

# **SIMULATIONS OF SPATIAL AND TEMPORAL VARIATIONS OF ELECTRIC-FIELD CONTOURS AT THE SURFACE BENEATH THUNDERSTORMS AS WOULD BE OBSERVED BY A NETWORK OF SOLAR-POWERED ELECTRIC-FIELD METERS**

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**ABSTRACT:** Electric field meters known as "field mills" have been used for many years to measure the vertical component of the atmospheric electric field near the ground for thunderstorm research and safety purposes. Typically, it is relatively expensive to deploy traditional field mills, even in small numbers, because of initial cost, installation cost, maintenance cost and power requirements (Maier and Strange, 1988; Marcotte and Mulvehill, 1991). Networks of multiple field mills for research or operational purposes are therefore relatively rare. A new electric-field meter developed by Campbell Scientific, Inc., under license from the University of Oklahoma, costs considerably less than traditional field mills, operates on solar power, has far fewer moving parts, is more flexible and easily programmable, and is relatively easy to maintain and calibrate. This development makes it feasible now to deploy networks of electric-field meters for many applications for which the costs would have been prohibitive in the past. In order to begin to understand how to deal with the data streams that will eventually come from such networks, and to develop means of displaying and interpreting the data, we have simulated the contours of electric field at the surface during growth, decay, and advection of various simple and complex charge distributions overhead, as if the fields were measured by a network of electric-field meters. The ultimate goals are both improved understanding of the behavior of thunderstorm electric fields at the ground and development of affordable means for improved early warning and all-clear notification with regard to the potential for lightning strikes

## **INTRODUCTION**

There is an obvious but largely unmet need for information to help those in charge of outdoor activities to assess the possibility of a nearby lightning strike before the first strike has occurred and at the end of storms when the time between successive lightning flashes can be tens of minutes (Jacobson and Krider, 1976). The cost to deploy traditional electric-field mills in appropriate numbers has been so prohibitively high that it has been justified in only the most extreme high-risk situations. Now, the new instrument by Campbell Scientific makes it economically feasible to deploy networks of many field meters at a fraction of the cost of past installations. In part because there have been few networks of electric-field meters, there has been little research done and reported in the scientific literature on the patterns of electric fields at the ground beneath thunderstorms and how they might be used to predict when and where a first ground strike might occur and to determine when the threat of a ground flash has decreased below some predetermined threshold. There has been little or no research using such tools on winter thunderstorms, squall lines, Mesoscale Convective Complexes, and Supercell Thunderstorms of the types frequently seen in the Great Plains.

Once networks of the new field meters are deployed and operated through several storm seasons, we expect that it will be possible to develop pattern-recognition algorithms that at least under specified circumstances could identify particular patterns in the temporal and spatial evolution of the contours of electric field at the ground beneath a thunderstorm (Rompala, 1991). Then it would be possible to display a field of appropriate symbols on a map to indicate areas at risk for a cloud-to-ground lightning strike within some period, in a manner similar to the Tornado Vortex Signature display for the WSR-88D radar. It is likely that not all types of storms will be amenable to early warning before first lightning, and it will be critical to determine the circumstances under which such warnings can be given and those under which they cannot.

## **SIMULATIONS**

In order to begin to develop techniques for handling with data from networks of field meters, we have produced simulations of the spatial and temporal variations of electric field at the ground as they would be observed by a network of field meters during the growth and decay of thunderstorms under various circumstances. We have done two kinds of simulations: 1) simple, but arbitrary, dipole model charge distributions over a model network of realistically distributed electric-field meters; 2) realistic charge

distributions in model storms with realistic parameterized cloud physics, charge generation, and lightning flashes over a uniform model network of observing stations.

In the first series of simulations, we used realistic locations and spacing for 42 electric-field meters based on the layout of the ARS Micronet, an existing network of remote meteorological observing stations in central Oklahoma. We used the simplest model of a thunderstorm charge distribution, a dipole over a ground plane, and postulated linear growth and decay of the amounts of charge in three situations: 1) charge growth stationary overhead, 2) charge distributions growing and moving horizontally as if advected by the mean wind, and 3) vertically oriented as well as tilted charge distributions with CG and IC discharge effects included. The purpose was to get an idea of how contours of constant electric field at the ground would vary spatially and temporally during a typical storm time period. We did not take the space-charge limitation of surface fields into account, so magnitudes of electric field greater than 10 kV/m to maybe 20 kV/m should be viewed with caution. At each location we calculated the electric field from the postulated charge distribution for each time step. We then used a statistical objective analysis technique, with a Barnes analysis as a background field, to interpolate contours of constant value of the field for each time step.

