Contribution of the ground corona ions to the convective charging mechanism

Serge Chauzy *, Serge Soula

Laboratoire d’Aérologie, UMR 5560, CNRS / Université Paul Sabatier, 14, avenue Edouard Belin, Toulouse, France

Abstract

The convective charging mechanism of thunderclouds is based on the vertical transport of space charge generated by corona from ground irregularities under the influence of the surface electric field. The present work estimates the amount of charge which is expected to reach cloud base by conduction and convection processes during the lifetime of a thunderstorm. This estimate is made using the numerical model PICASSO, previously designed to characterize the evolution of this corona space charge between ground level and cloud base. Experimentally determined values of surface electric field are introduced into the model in order to initiate the computation. These values are based on six events documented during four different field experiments carried out in Florida and in France. As an upper limit, the convective transport is uniformly applied as a linearly increasing vertical air speed profile and competes with the conductive transport. The fraction of the positive charge generated at the surface by corona which finally reaches the upper limit of the layer varies between 26 and 86%, essentially depending on the electric field evolution at altitude. Assuming that the vertical transport conditions remain the same over an area of 10 km × 10 km, the overall charge amount can be roughly estimated. It ranges between about 63 and over 300 C. Because the present assumptions probably lead to an overestimate of these amounts, such a range suggests that the convective charging mechanism is unlikely to be able to account for the major electrification process of the thundercloud. However, it could be considered as a relevant mechanism contributing to the lower positive charge center of the thundercloud, often observed close to cloud base. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Thunderstorm; Corona; PICASSO

* Corresponding author

0169-8095/99/$ - see front matter © 1999 Elsevier Science B.V. All rights reserved.
PII: S0169-8095(99)00013-7
1. Introduction

The early proposal by Bernard Vonnegut of the convective charging process as a serious candidate for thundercloud electrification (Vonnegut, 1953, 1963) arose shortly after the French scientist Grenet (1947) published a tentative explanation of the charge distribution observed within an average cumulonimbus. This mechanism, clearly pictured by a famous diagram (Fig. 1, after Vonnegut, 1963), is based on a strong interaction between the dynamical structure of convective cells and their ionized environment. According to this theory, the positively charged upper pole of the cloud system receives its electric charge from the positive space charge in excess at ground level. The lower negative charge accumulation zone proceeds from the transport, by the downdraughts of each cell, of the hydrometeors whose net charge comes from the attracted ions at the top of the cloud.

Although the electrode effect has been considered as a possible source of positive space charge involved in the convective charging mechanism, the efficiency of such a process is higher as this surface space charge is that produced by corona discharges from the ground irregularities under high surface field conditions. Standler and Winn (1979), Chauzy and Raizonville (1982), Chauzy and Soula (1987), and others provided experimental evidences of such a generation. Several experiments already showed that the structure of the terrain plays an important part in such a space charge creation. The most striking example of the influence of this local space charge on the surface field (Toland and Vonnegut, 1977) reveals that this field can reach 150 kV m\(^{-1}\) over a water surface that does not favor corona production, in contrast with the maximum intensities, ranging about 10 kV m\(^{-1}\), measured over land. Furthermore, as shown by Vonnegut and Moore (1959) the artificial generation of negative space charge at the ground has been proved to influence the development of the cloud electrification. Nevertheless, a reasonably

![Fig. 1. An idealized sketch illustrating the convection theory of thundercloud electrification (after Vonnegut, 1963).](image-url)
large charge concentration over the ground is necessary to make the convective charging mechanism efficient enough.

Therefore, this mechanism can hardly be considered as the major primary process for cloud electrification. The most recent works performed in this area of electrification processes seem to focus upon the microphysical inductive or non-inductive interactions, and especially those involving ice particles which have been discussed for years amongst the community (Takahashi, 1978; Brooks and Saunders, 1994; Saunders, 1994; Williams, 1995). However, since a large amount of charge is still generated from the ground irregularities under high field conditions, it is of importance to investigate on the eventual evolution of the space charge in relation to the cloud itself, and on the possible role played by this charge.

In order to estimate the amount of corona produced electric charge transferred from ground level up to cloud base, we use the numerical model PICASSO (Chauzy and Rennela, 1985) forced by experimental data. The model computes the fraction of charge density created at ground level that reaches a given altitude under the effect of conduction and convection processes. Experimental results of electric field evolution at ground level and aloft, and vertical air velocity as it is usually detected between ground level and cloud base are introduced into the model, in order to provide initial and lower boundary conditions.

