Anvil Lightning in the 29 May Kingfisher Supercell Observed during DC3

Elizabeth A. DiGangi[1*], Donald R. MacGorman[2], Michael Biggerstaff[3], Daniel Betten[3], Sean Waugh[1], Conrad Ziegler[2]

1. Cooperative Institute for Mesoscale Studies, University of Oklahoma, and NOAA/National Severe Storms Laboratory, Norman, OK, USA
2. NOAA/National Severe Storms Laboratory, Norman, OK, USA
3. University of Oklahoma, Norman, OK, USA

ABSTRACT: A supercell thunderstorm formed as part of a cluster of severe storms near Kingfisher, OK on 29 May 2012 during the Deep Convective Clouds & Chemistry (DC3) experiment. This storm produced 5” hail, an EF-1 tornado, and copious lightning over the course of a few hours. For part of the storm's lifetime, observations were obtained from mobile polarimetric radars and a balloon-borne electric field meter and particle imager, while aircraft sampled the chemistry of the inflow and anvil. In addition, the storm was within the domain of the 3-dimensional Oklahoma Lightning Mapping Array (LMA). This study focuses on a one-hour interval during which triple-doppler coverage was available for half the period, and a balloon carrying an electric field meter (EFM), radiosonde, and particle imager flew through the storm. Data from the S-Band WSR-88D in Oklahoma City (KTLX) were used to supplement mobile radar data. Flash rates, very high frequency (VHF) source densities, and charge analyses are examined to give an overview of the storm’s electrical nature during that period. The charge inferred from lightning is compared to the charge inferred from EFM measurements to test how well the lightning-inferred charge analysis can be expanded to the whole storm. For this paper, the focus is the lightning in the anvil, particularly those flashes that occurred several tens of kilometers from regions of deep convection. These flashes are examined relative to radar reflectivity, ground strike points (provided by the National Lightning Detection Network), and inferred charge structure to test hypotheses concerning how the flashes were initiated and what caused some flashes to strike ground so far from deep convection. For example, a local region of deeper convection formed within the distant anvil and was associated with the flash that struck the DC8 aircraft. The evolution of this local convection is consistent with it being produced by evaporation of precipitation in virga falling from the anvil, but convergence in the outflow from two adjoining storms probably also played a role.

∗ Contact information: Elizabeth DiGangi, CIMMS, Norman, OK, USA, Email: elizabeth.digangi@noaa.gov

INTRODUCTION

Lightning in supercell thunderstorms is often frequent and damaging in and near the region of deep convection. The anvils of supercell thunderstorms, where little or no precipitation is visible at the lowest radar elevation scans, can produce and propagate long horizontal lightning flashes far from the storm's core. While it is well understood that thunderstorm anvils contain electric charge, (e.g. Marshall et al. 1989; MacGorman and Rust 1998), only a few studies have investigated lightning activity in supercell anvils (e.g. Dye and Willet 2007; Kuhlmann et al. 2009; Weiss et al. 2012).

Secondary convection in the anvils of supercell thunderstorms is another little-studied but common phenomenon (Knight et al. 2004). It can pose a danger to aircraft and the public, especially when electrification is involved.

The Deep Convective Clouds and Chemistry (DC3) experiment was a collaborative field research program carried out by several organizations and federal agencies. The continuing goals of DC3 are to investigate the impact of deep midlatitude convection, including dynamic, microphysical, and lightning processes on the chemistry of the upper troposphere, as well as processes affecting lightning characteristics and the evolution of upper tropospheric chemistry for 24-48 hours after storms. Fieldwork took place 15 May to 30 June 2012 in three domains: Colorado, Alabama, and Oklahoma/West Texas. Storms from each domain were sampled by instrumented aircraft and ground support crews.

The subject of the present study is the lightning and secondary convection produced in the anvil of the 29 May Kingfisher supercell.

DATA AND METHODOLOGY

The 29 May Kingfisher supercell was sampled by the two C-band Shared Mobile Atmospheric Research and Teaching Radars (SMART-Rs) (Biggerstaff et al. 2005, SR1 and SR2) and one mobile X-band radar (NOXP). SR2 and NOXP are dual-polarimetric radars, though the polarimetric data are not used in this study. Two- and three-dimensional winds were derived from the radial winds measured by 2 – 3 of these radars, sometimes supplemented by data from the WSR-88D radar in Oklahoma City (KTLX). KTLX data are used extensively in this study because it provided better coverage of the storm's anvil than the mobile radars.

