BILINGUAL PUBLISHING CO.
Pioneer of Global Academics Since 1984

**Journal of Atmospheric Science Research**
https://ojs.bilpublishing.com/index.php/jasr

ARTICLE

# Review and Microphysics of the Maximum Electricity Atmospheric Activity in the World: the Catatumbo Lightning (Venezuela)

**Nelson Falcón***

Universidad de Carabobo, FACYT, Dpto de Física, Laboratory of Physics of the Atmosphere and Ultraterrestrial Space, Apdo. Postal 129 Avda, Bolívar Norte, Valencia 2001, Carabobo, Venezuela

ARTICLE INFO

*Article history*
Received: 28 December 2020
Accepted: 22 February 2021
Published Online: 21 May 2021

*Keywords*:
Catatumbo lightning
Atmospheric electricity
Microphysical of cloud
Aerosols
Methane

ABSTRACT

A review of the state of knowledge and phenomenology on the site of the greatest atmospheric electrical activity in the world, known as the Catatumbo Lightning, located southeast of Lake Maracaibo (Venezuela), is presented. A microphysical model is presented to explain the charging process through electrical displacement within the cells of the cloud, incorporating the role of the self-polarization of ice and methane molecules as pyroelectric aerosol, which accounts for the phenomenology and is consistent with electrification in thunderstorm. It is concluded that the pyroelectric model allows to explain the phenomenology of the rapid discharges of the flashes in the Catatumbo lightning and could be applied in outer planetary lightning.

## 1. Introduction and Overview

In the last decades the development of geomantic has made possible the remote sensing of electro meteors on a global scale thanks to the lightning detection systems: the Lightning Imaging Sensor (LIS) [1] and the World Wide Lightning Location Network (WWLLN) [2]. In addition to the advances that this has meant for the understanding of the global electrical circuit, these satellite systems have established the regions with the highest keraunic activity (atmospheric electricity level) in particular they have corroborated that the region south of Lake Maracaibo (Venezuela) as the largest lightning hotspot [3-5].

The electro meteors such as flash lightning and discharges cloud-cloud lightning are common in the whole region to the south of the Maracaibo lake (Venezuela) including the deltas of the rivers Catatumbo and Brave [6-8], where the report the highest flash rate (FDR) of the planet: 232,52 flash km$^{-2}$ years [5].

This phenomena, well-known as the Catatumbo Lightning or Maracaibo Lighthouse, is characterized by the persistent occurrence nocturnal of a dry lightning,; without rain nearby, and whose brightness in the sky, during almost the whole year, is such that it can be seen from far away. It`s can be observed from the Caribbean sea, in most of southwestern Venezuela, until the river Magdalena in Colombia.

The epicenter area of the Catatumbo Lightning doesn’t

**Corresponding Author:*
*Nelson Falcón,*
*Universidad de Carabobo, FACYT, Dpto de Física, Laboratory of Physics of the Atmosphere and Ultraterrestrial Space, Apdo. Postal 129 Avda, Bolívar Norte, Valencia 2001, Carabobo, Venezuela;*
*Email: nelsonfalconv@gmail.com*



DOI: https://doi.org/10.30564/jasr.v4i2.2740

vary from its first mention written by Lope de Vega (1534) [9]. The naturalistic Alexander von Humboldt (1807) describes the phenomenon like "electric explosion that are as phosphorescent radiances" [10] and geographer Agustín Codazzi (1841) points [11] out him as a continuous lightning for almost every night of the year, even in the period of drought.

Both 19th-century naturalists stand out the peculiar phenomena of Catatumbo Lightning: the persistent nocturnal flash of the Lightning (intra-clouds, without cloud-ground discharges) produced by a thunderstorm that is unaccompanied by rain. Also that is observed in direction of southeast of Maracaibo city, and the west of Santa Barbara city (Zulia state) during for most of the year; and consequently occurs outside of the Maracaibo lake. This observations have been confirmed by the expeditions of the of the Centeno and Zavrostky in the 20th-century [12-14] and most recently by the expeditions of the Falcon and Piter in 21th-century [6,7,15,16] in the interior of National park "Cienagas de Juan Manuel" ; that is a swampy region of about 226,000 acres in southwest of Maracaibo lake. This region, that contains the epicenters of the nocturnal flash of the intra-clouds discharges [6,17], is limited by the Santa Ana river basin in the north, and by Catatumbo river at south. The west limit is the regional road between towns Machiques and Casiguas The Cube; and the east limits are the deltas of these rivers and Maracaibo lake (Figure 1).

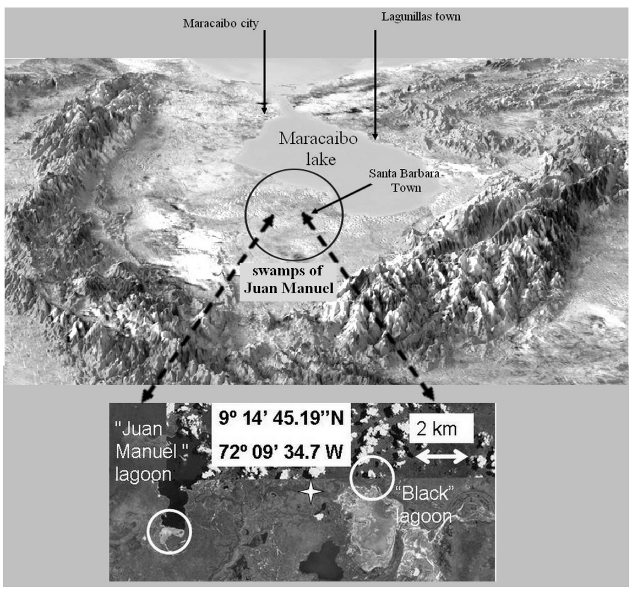


**Figure 1.** Geoposition of Catatumbo Lightning epicenters (Own source). The coordinates of center in the map is denote with cross .

