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13. ABSTRACT (*Maximum 200 Words*)

We designed and built a new balloon-borne electric-field-change instrument and launched five of them into thunderstorms to observe changes in the vertical component of electric field caused by lightning. We discuss examples of field changes observed at altitude and compare them with data from the National Lightning Detection Network (NLDN) for cloud-to-ground lightning flashes that were coincident in time. It appears that the field changes may have been caused by charge movements relatively near the instruments as compared with the ground-strike location of coincident flashes. Though we were unable to obtain field-change data coincident with Transient Luminous Events, we developed a working balloon-borne field-change sensor and demonstrated the feasibility of launching it in storms. We plan to continue these observations in STEPS 2000.

14. SUBJECT TERMS
Lightning, Electric Field Changes, Transient Luminous Events, x-rays, gamma radiation, National Lightning Detection Network

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## Introduction

In this report we describe the balloon-borne electric-field-change antenna developed with the funding provided in this grant and we present some preliminary results of deployment of several of them in storms during 1998. As reported in *Eack et al.* [1996], X-ray (or gamma radiation) pulses have been observed above a mesoscale convective system at an altitude of about 15 km (this and all other altitudes specified in this paper are MSL (above mean sea level)) with no significant steady electric field present. This raised the question of whether lightning flashes might be a cause of changes in electric field at those altitudes that are of duration too short to be recorded by the standard electric-field meters (EFM) of the type used for studies of the charge structure of storms [*Winn and Byerley*, 1975; *Marshall et al.*, 1995], but perhaps of sufficient magnitude and duration to cause production of bremstrahlung radiation such as that observed. (For the EFM that provided the eletric-field data discussed in *Eack et al.* [1996], pulses in the electric field with duration less than about 200 ms were not detectable.) Furthermore, if the cause of such field changes were cloud-to-ground lightning flashes, it might be the same class of field changes that, according to some hypotheses [*Taranenko and Roussel-Dupre*, 1996; *Pasko et al.*, 1996; *Bell et al.*, 1995] may be the causes of, or at least related to the causes of, the high-altitude discharge phenomena, such as red sprites and blue jets, known as Transient Luminous Events (TLE) [*Lyons*, 1996]. Field changes caused by lightning have also been shown to be theoretically capable of production of gamma radiation at altitudes well above storms [*Chang and Price*, 1995; *Roussel-Dupre* et al., 1998a]. The objective of this research was to observe electric-field changes at high altitudes (15 km or more), if possible in conjunction with coincident occurrences of TLE.

## Instrument Design

The principle of operation and basic electronic design of the field-change antenna are similar to that of "slow" and "fast" antennas discussed in *MacGorman and Rust* [1998]. The terms "slow" and "fast" refer to the character of the response of a system to a step-function input. For a typical "slow" antenna the time constant (time for response to decrease to 1/e of its original value) is about a second. In our instruments we set the 1/e decay time at 30 ms. We chose this relatively short decay time because we expected that the instrument would be going through regions of storms that could produce slowly varying fields that might saturate the electronics if the decay time were too long. Decay time of 30 ms is long enough that we can expect to see field changes caused by the transfer of charge to ground by the individual strokes of a cloud-to-ground lightning flash that is within range. The upper limit on frequency response was dictated by the trade-off between bandwidth and telemetry capabilities. In the case of the instruments that measure field change only, the 3 dB rolloff was set at 15 kHz for a sampling rate of 32 kHz. In the case of the instrument flown with a gamma detector in the same package, the sampling rate was limited to 15 kHz, so we set the 3 dB rolloff at 7.5 kHz. Requirements for a signal to trigger data capture were set in software in the on-board microprocessor. Typically, we required a field change equivalent to 80 V/m in a time of 30 µs, or 1 sample, to trigger the system. The duration of the records was 0.8 seconds. For the instrument with the gamma-ray detector also on board, the record was 50% pretrigger and 50% post-trigger. For the field-change-only instruments, the record was 25% pretrigger, 75% post-trigger. We chose the same well known and well characterized configuration for sensing elements that has been used for balloon-borne electric-field meters (EFM) for at least a decade: two alumninum spheres, each 0.15 m in diameter, mounted in opposition on a fiberglass rod. As in the EFM design, we enclose the electronics within the spheres, one of which serves as the "ground" reference and the other of which serves as both the sensor element and the telemetry antenna. We used lithium batteries to power the sensor electronics, a microprocessor, A/D converter, and the telemetry transmitter. The batteries typically last for at least two hours. This instrument does not need to rotate in either the vertical or horizontal plane, so there is no motor, there are no styrofoam vanes as on an EFM, and the fiberglass boom, which serves only as a means by which to suspend the instrument from the balloon, is shorter. The total mass of a complete instrument, including batteries, is about 1 kg.

