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A METHODOLOGY TO STUDY CHARGED CLOUD STRUCTURE BASED ON FIELD MILL NETWORKS BY SOLVING THE INVERSE PROBLEM OF COULOMB'S LAW.

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Abstract. We calculate electrical structures axially distributed in space based on measurements of electric field mill network on ground by solving the inverse problem of Coulomb's law. It is not trivial to use such approach and a methodology for dealing with mathematical problems of detecting solutions is presented. As an example we fit data from a field mill network by using this technique. A preliminary results and discussion are presented to improve this methodology in a more general case.

1 - INTRODUCTION

The use of inverse problem of Coulomb's law has been recently used by Lacerda et al. (2012) to estimate the position of charges inside the cloud. It is based in the use of field mill's network (EFMN) and radar's data.

Classically this approach is used in mechanics (Newtons's law), such as gravitational problems, trajectory of celestial bodies, underground prospection, etc (Tarantola, 1987). In these cases the knowledge of forces is used to obtain position and magnitude of massive objects. As the mass is a positive scalar the problem is reduced to obtain the distribution (position) of positive numbers (mass) trough the space.

In the case of Coulomb's Law we are dealing with distribution of positive and negative numbers (electric charges) trough the space. This fact leads us to establish some criteria to solve the inverse problem.

In this paper is discussed the use of this technique to get solutions that represent the structure of charges inside clouds that produce a record of 4 electric field measurements on ground, and discuss some limitations of this method.

The figure 1.1 shows a schematic of the network that records data on the ground (E1, E2, and E3, representing the measurements of electric field). The electric charge structure is represented by the letters q1, q2 and q3 (in a tripolar structure). The lines close to letters z (altitude represented by dot line) are the waited vertical electric field profile for a classical tripolar structure (positive, negative, positive centers). The slope of these lines represents the polarity of the charge center.

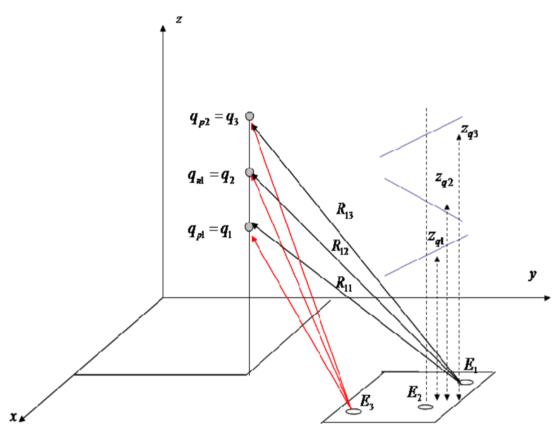


Fig. 1.1 Schematic representation of the **field mill** network (E1, E2, E3), the charge structure inside cloud (q1, q2, q3) and the waited electric field profile for a tripolar cloud structure (+, -, +) (Monteiro junior, 2011).

This approach was first performed by Lacerda et al (2012), for analise data of CHUVA project at Vale do Paraiba campaign. In that project a network of 5 electric field mill was built close to a polarimetric radar. The same approach was done to Belem campaing (not yet published).

2 – SIMULATION OF ELECTRIC STRUCTURE OF CLOUDS

First of all to check the inverse problem it was simulated a cloud according to that one measured by Stolzenburg et al. (1998b). Figure 2.1 presents the parameters adopted to simulate a four-pole cloud such as height and the charge density of each charge center. The total charge was arbitrarily defined.

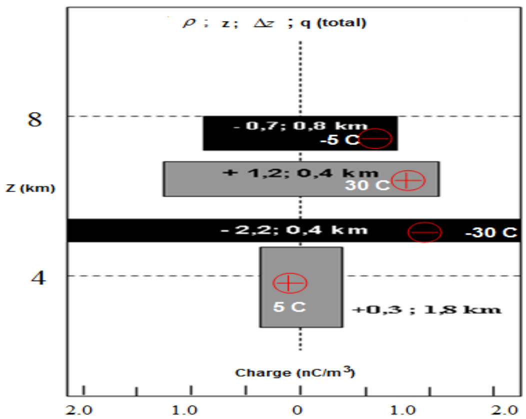


Figure 2.1 - Example of cloud structure detected by balloons close to the cloud. (Adapted of Stolzenburg et al, 1998b). The numbers inside the rectangles are charge density, Δz (thickness) for each center of charge and total charge.

