

Twelve years of continuous measurements of atmospheric electrical activity in México's Tropical highland

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RESUMEN

Se midieron ininterrumpidamente las variaciones de la actividad eléctrica en la atmósfera, de enero de 1988 a diciembre de 1999, en un observatorio de altura (2,250 m s.n.m.), y se analizaron para obtener resultados estadísticos confiables con relación a la ocurrencia de tormentas en la región sur del Valle de México. Como ejemplos, se muestran los perfiles individuales de la actividad eléctrica atmosférica asociada con tormentas severas. Los resultados dejan claro que se requiere de la secuencia de medidas eléctricas lo más rápida posible para obtener datos significativos y aplicables en relación con una serie completa de tormentas, considerando la media del tiempo de variación de las mediciones de la actividad eléctrica atmosférica a una altitud de 2,270 m s.n.m. La variación estacional indica que la mayor actividad de tormentas eléctricas se produce en el verano, con menos de 10 % en otoño e invierno. Se obtuvo una correlación significativa entre los datos de precipitación de una red de 66 estaciones y la frecuencia de descargas. Se dió especial atención a la cuestión de la actividad eléctrica atmosférica y el clima en el Valle de México.

ABSTRACT

Atmospheric electric activity measurements have been recorded continuously by a punctual lightning system at a tropical highland observatory from 1988 – onwards, and were analyzed to obtain lightning statistical confident results for thunderstorms occurrence on the leeward side of the southern mountain ridge of México's Valley. Shown, as examples, are individual profiles of the atmospheric electrical activity, associated with severe storms. The results make clear that the fastest possible sequence of electrical measurements is required to obtain significant and application oriented data in connection with a whole series of thunderstorms taking into account the mean time variation of the atmospheric electricity measurements at an altitude of 2270 m a.s.l. The seasonal variation indicates that the lightning flash peak currents were found to be larger in summer with less than 10% occurring in the autumn and winter. With rainfall data from a network of 66 stations, we obtained a significant correlation with the lightning frequency. Special attention was undertaken concerning the question of the atmospheric electrical activity and climate at the Valley of México.

Key words: Atmospheric electricity, lightning, electrical discharges

1. Introduction

The main lightning and thunderstorm data source for the present investigation is a set of continuous atmospheric electricity measurements collected routinely and archived from 1988 to 1999. The early evolution of tropical convection in the southern region of the high plateau of Central México was observed from a station located at the National Autonomous University of México campus (UC), (19° 19' 45" N lat .; 99° 10' 50" W long.) on an elevated basin in the tropics (2,270 m a.s.l.). An electrical observatory was established with three different punctual instruments for simultaneous measurements of the complex lightning phenomena, a product of many variable conditions and interactions in the atmosphere. Troncoso (1987) reviewed and discussed details and problems of the technical measuring equipment with description of the detector systems, data sampling process, evaluation, etc. The results given then, are essentially still valid today, although an electric field mill detector was added to the station and the methods of data evaluation have been considerably improved for some years.

Simultaneous measurements by three different instruments provide useful comparison between the different characteristics of atmospheric electricity activity (Milmer and Chalmers, 1961; Ette and Utah, 1973; Livingston and Krider, 1978). Figure 1, shows a map of the southern region of the Valley of México and the location of the 66 rain gauge sites used. Observations were conducted daily and mainly concentrated on the southern region, due to the fact that lightning sensor measurements covered electrical discharge events that occurred only within 20 km, a broadcast area of 1,257 km². Finally, wind, temperature and humidity data, were obtained from daily radio-sonde at México City's International Airport (16 km away from UC station).

2. Observations and discussion

As visual observations of lightning may not be sufficient, additional information can be provided by a lightning detection system, or additional weather information may be required to ensure consistency, accuracy, and adequate advance warning of the storm's arrival to provide additional time to seek safety. Lightning is always generated by and connected to a thunderstorm, but may strike ground many kilometers from the edge of the thunderstorm cell. In the present analysis, we recognize that the detection efficiency is as high as 80%-90% throughout the network area. Consequently, we made no corrections for the detection efficiency and plot actually measured flash density. All geographical plots in this paper are done with a small spatial resolution.

The data provided by the instruments used in the present study included:

i) Meteorological radar (C band, 4-8 GHz frequency, 5.6 cm wavelength), placed at "Catedral" hill, 45 km at NW from the UC station and at 3,780 m a.s.l., National Meteorological Service-National Water Commission (SMN-CNA).

ii) Network of 66 automatic tipping-bucket rain-gauges placed inside México City, General Direction of Construction and Hydraulics Operation - Government of the Federal District (DGCOH-GDF).