Keraunic activity maps are prepared by counting discharges (in VLF and HLF band) detected by the satellite during its flight on a given day, and dividing by the reference area. The statistics are repeated for various daily overflights, and are expressed in terms of number of discharges per year and per unit area ($km^{-2}$). This process generates a bias in the distribution since cloud-ground lightning discharges are more conspicuous than intra-cloud flashes; and the latter is not always accounted for by remote sensing when they occur simultaneously. The result is the underestimation of the atmospheric electrical activity in the swamps where the epicenters have been located by in situ observation from the ground. Thus, the epicenters reported by Albrecht and collaborators appear displaced towards the center of Lake Maracaibo in the direction of the town of Lagunillas [5], very distant from the Catatumbo river itself, for whose toponymy the phenomenon has been named (Figure 1). The same bias is repeated by other authors who use only satellite observations instead of in situ exploration of the region, despite being in close proximity [18].

Bypassing the dry, nocturnal, persistent and localized character of the Catatumbo lightning, by remote sensing bias, involves the simplification of interpreting the electrical activity of the Catatumbo lightning only as cloud-ground discharges [18,19], which certainly take place the shores of Lake Maracaibo, where storm clouds are discharged with rain.

**Figure 2.** General view of the Catatumbo lightning, towards the center of the Juan Manuel swamps (Own source). Top panel (Left) From Bravo river (09º 14' 15" N 72º 06' 31" W 41 m asl). (right) from lagoon "La Negra" (09º 14' 13" N 72º 06' 33 W 36 m asl) . Bottom panel from pile-dwelling "Punta Chamita" (09º 05.77' N 71º 42.88' W 1.96 m asl). [6,7]

Figure 2 shows the appearance of dry lightning, from its epicenters adjacent to the Catatumbo River. The on-site observations of the Catatumbo lightning, from the epicenters in swamps of the "Juan Manuel", from Santa Barbara city (Zulia) and even from the Maracaibo city, show that the flashes of the discharges occur repeatedly in the same cells of the cumulus-nimbus anvil cloud with periodicity

 DOI: https://doi.org/10.30564/jasr.v4i2.2740 

average of 28 flashes per minute [10-19]. In Figure 3 the selected sequence of the rapid flashes of the Catatumbo lightning is shown; Also note that the phenomenon appears towards the swamps, in the opposite direction to Lake Maracaibo. Then the characteristic times for the recharge of the cloud cell are of the order of 0.46 seconds which is a much shorter period, in three orders of magnitude, than the free fall time of the drops inside the cell of the cloud. Therefore, any charging mechanism, based on the decay, rupture and coalescence of raindrops within the storm cloud is insufficient for the continuous generation of cell recharge.

The usual explanation of electrical activity as the phenomenology of the Catatumbo lightning is attributed to the presence of convective flows, typical of the inter-tropical regions favored by the diurnal warming and by the thermal gradients between cloud and ground in the stormy zones with abundant convective movements [19]. Notice that the convective model does not explain for itself the electrical activity but rather the rainfall. To explain the lightning flashes, it is needed to add a series of very debatable models which could cause the separation of charges in thunderclouds [20]. And consequently the synoptic and mesoscale considerations invoked by some authors [18,19] do not explain electrical activity; neither they provide any hypothesis of which mechanism is responsible for the transformation of available convective energy into electrical energy [18].

The classical picture about charge generation inside thunderstorms involved convection and particle charging. The convective mechanism describes the cloud electrification without any charge transfers during the particles collisions but only by convection which redistributes the charge attached previously by hydrometeors [21,22]. However the electric field is two orders of magnitude smaller than the minimal break down field. Therefore this mechanism by itself is insufficient to generate the intracloud electric field required for lightings [23,24]. The charged particles will be separated thereafter by convection and gravitation due to their different masses, during collision and rebounding between ice particles and other hydrometeors, but this particle charging mechanisms is only valid for short ranges of cloud-temperature and result insufficient for the upper charge to look in thunderclouds [20, 24].

Since there has been no experiment to confirm conclusively the classical model of atmospheric electricity, thunderclouds as the sources of the global electric circuit; it remains a subject of debate [25]; moreover the mechanism of initial charge generation is quite controversial [25,26]. Field measurements and numerical model show that electrification of particles in thunderclouds is accomplished on the order of ten minutes after the initial precipitation within the cloud, in conflict with the predictions in the particle charging mechanism [26]. Also lightning flashes have been reported in volcanic eruptions, in Martian dust storms and other extraterrestrial atmospheres, as Jupiter, Saturn, Uranus and Titan [23,27,28].


**Figure 3.** Flashes of the Catatumbo lightning (Own source). View towards “Juan Manuel” swamps. (in the opposite direction to Maracaibo Lake), on the banks of the Catatumbo River, from “Encontrados” town (9°10′41″N 72°14′09″W 6 m asl). Notice the flashes are produced by a thunderstorm that is unaccompanied by rain neither cloud-ground discharges.

As the physical chemistry of aerosols, ice crystal and graupel, into the storm clouds, is associated to the generations of the atmospheric electrical phenomena can be we are question: What mechanism allows us to explain the transformation of available convective energy into electric potential energy, capable of accounting for the phenomenology observed in the Catatumbo lightning?. Particularly, how is the process of recharging the cloud cells (inside the thundercloud) to give the rapid succession of the flashes? A plausible mechanism for the charge generations and separation process inter clouds could be the electrical self-polarization, or pyroelectricity of some atmospheric aerosols; the pyroelectrics materials have the property of polarized spontaneity due to the intrinsic symmetry of the molecules that constitute it, this implies that the electrical displacement vector is not null, even without the presence of external electric fields [29,30].

The objective of the present work is to evaluate the role of the electrical auto polarization (pyroelectricity), due to intrinsic molecular geometry of aerosols into the thunderclouds charge process. For this we present the general model in seccion 2, the contribution of aerosols to electrical displacement vector, together with the discussion phenomenology about Catatumbo lightning in section 3; and the remarkable conclusions in the last section.

  DOI: https://doi.org/10.30564/jasr.v4i2.2740

## 2. Basic Assumptions and Microphysics Description

We consider an only and isolated thundercloud in hydrodynamic equilibrium, constituted by several cloud cells, between 1.6 km and 14 km of altitudes. The volume of unitary cell is ≈5 $10^{10}$ $m^3$, with cubic geometry and 3.6 km the side, of locates to an altitude between h and h+d of the surface. The cloud cell is in a region very near to planetary boundary layer. In the atmosphere without clouds, below to 60 km of altitude, there is an electrical vertical field which intensity for average latitudes, is given by [31]:

$$\vec{E}(z) = -[93.8e^{-4.527z} + 44.4e^{-0.375z} + 11.8e^{-0.121z}]\,\hat{z}\ KV\ /\ Km \tag{1}$$

Where z is the altitude in kilometers.

