Method LMA-EF for determination of position and intensity of electric charges inside thunderstorm clouds.

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ABSTRACT: In this paper we present experimental results obtained by the use of the method Lightning Mapping Array with Electric Field measurements on ground (LMA-EF). This method allows to measure the positions and magnitudes of the electric charges (Q) inside the thunderstorm clouds. The data used to validate the experiment were provided by the Vale do Paraiba CHUVA (Cloud processes of tHe main precipitation systems in Brazil: A contribUtion to cloud resolVing modeling and to the GPM (GlobAl Precipitation Measurement)) project campaign, that took place in São Paulo - Brazil between December of 2011 and January of 2012. The LMA data can provide us the position (R) of the electric charges centers and a network of electric field mill provides data of electric field (E). Combining LMA data with the measurements of electric field on the ground is possible to determine the magnitude of the electric charges, by using the inversion of the coulomb law in matrix form: $\mathbf{Q = (R^T.R)^{-1}.R^T.E}$. An algorithm was written to make this estimation automatically. After the determination of the electric charge structure, the algorithm recalculates the direct Coulomb's Law and checks the results by fitting data of electric field on ground.

INTRODUCTION

The direct detection of charges position inside thunderclouds requires instrumented balloons flight techniques and solution of Coulomb's Law (Stolzenburg and Marshall, 1994, Stolzenburg and al., 1998a, b and c). On the other hand the network of field mill is a less expensive tool to detect cloud structure (Jacobson and Krider, 1976, Livingston and Krider, 1978, Koshak and Krider, 1989) and can be combined with other technique (such as Radar data and lightning localization system (LLS), Lacerda et al, 2010) to estimate magnitude of charge centers.

For the first time we are combining the electric field measurement on ground with LMA measurements to detect the charge center positions inside clouds for calculating their magnitude by solving the inverse problem of Coulomb's Law. The inverse problem is not trivial and requires fast way to proceed computational calculations. This way is the matricial technique and will be presented in this paper.

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DATA ACQUISITION SYSTEM

The network of field mill was installed in the city of São José dos Campos, São Paulo State in the coordinates shown in table 1.

Table 1 Localization of field mill network

Site name	Latitude	Longitude
1	-23.211283	-45.860278
2	-23.209431	-45.880862
3	-23.224739	-45.862521
4	-23.201461	-45.873773

The LMA System was distributed inside and around the city of São Paulo, about 80 km far from the field mill network. Data of both systems were collected between September, 2011 and mars, 2012. As a case study we present a thunderstorm occurred at November 28 around 19:00 Hours UTC.

METHODOLOGY

The first step is to detect the position of charge center by grouping data of electromagnetic radiation source collected by LMA. The algorithm calculate the spatial density of emission by counting all emission source during variable intervals of time. The regions where maximum occur are chosen like possible centers. The distance of 3 km is used as minimum distance between two centers. The coordinates x, y, and z of these possible centers are grouped in a matrix $P_{(n,3)}$

$$P_{(n,3)} = \begin{pmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ \dots & \dots & \dots \\ x_n & x_n & z_n \end{pmatrix} \qquad (1)$$

Another matrix $S_{(m,3)}$ with coordinates X, Y and Z of sensors is mounted

$$S_{(m,3)} = \begin{pmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ \dots & \dots & \dots \\ X_n & Y_n & Z_n \end{pmatrix} \qquad (2)$$

The second step is using both matrix Q and S are used to build a matrix $R_{(m,n)}$:

$$R_{(i,j)} = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{2 \cdot z_j}{\left[(x_j - X_i)^2 + (x_j - X_i)^2 + z_j{}^2\right]^{\frac{3}{2}}} \qquad (3)$$

The third step is construct a column matrix with the measured electric field $E_{(j)}$ and then calculate

$$\boldsymbol{Q}_{(n)} = (\boldsymbol{R}^{\boldsymbol{T}} \cdot \boldsymbol{R})^{-1} \cdot \boldsymbol{R}^{\boldsymbol{T}} \cdot \boldsymbol{E} \qquad (4)$$

Where $Q_{(n)}$ is a column matrix with the magnitude of charges for the possible charge centers. Mathematical details about using equation 5 can be found in Tarantola (1987). Finally, we calculate the electric field produced by that configuration of charges for the positions where exist field mill, by using:

$$E_{d(i)} = \sum_{j=1}^{j=n} R_{(i,j)} \cdot Q_{(j)} \qquad (5)$$

If the value fits well the data we stop calculation, if not we return to step 1.