2. The PICASSO Model

The 1D model used in this study is called PICASSO (French acronym for ‘Production d’Ions Corona Au Sol Sous Orage’, i.e., ‘Corona ion production at the ground underneath thunderstorms’). It is the improved version of a model presented in detail in Chauzy and Rennela (1985) and adapted to experimental use by Soula (1994) and Qie et al. (1994). The latter paper describes in detail the structure and basic equations of the updated model.

The basic microphysical mechanisms involved in the computation include ion production from ground irregularities, attachment of small ions on aerosol particles, recombinations of small ions of opposite polarities, capture of small ions by charged aerosol particles. The dynamics of the system is described by the conduction current due to the ambient electric field, the convection current produced by the upward air motion, and the eddy diffusion process. The mobilities of the charged particles which contribute to the conduction current are chosen as follows according to Bricard (1965): $1.5 \times 10^{-4}$ m$^2$ s$^{-1}$ V$^{-1}$ (small positive ions), $2.0 \times 10^{-4}$ m$^2$ s$^{-1}$ V$^{-1}$ (small negative ions), $1.5 \times 10^{-6}$ m$^2$ s$^{-1}$ V$^{-1}$ (positive charged aerosol particles), $2.0 \times 10^{-6}$ m$^2$ s$^{-1}$ V$^{-1}$ (negative charged aerosol particles).

The convective transport which concerns both types of ions (small and large) and both polarities is superimposed to the conductive transport which essentially acts on small ions (with high mobility). Since no simultaneous measurement of the actual vertical air speed has been performed during the field experiments, we introduce the convection influence by considering a linear profile of vertical velocity between the surface and the top of the 1000 m layer, where the velocity reaches its maximum...
intensity $v_{\max}$. According to Robe and Emanuel (1996), the numerical value of $v_{\max}$ is of the order of a few meters per second. In order to estimate the maximum influence of convective motions, we consider a rather high value of $5 \text{ m s}^{-1}$ at 1000 m of altitude. Such a linear increase of the vertical air speed requires a horizontal air motion which is not taken into account by the computation performed by the 1D model. Nevertheless, this assumption remains acceptable as long as the horizontal advection does not change too much the electrical content of the rising air. This is the case for the data collected during the experiments in Southern France and in Northern Florida, where the production of corona ions takes place from a rather homogeneous land area. It might be a problem at Kennedy Space Center (KSC), located by the sea shore. However, the wind actually measured during the experiment at KSC was constantly blowing from the west to the east, i.e., from the land towards the sea. As it is extensively developed in Soula and Chauzy (1991), a simple calculation shows that the influence of the sea–land discontinuity can be neglected in this particular case.

The time and height evolutions of the space charge layer are computed within the boundary layer 1000-m thick, using a step-by-step method. Space and time resolutions are correlated and can be easily changed and adapted to the study performed. Usually, between lightning flashes, time and space resolutions are, respectively, 0.1 s and 10 m. They can be reduced to 0.01 s and 1 m, respectively, if the field changes during the lightning flashes are investigated. The first set of resolution values are used in the present investigation.

The initial conditions (especially initial concentrations of neutral aerosol particles and ions) are set up according to the studied case, i.e., to the location and to the initial electrical situation. The boundary conditions, especially the surface conditions, also depend on the experiment location. Thus, the expression providing the corona current produced from the ground irregularities when the surface electric field exceeds an onset value is experimentally determined from the measured electric field evolution. On the other hand, the upper boundary condition is such that the charged particles which cross up this border cannot come back down, which is a realistic assumption as far as the ions are supposed to be captured by cloud droplets and no longer contribute to conduction current.

Each run of the model is forced by the surface electric field actually measured during a field experiment. Finally, the model is able to provide the variation of the whole set of electrical parameters which describe the evolution of the space charge during the lifetime of the studied event. We especially consider here the electric field at a given height above ground, the space charge generated from the ground and the fraction of charge reaching the top of the studied layer as a function of time. PICASSO should therefore be able to estimate within a reasonable range the amount of charge feeding the thundercloud during its lifetime.