The electrical potential difference in a cubic unitary cell, isolated (air cell without aerosols), change monotonously with the altitude, together the variation of the electric field. In the lower troposphere also the pressure and the temperature decrease monotonously (Figure 4). If the potential difference is smaller than 1000 KV (dielectric break down for humid air) or 3000 KV (dielectric break down for dry air) there are not electrical discharges. Then Figure 4 show that the cell, in absence of steam condensation and the aerosols, does not reach the dielectric break down potential of the air.

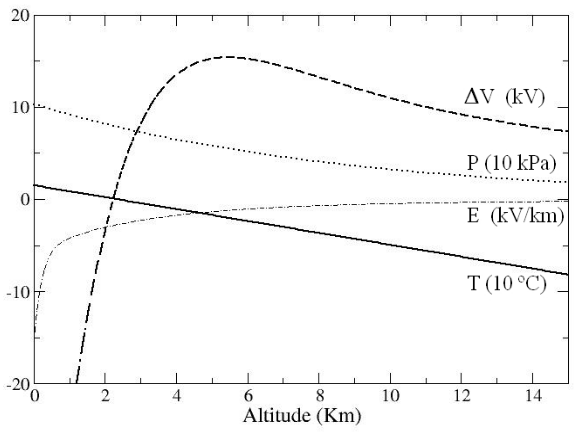


**Figure 4.** Physics magnitudes in the lower troposphere [30].

Now, we consider every cloud cell as a collection of molecular dipoles in thermal equilibrium. The Maxwell distribution of the molecular electrical dipoles contains all the possible orientations of the dipolar moment respect to the atmospheric electrical exterior field. If *n* denote the value spreads on the total number of molecules and *p* is the dipolar moment at the temperature *T*, then the electrical displacement average D, is:

$$\langle \vec{D} \rangle = \frac{\int \varepsilon \vec{E} \exp\left(-\frac{\vec{p}.\vec{E}}{k_B T}\right) dn}{\int \exp\left(-\frac{\vec{p}.\vec{E}}{k_B T}\right) dn} \tag{2}$$

With $k_B$ the Boltzmann constant, *E* is the atmospheric electric field and T the effective temperature.

The probability to found a molecule with the dipolar momentum vector in an angle a with the external electric field is equal to the area differential $dA = 2\pi r^2 sen\alpha\, d\alpha$, and then the differential fraction of the molecules number in the differential section of area is: $dn = dA/(4\pi r^2)^{-1} = (1/2)\, d(\cos\alpha)$; Consequently we can write

$$\langle \vec{D} \rangle = \frac{\int_{-1}^{1} \varepsilon \vec{E} \cos\alpha \exp\left(-\frac{\vec{p}.\vec{E}}{k_B T}\right) d(\cos\alpha)}{\int_{-1}^{1} \exp\left(-\frac{\vec{p}.\vec{E}}{k_B T}\right) d(\cos\alpha)} = \varepsilon_0 K\, E \tag{3}$$

We must study the mesoscopic aerosols, which act to intermediate scales in the convective clouds; limiting ourselves to those that for its chemistry composition in the air, present a dipolar moment electrically auto induced, and which relative abundance is a significant fraction of the air.

All of this leaves us basically with the water-ice and methane, in tetrahedral symmetry, of the symmetry group $T_d$ in Schoflield's notation. It must be considered that the crystalline configuration of the methane belongs to the $C_4$ symmetry group (it excludes the *NaCl* that is a cubic system). These molecules and its microcrystal are pyroelectrics, which polarize spontaneously when have been formed crystals lacking of symmetry centers. The electrical displacement vector is [29]:

$$\vec{D} = \vec{D}_0 + \vec{P} + \varepsilon_0 \vec{E} \tag{4}$$

With *P* is the polarization and *E* is the external electric field, i.e. the atmospheric electric field. The pyroelectricity is a property of certain materials are naturally electrically polarized and as a result contain large electric fields; those is: occur an electrical displacement, although the external field and the polarization are doing nulls.

In effect the crystals formation of pyroelectrics type in the cloud might create spontaneous dipolar fields, so as that the aerosols crystallize under some types of symmetry $C_1$ triclinic, $C_S$ or $C_2$ monoclinic, $C_{2v}$ rhombic, $C_4$ or $C_{4v}$ tetragonal, $C_3$ and $C_{3v}$ rhombohedra or $C_6$ and $C_{6v}$ hexagonal. The water-ice and the methane are tetragonal symmetry (Figure 5). We must estimate the average value of electrical displacement *D* for the water-ice and Methane.

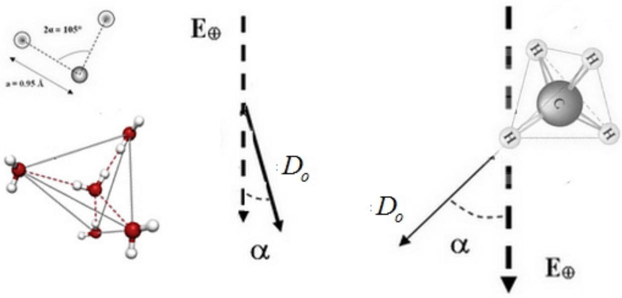

**Figure 5.** Tetrahedral molecular symmetry (Own source). The dipole moment is oriented, a degrees with respect to the atmospheric electric field. Water (left) Methane (right).

For the water and water-ice, the whole cloud cell from the altitude h to the top level h+d; with d the typical thickness of the cell:

$$\langle D\rangle_{H_2O} = \frac{\varepsilon_0}{d}\int_h^{h+d} k_{H_2O}(z)\,E(z)dz \qquad (5)$$

Where $K_{H2O}$ is the electrical conductivity of water, as function of altitude (z); the altitude (z) is also function monotonous of the temperature T in the troposphere.