The Oklahoma Lightning Mapping Array (LMA) and West Texas LMA defined the OK-TX domain, so high resolution lightning data are available for all DC3 storms. The LMA is a network of ground-based stations that record arrival time and determine three-dimensional locations of very high frequency (VHF) emissions from lightning (called VHF sources). The LMA thus provides high-resolution of the location and evolution of both in-cloud (IC) and cloud-to-ground (CG) lightning. Detailed descriptions of LMA networks and the OK LMA specifically can be found in MacGorman et al. (2008) and Thomas et al. (2004). The case this study addresses, 29 May, occurred in central Oklahoma, so OK LMA data are used. As in previous studies (e.g., Weiss et al. 2012), if a VHF source was mapped by fewer than seven stations, had a reduced χ^2 value greater than two, or was mapped to an altitude greater than 20 km above MSL, it was considered unreliable and not utilized. Flash rates were determined every minute. The timing and rates of flash initiations were calculated using lightning algorithms described by Lund et al. (2000) and incorporated in the Warning Decision Support System—Integrated Information (WDSS-II) software package (Lakshmanan 2007). The LMA data were first ingested into WDSS-II using the w2lma_ingest algorithm, and then passed through the w2lmaflash algorithm. Cloud-to-ground flashes were identified using data from the National Lightning Detection Network (NLDN). Anvil flashes were identified using the same criterion as Weiss et al. (2012) and Kuhlmann et al. (2009): flashes that began or extended more than 30 km downshear beyond the 30 dBZ reflectivity contour in the main storm into the anvil were considered anvil flashes.

We also analyzed data from a balloon-borne electric field meter (EFMs), radiosonde, and particle imager, which were launched into the targeted storm to collect detailed in-situ data. In this study, radiosonde data were used to establish the location of the melting layer, and EFM data were used to corroborate charge analysis.

OBSERVATIONS

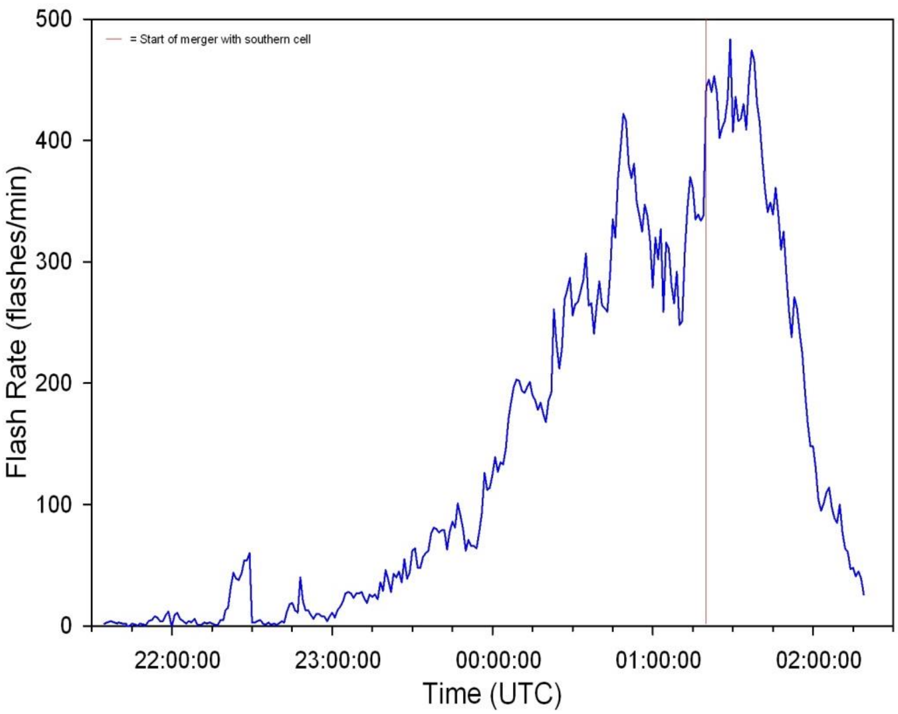

Figure 1: Lifetime 1-minute flash rates for the 29 May Kingfisher supercell. The vertical red line indicates the beginning of the merger with another storm.

Overview of the 29 May Kingfisher Supercell

The 29 May 2012 Kingfisher supercell began around 21:00 UTC in northwest Oklahoma. The first lightning flashes occurred shortly after 21:30 UTC. At about 22:00 UTC, the cell began to split; the right-mover was the target storm. The right-mover began steadily intensifying into a supercell around 23:00 UTC. Flash rates (Fig. 1) peaked at more than 400 flashes/min, and the storm produced 5” hail before the Kingfisher storm merged with another supercell over the Oklahoma City metro area. The merger took place between 01:20 and 01:38 UTC on 30 May, and the Kingfisher cell produced a small tornado before the merger was complete in the low levels. Flash rates peaked again, nearing 500 flashes/min within five minutes of the completion of the merger, before dropping rapidly as the merged storm weakened and died. The target storm will hereafter be referred to as the “Kingfisher storm”.

