Electrical Self-polarization in Intracloud Lightning Flashes

Nelson Falcon[1], Amilkar Quintero[1], Leopoldo Ramirez[2, 3]

1.University of Carabobo. FACYT, Physics Department. Theoretical Physics and Astrophysics Group.
Apdo. Postal 129 Avda. Bolívar Norte. Valencia 2001, Carabobo , Venezuela .
2. University of Beijing , Ph.D. student, China
3. Tte. (Av) Fuerza Armada Nacional , Venezuela

ABSTRACT: We present a theoretical microphysical model of thundercloud electrification that incorporates the influence of an aerosol with electrical self-polarization (pyroelectric) like methane. We estimate the water and methane dipole contribution to the internal electric field of a cloudy cell. Using a cloudy cell like a cube of 3.6 Km side, we obtain that the water contribution to the internal electric field, due to the electrical displacement vector generated by the atmospheric electric field of the Earth, is not enough to produce a typical discharge; the methane increases the electric field inside the thunderclouds and facilitates the electrical charge generation and separation process. We calculate the associated capacitance for the cloudy cell and the internal electric field. The results obtained for the charge of a cloudy cell due to a methane concentration (using a concentration lower than the air composition) and water, seem to agree with recent observations in lightning.

1. INTRODUCTION

The last decade was marked by fascinating discoveries in the field of atmospheric electricity, at the same time many important problems about thundercloud remained to be solved. An important unsolved question is the very rapid increase of the electric field amplitude inside thunderclouds, that is due to the microphysical evolution of the charges, before the first lightning flash, does not find an explanation in the classical models of thundercloud [MacGorwan and Rust, 1998]. The classical picture about charge generation inside thunderclouds involved convection and particle charging; since there has been no experiment to confirm conclusively the classical model of atmospheric electricity, it remains a subject of debate [Rakov and Uman, 2003].

Therefore the atmospheric electrical phenomena must involve the physical chemistry of some components of the local occurrence atmosphere [Tokano et al., 2001]. Hence we formulate to ourselves the following question: How do these components affect lightning production, including flash rate and charge separation mechanism in microphysical processes in thunderclouds?

A plausible mechanism for the charge generations and separation process inter clouds could be the electrical self-polarization or pyroelectricity of some atmospheric elements; 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 [Landau and Lifshitz, 1981]. In this work we incorporate the influence of the pyroelectrics materials, which could serve to explain the increase of the electric field inside the thunderclouds and the formation of the electrical charges. The methane is the sixth atmospheric component and its pyroelectricity has associate it as co-causal agent of the most eminent lightning flashes in Venezuela, the Lightning over the Catatumbo river [Falcon et al., 2001]. Our objective is to evaluate the role of the methane in thunderclouds charge process.

2. BASIC ASSUPTIONS AND ELECTRIC DISPLACEMENT

We consider an only and isolated cumuliform type cloud, constituted by several cloudy cells, which altitudes are between *1.6 Km* and *14 Km*, the volume of each cell is of the order of $5\ 10^{10}\ m^3$, according with the numerical models of clouds formation [Rogers, 1977], supposing it at hydrodynamic equilibrium. Also the cloudy cell geometry is considered to be a cubic region of side *d=3.6 Km*, as parallel plate capacitor or telluric capacitor [Iribarne and Cho, 1980], where the cell locates to an altitude *h* and *h+d* of the surface; where the value of the water dielectric constant *k* changes in function temperature. 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 [Gringel et al., 1986]:

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

Every cloudy cell is taken as a collection of water dipoles, and methane dipoles in a smaller fraction. The distribution of the electrical dipoles of the water molecules follow, in thermal equilibrium, a Maxwell distribution, for which the electrical displacement average ***D*** contemplates all the possible orientations of the dipolar moment respect to the atmospheric electrical exterior field. We must estimate the average value for the whole cloudy cell from the altitude *h* to the top level *h+d*; with *d* the typical thickness of the cell.

