

Atmospheric electric field effects of cosmic rays detected in Mexico City

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RESUMEN

Estudiamos los posibles efectos de los campos eléctricos atmosféricos, generados en las tormentas eléctricas, sobre la intensidad de los rayos cósmicos detectados en la superficie terrestre, analizando las variaciones de las razones de conteo de la componente nucleónica de los rayos cósmicos, obtenidas por el monitor de neutrones instalado en la ciudad de México, durante tormentas eléctricas ocurridas entre 1996 y 1997, años del mínimo solar. Comparamos nuestros resultados experimentales con la teoría general de los efectos meteorológicos en los rayos cósmicos, desarrollada por Dorman (1995).

Se observó una variación en la intensidad de alrededor de 0.2%. De acuerdo con Dorman (1995), el efecto puede estar entre 0.27 % y 0.81% en las razones de conteo del monitor de neutrones cuando las intensidades del campo eléctrico atmosférico se encuentran al rededor de 100 a 300 Vcm⁻¹. Nuestros resultados muestran que los campos eléctricos en la ciudad de México tuvieron menos intensidad que los campos eléctricos asumidos por Dorman (1995) o que los campos eléctricos no son uniformes en el tiempo y altura durante el desarrollo de la tormenta eléctrica.

PALABRAS CLAVE: Campo eléctrico atmosférico, rayos cósmicos.

ABSTRACT

We studied the possible effects of atmospheric electric fields, generated in thunderstorms, on the cosmic ray intensity detected at the Earth's surface by investigating the variations of the counting rates of the cosmic-ray nucleonic component, obtained from the neutron monitor installed in Mexico City, for thunderstorms during 1996 and 1997. These were years of minimum solar activity. We compare our experimental results with the general theory of cosmic ray meteorological effects by Dorman (1995).

The observed intensity variation is about 0.2%. According to Dorman (1995), the effect should be between 0.27% and 0.81% on the counting rate of the neutron monitor when the atmospheric electric field intensities are around 100 to 300 Vcm⁻¹. Our results show that either the electric field in Mexico City had less intensity than assumed by Dorman (1995), or the electric field is not uniform in time and height during the development of the thunderstorm.

KEY WORDS: Atmospheric electric field, cosmic rays.

1. INTRODUCTION

Short variations of cosmic ray intensity during rain and thunderstorm events (meteorological cosmic ray effects) were observed at Baksan by Alexeenko *et al.* (1985).

Data on short-term variations of the intensity of secondary cosmic rays during thunderstorms were presented by Alexeenko *et al.* (2001). The effect was studied separately for soft and hard components, with data provided on 11 and 14 thunderstorms, respectively.

Dorman (1995) developed a general theory of cosmic ray meteorological effects. On the basis of this theory, we investigated atmospheric electric field effects in the cosmic ray neutron component in Mexico City. According to the theory of Dorman (1995), it is possible to detect thunderstorm effects in neutron monitor counting rates.

Variations of the flux of secondary cosmic rays associated with electric field variations were reported by the Baksan Group in 1985 (Alexeenko *et al.*, 2002). They noted that the flux of the soft component (> 10 MeV) and the hard component (> 70 MeV) increased in the presence of a negative electric field.

The Japanese Group at Nagoya found that there is evidence for proton acceleration in the presence of positive electric field, and evidence was also obtained for increases of secondary cosmic rays in a positive electric field (Muraki *et al.*, 2003).

The Russian Group at Baksan presented the results of a correlation between the hard and soft components of cosmic ray showers and the atmospheric electric field during thunderstorm periods. They demonstrated that the quadratic effect (changing intensity of muons in an electric field of

any sign) is most pronounced for soft muons. They studied also the effect of lightning on the intensity of cosmic rays by statistics (Khaerdinov, N.S. *et al.*, 2003a,b,c).

2. THE DORMAN THEORY

About 7% of the neutron monitor counting rate is caused by negative soft muons captured by lead nucleons

$$\Delta N_m^- = -\frac{1}{bx} \int_{h_2}^{h_0} dh_2 \left\{ \int_{h_2}^{h_0} \left[\frac{exE(h)dh}{r(h)} \right] \int_0^{h_2} F^-(\epsilon_{\min}, h_1, h_2, h_0, x) \pm \left(\frac{m_m c}{t_m} \right) \right. \\ \left. \times \int_{h_2}^{h_0} dh_2 \int_{\epsilon_{\min}}^{\infty} d\epsilon \int_{h_2}^{h_0} \frac{dh}{r(h)} [b\epsilon x - a(h - h_2)]^{-2} \times \int_{h_2}^h \left[\frac{xeE(h')}{r(h')} \right] dh' \times \int_0^{h_2} F^-(\epsilon, h_1, h_2, h_0, x) dh_1 \right\} \quad (1)$$

The first integral on the right-hand side of (1) describes the atmospheric electric field muon absorption effect, part of which is caused by a change of pressure at the observing level and contributes to the barometric effect, while another part is due to a possible change of thickness of the shield.