3. Experimental works

In the past few years, the group involved in atmospheric electricity at the Laboratoire d’Aérologie participated in several field experiments in order to study the electrical
behavior of thunderclouds. Amongst the numerous storm situations documented during these experiments, those displaying the longer durations have been selected for the present study. The six events presented here come from four different summer experiments, two in Florida (1989, 1995), and two in Southern France (1994, 1996). The surface electric field was always measured with a field mill, previously calibrated on the site with the same standard field mill flush to the ground and devoted to this task, in order to obtain coherent measurements. The field aloft was also detected during some of these experiments with a system especially designed and described in Chauzy et al. (1991). In order for the results to be comparable from one case to another, the common characteristics of the studied events are given as follows. An active thunderstorm develops close to the measurement site for a period equal to or longer than 1 h, in order for the field evolution to display the typical signature. Thus, it is generally possible to observe the initial field increase in positive (upward directed) values, then the field discontinuities due to lightning flashes, the field excursion associated with precipitations, and sometimes the end of storm oscillations.

The joint triggered lightning experiments, organized at NASA Kennedy Space Center during the summer of 1989 (Soula and Chauzy, 1991), and at Camp Blanding near Gainesville by the University of Florida, during the summer of 1995 (Uman et al., 1996), both sites in Florida, gathered together groups from NASA KSC, University of Florida, ONERA (Paris, France), CENG (Grenoble, France), and other groups from several countries. In 1989, we performed the measurement of the local electric field at the ground and at several heights above the surface, up to 800 m, using a large tethered balloon. A detailed previous study (Qie et al., 1994) provides the most relevant initial conditions for the model run corresponding to the event of August 10. For the similar experiment carried out in 1995, more specifically for the event of July 20, we used the same conditions including the adapted relationship between the surface field and the corona current density, as well as the best fit for the initial neutral aerosol particle concentration.

In 1994 and 1996, the summer field experiments took place at the Laboratoire d’Aérogologie field site, the ‘Centre de Recherches Atmosphériques’ at Lannemezan, located at the foothill of the northern flank of the Pyrénées range, a typical plateau region. Our research group was associated to the radar group of the Laboratoire d’Aérogologie in order to characterize the location and the evolution of the thunderclouds. We studied and present here the results concerning one event from the 1994 experiment (July 31), and three events from the 1996 experiment (July 26, July 27, and August 7). The initial and boundary conditions indicated in Section 4 are also defined in a specific way for each experimental site and each event.

4. Modeling the vertical charge transfer

All model runs performed in this study are initiated by the surface electric field measured during each event. The source of ground corona ions is formulated through the general expression:

\[ J_c = c_1(E - E_0)^3 + c_2(E - E_0)^2 + c_3(E - E_0) \]  

(1)
Fig. 2. (a) Evolution of the electric field measured at the ground, (b) evolution of the electric field measured above ground (curve A) and of that calculated by PICASSO at 600 m above ground (curve B), (c) evolution of three electric charge densities (A. corona charge density, B. conduction charge density at 1000 m, and C. conduction and convection charge density at 1000 m) calculated by PICASSO. Case of August 10th, 1989 in Florida, Kennedy Space Center.
where $J_c$ is the corona current density (A m$^{-2}$), $E$ the surface ambient electric field (V m$^{-1}$), $E_0$ the field onset (i.e., the field value above which the corona effect takes place), and $c_1$, $c_2$, and $c_3$ three constants related to the structure of the terrain. The numerical values of these constants are determined, for each experimental site, by comparing the measured electric field evolution at a given height above ground to the corresponding computed variation. The values providing the best fit between both evolutions are introduced into the above mentioned expression. For the events documented in 1989 and 1995 in Florida, the following values of the three constants have been introduced, according to the study by Qie et al. (1994): $c_1 = 3.1 \times 10^{-20}$ A V$^{-3}$ m, $c_2 = 1.0 \times 10^{-22}$ A V$^{-2}$, and $c_3 = 0$. The corresponding intensity of the onset field $E_0$ is 1400 V m$^{-1}$.

Concerning the events documented during the 1994 and 1996 experiments in Southern France, the best fit corresponds to the values established by Saissac (1995): $c_1 = 9.4 \times 10^{-21}$ A V$^{-3}$ m, $c_2 = -8.97 \times 10^{-17}$ A V$^{-2}$, and $c_3 = 5.41 \times 10^{-13}$ A V$^{-1}$ m$^{-1}$, the field onset value being here 1300 V m$^{-1}$.