In Figure 1, the Location of the thunderstorm charge distribution is shown by points at 5 km and 10 km altitude. Normal fair-weather electric field is assumed to be -100 V/m, shown by the green shading. The red contour line shows the locus of points at which the electric field is zero. This snapshot is at time  $t = 0+$ , just at the beginning of the charge growth. In Figure 2, the contours of electric field show the situation after about 20 minutes of linear growth of the charges to ! 30 Coulombs at 5 km altitude and + 30 Coulombs at 10 km altitude. The maximum field has reached about 10 kV/m.

Figure 1. Layout of model network of electric-field meters

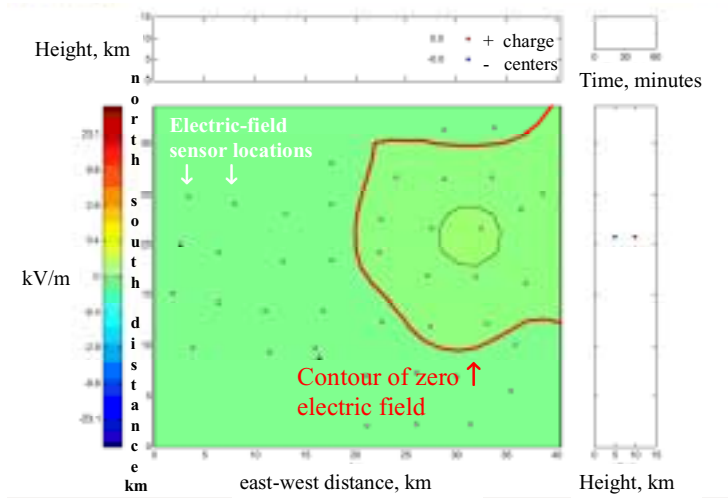


Figure 2. Contours of electric field at the ground beneath a dipole model thunderstorm charge distribution of 30 Coulombs at 5 km and + 30 Coulombs at 10 km.

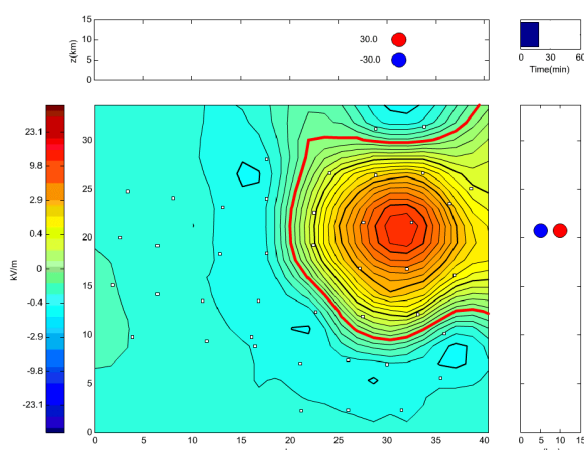
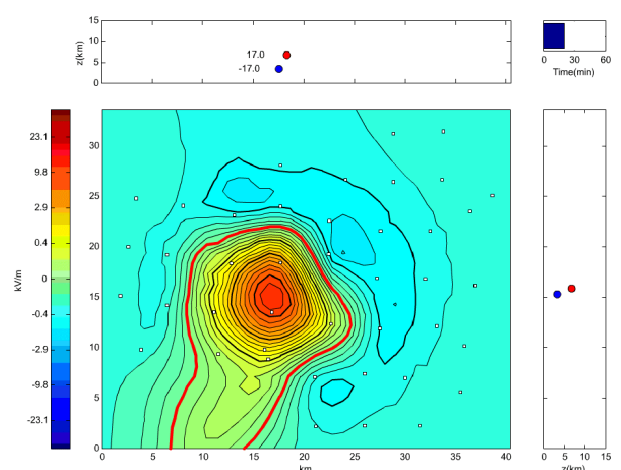


Figure 3. Contours of electric field after 20 minutes of linear growth to 17 Coulombs at about 4 km and + 17 Coulombs at about 8 km, advection by the mean wind, and wind shear.