To calculation the intrinsic electrical displacement $D_0$ , we will suppose a cloud-cell of methane as diluted (ideal) gas, in absence of external fields. Using the Gauss Law we obtained that intrinsic electrical displacement is equivalent to the superficial charge density ($\sigma$); this can be interpreted as, if in every point of the cell, the field is produced by the most near molecule of methane; despising the contributions of others molecules in conformity with the approximation of ideal gas, it is valid to suppose that $x \sim a$. Using the same approximation for the electric field intensity E, in the z-axis, for the methane then:

$$E_{dipole} = \frac{1}{4\pi\varepsilon_0}\frac{|\vec{p}|}{r^3} = -\frac{4}{4\pi\varepsilon_0}\frac{q2a.\cos\alpha}{\left(x^2+a^2\right)^{3/2}} \approx \frac{e\cos\alpha}{\sqrt{2}\,\varepsilon_0\pi a^2} \qquad (6)$$

Where *e* the electrons charge and *p* is the electrical dipolar momentum.

We assume that the local field is produced only the interaction between first neighbours. Since, as the Gaussian approximation for the cell is independent, in the classic description, of the volume of the cell, we have that in the limit case of a monomolecular cell, both expressions of electric fields must coincide ($E_{dipole} \sim \sigma/\varepsilon_0$), follows that [32]:

$$D_0 = \sigma \approx \frac{e\cos\alpha}{\sqrt{2}\,\pi\, a^2} \approx 6.93\left[\frac{C}{m^2}\right] \qquad (7)$$

If the cell is uniform, its charge density remains constant, treating a monomolecular cell or treating of a macroscopic cell, the cloud cell composition is a fraction ($0 \le f \le 1$) of methane, in this case the intensity of the auto induced field, in virtue of the realized approximations, finally we obtain for the molecule of methane:

$$E_0 \cong f\,\frac{6.93}{\varepsilon_0}\left[\frac{C}{m^2}\right] = 7.83\,10^{11}\; f\left[\frac{V}{m}\right] \qquad (8)$$

For the methane (in the cloud-cell of water and methane), the total electrical displacement, is the intrinsic pyroelectric displacement $D_0$ plus the induced by the electrical atmospheric field; the latter term can be calculated as in watery cell. The dielectric constant of the methane, in the low troposphere, is 1.67 [33]. Then in cloud cell the average value for the methane is:

$$\langle D\rangle_{CH_4} \approx 6.93\, f\left[C/m^2\right] + 1.67\,\frac{\varepsilon_0}{d}\int_h^{h+d} E\,dz \qquad (9)$$

The methane ($CH_4$) is the main element of the terrestrial atmospheric with pyroelectric properties, sixth atmospheric component (0.000187%) and its pyroelectricity has associate to generation of the Catatumbo Lightning [6,7], the maximum hotspot lightning in the world. Also in watery derivatives, the methane hydrides present in permafrost, have relevant activity in oceanic climatology. The methane is also the main ingredient of natural gas and other fossil fuel-energy resource. Besides the methane has been considered as an important factor in the formation of lightning in Titan [23,34] and the methane clouds have been associated with lightning in Jupiter, Saturn and Uranus[27,28].

## 3. Results and Discussion: Charge Process and Catatumbo Lightning

Now consider an unitary cloud-cell the water and methane; in accords with (4) then by the electric displacement vector is:

$$\vec{D} = \vec{D}_0 + \vec{P} + \varepsilon_0\vec{E} = \vec{D}_0 + \varepsilon_0(\chi_{H_2O} + \chi_{CH_4})\vec{E} + \varepsilon_0\vec{E} \qquad (10)$$

And, using (5) and (9), the average value is:

$$\langle D\rangle \approx 6.93\, f\left[C/m^2\right] + \frac{\varepsilon_0}{d}\int_h^{h+d} k_{H_2O}E\,dz + k_{CH_4}\frac{\varepsilon_0}{d}\int_h^{h+d} E\,dz - \frac{\varepsilon_0}{d}\int_h^{h+d} E\,dz \qquad (11)$$

Note that even for a null external electric field (E) there will be an electric displacement due to D0. The contribution of the polarization P and the self-polarization D0 increase the charges separation into the cell and possibilities the electronic avalanche for caused the intra-clouds lightning.

Using the variation with the temperature of the dielectric constant of water (in the lower troposphere the temperature decrease monotonously), we can found the electrical displacement into the clouds cell (Figure 6). We



DOI: https://doi.org/10.30564/jasr.v4i2.2740

use a methane concentration inside the cloud cell thousand times minor (f = 2 $10^{-9}$) to the average atmospheric composition. It is observed that for cloud cells between 2 and 15 km of altitude, the magnitude of the electrical displacement due to water vapor is only a fraction of the dielectric breakdown voltage of air; but its value increases significantly if the contribution of methane is considered, even for concentrations of one thousandth of the standard atmospheric composition. Note that in this tropospheric range the methane remains in the gas phase. Also we can see (Figure 6) that the potential produced by the electrical displacement D is a thousand times greater than the atmospheric electric field (Figure 4).

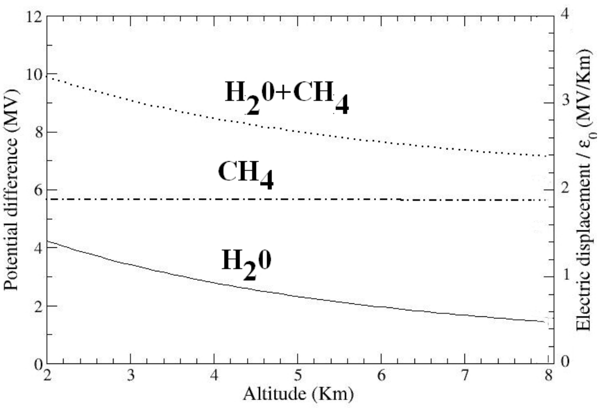


**Figure 6.** Electrical contributions of water and methane in cloud cell. (Own source).

In Figure 6 it is observed that the electric potential in the water cloud cell, decreases monotonically from the altitude of 2 km (maximum) and is always lower than the dielectric breakage electric potential of the air (0.4-3) MV / m. However, the incorporation of methane as an aerosol in the cloud cell, even for concentrations of one thousandth of the standard atmospheric composition, would have electric field intensity 2.5 times higher, and consequently the dielectric breakdown potential would be reached. In any case, the contribution of methane to the electric field in the cloud cell is always higher than the aqueous contribution that decreases with altitude.