Anvil Flashes and Anvil Convection

This study focused on a one-hour interval beginning at 23:00 UTC. Secondary convection in the anvil of the Kingfisher storm was first identified in the KTLX data at 23:12:13 UTC by the w2segmotionll algorithm in WDSS-II, which detects and tracks storm clusters (Lakshmanan 2009; Herzog 2013). Six seconds earlier, a lightning flash was initiated approximately 10 km SE of the storm’s base-scan 30-dBZ contour from KTLX. The flash extended 50 km E of its initiation point. Before and during the initiation of the secondary convection, a long, thin strip of low reflectivity roughly perpendicular to flow in the anvil persisted through the anvil region, visible in higher radar elevation scans. Fingers of low reflectivity descended below the melting layer throughout this strip. In addition, a small core of reflectivity approaching 30dBZ in the KTLX data at the eastern tip of the flash matched the position of the secondary convection identified by WDSS-II (Figure 2). There were at least five more very large flashes that initiated on the outer edge of the storm’s main reflectivity core and propagated to the secondary convection zones (Table 1).

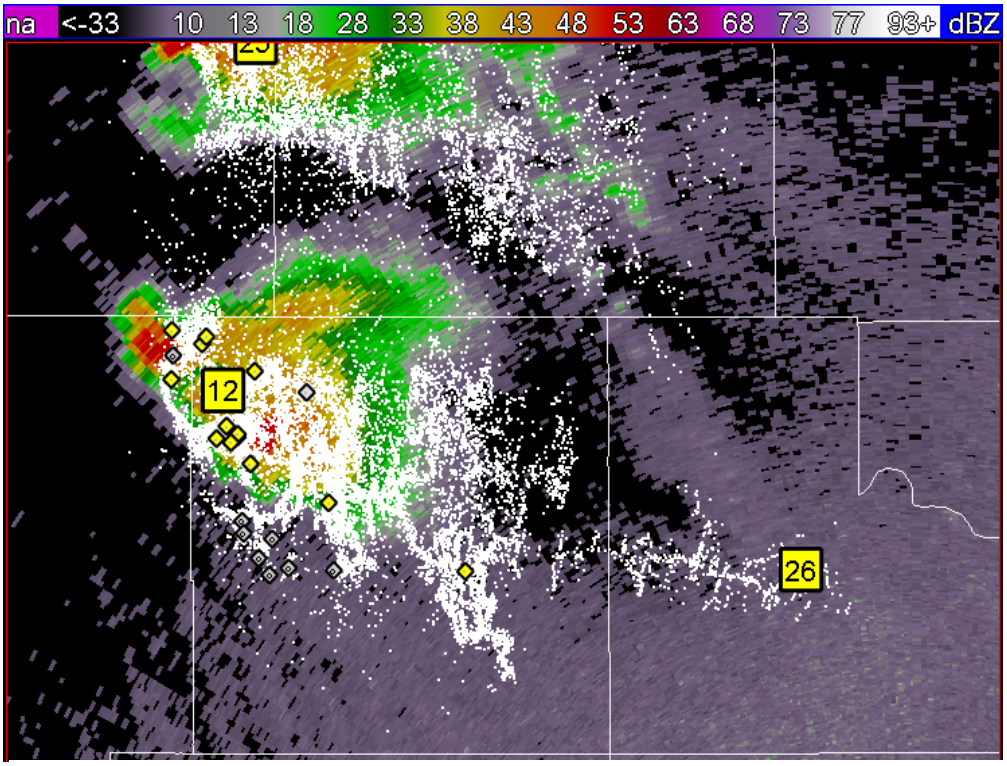

Figure 2: WDSS-II snapshot of KTLX reflectivity, VHF source points (white dots), flash initiation points (diamonds), and cluster identification (yellow numbered squares) at approximately 23:12:00-23:12:20 UTC. Marker 12 is the Kingfisher storm, and marker 26 indicates the secondary anvil convection detected by w2segmotionll.

Several large flashes subsequently began in the secondary anvil convection and remained completely within the anvil; the first of these took place at 23:41:16. These flashes appeared to be associated solely with the secondary convection, so they have not yet been addressed in this study.