RESULTS

The next figures show the result of these steps. In figure 1 we see a graph where axis x and y are latitude and longitude respectively converted to kilometers. The point (0,0) has been chosen arbitrarily close to the network. The circles are localization of charge centers and triangles represent positions of electric field mill. In the figure 2 and 3 axis x represents latitude or longitude and y are the height of charge centers.

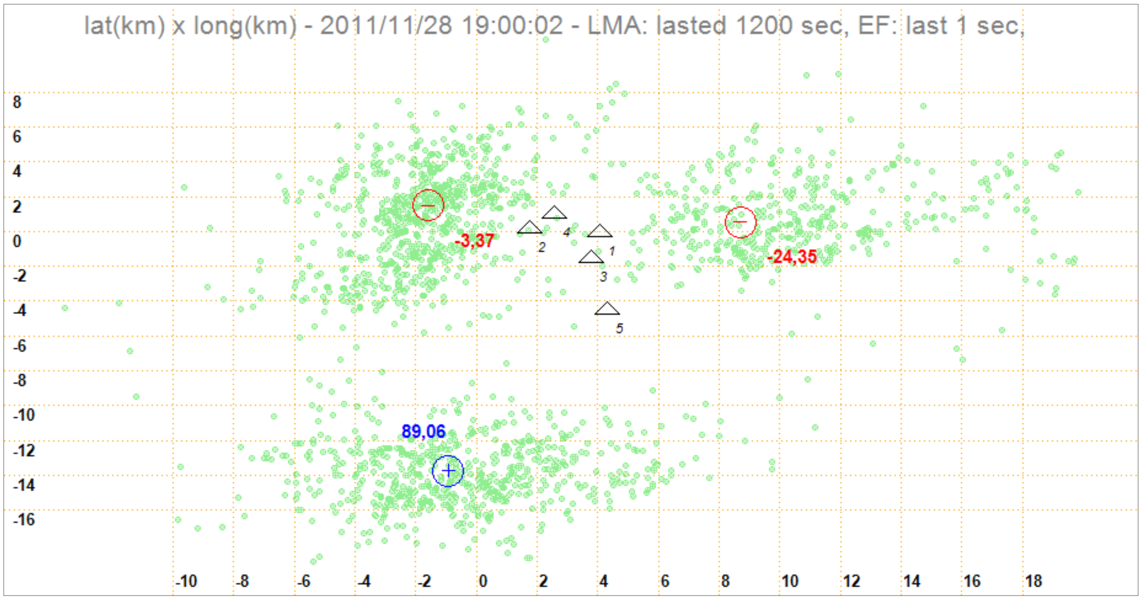


Figure 1. Position of charge centers (view from the top)