The pyroelectricity is a molecular phenomenon, it does not depend on the solid or gaseous phase [29], so that methane, even when in gaseous form, must contribute to the electrical displacement in the cloud cell; whether it is trapped in water ice, or mixed with steam (aqueous solubility 0.033%). This is the simplest hydrocarbon and is part of the atmospheres of the gaseous planets (Jupiter, Saturn, Uranus and Neptune) where lightning has been detected [28]; It is also the main atmospheric component of Titan's atmosphere, where it carries out a cycle of evaporation-condensation and precipitation with significant electrical activity [23-27]. Methane performs, in that satellite of Saturn, a cycle analogous to the water cycle on Earth (hydrological cycle).

In the electrical equivalent model of the storm cloud, the associated capacitance of the cell can be calculated at different altitudes (Telluric Capacitor Model) whose results [30] are shown in Figure 7 (Left). The maximum charge acquired by the cloud cell is limited by the dielectric breakdown voltage of humid air $\Delta V \approx 1$ MV, necessary for electrical activity to manifest. Suppose a cubic cell of 12.96 $km^2$ in area and different thickness; the total electrical charge of the cell is obtained as a function of altitude (Figure 7 right). It is observed, regardless of the size of the cloud cell, the charge values converge to the same value of approximately 25 C, which is in accordance with registered numerical values [24-31]. Also, at the height of 2 km, which is approximately the lowest height where the storm clouds are found, the value of the charge is null. The maxima electrical charge occurs at altitude at the 5 km, as the typical elevation of the cloud in Catatumbo lightning [15,16].

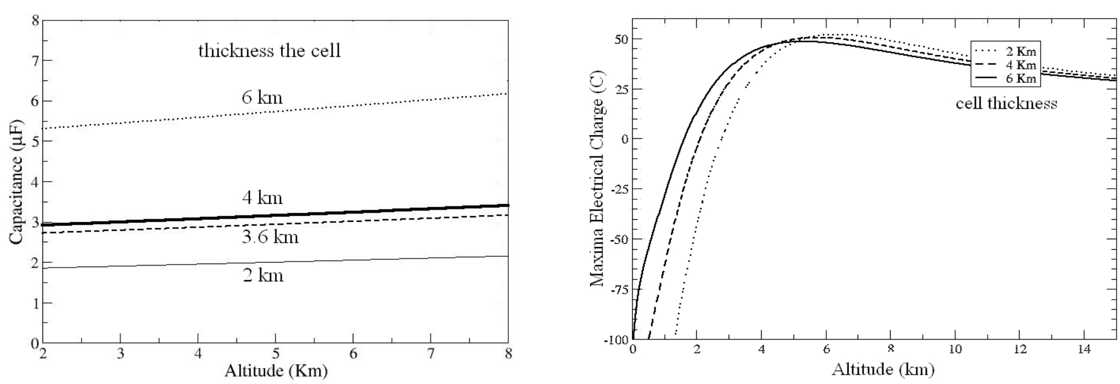


**Figure 7.** Electrical capacitance of the watery cell a different thickness (Left) [30]. Maxima electrical charge in the cloud cell before discharge (Right).

If only the influence of the water is considered, the breakdown potential, it is not sufficient for a discharge; namely the values of charge are insufficient to produce a discharge or lightning flash; even more, the results we obtained for the charge of a cloud cell are of the order of 20 microamperes, which certainly is a negligible quantity, when we speak about the charge of a body of very big size as a cell of thundercloud. But the combination of water in crystal of ice; with tetrahedral symmetry, together other pyroelectry aerosol; as the methane, to be increased the electrical displacement vector (D) inside the cell of thundercloud (Figure 6) upper the breakdown potential; even for concentrations of methane minor than the composition in a standard atmospheric.

The geographical explanation of Catatumbo lightning phenomenology is attributed to the presence of convective flows, typical of the inter-tropical regions favored by the diurnal warming and by the thermal gradients between cloud and ground in the stormy zones with abundant convective movements. But this it`s not sufficient to explain why the Catatumbo lightning is the first hot spot in lightning distribution over our planet. And neither explains the localized character and permanent for centuries. Notice that the synoptic meteorological descriptions [5,8] does not explain for itself the electrical activity but rather the rainfall and the pluviosity. To explain the lightning flashes, it is needed to evoke other any models which could cause the separation of charges in Thunderclouds and the transformation between convetive thermal energy into electrical discharges; and the description of the phenomenon as confluence of air mass at different temperature does not provide a satisfactory physical description of electrical activity.

The microphysical descriptions of the thundercloud cell in term of the Electric Displacement vector (D), provides an interesting mechanism for to explain the rapid flashes without transport of particles charges inside of the cloud (Figure 8).

Initially the molecules (potentially pyroelectric, or others with permanent dipoles), have any direction in relation to the atmospheric electric field (E). Then they are aligned with the external field, and consequently, the electric displacement vector (D) increases within the cloud. Once the value of D exceeds the breakdown value of the medium, a discharge is generated towards another cell of lower potential or towards ground; and the molecules rotate until they reach their minimum energy (principle of minimum action), that is to say in an antiparallel sense to the external field (E). This is an unstable equilibrium; and the thermal fluctuations of the convective movement, or the heat flow, cause the disorder of the molecules, misaligning them with respect to the external field (E). After a while, each molecule tends (due to the torque generated by the force of the external field E) to realign itself in the direction of the external field and they would remain there because it is a stable equilibrium; but D is also increased reaching the dielectric breakdown and generating the discharge again. And the cycle repeats itself, until the thermal flow ceases or precipitation is generated.

The characteristic time of the flashes, in Catatumbo Lightning, is the order to milliseconds, furthermore any mechanism that invoke the transport of particles in the charge processes, as ice or graupel falling into the cloud cell, would have a free fall time several orders of magnitude greater than the characteristic times of flashes. I.e the free fall time is the order to the square root of the cell length divided by the acceleration of gravity; 20 seconds for cell of the 1 km of longitude.

