The meteorology of storms that produce narrow bipolar events

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Using the near station data, we can determine the average propagation velocity of the event duration. Due to the relatively large location of the event, the current can be calculated using the charged transferred and multiplying the propagation velocity by the event duration.

From this and the dipole moment change, the amount of electrostatic dipole moment change:

\[ E = \frac{q}{C_0} \]

where \( E \) is the electrostatic field change, and \( r \) is the distance from the event to the near measurement point. Since the dipole moment change has already been determined by the electrostatic field change, this offset decayed to zero with a time constant similar to the reversal point. Event D had a positive electrostatic field change indicating that the measurement was made beyond the reversal distance.

The close station had a waveform that was essentially bipolar, with little of the bipolar radiation field evident. The close station indicated a waveform that was essentially unipolar, with little of the bipolar radiation field evident. The close station measures only the radiation field, this zero crossing form is crossing back though zero (Figure 1e). Since distant stations, only 20 were determined to be closer than 15 km from the event during the same period. During two years of NBE observations, approximately 850,000 lightning events were observed during the first three events, the electrostatic field change was negative, as is expected for the discharge of a dipole with positive over negative charge when measured within the channel.

The dipole moment changes for events A, B, C and D, were calculated from the electrostatic field to be 1.6, 0.5, 0.15 and 0.6 C-km. The discharge channel length of 4 km. The NBE transferred a peak current of 29 kA (assuming a uniform current over the channel). The dipole moment change for event D was made at 14.5 km, well beyond the reversal point.

The radiation field will fall off faster than \( r \) as described by:

\[ E = \frac{q}{C_0} \]

\[ E \propto \frac{1}{r^2} \]

where \( q \) is the charge transferred, \( C_0 \) is the capacitance of the channel, and \( r \) is the distance from the event to the near measurement point. This offset decayed to zero with a time constant similar to the reversal point. Event D had a positive electrostatic field change indicating that the measurement was made beyond the reversal distance.

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What is a narrow bipolar event (NBE)?

NBEs are compact (< 2 km), powerful (> 10 kW in VHF), and impulsive (~10 μs) electrical discharges in thunderstorms, also known as compact intracloud discharges (CID) [e.g., Smith et al. 1999].

Can be either positive or negative polarity (Wu et al. 2012), and have distinctive broadband waveform signatures (Eack 2004) sometimes confused for +CGs in the past by NLDN and other networks (Tessendorf et al. 2007).

NBEs are related to lightning but are likely optically “dark” (Jacobson et al. 2013).

As revealed by VHF sensors (both satellite and ground):
- The most powerful lightning-related VHF sources observed (Jacobson et al. 2013)
- Tend to occur at the beginning of intracloud discharges (Rison et al. 1999)
- Difficult to estimate altitude properly due to receiver saturation (Thomas et al. 2001)

![Waveform examples](Figure 2)

Positive and negative NBE examples from Eack (2004)
How do NBEs relate to thunderstorm structure and evolution?

Good question! This is still open for exploration.

What we know to date

- Tend to occur near strong (~40-dBZ) cores (e.g., Smith et al. 1999)
- Tend to occur at high altitudes (> 8 km; Wu et al. 2012)
- Correlated to cloud-to-ground (CG) flash rate (Suszcynsky and Heavner 2003)
- Correlated to 30-dBZ heights (Wiens et al. 2008)
- Certain individual storms can produce very high NBE rates (Wiens et al. 2008)

Outstanding issues

- What is distinctively different about storms that produce many NBEs?
- Case studies needed of NBE occurrence related to total flash rate and storm evolution

Wiens et al. (2008)
Data and Methodology

North Alabama Lightning Mapping Array (NALMA)
National Lightning Detection Network (NLDN)
National 3-D Radar Reflectivity Mosaics (NMQ)

McCaul LMA flash-counting methodology (McCaul et al. 2005)

No waveform data, so instead use concept of “NBE candidates”

- NALMA flashes containing 40+ dBW source (DB40)
- Flashes containing 40+ dBW initial source (NB40)
- Flashes containing 50+ dBW source (DB50)
- Flashes containing 50+ dBW initial source (NB50)

DB40 is least-stringent category, NB50 the most stringent

Modest altitude criteria to filter out very poor solutions
Notable NALMA NBE candidate cases (2002-2012)

The two ~6-h periods on 4 August 2011 are by far the biggest NBE candidate producers, by any metric.