## Observations

We have processed and analyzed data from two flights. The larger single-sphere package, with gamma detector in addition to the field-change antenna, was launched at 0010 UTC on June 19,1998 from the vicinity of Elmore City, Oklahoma. The instrument reached a peak altitude of 22.6 km at 0105 UT. The flight path is depicted in vertical and horizontal planes as a function of longitude in Figure A1. The numbers along the flight path denote the order of successive trigger times. In Figure A2 we show the waveforms recorded for triggers 9 and 21. In the case of trigger 9, there were two field changes separated by 60 ms when the instrument was at about 12 km altitude. The magnitude of the first of these field changes was about 160 V/m +/- 30 V/m. The magnitude of the second field change was about 70V/m +/- 30 V/m. At the same time, also separated by 60 ms, there were two positive cloud-to-ground flashes recorded by the National Lightning Detection Network (NLDN). The first was at 50.8 km along the ground from the sub-balloon point and 52.2 km from the balloon itself. The second was at 50.2 km along the ground from the sub-balloon point and 51.6 km from the balloon itself. Both of these had peak currents, according to the NLDN estimate, of about 60 kA. In the case of trigger 21, the instrument was at an altitude of approximately 14.5 km. The magnitude of the field change was approximately 235 V/m +/- 30 V/m. There was a positive cloud-to-ground flash located by the NLDN 73.4 km along the ground from the sub-balloon point and 74.8 km from the balloon itself. The peak current, estimated by the NLDN, was approximately 130 kA. There were no other flashes detected and located by the NLDN within about 100 km at these times. We have also examined data obtained with a field-change-only instrument launched at 0319 UTC, September 22, 1998, east of Oklahoma City. The next day, we recovered the instrument from a location near Prague, Oklahoma, about 62 km, from the launch point. One of the 9 triggers recorded had four rapid field changes of about 100 V/m each with time between each two of them of about 150 ms. This event is shown in Figure B1. The rapid field changes appear to be those of cloud-to-ground return-strokes.At the same time, within about a 50 km radius, there were 15 NLDN located flashes, some with multiplicities of 3, 4, and 5, and all but one were negative.

Discussion

For the cases on June 19, there were relatively few cloud-to-ground lightning flashes. No flashes other than the ones cited occurred within about 100 km and +/- 2 seconds, so that coincidences in time at least invite our further attention. For example, in the case of trigger 9, Figure 2, there were two field changes with 60 ms interval between them, two cloud-to-ground flashes separated by 60 ms at the same time as the field changes, and no other cloud-to-ground flashes within 100 km at that time. However, the time resolution of the waveforms is insufficient for us to identify them with any particular process in a cloud-to-ground flash. We note that the NLDN reported the flashes that were coincident with the field changes as positive, that is, they lowerd positive charge to ground, and at about the same distance, with about the same peak currents, yet the two field changes at the balloon were of opposite polarity and different in magnitude by a factor of 2. It should be noted that peak current is not necessarily linearly related to the total charge transfer of a return stroke, so that lack of correlation of these two quantities should not be taken as significant. However, the difference in polarity is more problematic. It leads us to consider a possibility that we cannot rule out that the field changes we observed could have been caused by an undetected cloud-to-ground flash or an intra cloud discharge that might or might not have been related to the ground flashes located by the NLDN. Presumably some portions of the discharge paths may have been relatively near our instrument at 12 km altitude. In the case of trigger 21, Figure A2, our measured field change was larger, the distance from instrument to NLDN located flash farther, and the NLDN peak current estimate larger than in the case of trigger 9. If we assume that the field change of trigger 21 was the result of charge transfer that occurred during a return stroke, a process that appears to be completed in about 1 ms or so [*Beasley et al.*, 1982], we can estimate the amount of charge transfer it would take at a distance of 74 km to cause the observed field change of 235 V/m at the balloon.