On the other hand, the initial neutral aerosol concentration $N_0$ plays an important part in the results of the computation, since aerosol particles trap the fast ions and slow them down drastically. Therefore, the higher this concentration, the smaller the fraction of the ground space charge that reaches the top of the layer. According to the geographical distribution summarized by Podzimek (1980), the value chosen for the Florida area is $N_0 = 5.0 \times 10^9$ m$^{-3}$. Concerning the events documented in 1994 and 1996 in Southern France, $N_0$ is taken equal to $1.0 \times 10^{10}$ m$^{-3}$, according to the local data frequently provided by routine measurements. Finally, when the experimental values of the electric field at the ground and at altitude, at the beginning of the event, show the presence of local space charge, the corresponding amount is calculated and introduced into the initial condition set of the model.
Amongst the available outputs provided by the model, we display the three different evolutions, during the whole event, of the following set of parameters: (i) the electric

![Graphs showing electric field evolutions](image)

**Fig. 3.** (a) Evolution of the electric field measured at the ground, (b) evolution of the electric field calculated by PICASSO at 600 m above ground, (c) evolution of three electric charge densities (A. corona charge density, B. conduction charge density at 1000 m, and C. conduction and convection charge density at 1000 m) calculated by PICASSO. Case of August 20th, 1995 in Florida, Camp Blanding.
field aloft, at a height which allows the comparison with the corresponding experimental evolution (in order to validate the computation); (ii) the cumulated positive electric charge generated by unit area of the ground from the beginning of the event, along with the total amount of charge that reaches the top of the 1000-m layer. We choose to display only the positive electric charge generated from the ground because, for all cases considered here, the global charge reaching the top of the layer is always positive, and therefore represents a fraction of the positive charge created at ground level. However, in one of the cases studied here, a fraction of the negative ions generated at the ground reaches the top layer.

Fig. 2 displays the first set of results corresponding to the event of August 10, 1989, at Kennedy Space Center (Florida). The surface field (Fig. 2a) stays positive almost all the time, which implies the production of only positive corona ions from the surface irregularities. The only short periods during which negative ions are produced are those corresponding to the short but large negative field changes due to lightning flashes. The validation of the model and its parameterization is provided by the measured and computed field evolutions at 600 m respectively presented in Fig. 2b, two evolutions rather similar in their general trends, although some discrepancies sometimes appear. The increase of the electric field at this level for both evolutions during the periods of rather stable surface field is remarkable. So, the differential evolutions at the ground and aloft are well reproduced by the model. In absolute value, the modeled field intensity is somewhat lower than that actually measured. Fig. 2c displays, as a function of time, the amount of cumulated positive charge generated per square meter of ground and that reaching the top of the studied layer computed with and without considering the convection transport. The charge production (curve A in the graph) is low during the
beginning of the event until 2325 hours and then, because the field at the ground reaches large values with some lightning flashes, it continuously increases to reach around

Fig. 4. (a) Evolution of the electric field measured at the ground, (b) evolution of the electric field measured at 44 m above ground, (c) evolution of the electric field calculated by PICASSO at 40 m above ground, (d) evolution of three electric charge densities (A. corona charge density, B. conduction charge density at 1000 m, and C. conduction and convection charge density at 1000 m) calculated by PICASSO. Case of July 31st, 1994 in Southern France.
0.6 × 10⁻⁶ C m⁻² at the end of the calculation at 0025. The transport by convection and conduction (curve C) starts early because it carries up part of the positive space charge already present at the beginning of the field evolution, and introduced into the model for its initialization. Of course, the transport by the sole conduction (curve B) starts later because of the low values of the field at the beginning of the event. Both
curves undergo a clear increase from 2355 hours because of a strong and long lasting production of positive ions at the ground a few minutes before. Evolution C increases

Fig. 5. (a) Evolution of the electric field measured at the ground, (b) evolution of the electric field calculated by PICASSO at 40 m above ground, (c) evolution of three electric charge densities (A. corona charge density, B. conduction charge density at 1000 m, and C. conduction and convection charge density at 1000 m) calculated by PICASSO. Case of July 26th, 1996 in Southern France.
more regularly because evolution B is affected by the large field decreases corresponding to lightning flashes after 2345. At the end of the period, the charge carried up by conduction and that transported by conduction and convection represent, respectively, 25 and 59% of the total positive corona charge produced at the ground.