The second integral describes the atmospheric electric field muon decay that arises from the instability of muons, (Dorman, 1974).

Furthermore, the expected variation in the neutron monitor counting rate caused by the atmospheric electric field effect on the negative soft muon flux is

$$\left[\frac{\Delta I_n(h_0)}{I_n(h_0)} \right]_{ae} = k \left[\frac{\Delta I_m^-(h_0)}{I_m^-(h_0)} \right]_{ae}, \quad (2)$$

where I_m^- is the negative soft muon intensity at atmospheric pressure h_0 , and k is a constant ($k = 0.07$).

On the basis of (1) and (2), Dorman estimated the expected atmospheric effect on the neutron monitor counting rate. For the case considered with $E(h) = 100$ and 300 Vcm^{-1} between $h_c = 700 \text{ g cm}^{-2}$ and $h_0 = 1000 \text{ g cm}^{-2}$ at $k = 0.07$, the effect was 0.27% and 0.81%, using 5 min of data.

3. DATA SELECTION

Two different selection criteria of data were used as being best suited to the two different methods of study explained in section 3.

3.1. Strong and long duration storms

Neutron counting rates were obtained from the neutron monitor installed in Mexico City. We use 5 min of data as

that together form mesoatoms with the generation of several MeV neutrons from the lead of the neutron monitor (Dorman, 1974).

According to Dorman, the atmospheric electric field effect on negative muon intensity changes can be obtained from the equation:

suggested by Dorman's Theory. Two periods of data, during the Solar minimum (1996, 1997), were selected to reduce the possible influence of the active Sun.

Furthermore, to eliminate the possible influence of geomagnetic disturbances, we choose days with thunderstorms during which the daily sum of geomagnetic index $K_p < 20$.

The thunderstorm data were obtained from the National Meteorological Service in Mexico City. The meteorological station is less than 10 km from the neutron monitor location. We search periods with thunderstorms of long duration (> 4 hrs.).

On the basis of these considerations, we find two intervals: the first from 14 to 19 of June and the second from 13 to 18 of July, both in 1996. During 1997 there were no thunderstorms satisfying our selection criteria.

Figure 1 and Figure 2 show the neutron data as a function of time for interval 1 (June 14 to June 19, 1996) and interval 2 (July 13 to July 18, 1996), respectively.

3.2. Strong and isolated storms

We alternatively selected intense thunderstorm isolated in time. We define as "isolated" thunderstorms all those without atmospheric electric activity 72 hrs before and after the selected thunderstorm. Intense thunderstorms include lightning, thunder and heavy rain. We found 9 thunderstorms in 1996 and 5 thunderstorms in 1997 fulfilling these criteria. In order to eliminate the influence of high frequency signals we used 5 min neutron counting rates filtered with moving averages of 7 data points.

