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The Kinematic and Microphysical Control of Storm Integrated Lightning Flash Extent

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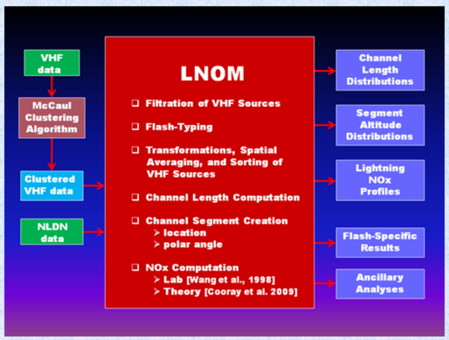
Objective

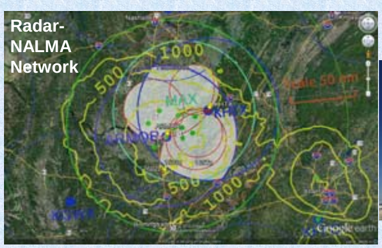
To investigate the kinematic and microphysical control of lightning properties, particularly those that may govern the production of nitrogen oxides (NO_x) in thunderstorms, such as flash rate, type (intracloud [IC] vs. cloud-to-ground [CG]) and extent.

Data and Methodology

- NASA MSFC Lightning Nitrogen Oxides Model (LNOM) is applied to North Alabama Lightning Mapping Array (NALMA) and Vaisala National Lightning Detection Network™ (NLDN) observations following ordinary convective cells through their lifecycle.
- LNOM provides estimates of flash type, channel length distributions, lightning segment altitude distributions (SADs) and lightning NO_x production profiles (Koshak et al. 2012).



- LNOM lightning characteristics are compared to the evolution of updraft and precipitation properties inferred from dual-Doppler (DD) and polarimetric radar analyses of UAHuntsville Advanced Radar for Meteorological and Operational Research (ARMOR, C-band, polarimetric) and KHTX (S-band, Doppler).



UAHuntsville ARMOR

Radars:
Multi-Doppler (30°)
ARMOR: 100 km
KHTX/Hytop: 100 km

NALMA:
NALMA sensors,
150, 250 km range rings
NA-LMA Altitude errors (m)

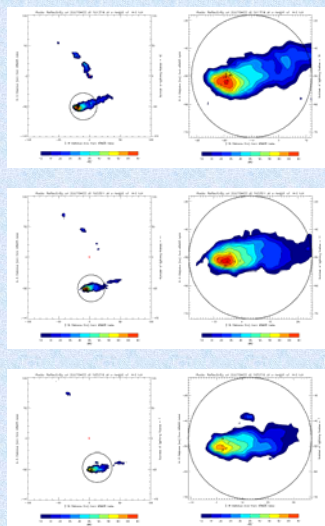
Center location of LNOM analysis cylinders shown at 1602, 1633, and 1657 UTC. Note storm on edge of DD lobes at 1602 UTC.

3 April 2007: Ordinary Convective Cell

- LNOM is applied in a Lagrangian sense (i.e., storm following) to well isolated thunderstorm cell on 3 April 2007 over Northern Alabama. Pulse severe (1" hail) at 1637 UTC.

LNOM Analysis Cylinders (LAC's), ARMOR Reflectivity (4 km), NALMA Flash Origins

ZOOM



1613 UTC

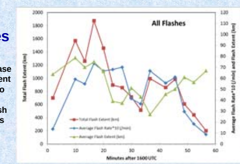
1633 UTC

1652 UTC

Time Evolution of Flash Properties

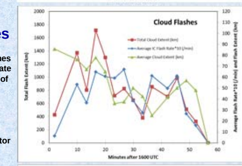
All Flashes

Note decrease in flash extent from 1616 to 1627 UTC even as flash rate remains elevated.



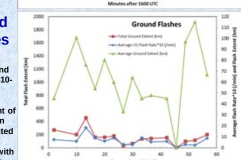
Cloud Flashes

Cloud flashes dominate rate and extent of all flashes. Flash rate controlled, although extent per flash is factor at times.



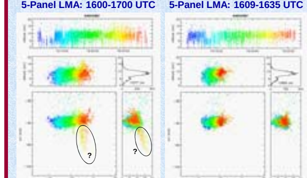
Ground Flashes

Peak in CG flash rate and extent at 1610-1616 UTC associated with descent of precipitation volume. Muted CG peak at 1634-1642 with hail descent.



5-Panel LMA: 1600-1700 UTC

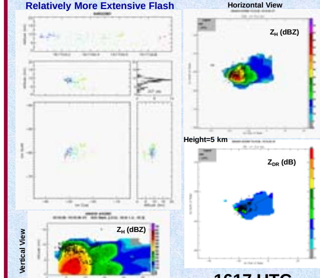
5-Panel LMA: 1609-1635 UTC



Note variation in vertical extent of flashes over time (≈ 1615 to 1630 UTC). Note likely artifact around 1645.