Table 1: Characteristics of anvil flashes connecting primary and secondary convection

Time (UTC)	Initiation	Altitude	CG?	CG Location
23:12:07	Kingfisher storm	7km	No	N/A
23:23:26	Kingfisher storm	9km	No	N/A
23:24:38	Kingfisher storm	5-7km (descended)	Yes	Kingfisher storm
23:34:27	Kingfisher storm	5-12km (two-tiered)	No	N/A
23:40:12	Kingfisher storm	7km	Yes	Kingfisher storm
23:47:33	Kingfisher storm	8-12km (two-tiered)	Yes	Kingfisher storm

The first echoes of the secondary anvil convection were visible at 23:24:11 UTC at 0.5^{o}. The anvil convection intensified, and by 23:37:02 UTC formed into a band. By the end of the analysis period, the secondary convection developed and matured into a strong storm with several reflectivity cores greater than 60 dBZ embedded within the anvils of the Kingfisher storm and of storms farther north.

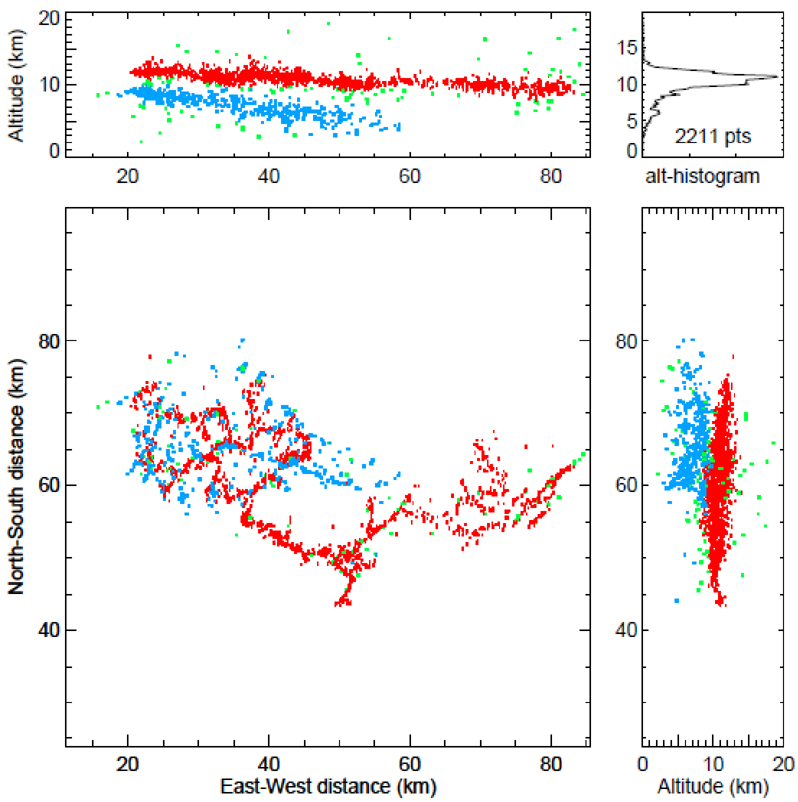

Figure 3: Anvil flash at 23:34:27 UTC extending from the southeastern edge of the Kingfisher storm to the southern tip of the anvil convection. Red coloring indicates the portion of the flash propagating through positive charge, and blue coloring indicates the portion of the flash propagating through negative charge.

THE SOURCE AND LOCATION OF ANVIL CHARGE

For the majority of the analysis period, all of the anvil flashes noted in this study initiated near the southeastern edge of the Kingfisher storm and propagated out to the secondary convection in the anvil. As noted by Kuhlman et al. (2009) and Dye et al. (2007), charge in the anvil would not be expect to survive over such long distances, so charge advected from the Kingfisher storm likely was supplemented with charge produced within the anvil.

The advent of large flashes initiated within the secondary convection and remaining completely within the anvil likely indicates a transition in the source of charge for the flashes. Because the transition occurred after the secondary convection formed and was coincident with the convection strengthening and maturing, we suggest that charge from the secondary convection began strongly influencing the production and propagation of flashes there. Weiss et al. (2012) suggested that an anvil mechanism described by Findeisen (1940) and Knight et al. (2004), which involved cooling from ice particles falling in the presence of a weak lower-level updraft, can form convection deep enough to produce local electrification in secondary convection. The evolution of lightning in the anvil of the Kingfisher storm, occurring as secondary convection formed in the vicinity of a weak line of reflectivity indicative of a convergence line, seems to be consistent with this mechanism.

An analysis of the lightning extending from the deeper convection into the anvil indicates that there was a layer of negative charge at about 6km and a layer of positive charge at about 12 km (e.g. Figure 3). The charge density profile provided by the EFM (which flew through the eastern edge of the Kingfisher storm) corroborates this, as the balloon track through the 6-12km altitude range passed through the precipitation echoes in the anvil, extending from the Kingfisher storm into the anvil. The uppermost layer at 11-12 km may have had involved screening layer charge (Schuur et al. 1991, Stolzenburg et al. 1994, Weiss et al. 2012).