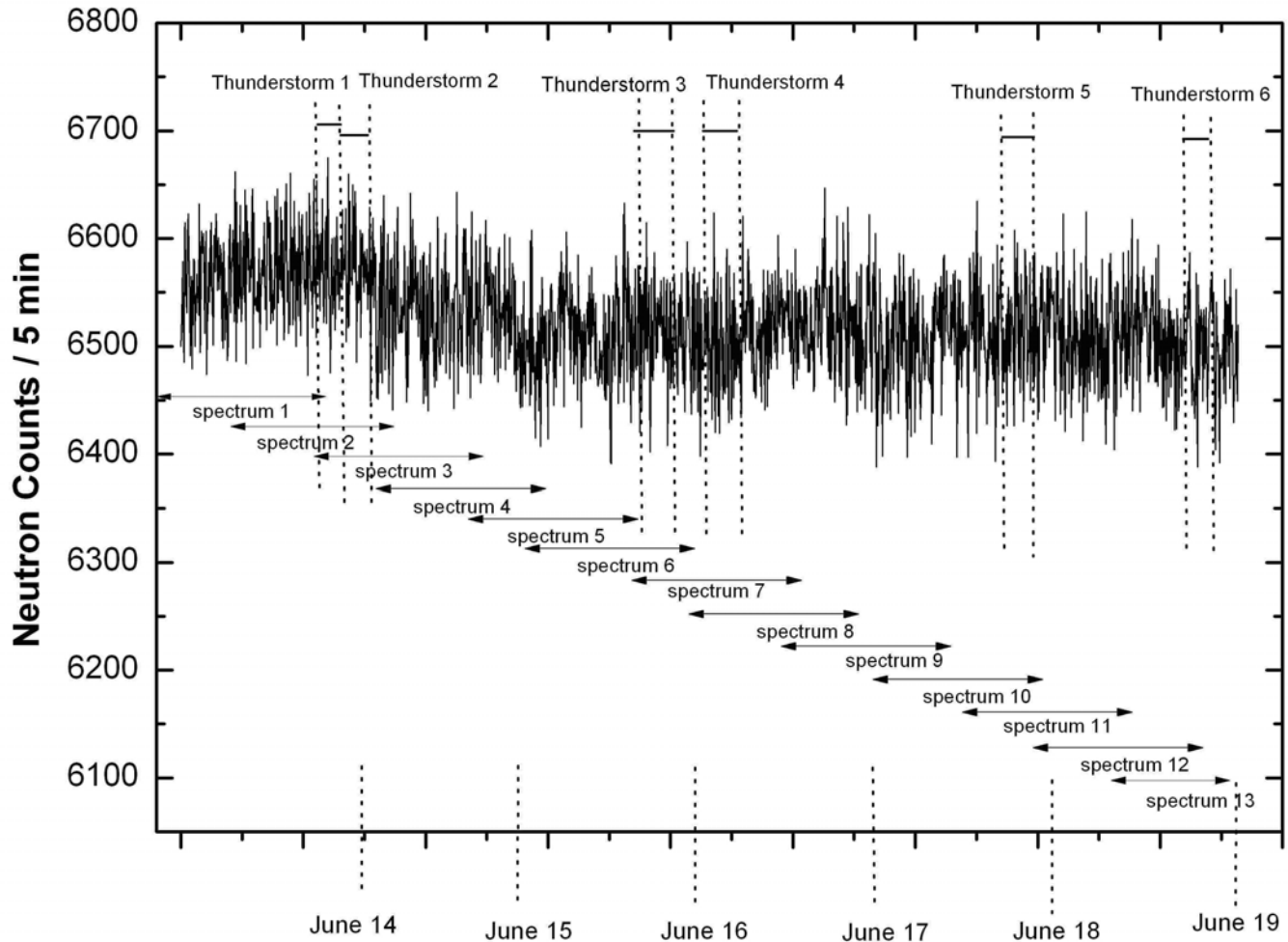


Fig. 1. Neutron counts as a time function for the interval 1, showing the 6 thunderstorms.

4. STUDY DESIGN AND METHODS

4.1. Dynamic spectrum

To find high frequency signals produced in the neutron monitor due to variable electric fields we use a Fast Fourier Transform (FFT) analysis to calculate power spectra. Our analysis uses series of 256 neutron monitor data points (a little more than 21 hours).

The data were partially overlapped. The start for the second series was 128 data points after the first series, etc. This technique was developed by Priestley (1981). It is known as *dynamic spectrum*. By using short intervals we guarantee that the temporary series represents a stationary process, a necessary condition for using an FFT spectral technique.

For the first interval we obtained 13 spectra. For the second data interval we obtained 11 spectra, because there were gaps in the neutron data.

The data periods for the spectral estimates are much longer than the actual thunderstorm interval. This technique allowed us to search for a signal of the electric field that can be seen as significant difference in the power spectra, for data recorded during thunderstorm time interval and data taken during quiet times.

Figure 3 and Figure 4 show examples of the results of dynamic spectra calculations.

In Figure 3 we appreciate that the spectra 10 and 11 of interval 1 have a power spectral density much greater than spectra 12 and 13, and furthermore have a strong decreasing tendency with the frequency. Spectra 10 and 11 are below the noise level.

In Figure 4 we can see the results of spectra 1, 2 and 3 of interval 2. None of these spectra have a dependence on the power spectral density or the frequency; in fact, they are typical white noise spectra. The noise level is too high; we cannot obtain any significant information from these spectra.