Select Individual Flash and Radar Structure

Relatively More Extensive Flash



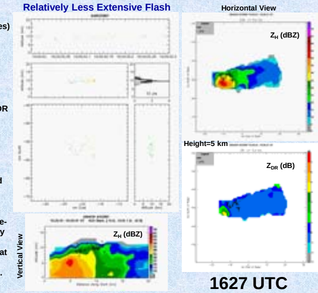
Lightning (VHF sources) avoid Z_{DR} column in developing updraft on west flank

Stronger ZDR column in weaker updraft at 1627 may result in vertically compressed flash.

Coalescence-freezing may limit CG production at later times with hail (?).

1617 UTC

Relatively Less Extensive Flash



1627 UTC

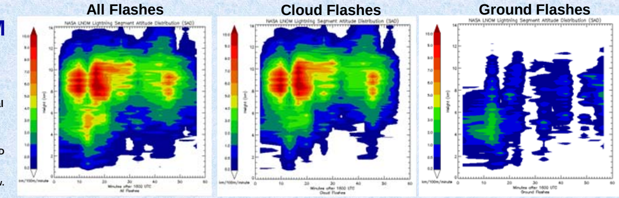
Time-Height Cross Sections

All Flashes | Cloud Flashes | Ground Flashes

LNOM SAD

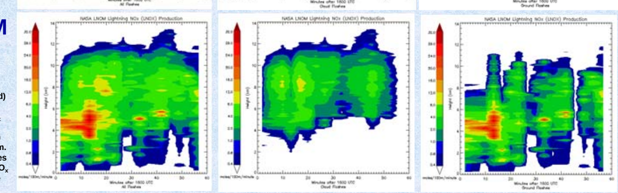
Note variation in SAD vertical extent and type.

Note how SAD "caps" the precipitation volume below.



LNOM NO_x Production

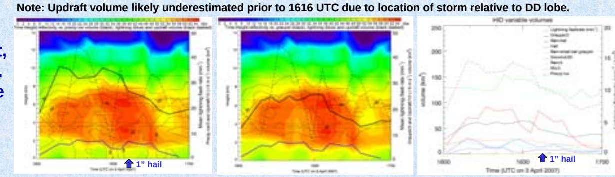
Ground (cloud) flashes dominate NO_x production at lower (higher) levels in storm. Ground flashes have larger NO_x peaks despite lower rates.



Note: Updraft volume likely underestimated prior to 1616 UTC due to location of storm relative to DD lobe.

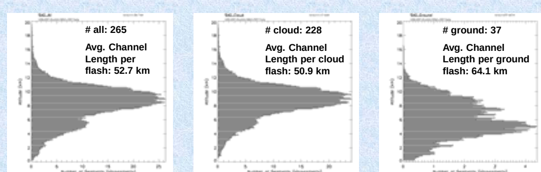
Radar Updraft, Precip. Volume

Temperature levels shown are 0°C, -5°C, -15°C, -20°C and -40°C



Storm Integrated SAD and NO_x Production over 1-Hour Lifecycle

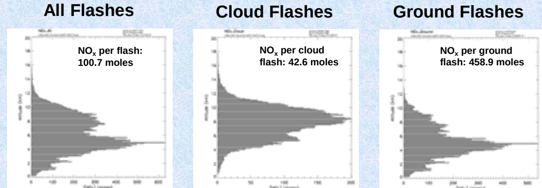
SAD



Cloud flashes dominate SAD aloft (>6 km) because of greater cloud flash numbers and differences in vertical extent by type.

All Flashes | Cloud Flashes | Ground Flashes

NO_x production



Ground flashes dominate NO_x production < 6 km height. For 6-8 km, comparable because NO_x per CG flash >> NO_x per IC flash compensates for CG SAD << IC SAD. Cloud flash NO_x production dominates > 8 km.

Summary and Discussion

- LNOM successfully run in Lagrangian mode for isolated, ordinary (pulse severe) thunderstorm.
  - Vertical SAD and NO_x production similar to long term means.
- Like flash rate, flash extent is generally correlated with production of precipitation ice and updraft at T < -5°C (when measured well by Doppler network).
  - Descent of precipitation ice mass (graupel and small hail) associated with peak in CG rate and extent (1610-1616 UTC).
  - Similar descent of hail core associated with lower CG flash rates and extent, especially at low levels (1634-1642 UTC).
- Updraft volume, precipitation type and processes (coalescence-freezing) at T < -5°C modulated flash (and likely charging) vertical extent.
  - Lofting of supercooled drops to -10°C and colder common even when > 5 m s^{-1} updrafts less widespread (e.g., 1627 UTC). Z_{DR} columns were typically lightning minimums.
  - Large reflectivity gradient at heights above -10°C (limited vertical extent of precipitation ice) resulted in narrow (yet active) charging and lightning zones at later times (e.g., 1627 UTC).
  - 1" hail reported at 1637 UTC with weak CG activity and limited vertical extent. Efficient wet growth of frozen drops?