It was computationally simulated a cloud with the distribution of charges as presented in figures 2.1, 2.6 and 2.8.

Table 1 presents the dimensions of the simulated cloud. The representation of the electric field generated on the ground, for the simulated cloud is presented in Figures 2.6 and 2.7.

height, z (m)	Charge (C)	Horizontal length (m)	Δz (m)	Charge density (nCm^{-3})
2800	5	3040	1800	0,3
5100	– 30	5830	400	– 2,2
6300	30	5600	800	1,2
7100	– 5	3000	800	– 0,7

Table 2.1 Cloud structure used in the simulation

To validate the simulation, the vertical electric field profile (VEFP) presented by Stolzenburg et al. (1998b) was roughly fitted and it is shown in the figure 2.2.

The simulation showed that the calculated VEFP depends on the distance to the structure of electric charges inside the cloud. The figures 2.3, 2.4 and 2.5 show the different electric field profiles for the same simulated cloud, that starts close to the cloud with a like four-pole structure (figure 2.3) then continues with a little far like three-pole structure, and finishes with a like dipolar structure, so far from the same cloud. The profile of the simulated electric field near the edge of the cloud shows a quadrupolar structure to the cloud (Figure 2.3). A little far from the edge of the cloud, the profile of the simulated electric field behaves as a tripolar structure (Figure 2.4). Far away from the cloud, the simulated electric field profile behaves as a dipolar structure for the cloud Figure 2.5)

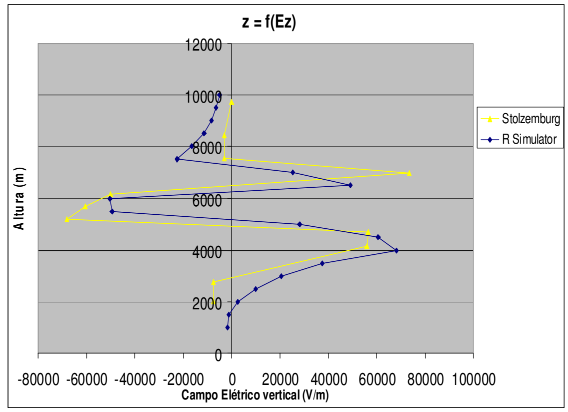


Figure 2.2 - Example of vertical electric field profile with altitude. Yellow curve is data of Stolzenburg et al, (1998b). Blue curve is the simulation of the cloud represented in figures 2.1 and 2.6). (Monteiro Junior, 2011).

In the figures 2.3, 2.4 and 2.5, the charge vertical axis is centered initially at the point (6000 m; 6000 m; z), (10000 m; 10000 m; z) and (12000 m; 12000 m; z), respectively. The scale at right side of figures represents the y coordinate of the point (x, y, z) where the vertical profile was calculated. Notice that the complex structure of cloud depends of the coordinate y which varies from this point to a region a little close up to a region far from the center of the cloud. This is an important parameter that may be used to choose the kind of structure to be adopted in the inverse problem, because the EFMN can be close or far from the cloud. In terms of physical mechanism this corresponds to the screening effect of some layers of charges one over each other.

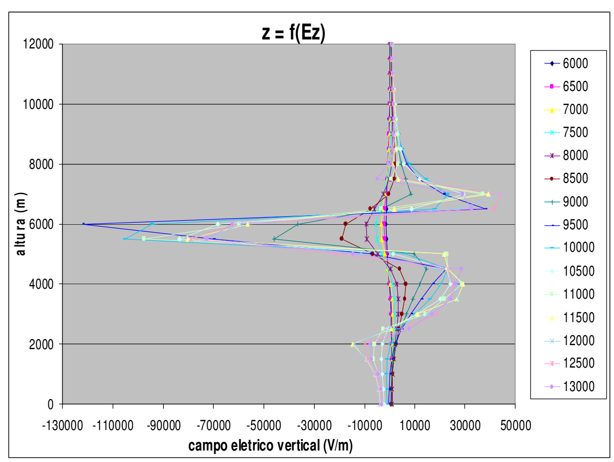


Figure 2.3 - Vertical electric field profile of a four-pole cloud, as represented in figure 2.1 and 2.6. The simulation begins at the point (6000, 6000, 0). (Monteiro Junior, 2011).