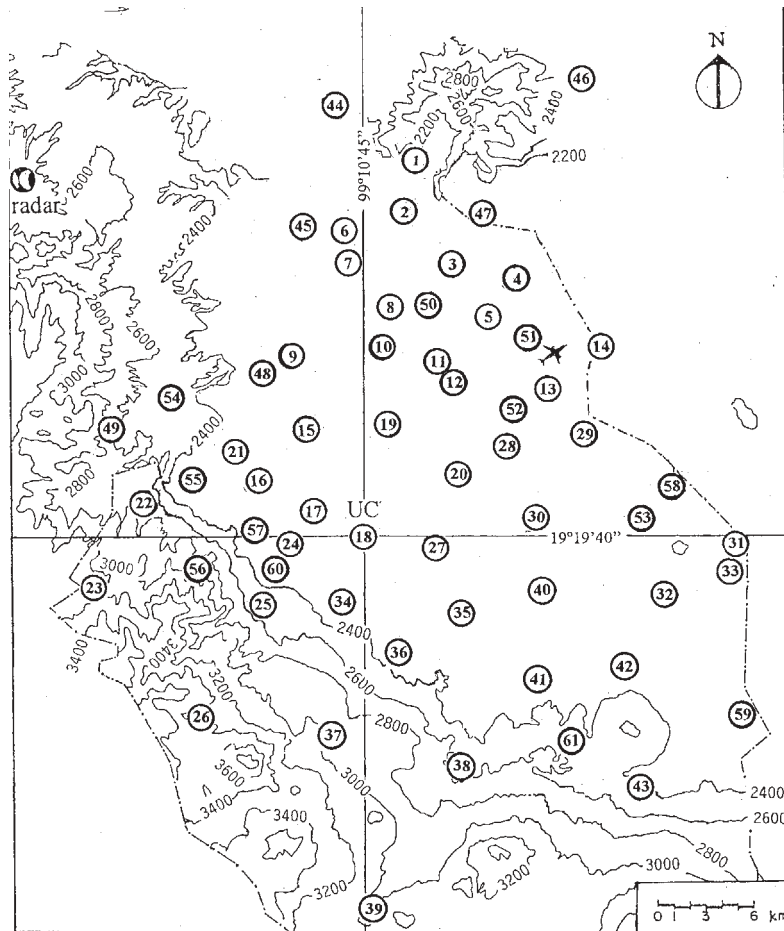


Fig. 1. Topography of the southern region of the Valley of México. Rain gauge locations are plotted with the station number inside a circle. Contours of ground surface elevation on meters, a.s.l. Stations: UC: University City; México City International Airport, and radar site.

- iii) UC station with three punctual instruments:
 - a) Omni directional atmospheric radio noise detector (27 KHz), range of approximately 100 km radius.
 - b) Atmospheric corona-point-discharge current detector, which responded to most discharges within a 18 km radius.
 - c) Electric field mill detector, with a range of 18 km radius. The electrical discharge source region is impossible to determine with a single detector. An atmospheric electrical event recording

by the UC instruments requires that three instruments detect the event, if only one or two sensors detect the event, it is rejected.

Arbitrarily, we define the initial time of an electrical event as occurring: 1) when the cloud to ground electrical discharge rate per hour increases to ten times the discharge rate per hour during the previous hour; and 2) when approximately, at the same time, rain intensity increases at least to 10 mm per hour. Under a small thunderstorm, the polarity of the field is initially positive (directed upward, as the customary physics definition); when the magnitude of the field reaches a few kV/m, there is usually an abrupt negative change due to a lightning discharge, and frequently polarity reversal. When there are large storms, the lightning rate can exceed 20 discharges/min.

The UC observatory is surrounded by a flat urban area. There are no industrial establishments in the vicinity of the observatory. The closest sources of air pollution are the downtown area of México City, and its airport (16 km from the observatory) with frequent air traffic situated in the northeast of the City. In general, the southern region of the Valley of México, Figure 1, is marked by two major topographic features:

a) a horseshoe shape area of ridges that bound the valley to the south forming an East-West oriented two dimensional barrier. The southerly synoptic wind, reaches the top of the ridge slopes from a relatively flat terrain 11.5 km below;

b) the northern sloping region of the horseshoe-shape mountain range is covered with black volcanic basalt (lava). Solar heating and radiational cooling on the lava surface generate strong up slope winds during daytime and down sloped winds at nighttime.

The topography has a marked influence in determining the preferred locations of flashes as found by López *et al.* (1986). Thunderclouds frequently form, develop and dissipate with little horizontal displacement, very seldom above 20 km/h. The cloud base altitude was mainly 1,000 m above the UC station level.

Observers normally report a thunderstorm event after an abrupt increase in rainfall intensity that is followed shortly by a nearby lightning discharge (Remillard, 1960; Shackford, 1960; Takahashi, 1962; Moore *et al.*, 1962). From observations of one thunderstorm, we reported that immediately after a discharge occurred, a rapidly-intensifying heavy rainfall at the ground could be detected at the approximate location observed for the discharge. To test these conclusions, it has been of interest to establish more carefully the series of events at rainfall, and to attempt measurements in proportions of the intensification before and after lightning discharges. Observations were made of summer thunderstorms forming over the southern region of the Valley of México and, as an example, we present, the thunderstorms that occurred on September 1, 1996, August 15, 1994 and August 16, 1994.

Using data from the instruments mentioned previously, experimental evidences of some different behaviors of the electric field variations were found. A total of 26.7 mm of rain in 48 min (from 05:10 to 05:58 fell over UC in September 1, 1996 (Fig. 2). The clouds over the region during this period were very convective. The following history is typical of the sequence of lightning and rainfall usually observed in an active thunderstorm in the Valley of México: As a convective cloud

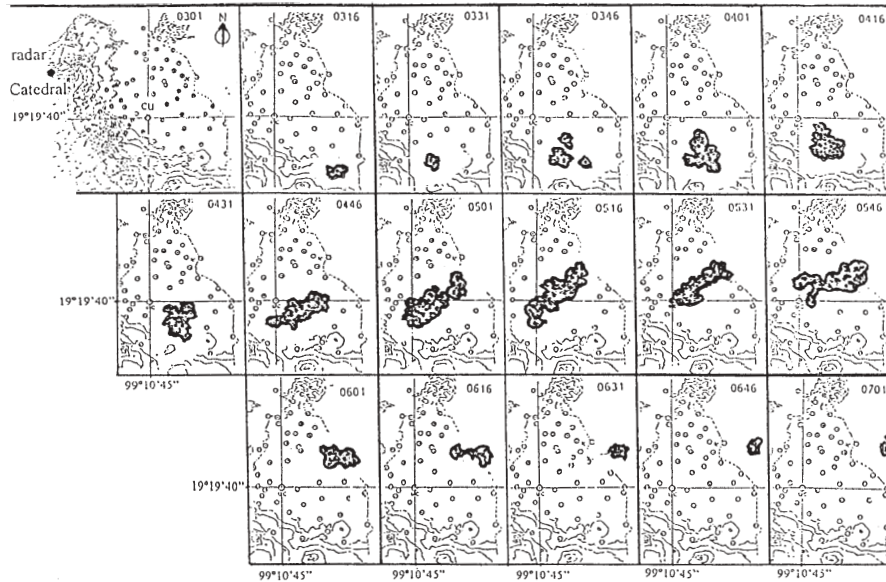


Fig. 2. A mosaic of rainfall (>10 mm) echo areas as detected by the “Catedral” radar, on September 1, 1996 (from 03:16 to 07:00, local time). In the upper right side of each frame, appears the local time. The sequence of frames is from left to right and from top to bottom