We have modeled the process as if it were the transfer of a point charge from altitude 5 km to ground at a distance of 74 km., just to get an estimate of magnitude of charge needed. It turns out to be about 1300 C, which seems unrealistically large even for a positive return stroke. Though it is possible, especially in the case of positive CG discharges, that there might be considerable horizontal extent of discharge channel, we assume for our purpose here that it would not make an order of magnitude difference in the observed field change at 74 km. By comparison, creation of a positive charge of 0.03 C at a distance of 1 km directly below the instrument would cause a field change of about the magnitude observed. This increases our suspicion that the field changes we recorded were caused by motion of charge closer to the balloon than the ground strike point of the coincident CG flash. Another feature of interest of trigger 21 is the ramp following the fast field change. It might at first appear to be evidence for a continuing current, but, noting that the time constant of the system is 30 ms, the actual field change would have been much larger than the observed 700 V/m over a period of about 235 ms. If the field change were a result of a flow of charge in the channel of the NLDN located flash to ground, 74 km distant, it would have taken unrealistically large amounts of charge. This again suggests that the field changes, both fast and slow, in Figure A2, are the result of charge motion relatively close to the balloon, possibly, but not necessarily, associated in some way with the distant ground flashes, and, in these cases at least, near the top of the cloud.

## Conclusions

We succeeded in observing electric-field changes, which we attribute to lightning, at altitudes in thunderstorms. However, we cannot unambiguously identify the specific process responsible for the field changes because of limitations of our time resolution and timing accuracy. Our tentative conclusion is that the field changes we saw were more likely a result of charge motion relatively near the instrument as compared with the distances of 50 km to 75 km to time-coincident ground flashes.

The question of what, if any, connection there might be between the ground flashes and any supposed charge motion near the instrument remains open. To be able to identify the processes responsible for the field changes observed at altitude we will need better timing accuracy, time resolution, and position data on future instruments, and, ideally, simultaneous data from a 3-d lightning mapping system that can determine the locations of sources of VHF radiation in the clouds with good time resolution, thus providing a picture of the structure of the discharge channel geometry.

We regret that during the MEaPRS field progam, and the following fall season in 1998, we were unable to get any instruments into storms that were being observed by either of the two observatories looking for Transient Luminous Events over storms. We demonstrated the feasibility of making balloon-borne electric-field-change measurements and we hope to obtain field-changes corrleated with TLE in the summer of 2000 in the Severe Thunderstorm Electrification and Precipitation program in western Kansas, eastern Colorado, an area much closer to the TLE observatory near Fort Collins, CO than we were able to operate in 1998. The development of a new sensor and the experience we gained during 1998 were tangible results of the funding of this grant.

## References

Beasley, W.H., M.A. Uman, P.L. Rustan, Electric fields preceding cloud-to-ground lightning flashes, J. Geophys. Res., 87, No. C7, 4883-4902, 1982.

Bell, T.F., V.P. Pasko, U.S. Inan, Runaway electrons as a source of red sprites in the mesosphere, Geophys. Res. Lett., 22, 2127-2130, 1995.

Chang, B. and C. Price, Can gamma radiation be produced in the electrical environment above thunderstorms?, Geophys. Res. Lett., 22, 1117-1120, 1995.

Eack, K.B., W.H. Beasley, W. D. Rust, T.C. Marshall, M. Stolzenburg, X-ray pulses observed above a mesoscale convective system, Geophys. Res. Lett., 23, 2915-2918, 1996.

Eack, K.B., D. M. Suszcynsky, W.H. Beasley, R.R. Rousell-Dupre, E. Symbalisy, Gamma Ray Emissions Observed in a Thunderstorm Anvil, Geophys. Res. Lett., 26,1999, accepted for publication

Lyons, W.A., Sprite observations above the U.S. High Plains in relation to their parent thunderstorm systems, J. Geophys. Res., 101, 29641-29652, 1996.

MacGorman, D. R., and W.D. Rust, The Electrical Nature of Storms, ISBN 0-19-507337-1, Oxford, 1998

Marshall, T.C., W. Rison, W.D. Rust, M. Stolzenburg, J. C. Willett, W.P. Winn, Rocket and balloon observations of electric field in two thunderstorms, J. Geophys. Res., 100, 20,815-20,828, 1995.

Pasko V. P., U. S. Inan, and T. F. Bell, Blue jets produced by quasi-electrostatic pre-discharge thundercloud fields, Geophys. Res. Lett., 23, 301, 1996a.