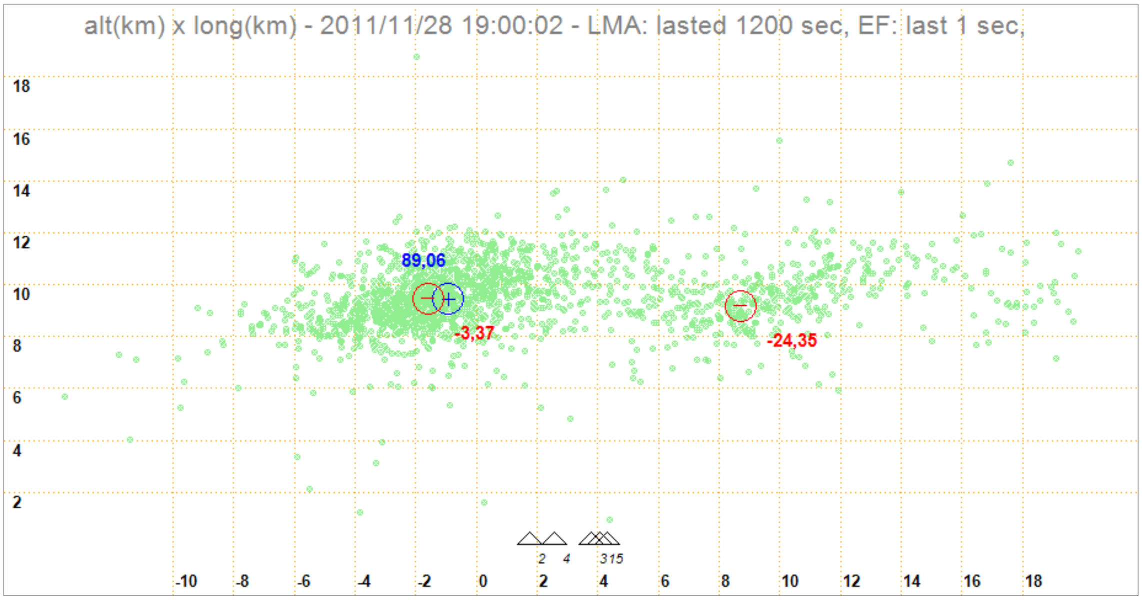


Figure 2. Position of charge centers (front view)

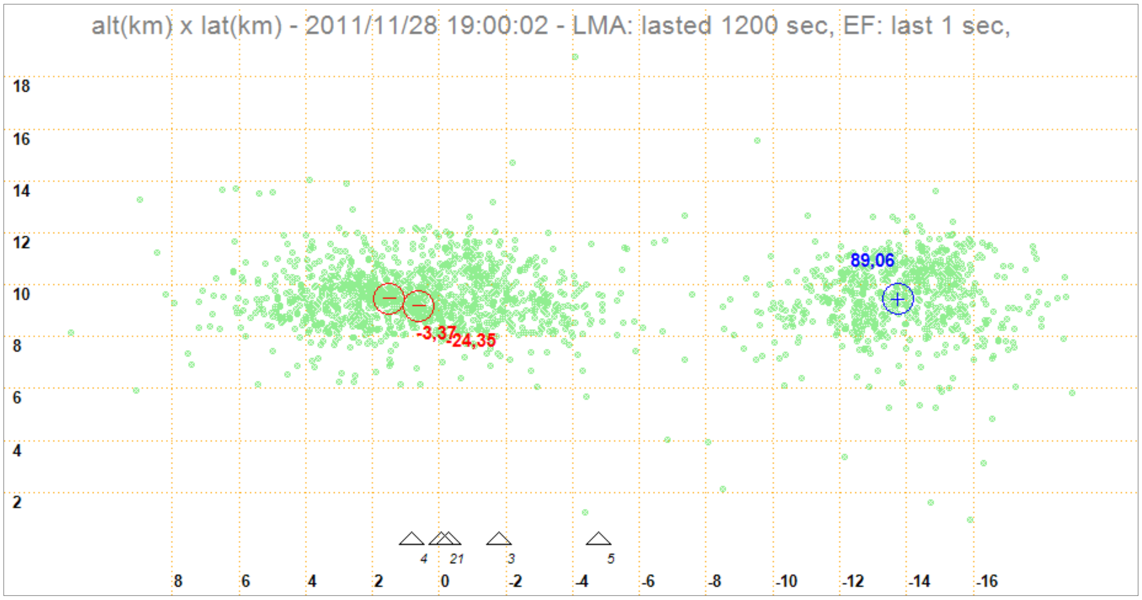


Figure 3. Position of charge centers (side view)

In the figure 4 we show the time varying magnitude of charges that we use to calculate the direct fields by using equation (6) to fit data. The figures 5 and 6 we show the fit for two sensors on ground.