Methane is a mesoscopics element which act in intermediate scales in the convective clouds and its ethereal chemistry composition present a dipolar moment electrically auto-induced. Methane has a lattice constant of *2a=1.095 Å* and an angle of *α=109.5°*. It must be considered that the crystalline configuration of the methane belongs to the C_4 symmetry group, these molecules is pyroelectrics, which polarize spontaneously when have been formed crystals lacking of symmetry centers. The crystals formation of pyroelectrics type in the cloud might create spontaneous dipolar fields, the electrical displacement vector is [Landau and Lifshitz, 1981]:

$$\vec{D} = \vec{D}_0 + \vec{P} + \varepsilon_0 \vec{E} \qquad (2)$$

With *P* is the polarization and *E* is the external electric field and ε_0 is the vacuum permittivity constant. Notice that, still in absence of an exterior electrical field, there will be a not null electrical displacement that would favor the charges separation and even might originate the avalanche needed in lightning models.

To estimate the intrinsic electrical displacement of methane, we will suppose a cloud of diluted (ideal) gas, in absence of external fields; by Gauss Law, the intrinsic electrical displacement is equivalent to the superficial charge density (σ); this is like, if in every point of the cell, the field is produced by the most near molecule of methane; despising others molecules contributions according with ideal gas approach , it is valid to suppose $x \sim a$; as the Gaussian approach is independent of the cloud volume, both expressions of electric fields must coincide ($E_{dipole} \sim \sigma/\varepsilon_0$). If the cloud is uniform, the cloud composition is a methane fraction ($0 \le f \le 1$), and in this case the intensity of the autoinduced field, in virtue of the realized approximations, we obtain for the methane molecule:

$$E_0 = \varepsilon_0 D_0 = -\frac{4}{4\pi\varepsilon_0}\frac{q2a.\cos\alpha}{\left(x^2+a^2\right)^{3/2}} \approx \frac{e\cos\alpha}{\sqrt{2}\,\varepsilon_0 \pi a^2} \approx f\,\frac{6.93}{\varepsilon_0}\left[\frac{C}{m^2}\right] = 7.83\,10^{11}\,f\left[\frac{V}{m}\right] \qquad (3)$$

With *e* the electrons charge and terms into brackets represent the units in international system. For a cloudy cell of water and methane, the electrical displacement due to the methane is equal to the intrinsic pyroelectric displacement plus the induced by the electrical atmospheric field.. Now, we are considering only two elements in the cloudy cell, water and methane, for the polarization term in equation (2); taking the average of the electric displacement vector for a cloudy cell, in terms of the dielectrics constants we obtain:

$$\langle D\rangle \approx 6{,}93\,f\left[C/m^2\right] + \frac{\varepsilon_0}{d}\int_h^{h+d} k_{H_2O}\,E\,dz + k_{CH_4}\frac{\varepsilon_0}{d}\int_h^{h+d} E\,dz - \frac{\varepsilon_0}{d}\int_h^{h+d} E\,dz \qquad (15)$$

The constant value *f*, that represents the concentration of methane in a cloudy cell consisted mainly of water, is very small to consider it in the factors of polarization that contribute to the total electrical displacement of the cloudy cell, however it is of vital importance for the factor of intrinsic electrical displacement. The figure 1 shows the results obtained for the electrical displacement module divided by the vacuum permittivity. The methane concentration in clouds is very small, we use a concentration thousand times minor to the methane atmospheric average composition, inside the cloudy cell ($f = 2\ 10^{-9}$).

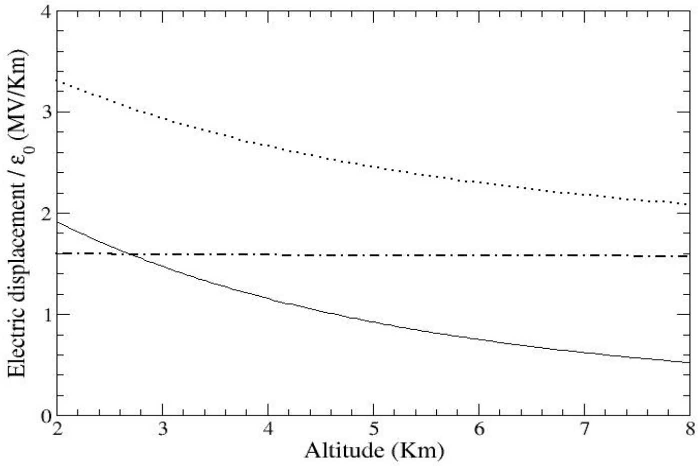

Figure 1: Contributions to the electrical displacement of the cloudy cell at different altitudes: water plus a fraction of methane (dotted line), only water (solid line), a methane fraction (dashed-dotted line).