Roussel-Dupre, R., E. Symbalisty, Y. Taranenko, and V. Yukhimuk, Simulations of high-altitude discharges initiated by runaway breakdown, JASTP, 60, 917, 1998a.

Taranenko, Y., and R. Roussel-Dupre, High-altitude discharges and gamma-ray flashes: A manifestation of runaway air breakdown, Geophys. Res. Lett., 23, 571-574, 1996.

Winn, W.P. and L. G. Byerley,III, Electric field growth in thunderclouds, Q.J. Roy. Meteor. Soc., 101, 979-994, 1975.

Figure Captions

Figure A1. Flight Path of Instrument Launched June 19, 1998, UTC.

Figure A2. Field Changes Observed June 19, 1998, UTC.

Figure B1. Field Changes Observed September 22, 1998, UTC.

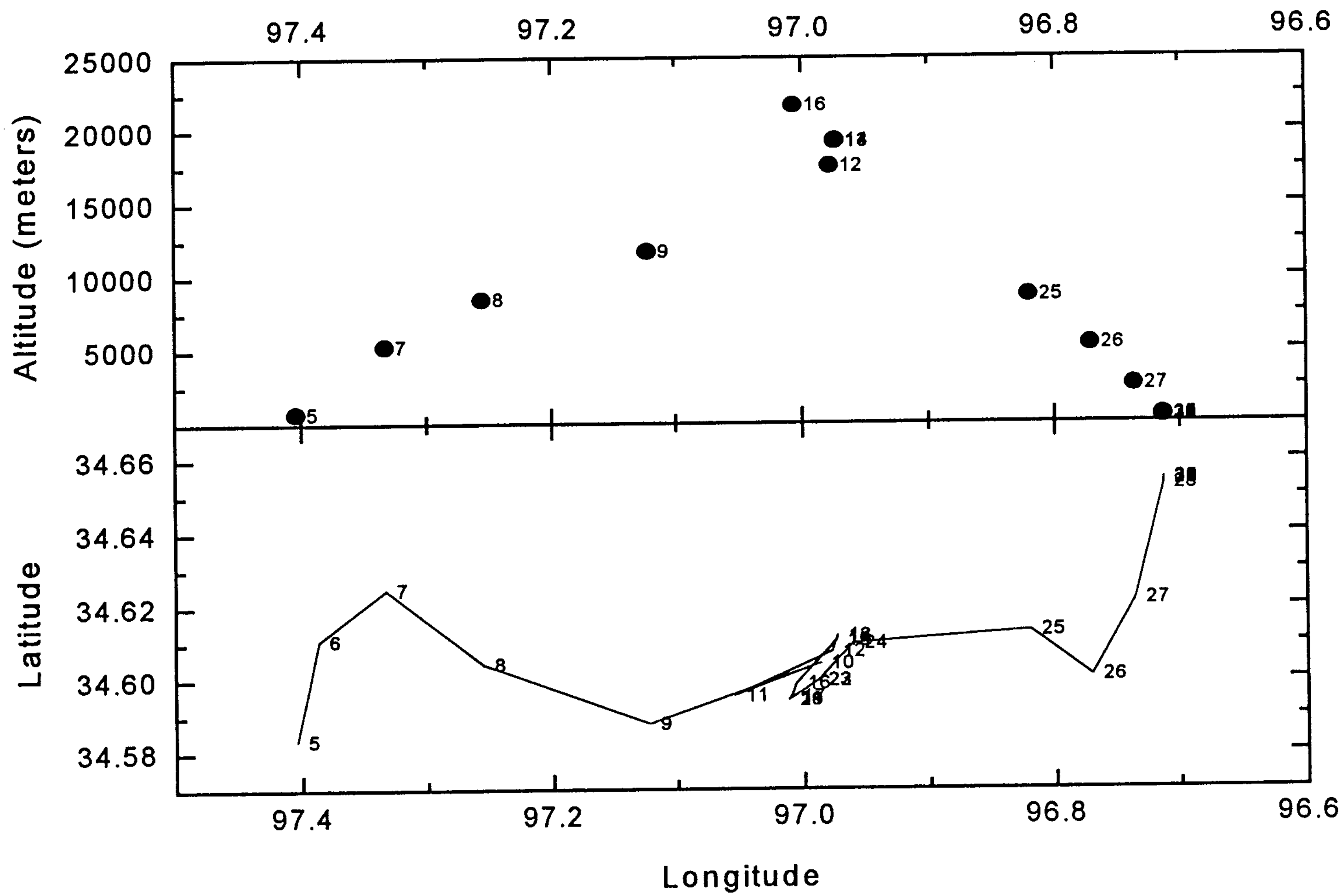


Figure A1: Flight Path of Instrument Launched June 19, 1998, UTC.. The numbers along the flight path denote the order of successive trigger times.