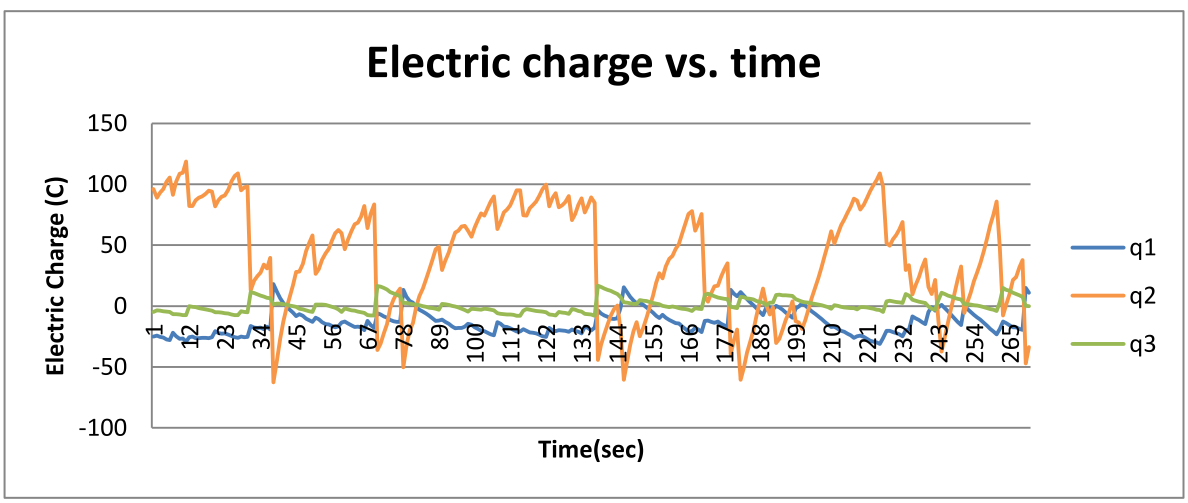


Figure 4. Charge magnitude calculated. The x-axis is the time in minutes and the axis y is the charge in Coulombs.

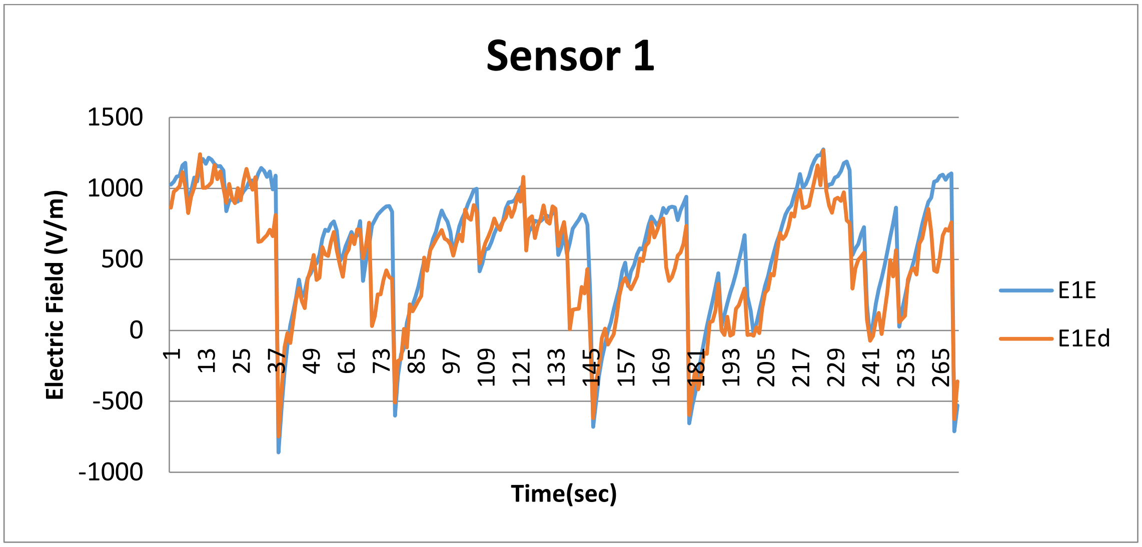


Figure 5. Calculated electric field for sensor 1. The red line is the calculated value and the blue line is the measured field in sensor 1.

