sigma^2$ in each case.

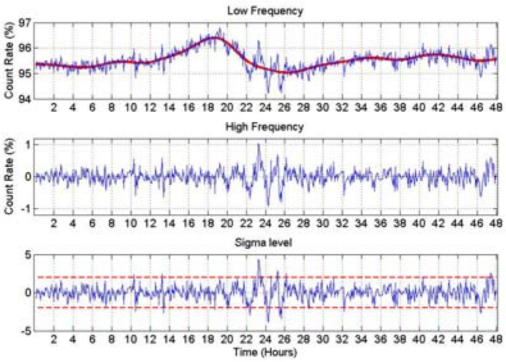


Figure 2: The filtering process of electromagnetic component for the TS of the 26-27 April, 2004. The top panel is the original electromagnetic data (blue), the resultant of the low pass filter is the red line. The middle panel is the high frequency component; the bottom panel is the high frequency variations, normalized with σ. The 2σ level is shown in red.

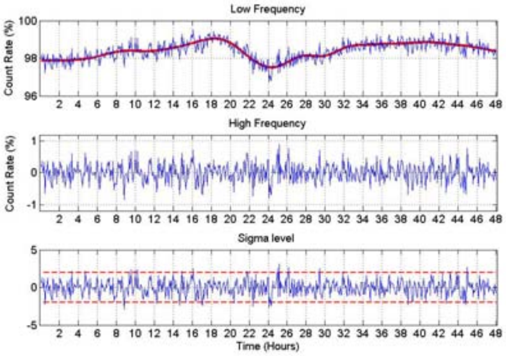


Figure 3: As Figure 2, for the muon component.

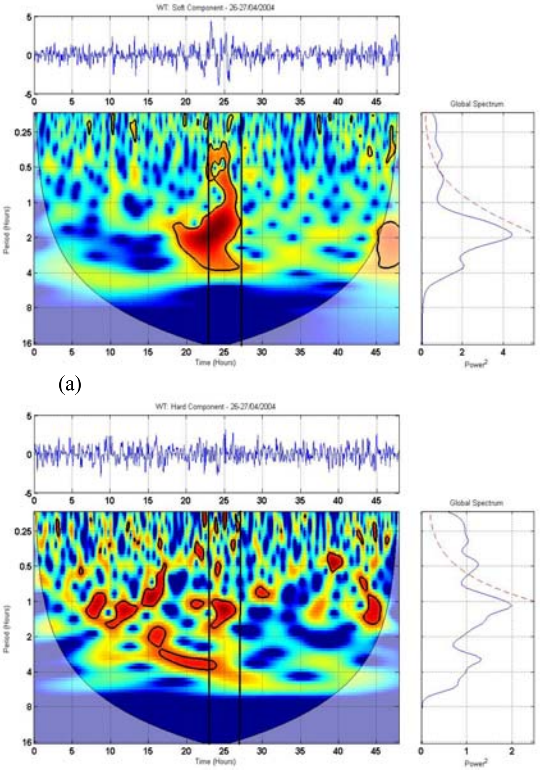
## Preliminary Results

The middle and bottom panels of figures 2 (EM) and 3 (muon) show enhanced variations in the interval of 22-26 hours, during the thunderstorm of 26 April, whose duration was from 23:45 PM to 03:00 AM of the 27 April (2345-2700 hours in the plot). This is an evidence of the TS electric field influence on Secondary Cosmic Ray.

Using the Morlet Wavelet for the cosmic ray data during the 25 TS events, the results obtained were: 44% of the events with a very clear enhanced variation in EM component during TS and

56% with variations before, after and during TS in EM and muon component.

The analysis showed frequently the existence of two variations in both components. One of short duration (10-40 minutes) and other of longer duration (2-5 hours), the first variation is product of TS, and the second variation possibility is due to the humidity present in the atmosphere caused by rain and clouds. The first variation appears in all the events analyzed in both components, whereas the lower frequency variation is found only in some events (80% EM and 52% muons). (See figure 4)