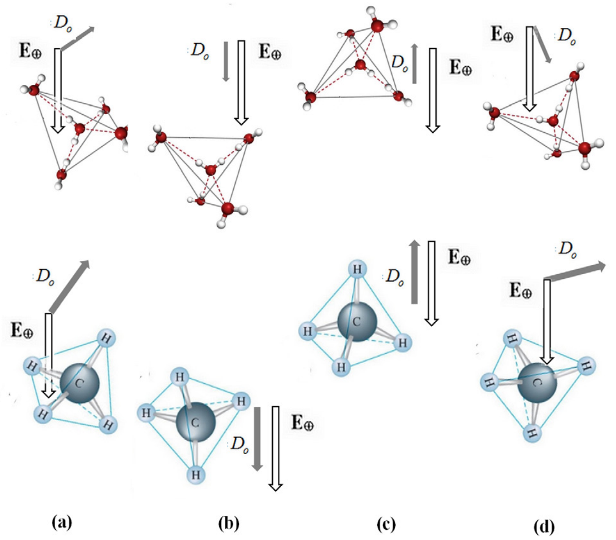


**Figure 8.** Mechanism of discharges in storms clouds by pyroelectricity (Own source). (a) Initially the molecules have any arbitrary orientation with respect to the atmospheric electric field E (b) the molecules are aligned with the external field E increasing the total electric displacement vector D, until reaching the dielectric breakdown (c) after the discharge after the discharges the molecules are reoriented, the electric displacement D is minimal and there are no discharges (d) the convective flows supply thermal energy, they mess up the intrinsic moments ($D_0$) in any orientation, and the cycle repeats. Top panel: for water ice. Bottom panel: for gaseous methane. The relative level in the picture represents the total energy.

By other hand, in the region of the national park swamps of " Juan Manuel", at south southeast of the Maracaibo lake, the activity of Catumbo Lightning is present all years, inclosing in the dry station. In Figure 9 we can



DOI: https://doi.org/10.30564/jasr.v4i2.2740

see the Keraunic the Local Number (NCL) detected by Lightning Imaging Sensor satellite (LIS) over 2ºx2º , center in geography coordinates 9.5 N -72 W, data averaged over a five-year period (2009-2013). We obtain, for example NCL= 5.08 ± 1.25 rms in December; 1.33± 0.63 for January and 2.59± 1.31for February. Others authors [5,8] report values nulls for NCL in dry station, maybe for an mistake in the localization of epicenter: centered in Lagunillas or Maracaibo Lake, instead of swamps of "Juan Manuel".

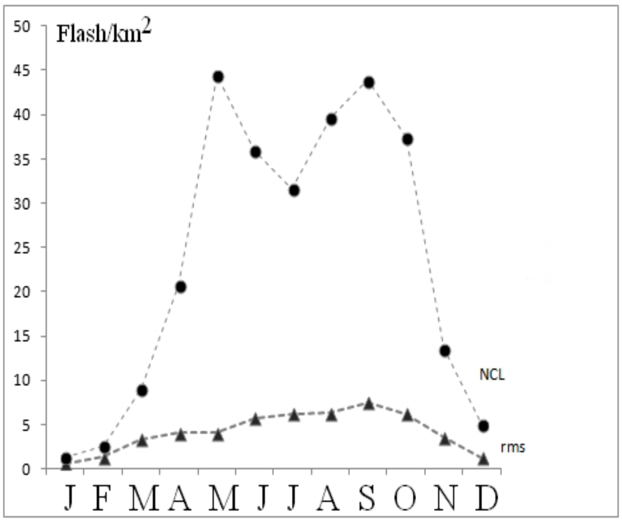


**Figure 9.** Average 2009-2013 of Keraunic the Local Number (NCL) detected by Lightning Imaging Sensor satellite (LIS) over 2ºx2º , center in geography coordinates 9.5 N -72 W. (Own source)

During the dry stations, the swarms exhale more methane towards the planetary boundary layer and could be trapped in the convective cumulus clouds, showing the same phenomenology of electrical activity, even when they are not thunderstorm.

Another question is the fluorescence of methane [35]. Fluorescence occurs when the methane absorbs photons, the electrons are excited into a higher energy state and subsequently de-excites, emitting light at lower energy in the visible rangue. The fluorescence is emitted at 430, 434, 486 and 656.3 nm, in the violet-blue and red region of the visible spectrum [35]; in according to phenomenology picture of Catatumbo lightning (Figure 2 and Figure 3). Also the methane fluorescence to appear associated to planetary lightning in Jupiter and Saturn [28].

Now, we can summarize the qualitative description of Catatumbo lightning as in the Figure 7.

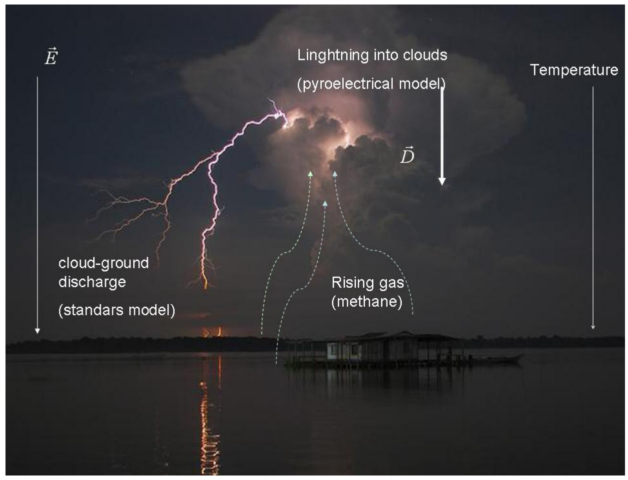


**Figure 10.** Phenomenological picture about the charge mechanism in thunderclouds of the Catatumbo lightning [30]. See from pile-dwelling "Punta Chamita" (09º 05.77' N 71º 42.88' W 1.96 m asl) in direction to the swamps; not to the center of Maracaibo lake.