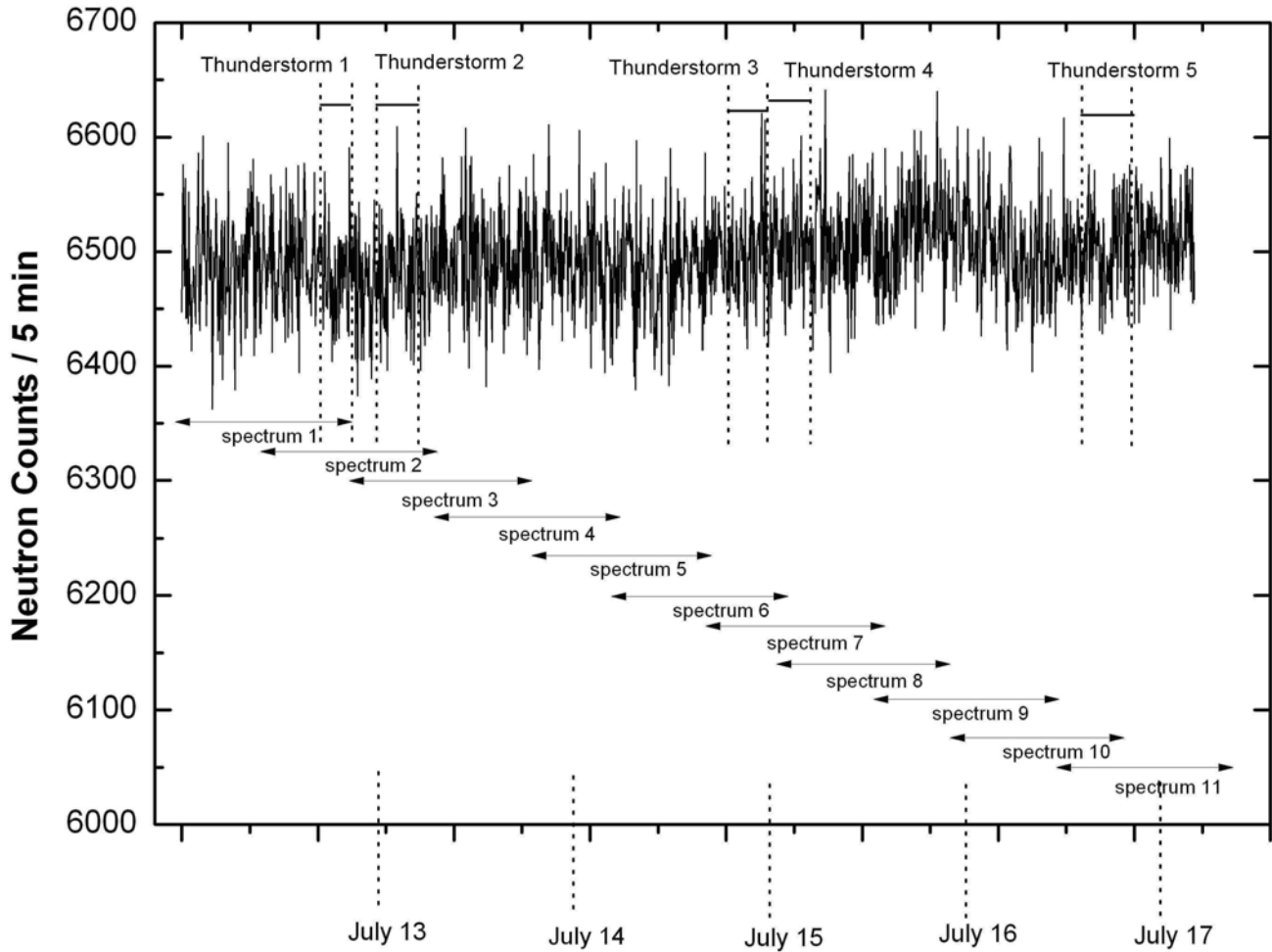


Fig. 2. Neutron counts as a time function for the interval 2, showing the 5 thunderstorms.

4.2. Superposed epoch analysis

In the search for identifiable signals of thunderstorms in secondary neutron cosmic ray intensity, we alternatively selected intense thunderstorm isolated in time (section 2.2).

This lowered the time resolution of our data but, as we saw in the results of the last section, it is very difficult to find identifiable high frequency signals of thunderstorms in cosmic ray data. Therefore we searched among low frequency signals.

We define a TTU (Time Thunderstorm Unit) as the time elapsed during a thunderstorm. Each thunderstorm has a TTU from two to five hours in our case. This procedure allowed us to separate the time intervals before and after the thunderstorm in a normalized manner.