The research presented here is ongoing, and will continue to investigate the processes that produced the influence of the secondary convection on anvil lightning.

REFERENCES

Biggerstaff, M. I., Wicker, L. J., Guynes, J., Ziegler, C., Straka, J. M., Rasmussen, E. N., … Weiss, C. (2005). The Shared Mobile Atmospheric Research and Teaching Radar: A Collaboration to Enhance Research and Teaching. *Bulletin of the American Meteorological Society*, *86*(9), 1263–1274. doi:10.1175/BAMS-86-9-1263

Dye, J. E., & Willett, J. C. (2007). Observed Enhancement of Reflectivity and the Electric Field in Long-Lived Florida Anvils. *Monthly Weather Review*, *135*(10), 3362–3380. doi:10.1175/MWR3484.1

Findeisen, W., 1940: Die entstehung der 0°-isothermie und die fraktocumulus-bildung unter nimbostratus (The origin of 0°C isothermal layers and of fractocumulus beneath nimbostratus). *Meteor. Z.*, **57**, 49–54.

Herzog, B. S., 2013: Total Lightning Information in a 5-Year Thunderstorm Climatology. M.S. Thesis, School of Meteorology, University of Oklahoma, 110.

Knight, C. A., Jay Miller, L., & Hall, W. D. (2004). Deep Convection and “First Echoes” within Anvil Precipitation. *Monthly Weather Review*, *132*(7), 1877–1890. doi:10.1175/1520-0493(2004)132<1877:DCAFEW>2.0.CO;2

Kuhlman, K. M., MacGorman, D. R., Biggerstaff, M. I., & Krehbiel, P. R. (2009). Lightning initiation in the anvils of two supercell storms. *Geophysical Research Letters*, *36*(7), L07802. doi:10.1029/2008GL036650

Lakshmanan, V., Smith, T., Stumpf, G., & Hondl, K. (2007). The Warning Decision Support System–Integrated Information. *Weather and Forecasting*, *22*(3), 596–612. doi:10.1175/WAF1009.1

Lakshmanan, V., Hondl, K., & Rabin, R. (2009). An Efficient, General-Purpose Technique for Identifying Storm Cells in Geospatial Images. *Journal of Atmospheric and Oceanic Technology*, *26*(3), 523–537. doi:10.1175/2008JTECHA1153.1

Lund, N. R., MacGorman, D. R., Schuur, T. J., Biggerstaff, M. I., & Rust, W. D. (2009). Relationships between Lightning Location and Polarimetric Radar Signatures in a Small Mesoscale Convective System. *Monthly Weather Review*, *137*(12), 4151–4170. doi:10.1175/2009MWR2860.1

MacGorman, D. R., Rust, W. D., Ziegler, C. L., Mansell, E. R., Schuur, T. J., Biggerstaff, M. I., … Eack, K. B. (2008). TELEX The Thunderstorm Electrification and Lightning Experiment. *Bulletin of the American Meteorological Society*, *89*(7), 997–1013. doi:10.1175/2007BAMS2352.1

Macgorman, D. R. and W. D. Rust, 1998: The Electrical Nature of Storms. Oxford University Press.

Marshall, T., W. Rust, W. Winn, and K. Gilbert, 1989: Electrical structure in two thunderstorm anvil clouds. *J. Geophys. Res.*, **94**, 2171–2181.

Structure of the Stratiform Precipitation Region Trailing an Oklahoma Squall Line. *Journal of the Atmospheric Sciences*, *48*(6), 825–842. doi:10.1175/1520-0469(1991)048<0825:EAKSOT>2.0.CO;2

Stolzenburg, M., Marshall, T. C., Rust, W. D., & Smull, B. F. (1994). Horizontal Distribution of Electrical and Meteorological Conditions across the Stratiform Region of a Mesoscale Convective System. *Monthly Weather Review*, *122*(8), 1777–1797. doi:10.1175/1520-0493(1994)122<1777:HDOEAM>2.0.CO;2

Thomas, R. J. (2004). Accuracy of the Lightning Mapping Array. *Journal of Geophysical Research*, *109*(D14), D14207. doi:10.1029/2004JD004549

Weiss, S. a., MacGorman, D. R., & Calhoun, K. M. (2012). Lightning in the Anvils of Supercell Thunderstorms. *Monthly Weather Review*, *140*(7), 2064–2079. doi:10.1175/MWR-D-11-00312.1