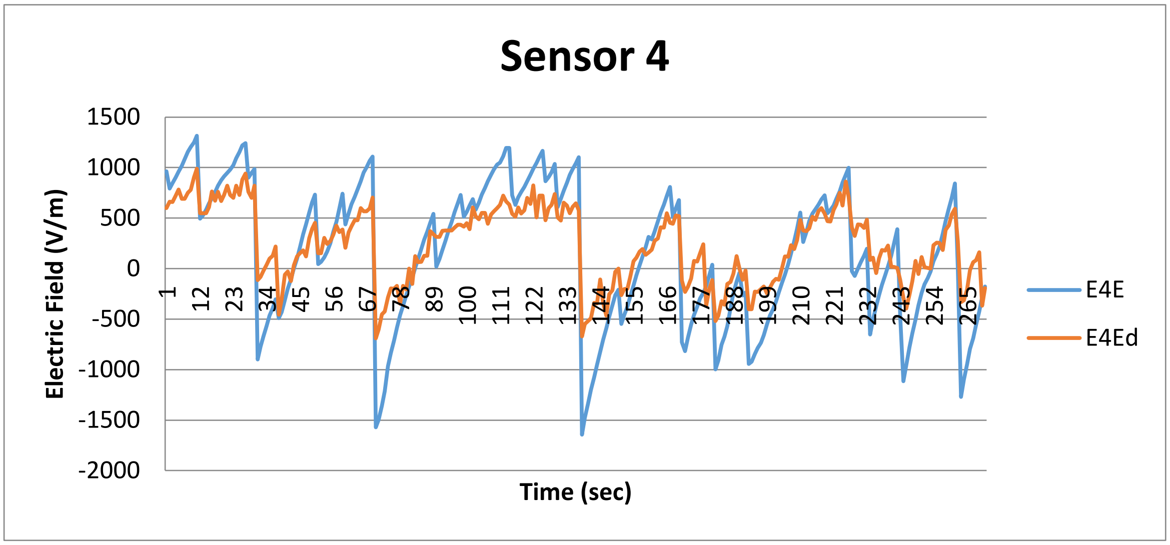


Figure 6. Calculated electric field for sensor 4. The red line is the calculated value and the blue line is the measured field in sensor 1.

In figure 7 and 8 we show the graph of dispersion for calculated and measured electric field for sensors 1 and 4 respectively.

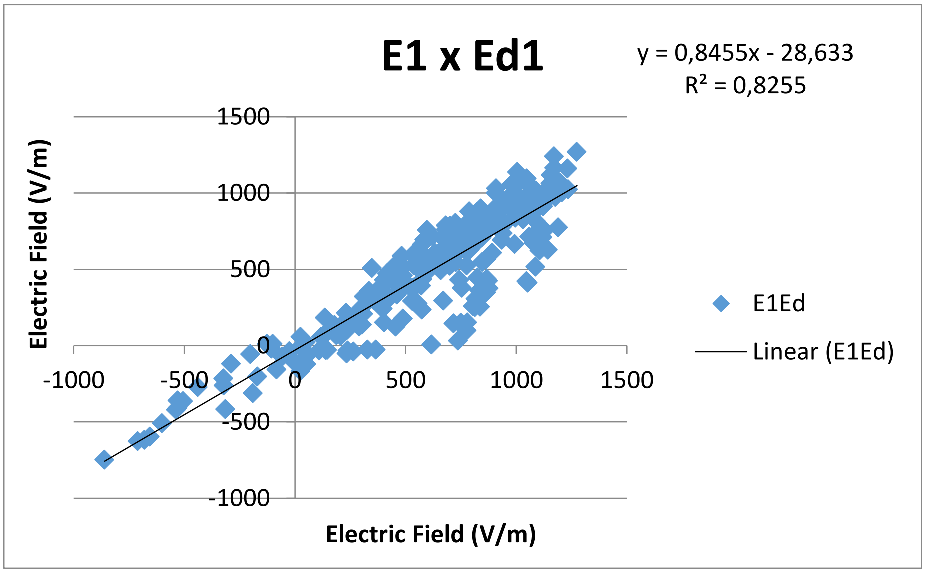


Figure 7. Dispersion graph for calculated and measured values of electric field for sensor 1. The axis x and y are in Volts.