Fig. 3 shows the same kind of results concerning the thunderstorm of July 20, 1995 documented at Camp Blanding, Florida. The recorded sequence displays a great deal of field changes due to lightning flashes and during several sequences, the surface field polarity reverse causes the occasional generation of negative space charge (Fig. 3a). The field aloft at 600 m was not measured but it is calculated by the model (Fig. 3b) and its evolution is quite different from that at the ground. In this case, the field aloft takes large negative values around 1918 hours. Since the electric field at the ground and aloft undergoes a period of negative polarity, a fraction of the negative space charge produced reaches the top of the layer and causes the equivalence of a depletion in the cumulated amount of positive charge that leaves the layer. From the evolution of the charge densities (Fig. 3c), the evolution of that produced by convection is more affected by the negative charge. The positive corona charge is produced at two periods, one between 1848 and 1858 and the other between 1925 and 1940. At the end, both charge densities at the top of the layer are positive and that calculated with the convection transport is larger. They are, respectively, 22% and 39% of the positive corona charge produced at the ground.

The data gathered during a first event recorded on July 31, 1994, in Southern France, are displayed in Fig. 4. The measured electric field evolution in Fig. 4a shows a typical behavior at the ground corresponding to the essential part of the complete lifetime of the thunderstorm: the first increase from low values to positive values by slow variation.
between 1445 and 1455 hours, positive and negative field changes corresponding to lightning flashes with field recovery by slow evolution (1455–1505), a global slow field.

Fig. 6. (a) Evolution of the electric field measured at the ground, (b) evolution of the electric field calculated by PICASSO at 40 m above ground, evolution of three electric charge densities (A. corona charge density, B. conduction charge density at 1000 m, and C. conduction and convection charge density at 1000 m) calculated by PICASSO. Case of July 27th, 1996 in Southern France.
decrease due to the arrival of the rain (as it is characterized in Soula and Chauzy, 1997) with large change decreases due to close lightning flashes (around 1515) and a positive field recovery with lightning flashes field discontinuities and field stabilizations (1525 and after). The field is measured at 44 m (Fig. 4b) and calculated at 40 m (Fig. 4c) by PICASSO in order to check the relevant restitution of the model (both evolutions display too many rapid field changes to be superimposed as on Fig. 2b). In this case also the global evolution is respected. However, the model provides lower values in the second half of the evolution. Fig. 4d shows the evolutions of the charge densities issued from the model run. Most part of the positive corona charge (curve A) is produced at the ground between 1455 and 1515 and its arrival at the top (1000 m) rapidly occurs a few minutes later (curves B and C). The total amount of the generated charge is rather weak, around $1.06 \times 10^{-6} \text{ C m}^{-2}$ for the corona and the conduction carries up 39% of this charge (curve B) while both conduction and convection associated carry about twice this proportion 74% (curve C). As in other cases, the corresponding field evolution undergoes many field changes due to lightning flashes, during which negative charges are generated from the ground.

Three other events from the 1996 experiment carried out in Southwestern France are presented in Figs. 5–7. That summer of 1996 was especially active in terms of thunderstorms. Some of them produced very high precipitation rates, on the order of those recorded in tropical areas, up to 100 mm h$^{-1}$. In these three cases, we present the measured surface field (a), the calculated field at 40 m (b) and the three charge densities calculated (c). We can make the same general comment about both field evolutions which indicates that the field aloft undergoes an evolution with more dynamics in the values and the different phases. For the charge densities, the proportions of both top
charge fluxes can be very different from one case to another. They are large in the case of July 26 (Fig. 5c) and their evolution is quite continuous because the field is always high and positive right from the beginning of the record (Fig. 5a and b) except at 1645