grows over the observatory, the cloud base becomes dark and the potential gradient at the summit reverses in polarity, showing the accumulation of negative charge overhead. The negative potential gradient increases in magnitude and point discharge commences from the exposed objects. Soon, discontinuities in the record of potential gradients appear, indicating that the first lightning discharges have occurred; usually these first discharges are completely within the cloud.

During convective processes, the atmosphere developed a series of clouds electrically charged and polarized, in such a way that the first lightning discharges, invariably intra-cloud, occurred, in a first phase. An air-current passing over a mountain range is subjected to various kinds of deformations as described by Queney (1948). The air-flow over the southern volcanic mountain chain (Cuatzin and Ajusco ranges) was apparently modulated by greater low level moisture availability over the low southern plain, with the convective intensity of the southern cells being initially most intense from our size up observations. There seem to be more convective activity, hence, more cloudiness over the southern regions of the Valley than over the northern mountain interior plateau. We should anticipate that mountain ranges differ in their heating and cooling effects in high plateaus. The initial lightning discharge activity began at 02:31 (LT), as it is shown in Figure 3a.

We now proceed with the description of the temporal development of the high discharge count rate period of the atmospheric electrical event. Figure 3a shows the total count rate of the electrical

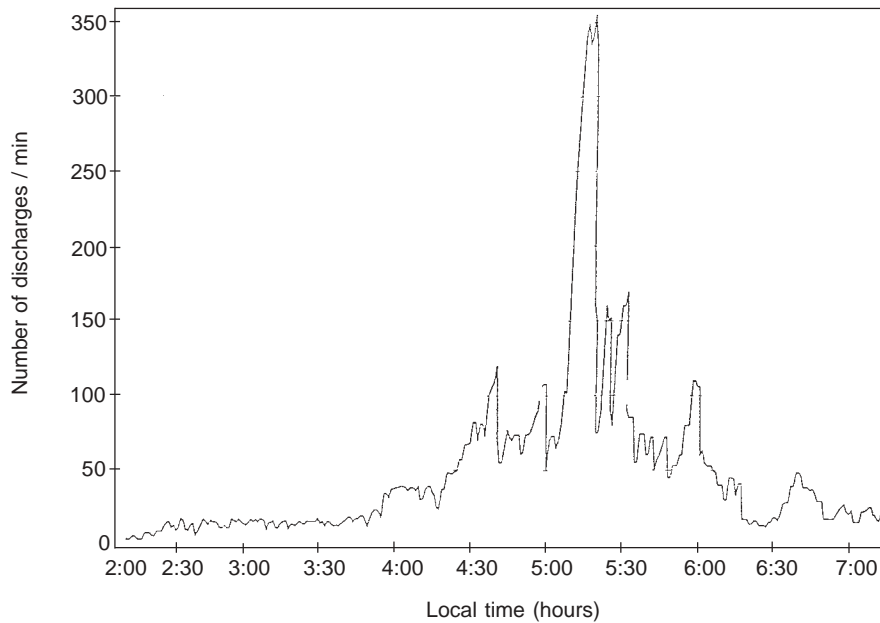


Fig. 3a. Atmospheric electrical activity on September 1, 1996

discharges as a function of time. Beginning at about 02:14 (LT), the discharge flux after 04:11 (LT) very rapidly increases to about 100 times the background level, and then rapidly returns almost to the background level. The high discharge flux has a total duration of about 30 min (Fig. 3a). Data from the network of 66 rain gauges are used to compute an optimum severe rainfall location and to determine its trajectory (Fig. 3b). This event coincides with severe rainfall over a small area as reported by only 13 rain gauge stations (Fig. 2). The initial rainfall time at 03:01 was over the Milpa Alta rain-gauge station, the southernmost station of the network. The rainfall then rises exponentially, runs into the north with different initial times as it reaches up at each station. An increase of the value and scope of enhanced flow and heavy rains fall over the area, occupied by six closed rain-gauge stations from the network, from 04:51 to 05:25. These observations provided some 34 min of heavy rainfall in excess of 22 mm, an intensity of 30.13 mm/h. At 03:16 the “Catedral” radar shows an initial rainfall echo over the same Milpa Alta area. In viewing the radar pictures, the reader should remember that only the same circular plane from the radar is able to be considered in any search for the appearance of new echoes after a lightning discharge. Figure 2 depicts a mosaic of rainfall (> 10 mm) echo areas as detected by the “Catedral” radar. There is a very interesting relationship between the periods of higher count rate of rainfall and the observed lightning activity. This enabled us to correlate lightning strike positions with the location of the cloud systems as obtained from our weather radar and to study the relationship between electrical activity, radar echo intensity, and rainfall rated. The results will be presented in a separate paper.