We define T_0 as the TTU when the thunderstorm takes place. T_1 is the time from the end of T_0 to the following TTU. T_{-1} is the TTU prior to the storm, and so on. We take 5

intervals before and after T_0 ; the total period for each thunderstorm is around 2 days. The average intensities $I_{-5}, \dots, I_0, \dots, I_5$, were weighted per TTU for each thunderstorm, and then we calculated an average weighted global intensity ($\langle I_{-5} \rangle, \dots, \langle I_0 \rangle, \dots, \langle I_5 \rangle$) for each thunderstorm. The results are shown in Figures 5, 6, and 7.

Figures 5 and 6 show the percentage variation of the average global intensity per TTU for 1996 and 1997, respectively. In Figure 5 we can see decay in intensity just before the start of the thunderstorm. In Figure 6, the decay starts at the same time as the thunderstorm. In these figures, from TTU = 0 to the end (TTU = 5), the tendency is very similar.

This change in intensity may indicate a tendency in global intensity due to intense thunderstorms.

The percentages are very similar for thunderstorms of 1996 and 1997. Every data group was weighted for its TTU,

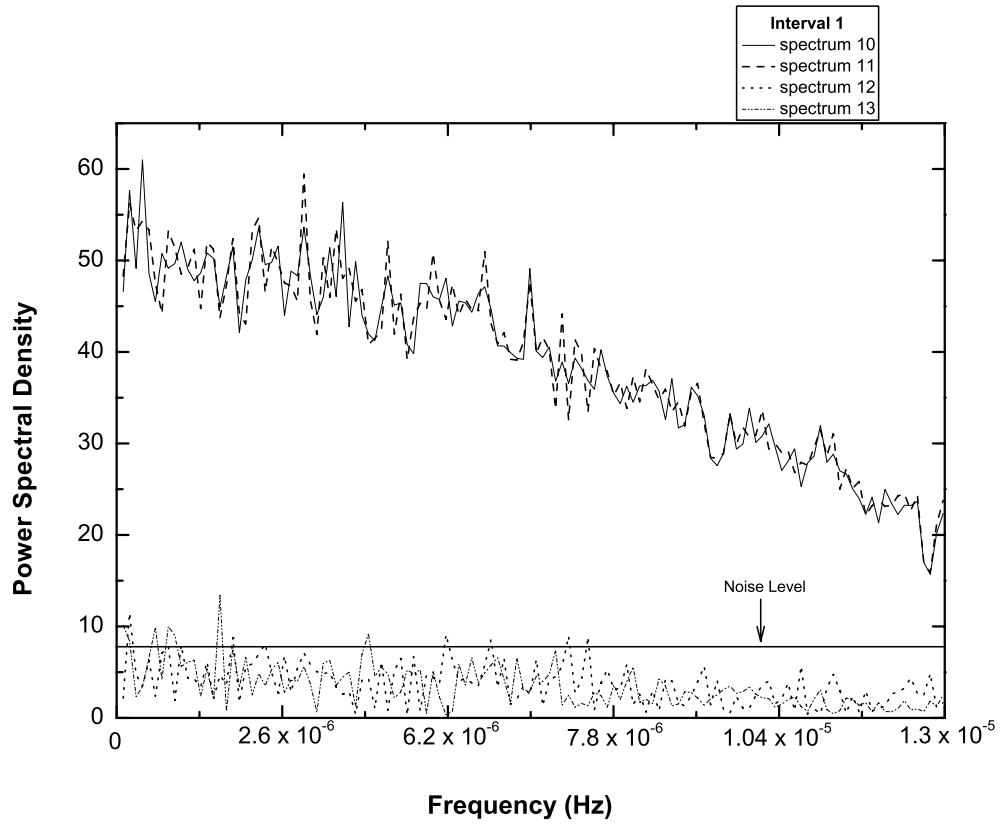


Fig. 3. Spectra 10, 11, 12 and 13 for the interval 1, showing the noise level.