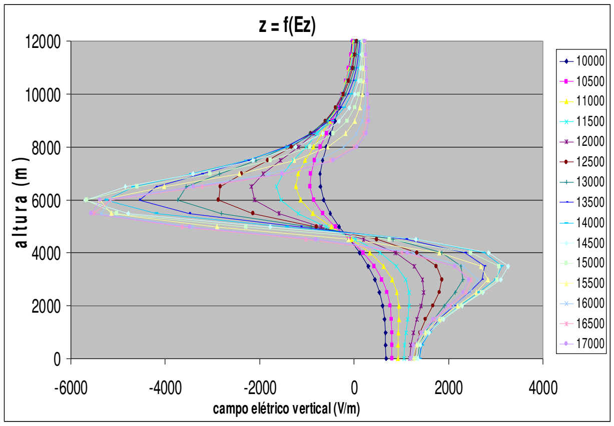


Figure 2.4 - “Tripolar like structure” of vertical electric field profile for the same cloud represented in figure 2.1 and 2.8. The simulation begins at the point (10000, 10000, 0). (Monteiro Junior, 2011).

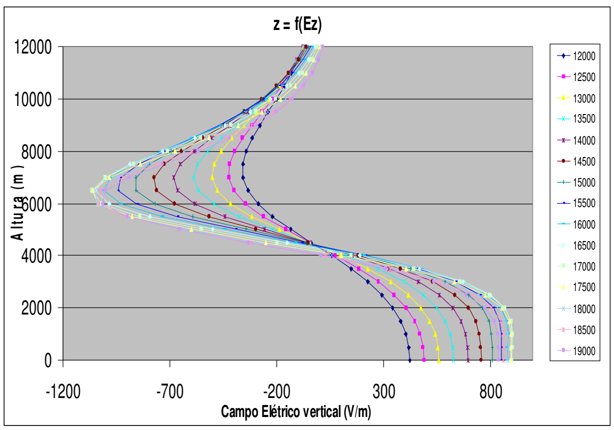


Figure 2.5 - “Dipole like structure” of vertical profile of a quadripolar cloud (the same cloud represented in figures 2.1 and 2.8). The simulation begins at the point (12000, 12000, 0). (Monteiro Junior, 2011).

In the figures 2.6 and 2.7 it is shown the vertical electric field on the ground for the simulated cloud. The coordinate x varies from 0 to 7000 m and the coordinate y varies from 0 to 12000 m. It was calculated E(x,y,z) = E (n.500, y, 0), where n=0,1,2…15. This means that it was fixed the coordinate x, at every 500 m and calculated the electric field depending only in coordinate y.

We emphasize that depending on the distance from the cloud, the electric field network will measure only positive values, only negative values or both positive and negative values for the electric field. Then it is possible to have low or null values for the electric field for some EFM records and high values for others EFM even close to the cloud.

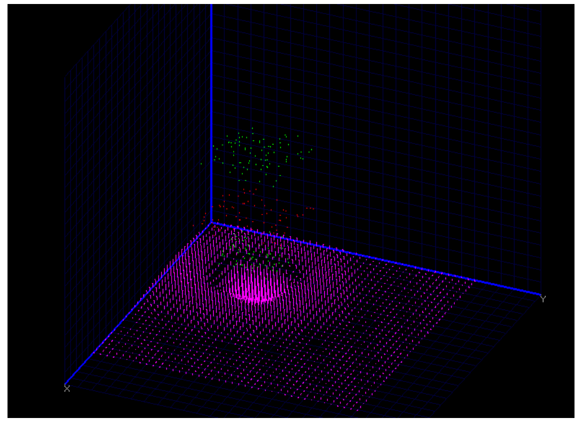


Figure 2.6 - 3D representation of horizontal profile of electric field of simulated cloud. Green points represent positive distributed charge. Red points represent negative distributed charge. Pink arrows represent electric field on ground. (Monteiro Junior, 2011).