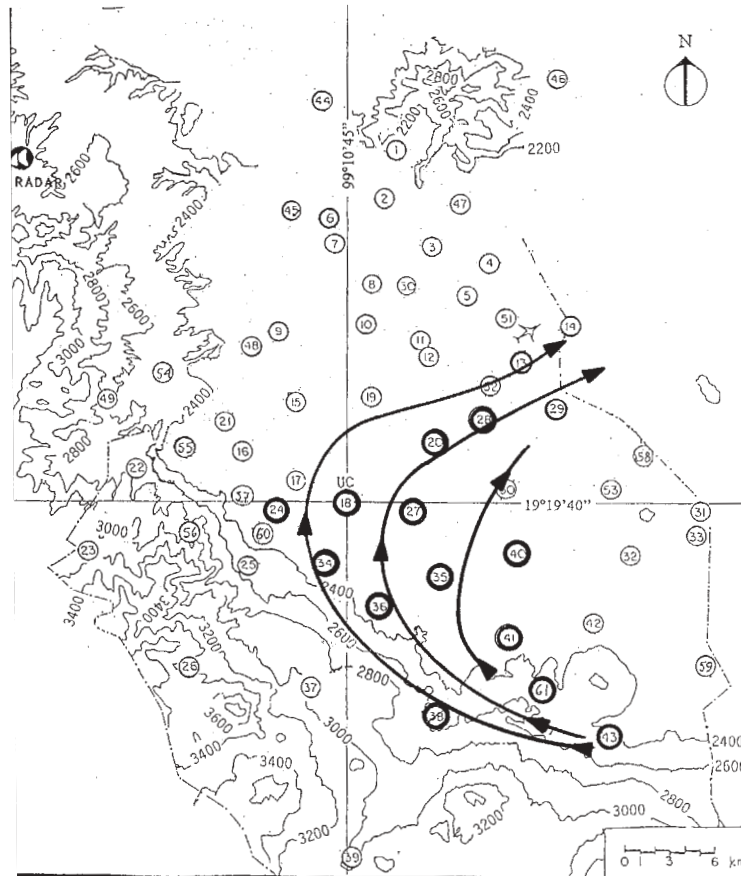


Fig. 3b. Trajectory of the severe storm from 03:01 to 05:45 (local time), on September 1, 1996.

Rain and thunderstorms in the Valley of México area are frequent in the summer season (May-September) (Table 1), and to a much less extent in the autumn and winter (October-April). In this regard, México receives most of the annual lightning activity in the summer months, with its maximum in July.

As pointed out before, in this study we present an initial analysis chiefly based on the UC station data. These sensors confirmed that the UC lightning network detected all the cloud-to-ground flashes produced by the thunderstorms of August 15 and 16, 1994. Storm rain rates are computed from the rain-gauge network as was mentioned before. The trajectories of the severe rainfalls show a concordance with the atmospheric electrical variations (Figs. 4b and 5b). The maximum rainfall rates were in the order of 54.6 and 43.6 mm/h in 15 and 16, August respectively. The

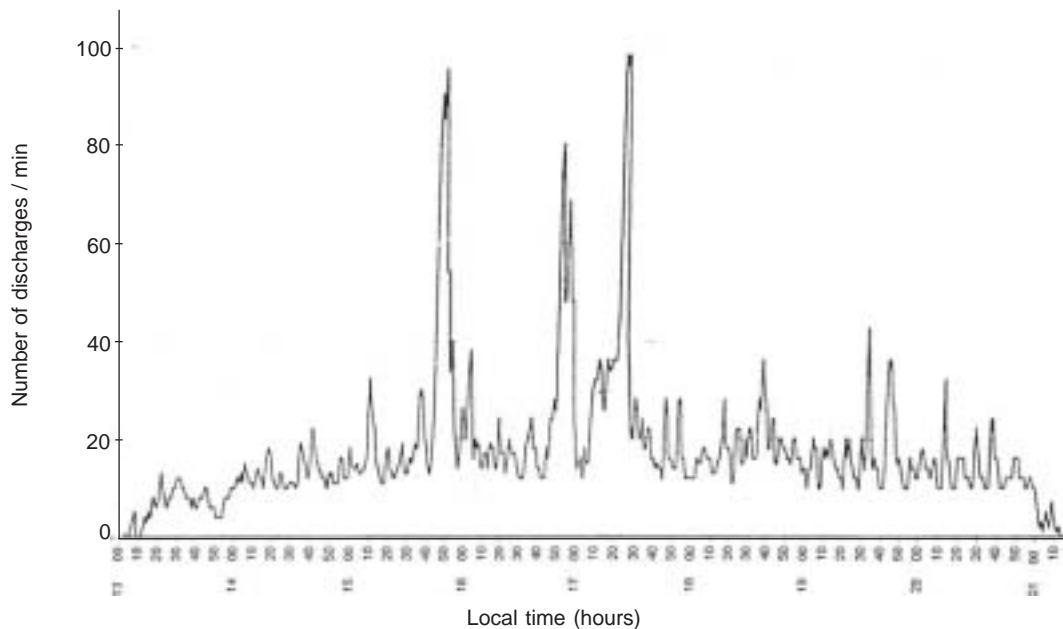


Fig. 4a. Atmospheric electrical activity on August 15, 1994

fraction of intra cloud flashes (90%) produced by these storms is far greater than the more typical values of 50-70% reported for isolated air-mass thunderstorms by Livingston and Krider (1978).

At 13:13, on August 15, the electric field change sensors on the station detected the initial intra cloud discharge from this storm. From 15:43 to 16:05 and from 16:50 to 17:30, the thunderstorm produced a large number of discharges to the ground (Fig. 4a). Multiple stroke discharges are more common during mature and dissipative phases of the storms when the spatial distribution of the charge tends to be complex (Krehbiel, 1986). An abrupt decrease in the total flash rate occurs after the first phase, and again increases, but during the thunderstorm collapse flash activity disappears.