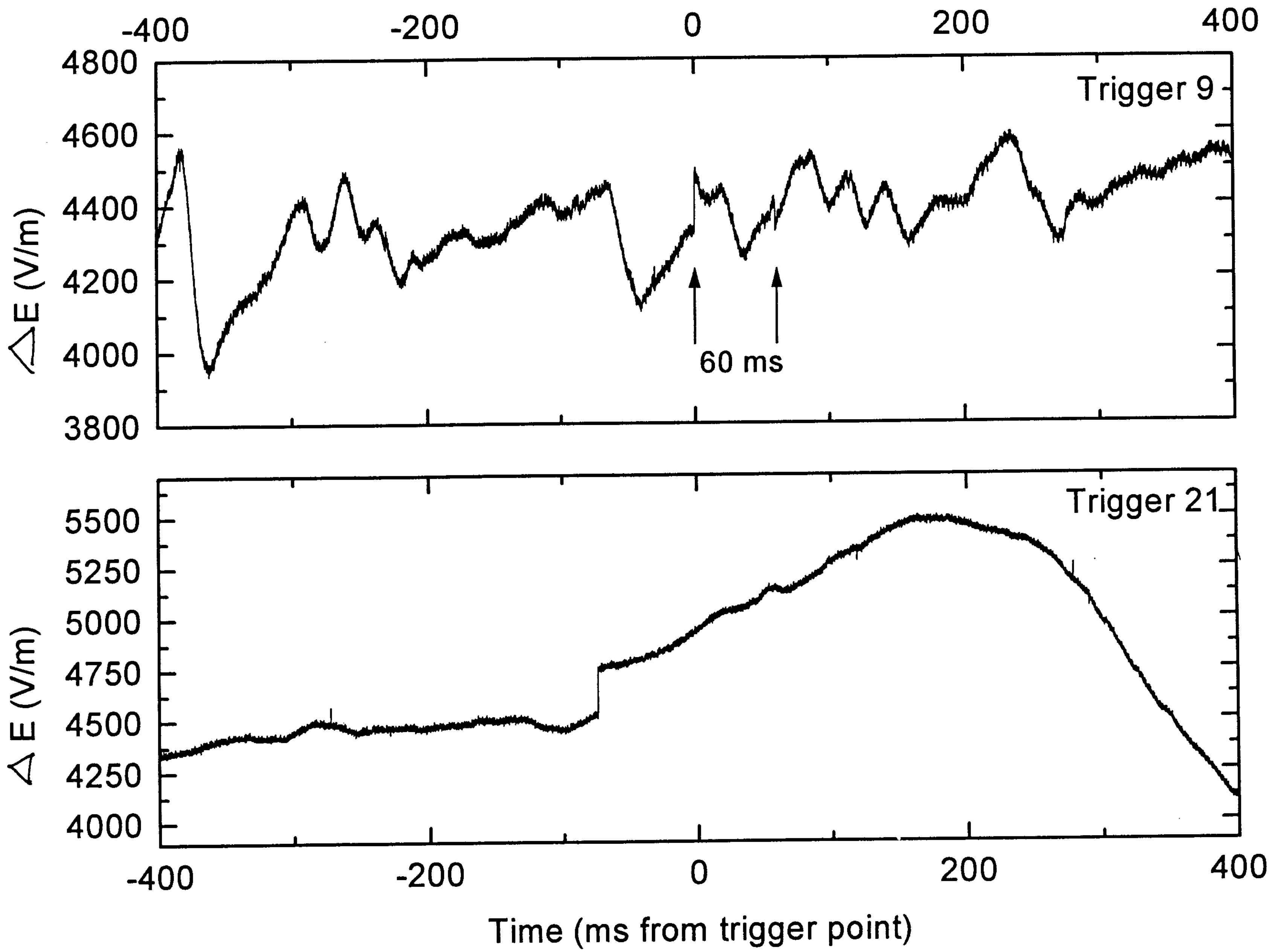


**Figure A2: Field Changes Observed 6/19/98, UTC.**
Trigger 9 at 12 km altitude, latitude 