3. CHARGE PROCESS

In the approximation of the cloudy cell like a telluric capacitor, following the typical atmospheric assumption [Irribarne and Cho, 1980]; we must consider the capacity associated with cell, the potential difference inside the cell and the charge acquired just before the discharge; using this approach and the typical side of the cloudy cell, we calculated the associated capacitance and we obtain $3\ \mu F$. With the electrical displacement vector, we calculated the potential difference between the low limit and the top limit of the cloudy cell for the used components. With the capacitance and the potential difference it is easy to calculate the acquired charge, the figure 2 shows the charge that we obtain.

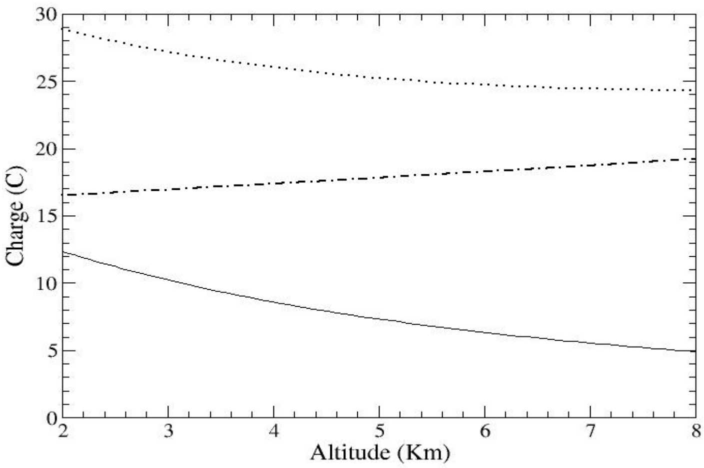

Figure 2: Maximum charge accumulated by the cloudy cell depending on the altitude of different components; water plus a fraction of methane (dotted line), a methane fraction (dashed-dotted line) and only water (solid line).

The results obtained for the charge of a cloudy cell considering the presence of methane seem to be in the range of the recent observations in lightning [Rakov and Uman, 2003]. For any methane concentration bigger than the used one, the methane electrical displacement would be larger than water electrical displacement, which increases notably the charge of the cell; also if the methane concentration in the cloud is null, there will exist a value of electrical displacement due to water influence, which is not the sufficiently big to produce a discharge.

4. CONCLUSIONS

When we use the telluric capacitor model, then the water dielectric constant increases with the altitude, due to the monotonous decrease of the temperature. This proper factor of the water molecules is proportional to the capacitance what seems to indicate that the cloudy cell is charging as the water go up. In agreement of the numerical models, the break down potential of a cloudy cell, only of water, it is not sufficient for a discharge. Increased the relative concentration of methane or probably of others pyroelectric elements in the cloudy cell, the electrical activity meets increased.

The lightning flashes phenomenology and especially of the electrical discharges cloud to cloud and cloud to ground show that these manifestations are frequent in low latitudes (lower than 60° of latitude), in the night hours and in cumulonimbus clouds type [Rakov and Uman, 2003]. The usual explanation of this phenomenology is attributed to the presence of convective flows, typical of the intertropical regions favored by the diurnal warming and by the thermal gradients between cloud and ground in the stormy zones with abundant convective movements [Lang and Rutledge, 2002]. Notice that the convective model does not explain for itself the electrical activity but rather the rainfall.

Also, the accumulation methane is major in low latitudes [Suess et al., 1999], it continues being major in the night hours when the methane is not photodissociated and is major in cumulonimbus clouds where the opaqueness filters the solar radiation that avoids its photodissociation and allows its relative accumulation in the interior of the same ones. Notice that (see figure 1), they do not need big relative concentrations in the interior of the cloudy cells; it is enough with scarcely a relative concentration thousand times minor than the air, without photodissociation, to generate the lightning flashes.

We are inclined to think that the presence of aerosols and/or pyroelectrics particles are co-helper to the electrical activity observed in no hydroscopic environments such as the volcanic eruptions and the sandstorms, where the lightning flashes demonstrate without the presence of rainfall.

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