Evolution of the storm of August 16, 1994 (see Fig. 5a for its electrical activity), typifies late afternoon mesoscale convective systems observed in the central México. Genesis occurred along a stationary front in a region of pre-existent thunderstorms that had been triggered initially by daytime heating and had persisted into the evening hours.

By 20:15, a squall line, which presumably developed in response to an advancing lower tropospheric short-wave, began sweeping away the lingering convection to the southeast of the Valley (Fig. 5b).

During the period from January 1 to December 31, 1994 (Fig. 6), several thunderstorms developed over the southern region of the Valley of México. These storms produced severe weather, including large rainfall, some times large hail, and strong winds, as the storm mass moved from south to northeast, across the southern area of the Valley.

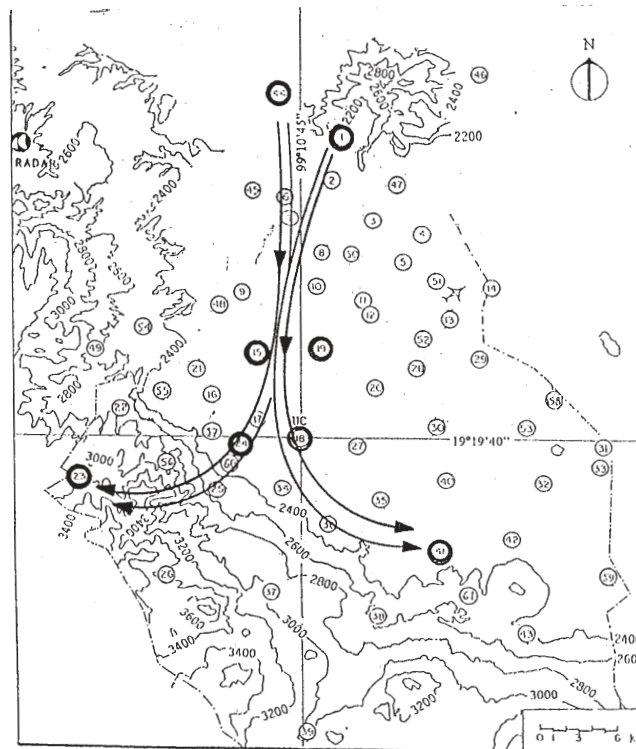


Fig. 4b. Trajectory of the severe storm from 16:00 to 20:10 (local time), on August 15, 1994

As one of our main emphasis in this paper is to examine the frequency of simultaneous atmospheric electrical and rainfall events, and given no radar information availability at that time, we have only used rainfall information from the rain-gauge network. The minimum average rainfall intensity of the storms selected was chosen at 20 mm/h. A period during which the initial, mature and ending time of the variations of the “electro-atmospheric radio frequency noise”, all exceed a threshold, was regarded as one event. The same was done for the “discharge currents” as well as for the “electric fields”. For comparison, Figure 6 shows the monthly distribution of the electrical-to-rainfall events. The annual total was 183 events for the electrical noise detector, 142 events for point discharge currents, and 141 events for electrical field, supplemented by 149 severe rainfalls as measured from the network. The electrical noise total from the table of Figure 6 is too large because the electrical noise detector has a range greater than 100 km, larger than the other sensors. We have imposed the following criteria to all of the observed events: The first condition is the exclusion of data when one of the atmospheric electric variations is not registered at the same time of an occurrence period of enhancement by the other instruments. The second criterion is that detectors must observe the variations to last for nearly the same successive minutes, which enables

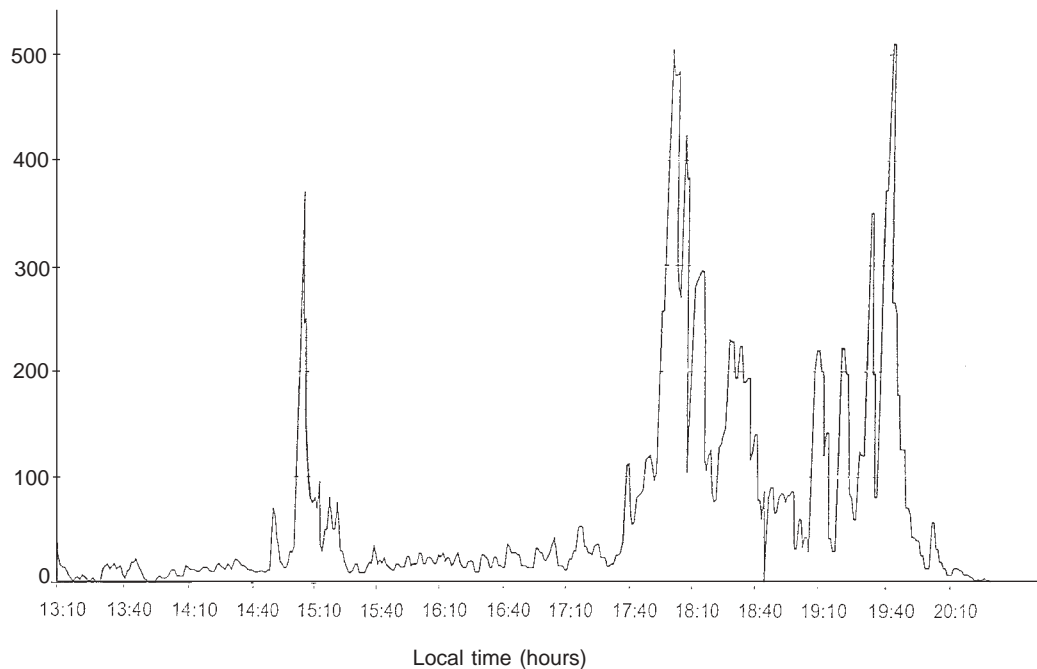


Fig. 5a. Atmospheric electrical activity on August 16, 1994

us to estimate the rate for simultaneity for these events. This criterion is, in turn, indicative of our using only rather intense discharges. A considerable number of rainfall events have been excluded because of the second condition. After applying this second criterion, the number of events in itself is not as large. Due to the first condition, another considerable set of low frequency events has also been excluded. As a conclusion, only electrical events that satisfied the preceding criteria have resulted for inclusion in Figure 6. Also, we have limited our attention only to the question of whether or not a particular kind of severe weather event occurred on a day, not to how many occurred on any particular day. Consequently, the numbers on the Table refer to days with severe weather events during each month.