The situation depicted in Figure 3 is similar to that in Figure 2, but in this case, while growing, the dipole charge distribution was advected from the southwestern edge of the network to the position shown, and tilted as if affected by vertical wind shear. The charges are at slightly lower altitudes as well.

In the second series of simulations, we used a three-dimensional storm model with detailed microphysical parameterizations that provides self-consistent fields of space charge in a thunderstorm environment. There are 12 bulk hydrometeor categories (cloud droplets, rain, three ice crystal habits, aggregates, three graupel densities, frozen drops, and small and large hail), each with an associated charge density. The branched lightning parameterization of Mansell et al., 2002 is used with an electric field initiation threshold that decreases exponentially with increasing altitude (the runaway or breakeven threshold). Small ions are treated explicitly, and a parameterization of surface corona emission is included. Corona emission turns on when the vertical component of the surface electric field exceeds a magnitude of 5 kV/m. For figures shown here we used a noninductive charging parameterization with reversal temperature at -15C in order to favor 'normal' charge polarity. The inductive graupel-droplet charging is mainly responsible for causing a lower positive charge (LPC) region to develop, leading to negative CG flashes. Simulations were performed in a 45-km by 45-km by 18-km domain with horizontal spacing of 500m and vertical spacing that stretches from 200 m at the ground to 500 m aloft. The storm was initiated with a warm bubble with randomized thermal perturbations. Each simulation was run for at least two hours, by which time almost all convection had decayed. Because there is no feedback from the electrification to the dynamics, each run is identical in terms of dynamics and microphysics. The model is initialized with a profile of positive and negative small ions to produce a 'fair weather' electric field profile.

In Figure 4, at a time of 24 minutes into the model run, the first contour of electric field at 1kV/m appears. In Figure 5, the first contour of 6 kV/m appears 50 minutes into the model run, at about the same time

Figure 4. First 1 kV/m contour, 24min.

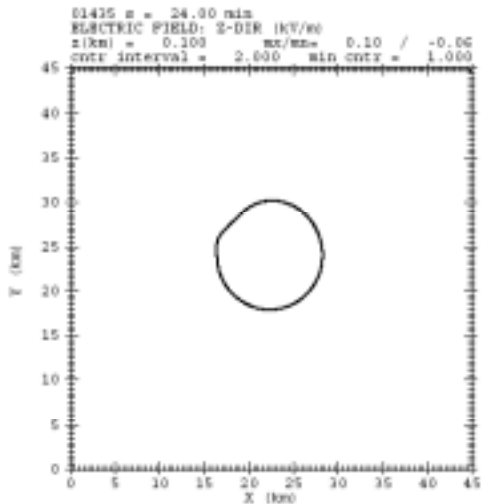
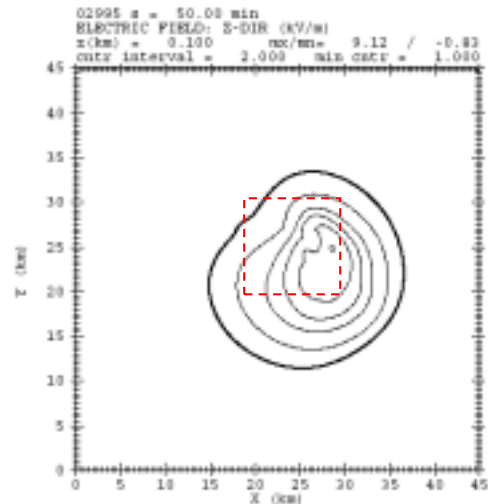


Figure 5. First 6 kV/m contour, 50 min.



that perturbations in the 4 kV/m and 5 kV/m contours appear at about x = 25 km, y = 25 km, as shown by the red dashed-line box, which is about 10 km by 10 km. In Figure 6, at 52 minutes into the model run, the effects of the lower positive charge development can be seen as the first contour of !1kV/m appears within the box.

Figure 6. First !1 kV/m contour, 52 min.