## 4. Remarkable Conclusions

After two decades of remote sensing of electrometeors, it is confirmed that the Catatumbo Lightning is the highest point of Keraunic activity on the planet. Likewise, the WWLLN and LIS satellites have made it possible to elaborate frequency distribution maps of the "hot" areas where electro-atmospheric activity is particularly notable. These advances together with the observation of planetary lightning have constituted an advance for the understanding of the global electric circuit and the role of the thundercloud in the regeneration of the atmospheric electric field.

The Catatumbo lightning is a persistent electro-atmospheric phenomenon for more than four centuries and confined to a geographic area south of Lake Maracaibo in Venezuela. In situ exploratory studies have determined the epicenter region within the "swamps of Juan Manuel" National Park, at the confluence of the Bravo and Catatumbo rivers in the southeastern region of Lake Maracaibo. In this region the phenomenon manifests itself even in summer, as a dry lightning without rainfall and with the characteristic intra-cloud and cloud-cloud discharges without cloud-ground discharges; which mean frequency of the 28 flash of the lightning per minute. On the shores of Lake Maracaibo, and within said lake, the thunderclouds that move from the swamps towards the center of the lake, present a majority of cloud-ground discharges and the phenomenological characteristics typical of marine storm clouds, especially at the beginning of the night.

The unusual activity of Catatumbo lightning requires an understanding of the generating and charging mechanisms within the cloud cells. These remain controversial since the characteristic times of occurrence of the flashes is much shorter than the time of charge generation. Furthermore, the quantification of the charge generated by microphysical processes does not seem sufficient to explain the electric charge acquired by the cloud cell to produce the lightnings. On the other hand, synoptic explanations based on confluences of winds at different temperatures (between day and night and / or between the ground and the lake) not only do not explain the mechanism of conversion of available convective energy into electrical energy, but also predict an unusual electro meteor activity in all tropical freshwater bodies (lakes-lagoons), which is not observed; for example in the lake of Valencia in Venezuela.

The presence of methane in several planetary atmospheres with conspicuous keraunic activity, and lacking hydrological cycles, such as the gaseous planets and the satellite Titan, suggest that the charging mechanisms have to do with the pyroelectric properties of aerosols and the auto polarization properties of the atmospheric molecules. The calculations show that the electric displacement vector in water vapor clouds does not seem sufficient to reach the rupture potential within the thundercloud. However, the incorporation of methane concentrations even below the atmospheric composition of dry air, raises the electric potential of the cloud by two orders of magnitude and also provides a microphysical mechanism for the electrification of the clouds, consistent with the rapid frequency of the flashes of the Catatumbo lightning.

However, it is still far from the complete understanding of the phenomenon since it requires in situ explorations that allow determining the amount of methane and other pyroelectric aerosols within the convective clouds of the Catatumbo lightning.

## References

[1] Christian, H.J., Blakeslee, R.J., Goodman, S.J., Mach, D.A., Stewart, M.F., Buechler,D.E., Koshak, W.J., Hall, J.M., Boeck, W.L., Driscoll, K.T., Boccippio, D.J., (1999) .The Lightning Imaging Sensor. In: Proceedings of the 11th International Conference on Atmospheric Electricity. Huntsville, AL, NASA, pp. 746-749.

[2] Abarca, S.F., Corbosiero, K.L., Galarneau Jr., T.J., (2010) An evaluation of the WorldWide Lightning Location Network (WWLLN) using the National LightningDetection Network (NLDN) as ground truth. Journal of Geophysical Research115, D18206. DOI: 10.1029/2009JD013411.

[3] Albrecht, R., Goodman, S., Buechler, D. E.; Chronis, T., (2009) Tropical frequency and distribution of lightning based on 10 years of observations from space by the Lightning Image Sensor (LIS) in Proc. Fourth Conference on the Meteorological Applications of Lightning Data, Phoenix AZ, Am. Met. Soc 9, https://ntrs.nasa.gov/api/citations/20110015779/downloads/20110015779.pdf.

[4] Albrecht, R.I., Goodman, S.J., Petersen, W.A., Buechler, D.E., Bruning, E.C., Blakeslee,R.J., Christian, H.J., (2011) The 13 years of TRMM Lightning Imaging Sensor:from individual flash characteristics to decadal tendencies. In: Proceedings ofthe XIV International Conference on Atmospheric Electricity. 08-12 August2011, Rio de Janeiro, Brazil. https://ntrs.nasa.gov/citations/20110015779.

[5] Rachel I. Albrecht, R.I. Steven J., Goodman, D.E. Buechler, R.. Blakeslee, J and Hugh J. C. (2016) Where are the lightning hotspots on Earth?Bulletin of the American Meteorological Society · February. DOI: 10.1175/BAMS-D-14-00193.1.

[6] Falcón, N., Pitter, W., Muñoz, A., Barros, T., Viloria, A., and Nader, D. (2000).Modelo Electroatmósferico del Relámpago sobre el Río Catatumbo, Sci. J. from Exp. Faculty of Sc.(Ciencia) 8, 2,155-167. https://produccioncientificaluz.org/index.php/ciencia/article/view/9042/9032

[7] Falcón, N. “Sobre el Origen y Recurrencia del Relámpago del Rio Catatumbo”. Faraute de Ciencias y Tecnología, 1, 1, 40-49, 2006. http://servicio.bc.uc.edu.ve/facyt/v1n1/1-1-4.pdf.

[8] Tarazona, J., Ferro, C., Urdaneta, A.J., (2006) Cartographic representation of theVenezuelan keraunic activity. In: Proceedings of the Conference of theInternational Council on Large Electric Systems. August 28–September 1, Paris, France.

[9] Lope de Vega, F. (1953) Obras Escogidas: La Dragontea, pp. 324, Madrid: Aguilar Ed.

[10] Humboldt, A. (1991). Viaje a las regiones equinocciales del Nuevo Continente, pp. 226. Caracas: Monte Ávila Editores.

[11] Codazzi, A. (1960) Resumen de la Geografía de Venezuela, pp. 23, Caracas: Biblioteca Venezolana de Cultura.

[12] Centeno, M. (1968) “El Faro de Maracaibo” o “Relámpago del Catatumbo”. Boletín de la Academia de Ciencias Físicas, Matemáticas y Naturales 28 (79) 353-365.