Some comparisons of the monthly data from our station as well as from the rain gauge network are made with a high number of records during the period May 15-to-September 15, 1994. Within this period, a maximum number of peaks of high frequency took place on the July-August records. Summer thunderstorms in México are usually associated with the passage of hurricanes on the Pacific Ocean at the beginning of the season, and from the Caribbean Sea and Gulf of México during the second half of the summer.

The results of our survey for 1988 to 1999 are presented in monthly averages in Figure 7, those relative to the rainy activity were not included because we did not have data for the twelve years.

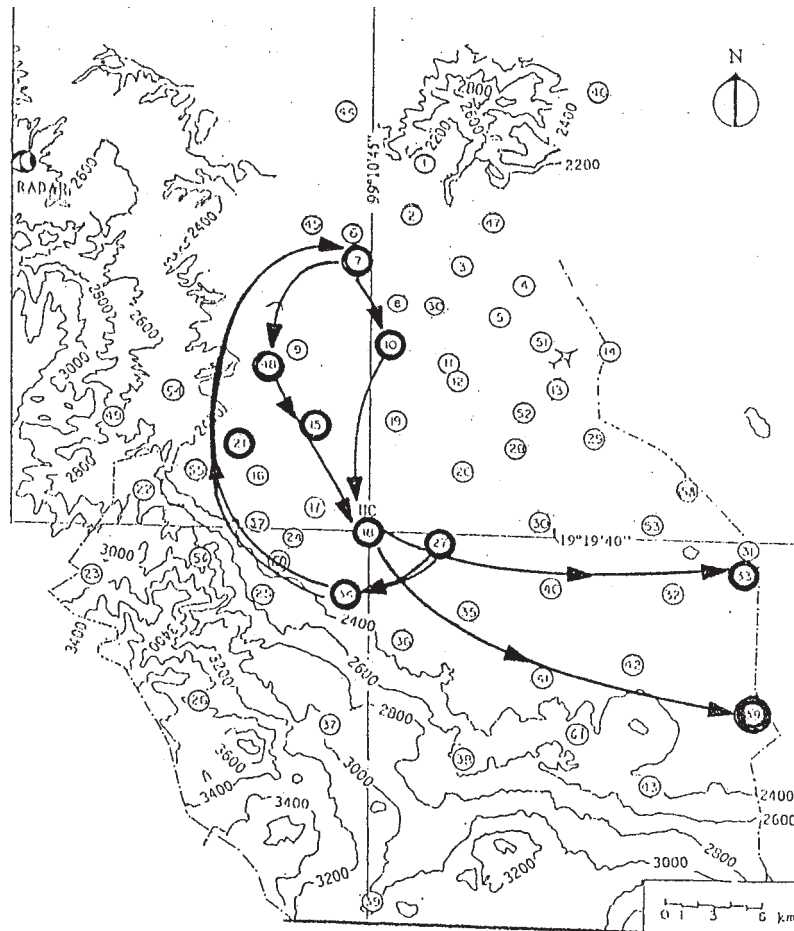


Fig. 5b. Trajectory of the severe storm from 14:37 to 20:13 (local time), on August 16, 1994

To the best of our knowledge, the information presented in this section is the first contribution on the phenomenology of atmospheric electrical discharges in the Mexican region, where no statistics of electrical discharge occurrences have been reported. It can contribute to evaluating the significance of this area, with its unique electrical discharge patterns, to the global distribution of lightning activity. Such real time data are acquired throughout the year on a 24-hour basis by the electrical noise detector and archived in a permanent database that can be accessed by users who do not require real time data. Most, though not all, of the data for point charge and electric field detectors was obtained during daylight hours at the observing station in the local time sector from 06:00-to-22:00. All data sources were analyzed at the time each overlapping. This could provide more details about

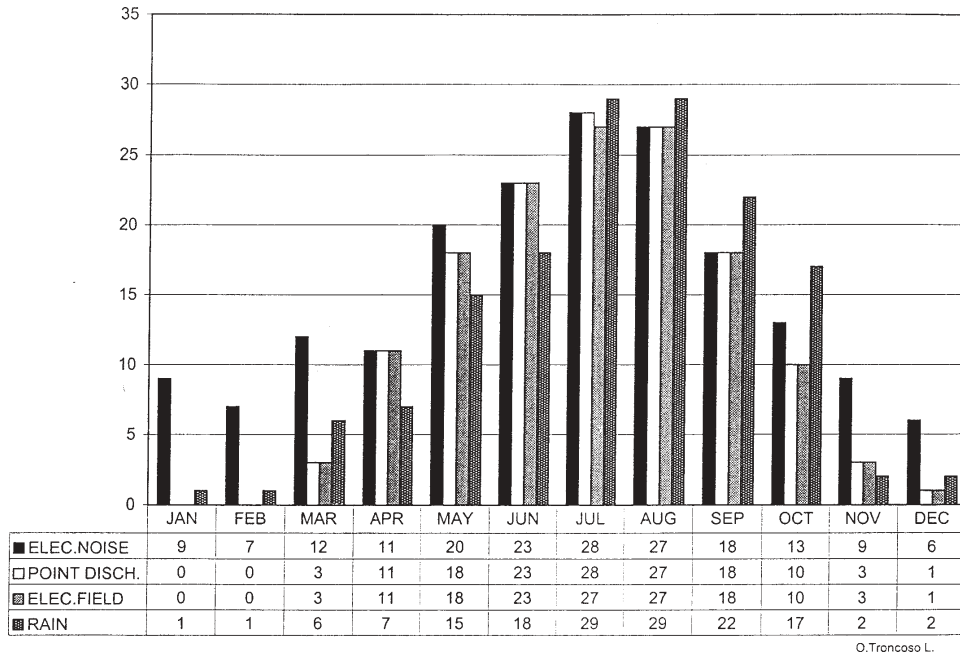


Fig. 6. Histogram and table of monthly atmospheric electrical events and severe rainfalls during 1994