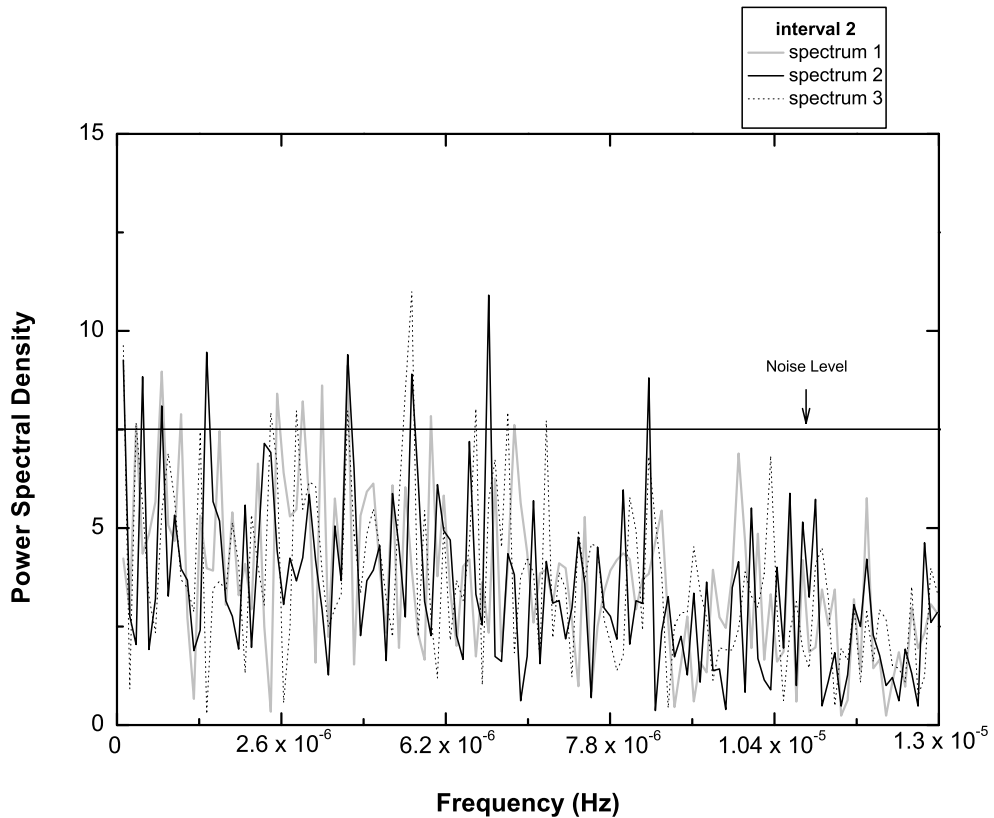


Fig. 4. Spectra 1, 2 and 3 for the interval 2, showing the noise level.

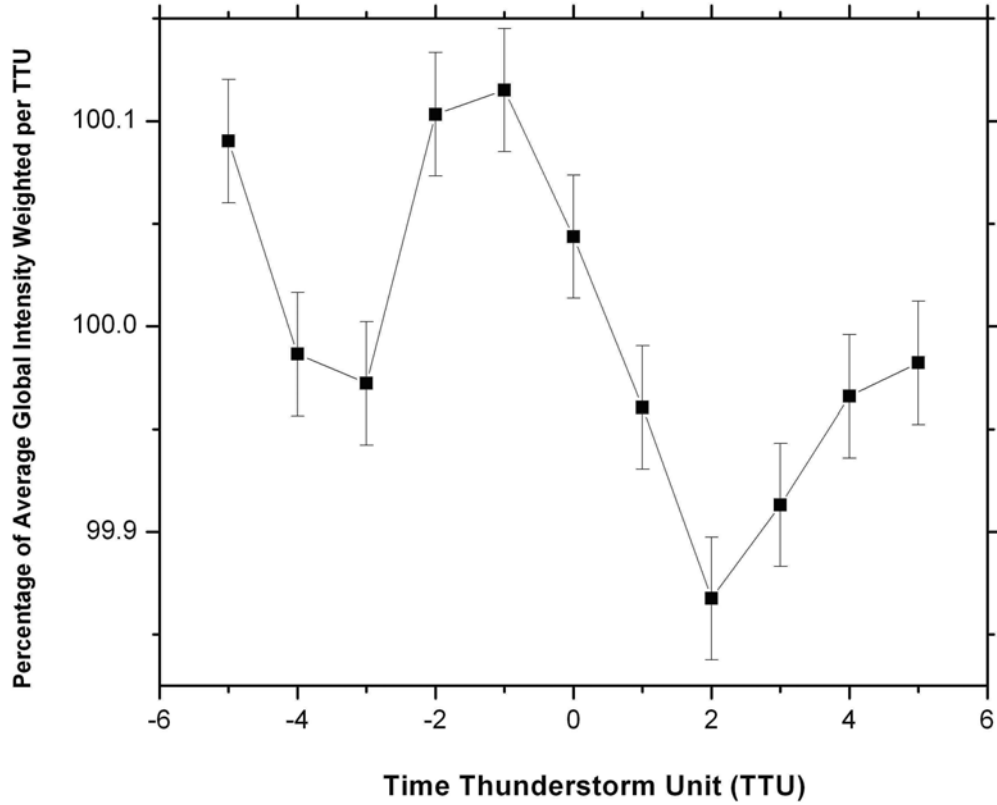


Fig. 5. Percentage of average cosmic ray intensity per TTU for thunderstorms in 1996.