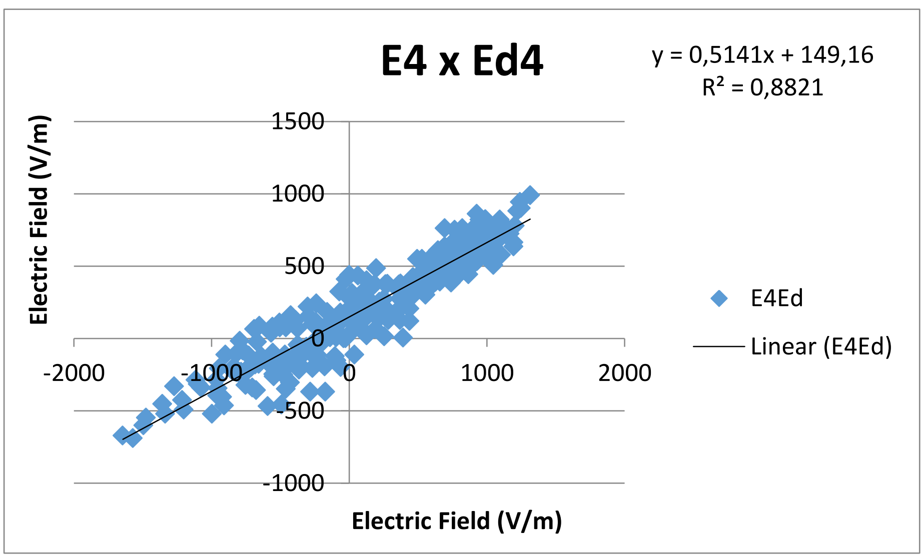


Figure 8. Dispersion graph for calculated and measured values of electric field for sensor 4. The axis x and y are in Volts.

DISCUSSION OF RESULTS

This method is efficient and can be used in real time because of the few mathematical operations realized. The fit is in good agreement with data. But some problems require still more analyses.

The accuracy of method fails for some cases:

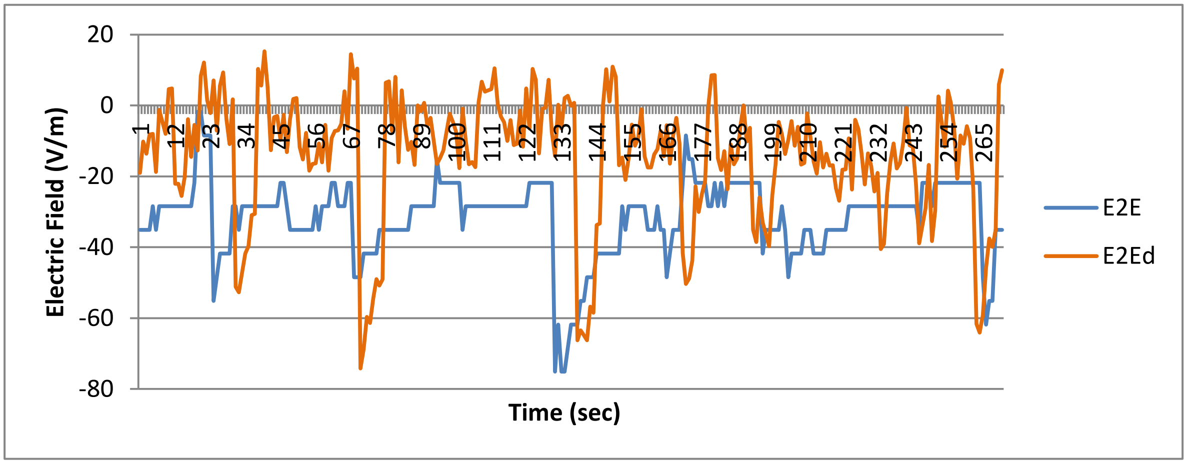
a) Centers far from the field mill network, more than 15 km.

b) If there are singularities in matricial product during calculations

c) For low value of measured field the precision of calculated value is still low.

A positive charge of around 100 C is located close to a negative center of magnitude of 28 C in an atypical horizontal distribution. The cloud is over the network. On the other hand we can notice that the calculated value of the positive center doesn't vanishes after discharges, but it decrease and increase again. If this analysis is correct, we conclude that mechanism of charge generation is continuously producing charge that tends to make the value of charge return to initial values.

As an example of low precision we show the figure 9. The calculated red curve was divided by ten to compare with measured blue curve. Notice that the precision is not so good and general aspect of both curves seems be in poor agreement.



Some hypothesis for explain these situations are possible but they are still under observation and requires more analysis.

CONCLUSION

In this paper we present experimental results obtained by the use of the method Lightning Mapping Array with Electric Field measurements on ground (LMA-EF). This method allows to measure the positions and magnitudes of the electric charges (Q) inside the thunderstorm clouds. The main conclusion is that the method is good for calculating the time dependent magnitude of charges inside the cloud.

Magnitude of charge of order of 100C for positive center and of -28 C for negative charge center is obtained. Such research is istill beginning and needs to be applied in more cases to produce a better confidence.

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