27 April 2011 tornado super outbreak

4 August 2011
4 August 2011 Svr Wx Reports (thru 12 UTC)
NALMA NBE Candidates vs. Max Flash Rate Densities (2002-2012)

- **n40dbw vs. maxFRD**
  - Flash contains 40 dBW source anywhere (DB40)
  - Two ~6-h periods on 4 August 2011

- **nnbe50 vs. maxFRD**
  - Flash contains 50 dBW as initial source (NB50)

**Standout NBE candidate cases are middle of the road in terms of max flash rates**
Equilibrium Level ~14.8 km!

CAPE 2047.
CAPV 2313.
4 August 2011 NMQ composite reflectivity (contours) and 40 dBW flashes (X) 100-km and 200-km NALMA Range Rings (dashed circles)

Cell mergers appear to be associated with enhanced NBE candidate activity
Bulk Regional Time Series
• Includes all observations within 200 km range of NALMA center
• Superficial comparison suggests good correlations among 30/40 dBZ volumes and various flash parameters, including NBES
Bulk Spearman’s Rank Correlations

**Echo volumes vs. TFR/CGs**

- NALMA Range/DE effects
- NBE candidates best correlated to 40-dBZ echo volumes.
- DB40 category highest correlations
- Higher NBE correlations to +CGs interesting (Tessendorf et al. 2007)

**Echo volumes vs. NBE candidates**

**NBE candidates vs. TFR/CGs**

DB40/NB50 correlation = 0.52
Basic idea – Identify and track features in radar data, link lightning and other observations to those features using simple temporal/spatial criteria for later statistical or case study analysis.

CSU Lightning, Environment, Aerosols, and Radar (CLEAR) statistical framework

Sub-sectioned NMQ

Fuchs et al. (2013) tracking
Twin thresholds - 30 & 40 dBZ
2-D median filter (4-km)

NALMA flashes/sources
NLDN Flashes
NBE Candidates

Lang and Rutledge (2011)
Examination of Merger
Tracks 7 & 30

LMA total flash rate \([x10 \text{ (5 min}^{-1})]\)
NLDN CG flash rate \((5 \text{ min}^{-1})\)
NMQ Volume 30 dBZ \((x100 \text{ km}^3)\)
NMQ Volume 40 dBZ \((x100 \text{ km}^3)\)

40 dBW sources \((5 \text{ min}^{-1})\)
50 dBW initial sources \((5 \text{ min}^{-1})\)

DB40 well correlated to storm metrics during two-hour analysis window
NB50 somewhat correlated to reflectivities, no statistically significant correlation with TFR, CGs
Vertical analysis
Tracks 7 & 30

LMA total flash rate [x10 (5 min⁻¹)]
NLDN CG flash rate (5 min⁻¹)

NMQ Volume 20 dBZ (km³)
NMQ Volume 30 dBZ (÷2 km³)
NMQ Volume 40 dBZ (÷4 km³)

Solid: T < 0 C
Dash: T < -20 C
Dot: T < -40 C

40 dBW sources (5 min⁻¹)
50 dBW init. sources [÷10 (5 min⁻¹)]

DB40, TFR, and CGs highly correlated to vertical intensity

NB50 loosely correlated at best
NBE candidate burst cell
• Ground zero for merger of larger storms
• Mid-strength reflectivity structure
• Comparable in terms of total flash production
Conclusions and Future Work

NBE candidates occurred within strong convection
• But not always the strongest!
• DB40 best correlation to storm metrics (influence of TFR?)
• NB50 worst correlation (Sampling issues?)
  • Low to no correlation with other lightning
  • Some statistically significant correlation to radar metrics
• NBE candidate burst associated with cell merger

Intense convection a necessary, but not sufficient, condition for NBE production?
• Results consistent with NBEs requiring an additional trigger
• Effect of solar proton storm on 4 August 2011?

To Do
• Further analysis of this case – additional time periods
• Examine other cases (e.g., 2<sup>nd</sup> most NBEs - 7/31/2012)
• Statistics for NBE/No-NBE storms