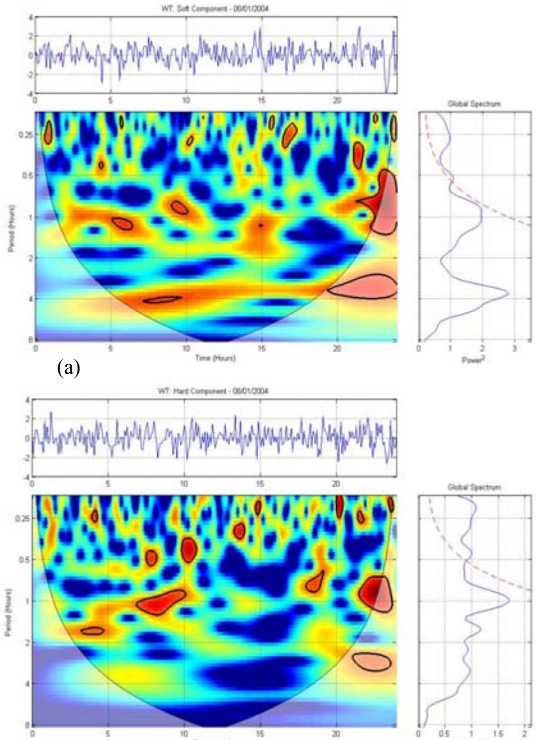


(a)

(b)

Figure 4: Variations of short and large duration. (a) is the electromagnetic component wavelet spectra of the 26-27 of April of 2004, and (b) is the corresponding muon component spectra. The top panels are plots of the counting rates (%) cosmic ray data in units of standard deviation. The period of the thunderstorm is limited per the black lines. To the right is the global spectrum and the red line is the red noise level.

In a second analysis with the wavelet transform, we selected 13 quiet days free of TS, rain and clouds (cumulus and cumulonimbus) to compare with the 25 TS events data periods.



(a)

(b)

Figure 5: Variations of short and large duration in a quiet day (8 January, 2004); similar to figure 4.

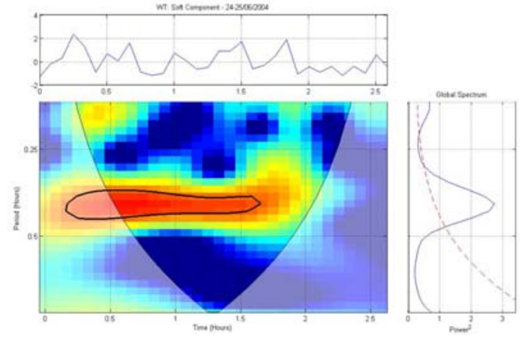


Figure 6: Variations of the EM Component during TS period.

In quiet days as figure 5, we found also variations of short and long period. However they can not be clearly attributed to any atmospheric phenomena. On the other hand, even if the variations seem to be important, they only look so because of the normalization necessary to construct the wavelet spectrum.

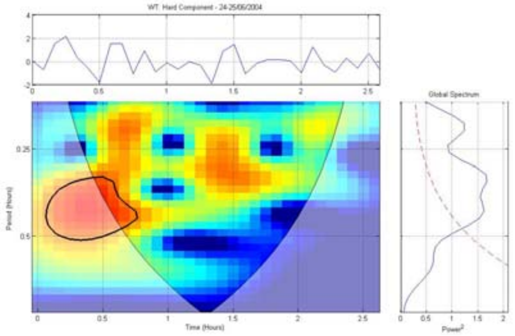


Figure 7: Variations of the muon component during TS period.

In figures 6 and 7 we present examples of the variations during a TS period (it correspond to the storm of 24-25 of June of 2004), the presence of disturbances of high frequency in EM and muon components is very clear, due to the resolution of the data (5 min.) the periodicities found are from 10-40 minutes, to see periodicities of lower frequency it would be necessary to use a larger data range, as in figure 4.

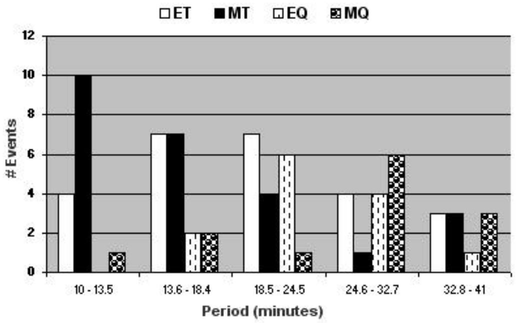


Figure 8: Periodicities present in TS (ET and MT) and quiet days (EQ and MQ).

Figure 8 shows that the EM and muon components during TS (ET and MT) present periodicities in higher frequencies than those shown by quiet days data (EQ and MQ). 72% of ET and 84% of MT are concentrated in periodicities from 10 to 24.5 minutes, whereas approximately the 95% of EQ and 76% of MQ are in periodicities of 18.5 to 41 minutes.

## Conclusions

The variations in the intensity of the secondary EM and muon components of cosmic rays during periods of thunderstorms tend to have periodicities at higher frequencies than during quiet time periods.

Although not shown in these results, the power of cosmic ray variations during thunderstorms is bigger than during quiet periods.

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