Fig. 7. (a) Evolution of the electric field measured at the ground, (b) evolution of the electric field calculated by PICASSO at 40 m above ground, (c) evolution of three electric charge densities (A. corona charge density, B. conduction charge density at 1000 m, and C. conduction and convection charge density at 1000 m) calculated by PICASSO. Case of August 7th, 1996 in Southern France.
where a large decrease clearly corresponds to a FEAWP (field excursion associated with precipitation) as it is shown by Moore and Vonnegut (1977). In this case, the surface charge densities reach large values, $3.6 \times 10^{-6}$ C m$^{-2}$. In the case of July 27 (Fig. 6), the proportion of charge reaching the top layer is rather low, specially if the convection is not considered (curve B) probably because the field aloft stays rather low (Fig. 6b). The last case (Fig. 7), that of August 7, is the most atypical because the surface field undergoes long negative excursions (Fig. 7a) and, moreover, most of the lightning flashes induce positive discontinuities. Consequently, a large amount of the positive charge produced at the ground does not reach the top of the layer (Fig. 7c). From the field at the ground that takes strong negative values, a non-negligible amount of negative ions are produced and, taking the convection process into account (Fig. 7c, curve C), a part of them reaches the top layer and affects the budget of the charge flux. The evolution of this flux is very fluctuating as compared to that of curve B (without the convection) and to the other cases. Finally, both proportions are close in this case since they are, respectively, 21% and 26%.

5. Discussion and conclusions

The 1D PICASSO model, as any numerical model, simplifies the actual processes involved in the charge transfer. In order to roughly evaluate the deviation from the real world, we use the comparisons between the measured and computed electric field evolutions at altitude. The average deviation for the Florida experiments is around 25% and that obtained for the French site reaches 20%. Therefore, the numerical results
indicated in this section have to be considered with the corresponding level of confidence.

The main issue of this study proceeds from the charge amount which actually reaches the top of the considered layer, i.e., the amount of charge able to interfere with the cloud electrostatical structure. The last graph of each of the Figs. 2–7 displays the evolution of such charge amounts throughout the lifetimes of the corresponding storms. Table 1 summarizes the global results about the cumulative charge produced and carried up to the top layer. From a storm to another, the fraction of the positive charge generated at the ground which reaches cloud base varies within a wide range and is largely affected by the influence of the convection process. Nevertheless, the global charge density produced at the ground during the studied periods varies within a rather narrow range: from $0.6 \times 10^{-6}$ C m$^{-2}$ to $3.6 \times 10^{-6}$ C m$^{-2}$ and in four cases it stays close to $1.0 \times 10^{-6}$ C m$^{-2}$. Both cases from Florida provide low values of such density but the proportions are very comparable to those of the cases issued from France. We do not observe any clear correlation between the amount of charge produced at the ground and the charge proportion reaching the top layer even if both parameters are related to high electric field values. As a matter of fact, a high proportion can be achieved from a low corona charge density (August 10 in Florida) as well as from a high one (July 26 in France). The proportion ranges from 18% to 75% without the influence of convection and from 26% to 86% when convection is taken into account. For one given case, this proportion can be enhanced by a factor as high as 2.4 by the convection process and most of the time this factor ranges around 2. Both proportions can be close anyway for low or high values.

It is easy to observe that these fractions strongly depend on the conduction effect of the ambient electric field. The higher the field aloft, the larger the fraction of positive electric charge reaching cloud base. Unlike the process of conduction which basically affects only the small ion population (because of its higher mobility) the convective transport is effective on both kinds of ion, small and large. The proportion in the case where the convection is taken into account is weak (26%) in only one case (August 7, 1996, in France) because it is reduced by the negative ion population produced in large quantity and carried also by convection. The model considers the global charge densities aloft taking into account the contribution of negative ions. In other cases, the proportion is larger than 39% and reaches 86%. The maximum value of the charge density reaching the top layer is $3.11 \times 10^{-6}$ C m$^{-2}$ and the typical value ranges from $0.4 \times 10^{-6}$ C m$^{-2}$. Since five cases out of six stay within this interval, we can consider that this parameter is relatively stable from one case to another.

A further step can be the evaluation of the total electric charge transported from the ground to the cloud during the thunderstorm lifetime. In order to roughly estimate the total charge amount which actually reaches the base of a given thundercloud, we assume that the present mechanism covers a surface area of about 10 km $\times$ 10 km. The charge density calculated by the model can therefore be integrated over this area. Doing that, we probably overestimate the updraught area, although this area sounds realistic concerning the conduction influence of the thundercloud. Therefore, the most probable value of the total amount of electric charge likely to reach cloud base ranges between the values obtained with and without the convection current.
Table 1

Result of model PICASSO in term of corona charge density produced at the ground (column 1), charge density reaching the height of 100 m by conduction alone (column 2) and by conduction and convection (column 3). The charge integrated over a $10 \times 10$ km$^2$ area is estimated for the three types of charge.

