Characterizing Lightning’s Response to the Spatial Distribution of Updraft Characteristics

Sarah M. Stough\textsuperscript{1}, Lawrence D. Carey\textsuperscript{1}, Christopher J. Schultz\textsuperscript{2}, and Daniel J. Cecil\textsuperscript{2}

\textsuperscript{1}Department of Atmospheric Science, University of Alabama in Huntsville, Huntsville, AL
\textsuperscript{2}Earth Science Office, NASA Marshall Space Flight Center, Huntsville, AL

This work was supported by NASA Severe Storms Research funding (NNH14ZDA001N), provided to UAH authors under contract from the NASA MSFC (NNM11AA01A).
Lightning’s Connection with Convective Intensity

• Research has shown the physical basis of lightning’s relationship with the thunderstorm updraft (e.g., lightning jump) (Schultz et al. 2009, 2015, 2017; Darden et al. 2010; Gatlin and Goodman 2010)

• Lightning production connected with microphysics, microphysical properties of convection influenced by kinematics

• Better interpret lightning in the context of convective intensity by refining the understanding of connections between lightning and the mixed-phase updraft

1. What are the details of lightning’s response to kinematics of the mixed-phase updraft?
2. Are there meaningful spatial relationships?
Roles of Mixed-Phase Updraft

- Non-inductive charging: primary mechanism thought to result in electrification, lightning (Takahashi 1978)
  1. Particle-scale charge transfer via rebounding collisions between large, small ice in presence of supercooled water
  2. Cloud-scale charge buildup via differential sedimentation of charged particles

- Generally, convective updraft thought to
  1. Supply necessary mixed-phase microphysics
  2. Promote continued rebounding collisions
  3. Affect cloud-scale charge separation

- Deep convection presents complex landscape of microphysical properties, distributions that affect charge structure (Stolzenburg et al. 1998)
  - Complexity attributed in part to gradients in vertical velocity, differential sedimentation, and horizontal flows (e.g., Bruning et al. 2010)
Roles of Mixed-Phase Updraft

Refine context of lightning in convective intensity by addressing spatial complexities of mixed-phase updraft that affect lightning properties by influencing microphysics distributions and charging

• **In-depth case study analysis** -> statistics from multiple storms

• Characterize distributions of vertical motion in three-dimensional space

• Consider flash properties, including size, initiation and propagation location, and inferred polarity
Case Study – 22 April 2017

- Supercell thunderstorm sampled during VORTEX-SE intensive operations period
  - Produced large hail (1.00” – 1.75”), damaging wind reported
  - Instrumentation:
• Vertical velocity contours
  • Solid black: 5 m s\(^{-1}\) min., +5 m s\(^{-1}\) increments
  • White or gray dotted: 0 m s\(^{-1}\)
  • Blue dashed: -5 m s\(^{-1}\) max., -5 m s\(^{-1}\) increments

• Wind barbs: along-plane flow

• Plotted points: VHF lightning flash initiation locations

• Radar reflectivity: merged ARMOR and KHTX

• Vertical divergence, \(\frac{dw}{dz}\)

• Magnitude of horizontal gradient of vertical velocity, \(|\nabla_H w|\)
Lightning Distribution within Vertical Updraft Structure

- Lightning flash initiation points located in vertical motion > 10 m s\(^{-1}\)

- Flashes primarily initiate in regions of weak vertical divergence, convergence
Lightning Distribution within Vertical Updraft Structure

- Lightning jump period - flash initiations maximized at updraft base, peak
- Flash initiations occur outside of core of maximum vertical velocity (25 m s\(^{-1}\)), no other strong patterns with respect to W values

Flash initiations maximized in regions of weak vertical divergence, convergence
Lightning Distribution within Vertical Updraft Structure

- Lightning jump period - flash initiations maximized at updraft base, peak
- Flash initiations maximized in regions of weak vertical divergence, convergence

- Upper-level initiations align with $W_{\text{particle}} = 0 \text{ m s}^{-1}$, (Lhermitte and Williams 1985, particle balance level)
Vertical Distribution of Lightning

- Time-height cross-section of NALMA VHF sources and flash initiation locations
- Evidence of persistent signature associated with PBL in upper levels
Lightning Distribution within Vertical Updraft Structure

- Observe similar spatial patterns in more complex vertical velocity structure
- Flash initiations occur between series of convergent, divergent, convergent regions
- Possibly indicative of multiple PBLs of different hydrometeor distributions
Summary: Lightning in Vertical Updraft Structure

- Vertical divergence presents variation in vertical motion, varying impacts on differing charged hydrometeor distributions.
- Differential fall speed under influence of varying vertical motion redistributes charged particles into charge regions.
- Lightning initiations favor non-divergence.
Lightning Distribution in Horizontal Updraft Structure

Lightning initiations occur in regions of weak horizontal gradients of vertical motion.
Lightning initiations occur in regions of weak horizontal gradients of vertical motion.

Initiations also occur within regions of maximum vertical motion (near peak of updraft).
Lightning Distribution within Vertical Updraft Structure

- Flash initiations typically located in regions with a weak horizontal gradients in vertical motion

22 April 2017 - 2138 UTC - Vertical Cross-Sections @ y=40 km
W contours in 5 m/s increments
Lightning Distribution within Vertical Updraft Structure

- Flash initiations typically located in regions with a weak horizontal gradients in vertical motion

- Overlap of flash initiations with strong gradients in vertical motion occur in coincidence with cross-flow
Summary: Lightning in Horizontal Updraft Structure

• Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion
Summary: Lightning in Horizontal Updraft Structure

- Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion.

- Depending on direction of flow with respect to main updraft,
Summary: Lightning in Horizontal Updraft Structure

- Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion.
- Depending on direction of flow with respect to main updraft, charge particles may become mixed -> reduce potential & lightning initiation.
Summary: Lightning in Horizontal Updraft Structure

- Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion.

- Depending on direction of flow with respect to main updraft, charge regions may develop -> increase potential & lightning initiation.
Summary: Lightning in Horizontal Updraft Structure

• Horizontal variations in vertical motion present varying orientations of charged particle distributions under the influence of vertical motion.

• Depending on direction of flow with respect to main updraft, charge regions may develop -> increase potential & lightning initiation.
Lightning Distribution within Vertical Updraft Structure

- Flash initiations typically located in regions with a weak horizontal gradients in W
- Overlap of flash initiations with strong gradients in vertical motion occur in coincidence with cross-flow

• In LMA-based charge analysis, see evidence of charge separation around gradient in vertical motion
Lightning Distribution within Vertical Updraft Structure

- Flash initiations typically located in regions with a weak horizontal gradients in W
- Overlap of flash initiations with strong gradients in vertical motion occur in coincidence with cross-flow

22 April 2017 - 2138 UTC - Vertical Cross-Sections @ y=40 km
W contours in 5 m/s increments

- In LMA-based charge analysis, see evidence of charge separation around gradient in vertical motion
Summary and Future Work

- Lightning locations spatially related with updraft characteristics; specifically where changes in W are negligible in the horizontal and negligible or decreasing in the vertical

  • Consistent results over storm analysis period, 2056-2206 UTC
  • Spatial behavior also subject to effects of advection (e.g., Bruning et al. 2010)

- Microphysics response to updraft characteristics also suggests vertical divergence related to storm-scale charge separation
  • Similarities with Lhermitte & Williams’s (1985) particle balance level discussion

- Implications: Spatial relationships influence bulk lightning, updraft trends that inform on intensity – additional observations needed to quantify added benefits

- Future work: Electrification modeling planned to quantify microphysics vs. kinematic influence on charge arrangement and effects on lightning location, frequency