34.59°N, longitude 97.12°W.

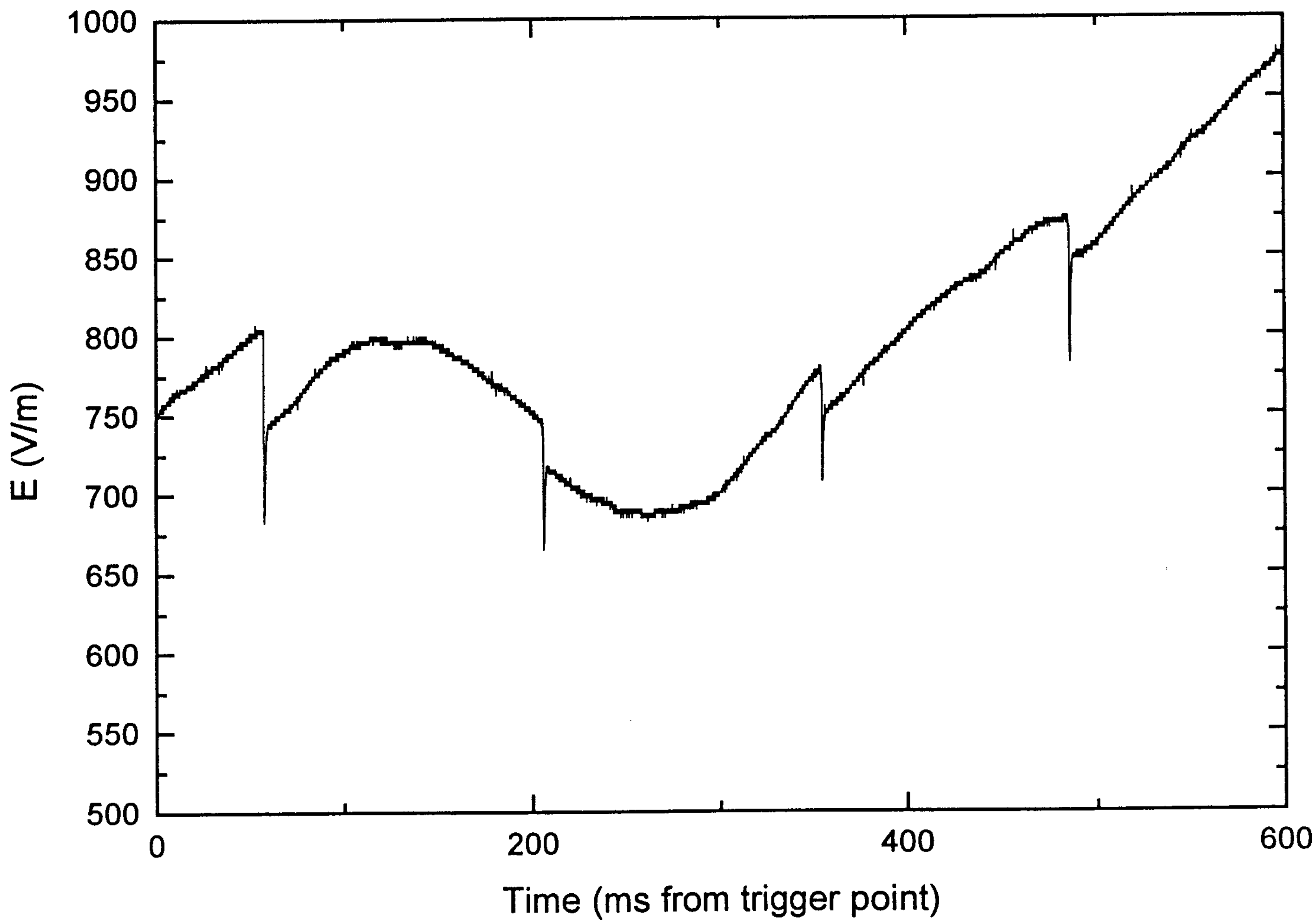


**Figure B1. Field Changes Observed 9/22/98, UTC**