[13] Zavrostky, A. (1975) .El nivel actual de los conocimientos acerca del “Faro del Catatumbo”. Revista Forestal Venezolana Nº 25, Ediciones ULA.

[14] Zavrostky, A. (1991) Faro del Catatumbo: lo conocido y lo desconocido. Carta Ecológica . Ediciones ULA Nº 56.

  DOI: https://doi.org/10.30564/jasr.v4i2.2740

[15] Falcón, N.; Muñoz, A.; Pitter, W. (2001) El Relámpago del Catatumbo: Fenomenología de un Evento Electro-Atmosférico en Venezuela XXVIII Bienal de la Sociedad Española de Física. Sevilla (España) ISBN 8493215015.

[16] Falcon, N., Williams, P., Muñoz, A., Nader, D., (2000) Microfísica del relámpago del Catatumbo. Universidad de Carabobo, Valencia, Venezuela. Ingeniería UC,Junio, vol. 7, número 001. http://servicio.bc.uc.edu.ve/ingenieria/revista/a7n1/7-1-8.pdf.

[17] Falcon, N., (2011) Phenomenology and microphysics of lightning flash of the Catatumbo River (Venezuela). Proc. 14th Int. Conf. on Atmospheric Electricity, Rio de Janeiro, Brazil, ICAE, 1-4.
DOI: 10.13140/RG.2.1.3378.0240.

[18] Muñoz, Á.G., Díaz-Lobatón, J., Chourio, X, Stock, M.J. (2016) Seasonal prediction of lightning activity in North Western Venezuela: Large-scale versus local drivers Atmospheric Research 172-173 147-162 https://doi.org/10.1016/j.atmosres.2015.12.018.

[19] Bürgesser, R. E., Nicora, M. G, Ávila E. E. (2012) Characterization of the lightning activity of "Relámpago del Catatumbo.". J. Atmos. Sol. Terr. Phys., 77, 241-247.
DOI: 10.1016/j.jastp.2012.01.013.

[20] Desch, S. J., Borucki, W. J., Russell, C. T. and Bar-Nun, A., (2002) Progress in planetary lightning, Rep. Prog. Phys. 65, 955-997. http://www.astro.wisc.edu/~ewilcots/courses/astro340s04/readings/planetarylightning.pdf.

[21] Masuelli, S., Scauzzo, C. M. and Caranti, G. M. , (1997) Convective electrification of clouds: A numerical study, J. Geophys. Res. 102, D10, 11049-11059.

[22] Tzur, I. and Levin, Z., (1981) Ions and Precipitation Charging in Warm and Cold Clouds as Simulated in One-Dimensional Time-Dependent Models, J. Atmos. Sci. 38, 2444-2461. https://ui.adsabs.harvard.edu/link_gateway/1981JAtS...38.2444T/doi:10.1175/1520-0469(1981)038%3C2444:IAPCIW%3E2.0.CO;2.

[23] Tokano, T., Molina, G.J., Lammer, H. and Stumptner, W. (2001) Modelling of thunderclouds and lightning generation on Titan, Planet. Space Sci. 49, 539-544.
DOI: 10.1016/S0032-0633(00)00170-7.

[24] Saunders, C.P.R., (1993) A Review of Thunderstorm Electrification Processes, J. Appl. Meteorol, 32, 642-655. https://doi.org/10.1175/1520-0450.

[25] Rakov, V.A. and Uman, M.A.(2003) .Lightings Physics and Effects. Cambridge Univ. Press. pp. 1-12, 321-341.
DOI: 978-0-521-03541-5.

[26] Saunders, C. (2008) Charge Separation Mechanisms in Clouds. Space Sci Rev 137: 335-353.
DOI: 10.1007/s11214-008-9345-0.

[27] Desch, S. J., Borucki, W. J., Russell, C. T. and Bar-Nun, A. (2002) Progress in planetary lightning, Rep. Prog. Phys. 65, 955-997. https://iopscience.iop.org/article/10.1088/0034-4885/65/6/202/pdf.

[28] Yair, Y. (2012) New results on planetary lightning. Advances in Space Research 50 293-310. https://www.sciencedirect.com/science/article/abs/pii/S0273117712002566.

[29] Landau, L., and Lifshitz, E., (1975) Electrodinámica de los medios Continuos, Reverté Barcelona, pp.70-73.ISBN 978-84-291-4089-7.

[30] Falcon, N. and Quintero. A. (2010) Pyroelectrical Model for Intracloud Lightning. Exp. Faculty of Sc. (Ciencia) , 18 , 2, 115-126.. http://produccioncientificaluz.org/index.php/ciencia/article/view/9973.

[31] Gringel, W., Rosen, J.K. and Hoffman, D.J., (1986). Electrical structure from 0 to 30 km; in the Earth's Electrical Environment, Krider, E. P. & Roble, R.I. Ed. Washinton DC Nacional Academia Press, pp 166-182.

[32] Falcón, N.; Quintero, A.,Ramirez, L. (2007) Electrical Self-polarization in Intracloud Lightning Flashes. Proceedings of th 13th International Conference on Atmospheric Electricity (ICAE) Y. Zhao y X. Qie Beijing-China Eds. Volumen I, 280-283. http://www.casnw.net/icae2007.

[33] Lide, D.R. ed. (1997) Handbook of Chemistry and Physics, CRC England, pp3467. ISBN-10: 0849304776.

[34] Quintero, A.; Falcón, N., Ramirez, L. (2007) The Methane Influence as a Self-Polarized Aerosol in Titan's Electrical Activity 13th International Conference on Atmospheric Electricity (ICAE) Zhao,Y y Qie, X Ed. Beijing. I, 307-310. http://www.casnw.net/icae2007.

[35] Danko, M., Országh, J., Lacko, M. , Š. Matejčík (2011) Electron Induced Fluorescence Spectra of Methane. WDS'11 Proceedings of Contributed Papers, Part II, 192–197. https://www.semanticscholar.org/paper/Electron-Induced-Fluorescence-Spectra-of-Methane-Danko-Orsz%C3%A1gh/1d1d772760162fbd1abe336683c433b39f5adf64.