<table>
<thead>
<tr>
<th>Event</th>
<th>Corona charge density (C m$^{-2}$)</th>
<th>Conduction charge density (C m$^{-2}$) proportion, %</th>
<th>Cond. conv. charge density (C m$^{-2}$) proportion, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Charge over 100 km$^2$</td>
<td>Charge over 100 km$^2$</td>
<td>Charge over 100 km$^2$</td>
</tr>
<tr>
<td>August 10th, 1989 Florida</td>
<td>$0.63 \times 10^{-6}$ 63 C</td>
<td>0.16 $\times 10^{-6}$ (25%)</td>
<td>0.37 $\times 10^{-6}$ (59%)</td>
</tr>
<tr>
<td>August 20th, 1995 Florida</td>
<td>$1.24 \times 10^{-6}$ 124 C</td>
<td>0.27 $\times 10^{-6}$ (22%)</td>
<td>0.49 $\times 10^{-6}$ (39%)</td>
</tr>
<tr>
<td>July 31st, 1994 Southwestern France</td>
<td>$1.06 \times 10^{-6}$ 106 C</td>
<td>0.42 $\times 10^{-6}$ (39%)</td>
<td>0.78 $\times 10^{-6}$ (74%)</td>
</tr>
<tr>
<td>July 26th, 1996 Southwestern France</td>
<td>$3.62 \times 10^{-6}$ 362 C</td>
<td>2.71 $\times 10^{-6}$ (75%)</td>
<td>3.11 $\times 10^{-6}$ (86%)</td>
</tr>
<tr>
<td>July 27th, 1996 Southwestern France</td>
<td>$1.42 \times 10^{-6}$ 142 C</td>
<td>0.25 $\times 10^{-6}$ (18%)</td>
<td>0.63 $\times 10^{-6}$ (44%)</td>
</tr>
<tr>
<td>August 7th, 1996 Southwestern France</td>
<td>$2.45 \times 10^{-6}$ 245 C</td>
<td>0.50 $\times 10^{-6}$ (21%)</td>
<td>0.63 $\times 10^{-6}$ (26%)</td>
</tr>
</tbody>
</table>
Under this assumption, and except for the case of July 26, 1996 which provides a very high charge amount, the total charge reaching cloud base ranges roughly from around 40 to 80 C. Table 1 summarizes the whole set of results provided by the model. Comparing the data from the last two columns indicates the maximum contribution of convection to the total vertical transport of the electric charge. Again, the evaluation of the total charge relies on the area concerned by the corona emission, and this area certainly varies from a thunderstorm to another. Anyway, the values provided by this study must be considered as providing orders of magnitude.

If we recall that the total maximum amount of charge likely to reach cloud base is probably overestimated, and if we consider that the charge amount neutralized by a single flash often reaches values of the same order of magnitude, we can hardly consider that this convective/conductive mechanism is responsible for the overall electrification of the thunderclouds considered here. However, this positive charge transferred to cloud base can account for the formation of the third pole called ‘Lower Positive Charge’ (LPCC) by Krehbiel (1986). Actually, the interaction mechanisms of the charge with the cloud dynamics probably depend on the transport mechanism. The fraction of the space charge mainly carried up by convection covers a limited area underneath the thundercloud and likely follows the streamlines of the updraughts. Thus, this fraction is able to penetrate the cloud and participate in the cloud dynamics. The fraction essentially transported by conduction is certainly distributed over a larger area beneath the cloud, and therefore is probably captured by the droplets of cloud base. As it was earlier proposed by Malan (1952), this process might be essential to the formation of the LPCC. Although several other processes can account for the detection of such a pole (Jacobson and Krider, 1976; Holden et al., 1980; Marshall and Winn, 1982; Jayaratne and Saunders, 1984; Marsh and Marshall, 1993), the present investigation provides a serious candidate with a reasonable estimation of the amount of charge compatible with the observations.

Acknowledgements

The authors thank the Direction des Recherches, Etudes et Techniques, and the Programme Atmosphère et Océan à Moyenne Echelle of the Institut National des Sciences de l’Univer for their financial and scientific supports. They are grateful to Bill Jafferis (from NASA) and Martin Uman (from the University of Florida), for their respective organization of the 1989 and 1995 experiments in Florida.

References


Chauzy, S., Rennela, C., 1985. Computed response of the space charge layer created by corona at ground level to external electric field variations beneath a thundercloud. J. Geophys. Res. 90, 6051–6057.