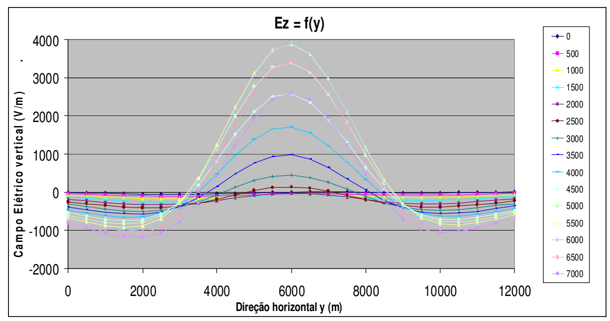
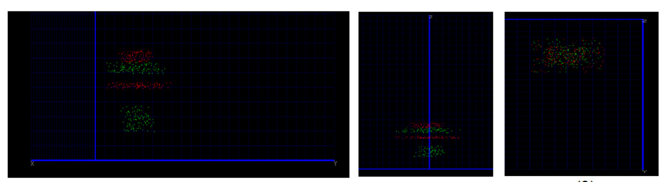


Figure 2.7 - Horizontal profile of vertical electric field on the ground, of the quadripolar simulated cloud. E(x,y,z) = E (n.500, y, 0), n=0,1,2…15. The coordinate x is represented on the right side of figure representing every curve in different colors. (Monteiro Junior, 2011).



(1) (2) (3)

Figure 2.8 - Representation of the quadripolar structure adopted by the simulator that produces vertical profiles of figures 2.2, 2.3, 2.4, 2.5 and 2.7. (1) vertical position of distributed centers (2) vertical position of distributed centers by other view point. (3) projection on xy plane. (horizontal). Vertical intervals represented by tin blue lines are 1km).

This simulation was used to check what kind of structure (di, tri or quadripolar) may be used. It shows that this choice depends on the distance between the cloud and the EFMN. Figure 3.1 shows a georeferenced image of the EFMN (red x) and the radar’s image of the cloud at Vale do Paraiba campaign during CHUVA PROJECT. The radar is represented as XPOL in the left-up side of figure.

3 – Methodology

The methodology of solving the inverse problem of Coulomb's law includes several steps represented below.

Step 1. Compute the position of network and radar. This is shown in figure 3.1. The colors represent the reflectivity of radar. The red color in figure 3.1 represents the region where we can choose the coordinates X and Y of the charge center (reflectivity greater than 45 dBz).

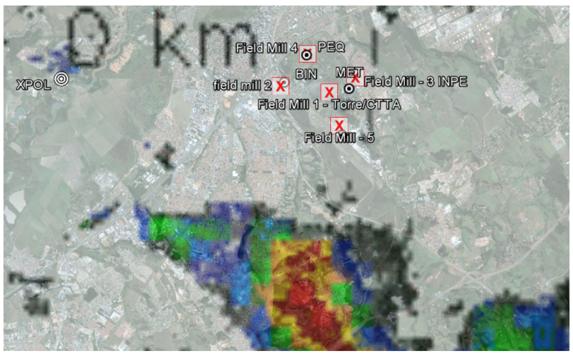


Figure 3.1 - Position of field mill network and radar XPOL, at vale do Paraiba campaign (Chuva Project).

Step 2. Compute the coordinates x and y of the charge center, that initially are considered aligned in z coordinate. This is shown in figure 3.2.

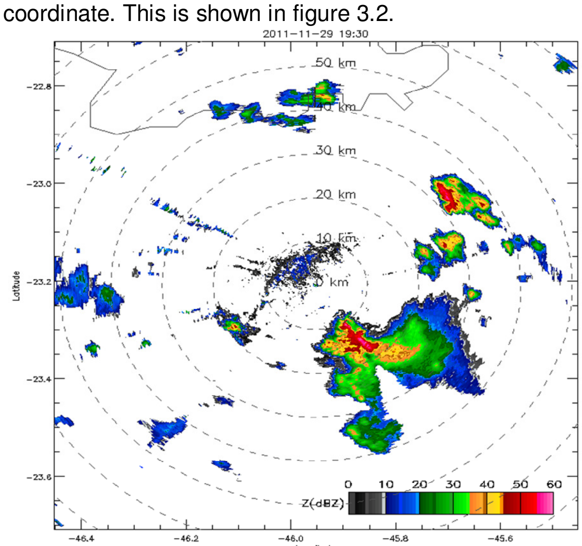


Figure 3.2 - Example of radar image to detect coordinates x and y of the charge centers at Vale do Paraiba campaign (Chuva Project). The red color in figure represents the region were we can choose the coordinates X and Y.