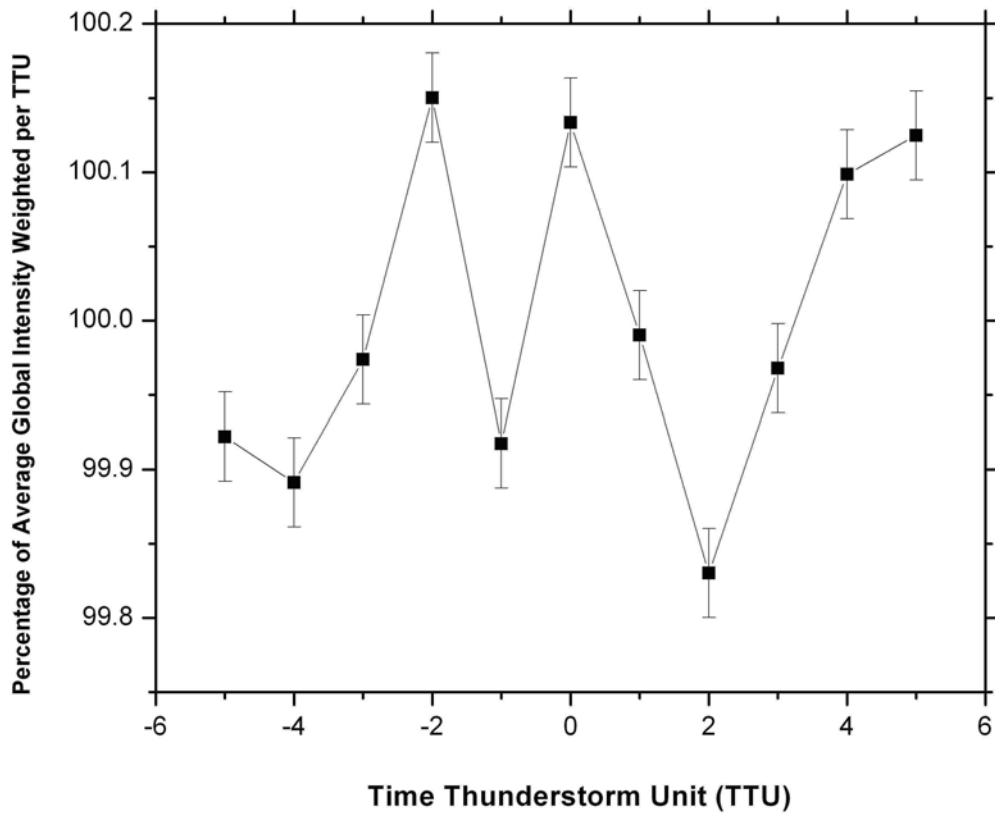


Fig. 6. Percentage of average cosmic ray intensity per TTU for thunderstorms in 1997.

thus we may eliminate the possible influence of longer thunderstorms than others.

Figure 7 shows the variation of global intensity for all thunderstorms, a comparison between thunderstorms of 1996 and 1997, and we see that the tendency of the intensity to decay is present. Furthermore, these three figures are similar. Point T_{-1} makes the difference, but the tendency in the global intensity is the same. This tendency may be due to a possible influence of the electric fields of thunderstorms on the average global intensity.

5. DISCUSSION AND CONCLUSIONS

The dynamic spectrum showed a weak signal of the influence of thunderstorms on cosmic ray intensity fluctuations; only two spectra have a higher power than others, and show frequency dependence (Figure 3), while the rest are similar to Figure 4. Spectra 10 and 11 in Figure 3 correspond to an intense thunderstorm registered in Mexico City in 1996 (thunderstorm 5 in Figure 1). According to these results, high frequency signals of electric field influence on cosmic ray intensity are rare and ambiguous. If we could use a better time resolution (< 5 min), we might be able to observe some electric storm effects in the cosmic rays intensity.