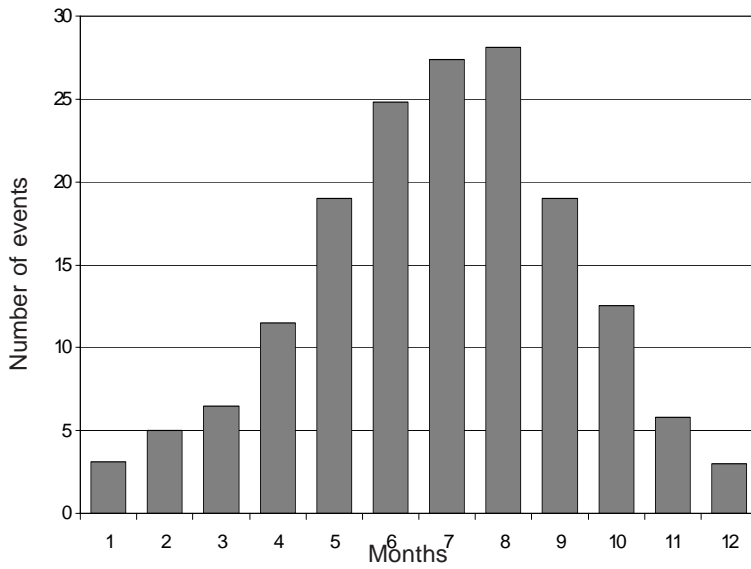


Fig. 7. Monthly average values of atmospheric electrical events from 1988 to 1999

processes of certain basic patterns that develop, and can be identified and followed. The time delay of the onset of raining behind the earlier sudden lightning disturbance is found to lie in a range from 1 to 43 min. The observations of atmospheric electrical events provide direct evidence of an important coupling mechanism between terrestrial electricity and severe rainfall. Further experimental studies should clarify details of the low atmosphere electrical-raining interactions. As was suggested by Anderson *et al.* (1965), lightning characteristics may differ more in different climates than has been suggested so far.

3. Conclusions

The results of a continuing survey for twelve lightning seasons in the Valley of México, from January 1, 1988 to December 31, 1999, based on daily registrations on three punctual lightning detectors is presented in Figure 8 and Table 1. We have computed the lightning occurrence for the corresponding months in consecutive years. The lightning season in Mexico's Valley lasts from June to September. The number of lightning days (defined as the number of days in which lightning is seen visually or a thunder is heard, by a meteorological observer) varies sharply with season from 2 in the winter to 26 in the summer. The lightning producing clouds in this synoptic setting are usually cumulonimbus clouds, with cloud base temperatures of about 5 degrees centigrade, and a vertical dimension of 6-to-9 km. The cumulonimbus are characterized by intense lightning activity and high rain rate, some times accompanied by hail. The thunderstorms in these events (about 62 %) are usually formed over the southern regions of the Valley of México.

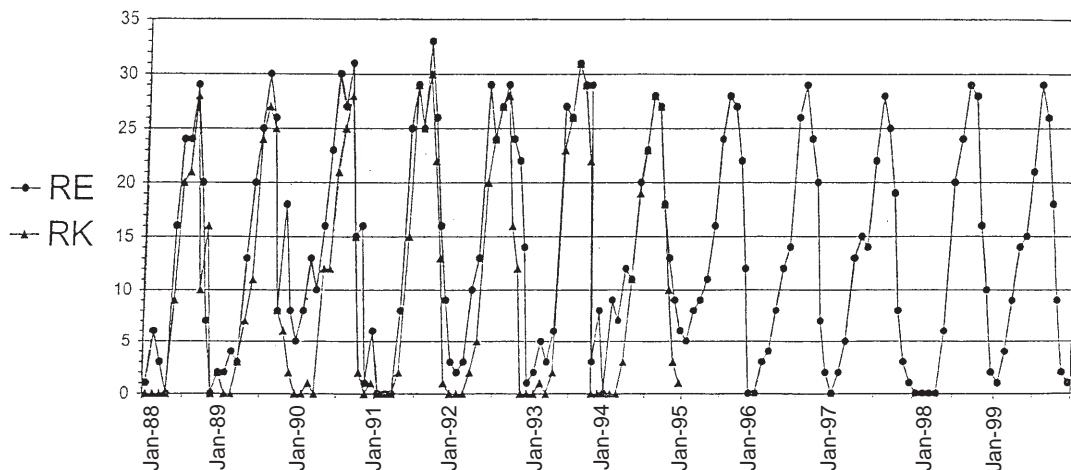


Fig. 8. Monthly records of atmospheric electrical activity from 1988 to 1999. RE = radio noise data; RK = corona point discharge data

The interaction between the evolution of cumulus and landscape discontinuities is highly nonlinear and complicated by various factors such as atmospheric thermodynamic structure and the characteristic length scales of the landscape discontinuities. Its existence and characteristics have been observed in our mountainous region under certain weather conditions of the summer regime.

Measurements made on a mountain summit showed that a high proportion of cloud elements sampled carried appreciable electric charges. Hence, it seems probable that electric charges play an important role in rain formation.