Step 3. Use the Rhi to detect the region where charges are probably located in the vertical axis. In Figure 3.3 we see these regions and Δh represents the region of the space that we can choose the coordinate Z.

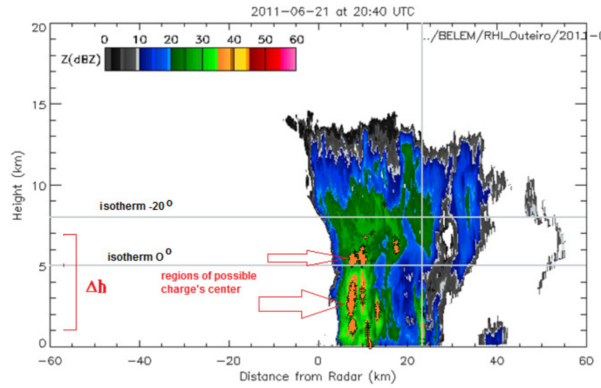


Figure 3.3 - Example of Rhi used to detect coordinate z. Adapted from Lacerda et al, (2012) at Belem Campain (Chuva Project). The orange color in figure represents the region were we can choose the coordinate Z. The horizontal lines represent the region between O° and -20° C. And can be used to improve the results.

Step 4. Select the charge structure that we will be investigate. This step is related to the distance from the cloud structure to the EFMN. This can be seen in figure 3.1, where this distance can be evaluated.

Step 5. Construct the matrix R and calculate the charge's structure.

For example, the coordinate z of the charge centers were chosen between 2000 and 10000, in the Vale do Paraiba Campaign and calculations of the electric charge q at every center were performed using Eq 1 (Tarantola, 1987).

$$\mathbf{q} = (\mathbf{R}^{\mathbf{T}}.\mathbf{R})^{-1}.\mathbf{R}^{\mathbf{T}}.\ \mathbf{E} \qquad \text{Eq (1)}$$

where

$$Rij := 2k \cdot \frac{(zj - zi)}{\left[(xj - xi)^2 + (yj - yi)^2 + (zj - zi)^2\right]^{\frac{3}{2}}}$$

Eq (2)

"*R is a i x j matrix and i refers to the position of sensor on ground and j to the charge center and k= (1/4πε$_o$) with ε$_o$ being permissivity of vacuum;* ***q*** *is a i x 1 matrix and* ***E*** *is a j x 1 matrix of measurements*". (Lacerda et al., 2012).

To compare the measured and calculated electric field, Ej and Ec, respectively, we compute

$$Ec_i = \Sigma_{ij} (R_{ij} \cdot q_j) \qquad \text{eq.(3)}$$

and

$$\eta = Ec_i/E_j \qquad \text{eq (4)}$$

maintaining 0 ≤ η ≤ N. N is arbitrarily choose. For example, in some cases we made N=0.1.

In the case of Vale do Paraiba campaign was adopted the dipolar structure. The results of the plot of Ec against Ej in that case are presented in next section.

3 - RESULTS AND DISCUSSION

In a recent study at Vale do Paraiba campaign Lacerda et al., (2012) used this methodology to fit data of a EFMN. The results are presented in figures 3.1, 3.2 and 3.3 where data are fitted against calculated electric field at several points. Figures 3.1, 3.2 and 3.3 show the measured electric field at three different sites and also the fit of the curve for 5 points.