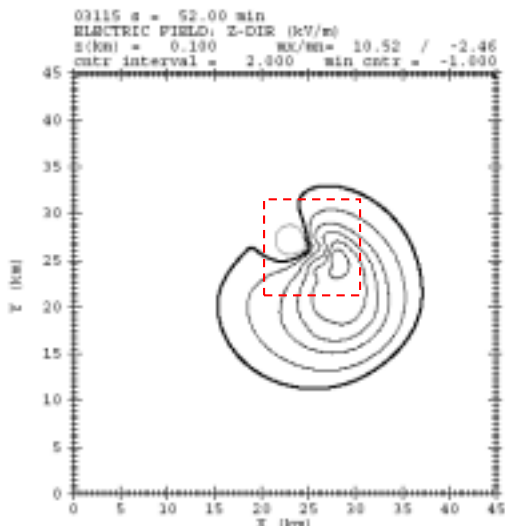
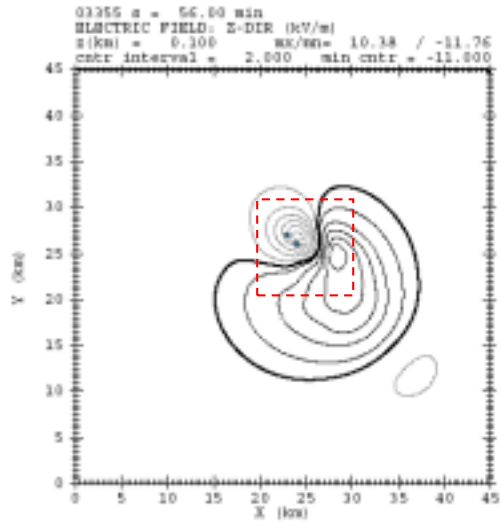


Figure 7. First !CG near !5kV/m contour, 56 min.



In Figure 7, at 56 minutes, the first and second negative CG flashes of the storm have occurred, with strike point between the  $!4\text{kV/m}$  contour and the  $!5\text{kV/m}$  contour. This sequence suggests to us that in cases for which this model may be applicable, it ought to be possible, at least under some circumstances, to predict within a box of about 10 km on a side, where the first CG flash may strike. In Figure 8 we have shown the field contours at

Figure 8. Last  $!CG$  near  $!2\text{kV/m}$  contour, 110 min.

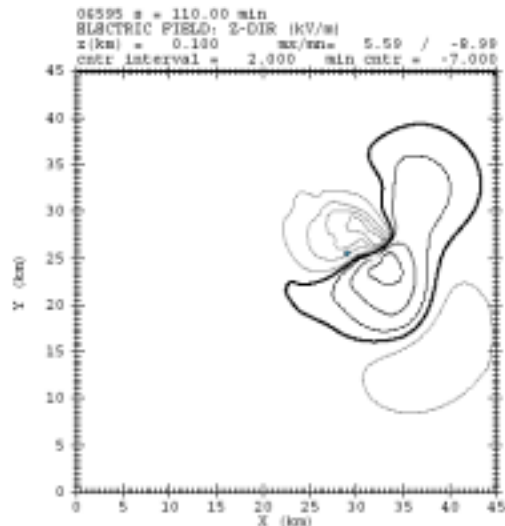
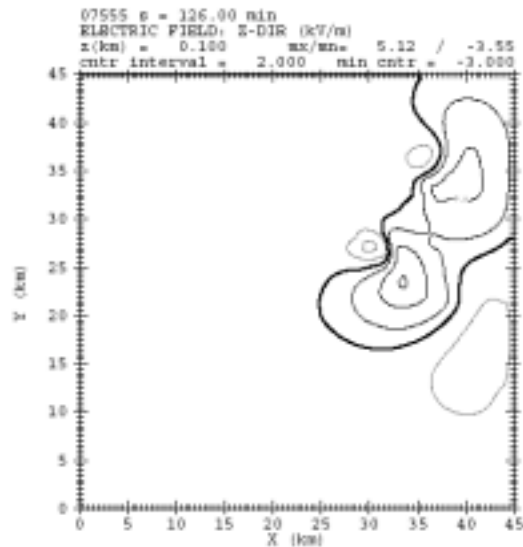


Figure 9. Field contours at 126 min.



the time of the last negative CG flash. Finally, in Figure 9, we show the contours 16 minutes after the last CG flash. The greatest negative field is now  $!2\text{kV/m}$ , and the area covered is greatly reduced. In isolation this might not tell much, but in sequence, showing the collapsing contours, this kind of pattern might be suitable for use as an indication that no further ground strikes are likely, at least under some circumstances.

## CONCLUSION

These examples are intended to suggest that under at least some circumstances it ought to be possible to recognize certain patterns in the contours of electric field at the ground that relate to potential threats. The next step is to deploy a network of field meters and to begin to collect and analyze real data from small networks of electric-field meters.

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