The present study was undertaken based on the data from three punctual sensors with different electrical properties and a rain gauge network. It would be necessary to study many more similar events. New results of such measurements would gain full value only when coordinated and compared with results obtained by other groups with more conventional methods.

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Table 1. Monthly records of atmospheric electrical activity from 1988 to 1999

| Year | 88 | | 89 | | 90 | | 91 | | 92 | | 93 | | 94 | | | 95 | 96 | 97 | 98 | 99 | S/12 |
|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----|----------------|----------------|----------------|----------------|----------------|------|
| Month | R _E | E _K | R _E | R _X | R _E | E _X | R _E | E _X | R _E | R _X | R _E | E _X | R _E | E _X | E | R _E | R _E | R _E | R _E | R _E | P |
| JAN | 1 | 0 | 2 | 0 | 8 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 9 | 0 | 0 | 5 | 3 | 2 | 0 | 1 | 2.9 |
| FEB | 6 | 0 | 4 | 0 | 13 | 1 | 0 | 0 | 3 | 0 | 5 | 1 | 7 | 0 | 0 | 8 | 4 | 5 | 0 | 4 | 4.9 |
| MAR | 3 | 0 | 3 | 3 | 10 | 0 | 0 | 0 | 10 | 2 | 3 | 0 | 12 | 3 | 3 | 9 | 8 | 13 | 0 | 9 | 6.7 |
| APR | 0 | 0 | 13 | 7 | 16 | 12 | 8 | 2 | 13 | 5 | 6 | 2 | 11 | 11 | 11 | 11 | 12 | 15 | 0 | 14 | 9.9 |
| MAY | 16 | 9 | 20 | 11 | 23 | 12 | 25 | 15 | 29 | 20 | 27 | 23 | 20 | 19 | 19 | 16 | 14 | 14 | 6 | 15 | 18.8 |
| JUN | 24 | 20 | 25 | 24 | 30 | 21 | 29 | 29 | 24 | 24 | 26 | 26 | 23 | 23 | 23 | 24 | 26 | 22 | 20 | 21 | 24.5 |
| JUL | 24 | 21 | 30 | 27 | 27 | 25 | 25 | 25 | 27 | 27 | 31 | 31 | 28 | 28 | 26 | 28 | 29 | 28 | 24 | 29 | 27.5 |
| AUG | 29 | 28 | 26 | 25 | 31 | 28 | 33 | 30 | 29 | 28 | 29 | 29 | 27 | 27 | 27 | 27 | 24 | 25 | 29 | 26 | 25.8 |
| SEPT | 20 | 10 | 8 | 8 | 15 | 15 | 26 | 22 | 24 | 16 | 29 | 22 | 18 | 18 | 18 | 22 | 20 | 19 | 28 | 18 | 20.6 |
| OCT | 7 | 16 | 18 | 6 | 16 | 2 | 16 | 13 | 22 | 12 | 14 | 0 | 13 | 10 | 10 | 12 | 7 | 8 | 16 | 9 | 12.3 |
| NOV | 0 | 0 | 8 | 2 | 1 | 0 | 9 | 1 | 14 | 0 | 8 | 0 | 9 | 3 | 3 | 0 | 2 | 3 | 10 | 2 | 5.5 |
| DEC | 2 | 2 | 5 | 0 | 6 | 1 | 3 | 0 | 1 | 0 | 0 | 0 | 6 | 1 | 1 | 0 | 0 | 1 | 2 | 1 | 2.3 |
| TOTAL | 132 | 90 | 157 | 110 | 196 | 115 | 174 | 127 | 198 | 126 | 180 | 130 | 169 | 143 | 141 | 157 | 138 | 149 | 136 | 149 | |

References

- Anderson, R., S. Björnsson, D.F. Blanchard, S. Gathman, J. Hughes, S. Jónasson, C.B. More, H.J. Survilas and B. Vonnegut, 1965. Electricity in volcanic clouds. *Science*, **148**, 1179-1189.
- Ette A.L.L. and E.U. Utah, 1973. Studies of point discharge characteristics in the atmosphere, *J. Atm. Terr. Phys.*, 1799-1809
- Krehbiel, P.R. 1986. *The electrical structure of thunderstorms, in The Earth's Electrical Environment* (E.P. Krider and R.G. Roble, eds.) Nat. Acad. Press, Washington, D.C., p. 90-113.
- Livingston J.M. and E.P. Krider, 1978. Electric fields produced by Florida thunderstorms, *J. Geophys. Res.*, **83**, 385-401.
- López R.C., J.R., Doguherly and R.L. Holle, 1986. Some relationships between radar echoes and lightning from mapping systems. 23rd Conf. On Radar Meteor. and Conf. on Cloud Physics. Snowmass, Amer. Meteor. Soc.
- Milner, J. W. and J. A. Chalmers, 1961. Point discharges from natural and artificial points (Part II), *Q. J. R. Meteorol. Soc.*, **87**, 592-596.
- Moore C.B., B. Vonnegut, J.A. Machado and H.J. Survillas, 1962. Radar observations of rain gushes following overhead lightning strokes. *J. Geophys. Res.* **67**, 207-220.
- Queney, P., 1948. The problem of airflow over mountains: a summary of theoretical studies. *Bull. Amer. Met. Soc.*, **29**, 16-26.
- Shackford, C.R., 1960. Radar indications of a precipitation-lightning relationship in New England thunderstorms. *J. Meteor.*, **17**, 15-19.
- Takahashi, T., 1962. Electric charge generation by breaking ice pice. *J. Meteor. Soc., Japan*, Ser. **2**, 40, 277.
- Troncoso, O.L., 1987. Study of electric field changes accompanied by atmospheric radio noise at 10 KHz at México Valley. *Rev. Mex. Fis.*, **33**, 247-263.