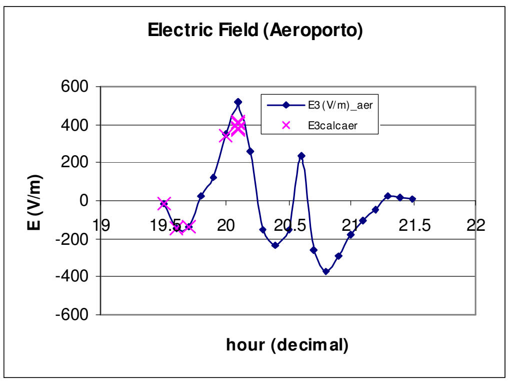


Figure 3.1 - Measured E_i (line) versus Calculated Ec_i (x) at Aeroporto position. (Lacerda et al., 2012)

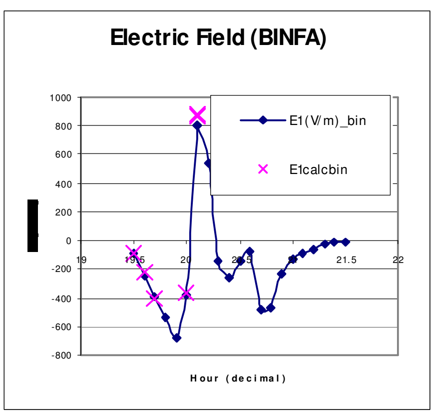


Figure 3.2 - Measured E_i (line) versus Calculated Ec_i (x) at BINFA position (Lacerda et al., 2012).

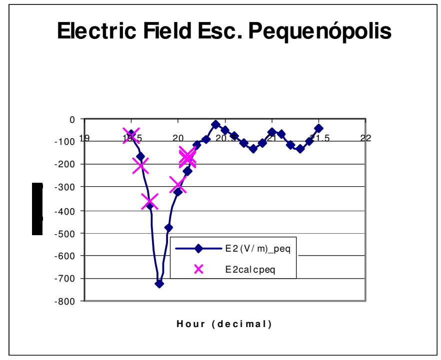


Figure 3.3 - Measured E_i (line) versus Calculated Ec_i (x) at Escola Pequenópolis position (Lacerda et al., 2012).

Acoording to Lacerda et al (2012):

"*The two points that were not fitted between those points of figures"* 3.1, 3.2 and 3.3 *"correspond to situations where it was not possible to localize precisely charge center's in radar image and It would be very difficult to find a solution that could be physically reasonable with only few measurements. The last point was poorly fitted because of the same difficulty, and several essays were proceeded. The cloud structure was probably too complicated to get a reasonable solution"* at that moment.

.

"Results show a cloud with inverted dipole with electric charge varying between -13 C and -78 C (height from 4800 to 7900 m), and 15 C up to 54 C (height from 2800 to 5000) for negative and positive centers respectively".

4 - DISCUSSION

As a discussion of this methodology Lacerda et al. (2012) enumerate several points, that we reproduced below:

"*1. The methodology is strongly dependent of the localization of the charge centers and requires the use of another technique",* to locate precisely the charges centers.

"2. The choice of the cloud structure is arbitrary and depends on the information given by another technique."

The use of instrumented balloons, for example, can solve these two difficulties. (Stolzenburg, 1998a, b and c).

When we used the centers aligned vertically:

"3. The polarity and magnitude of calculated electric field, E_c, remains the same for different choices of center's position for a set of Ek (measurements of E for every sensor in a instant t_k), but the calculated magnitude of the electric charges vary."

If we don't know precisely the locations of charges centers:

"4. The choice of charge magnitude depends on another information given by another technique." For example, information about microphysical processes inside the cloud.

"5. The solution of inverse problem of Coulomb's law may be preferentially used for small thunderclouds localized close the field mill network."

In these cases the most probable cloud structure to be adopted for calculations is a dipolar structure.

Finally, these authors conclude that:

"Temporal data of three sensors (BINFA, Esc. Pequenópolis and Aeroporto) were reasonably fitted by the recalculated electric field," by solving the inverse problem of Coulomb's law.

5 - CONCLUSIONS

We developed a methodology to calculate electric charges structure inside clouds by using the solution of inverse problem of Coulomb's law, based on measurements of electric field on ground and radar's data. This methodology requires the use of another technique to decide about the magnitude of charges if we don't have a precise localization of charge's center. If we have a precise localization of electric charges centers, the magnitude is univocally determined, if not, we have to use additional information (based on microphysical considerations, or balloon prospection, for example) to decide about the magnitude of those electric charges. The results of preliminary application of this technique are enough good to encourage the improvement of it. It is important to add data from instrumented balloon to detect the density and polarity of electric charges inside the cloud.

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