With a superposed epoch analysis, we find a systematic tendency of cosmic ray intensity during thunderstorms. Figures 5 and 6 show the tendency of cosmic ray intensity to decrease from $TTU=T_0$ to $TTU=T_2$, for the solar minimum year (1996) and the year of the start of Solar activity (1997). This tendency was persistent in all thunderstorms (1996 and 1997), with the exception of point T_{-1} . Figures 5, 6 and 7 show the same trends. This may be a sign of the influence of atmospheric electric fields on neutron monitor counting rates in Mexico City. There is no clear tendency of cosmic ray intensity before the storm, but a definite decrease follows and is of similar magnitude always. The measured decrease is about 0.2%; according to Dorman's Theory we would expect an effect of around 0.27% to 0.81% in neutron monitor counting rates for electric fields of 100 to 300 Vcm^{-1} .

Our results may mean that the atmospheric electric fields in Mexico City are smaller than those assumed by Dorman in his calculations, or that these fields are not uniform and vary in time and space during the thunderstorm, thus reducing the net effect on cosmic rays.

Use of an electric field meter may enable us to obtain better results for study of atmospheric electric field effects on cosmic rays: this would greatly improve the quality of experimental data.

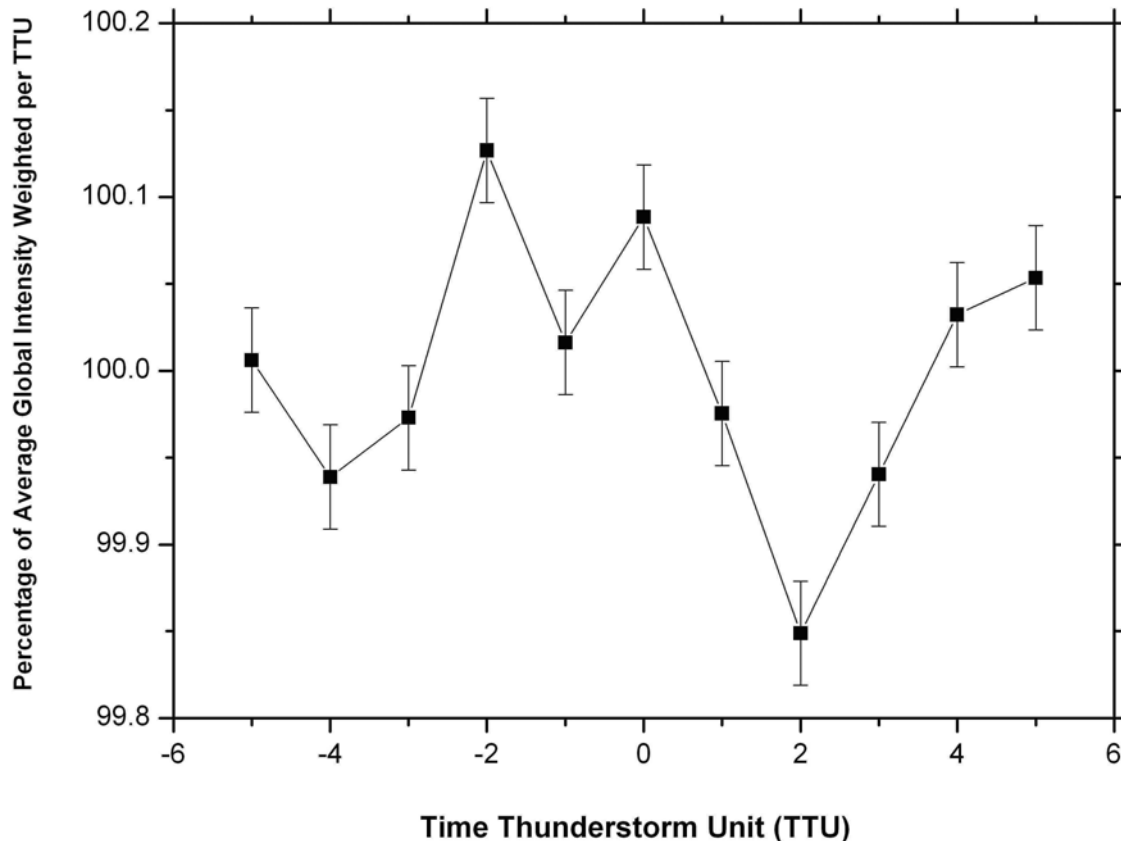


Fig. 7. Percentage of average cosmic ray intensity per TTU for all thunderstorms considered (1996 and 1997).

The most important result obtained here is that there is a systematic observable decay in cosmic ray intensity during and after thunderstorms. This decay may be due to the presence of strong electric fields in the atmosphere.

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