Insight into the Physical and Dynamical Processes that Control Rapid Increases in Total Flash Rate

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Figure credit above to Williams et al. 1999, Atmos. Res.
The Conceptual Model Behind a Lightning Jump

1) The flash rate increases rapidly ($t_0$)
2) A peak flash rate (i.e., intensity) is reached ($t_1$)
3) Severe weather occurs a short time later ($t_2$)


Assumed physical basis: “The updraft appears to be causal to both the extraordinary intracloud lightning rates and the physical origin aloft of the severe weather at the surface”

• Updraft properties were not directly measured in this study
• Authors are not specific in which updraft properties govern the jump
Underlying Physical Basis for these Assumptions

- Current lightning jump studies have relied on observations from previous studies:
  - Strong correlation between mixed phase ice mass and flash rate
  - Strong correlation between updraft volume and flash rate
  - Weaker correlation between maximum updraft speed and total flash rate

*Flash Rate*  
*Reflectivity*  
Goodman et al. 1988, GRL

*Flash Rate*  
Tuttle et al. 1989, JAS
Motivation

- Provide more direct verification of the central hypothesis that the lightning jump is a direct indicator of rapid updraft intensification (size/magnitude)

  - Current physical conceptual model for lightning jump based on physical/dynamical inferences

  - Fragmented information in several studies

  - Little to no direct measurement of properties during the short duration of time around a lightning jump
Sigma Level

Schultz et al. 2009; 2011 definition of a lightning jump:

\[ DFRDT_{to} \geq 2 \times \sigma_{(DFRDT_{t-2...t-12})} \]

- Yes/No Answer

- No information on magnitude of the flash rate increase

Sigma level = \[ \frac{DFRDT_{to}}{\sigma_{(DFRDT_{t-2...t-12})}} \]

Thus a sigma level of 2 is the same as a 2\(\sigma\) lightning jump from Schultz et al. 2009, 2011

- This formulation provides continuous monitoring of increases in flash rate and the magnitude of that flash rate increase relative to the recent flash rate history.
  - Calhoun et al. 2015, this session
  - Chronis et al. (2014); WAF
Multiple Doppler

- ARMOR-KHTX Multi-Doppler Domain
- Multi-Doppler synthesis procedure follows that outlined in Mohr et al. (1986), Deierling and Petersen (2008), Johnson (2009)
  - Radar volume scans edited using NCAR SOLOII
Sample Set

- **38 thunderstorms**
  - 19 storms with at least 1 lightning jump
    - (i.e., Schultz et al. 2009; 2011)
  - 19 Storms without a lightning jump

- **Morphology**
  - Multicell - 23
  - Supercell - 6
  - QLCS - 2
  - Low topped - 7

- **Examine all sigma levels broken down into 3 categories**
  - sigma level 0 up to 1
  - sigma level 1 up to 2
  - sigma level 2 and above

- **Period of examination 15 minutes**
  - Autocorrelation analysis modeled after Chronis et al. (2014; WAF) provided this temporal window

- **Properties examined**
  - Mixed phase Updraft Speed/Volume
  - Mixed phase Graupel Mass
Mixed Phase (-10 to -40°C) Graupel Mass Change

Graupel Mass Change Normalized by Storm Size

- Box plots demonstrate that in the median, an increase in flash rate corresponds to an increase in graupel mass

- No significant difference between medians of 1-2 sigma level category and 2+ category.

- 43% change vs 45% change in median

- Strongest Z score/P-level is between 0-1 sigma level and 2+

+ - flash rate below 25 fpm
* - flash rate ge 25 fpm

Rank Sum Testing

<table>
<thead>
<tr>
<th></th>
<th>Z Score</th>
<th>P_Level (one tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 and 1 σL</td>
<td>1 and 2 σL</td>
</tr>
<tr>
<td>Norm gmass</td>
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<td>0.85</td>
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</table>
5 and 10 m s\(^{-1}\) Updraft Volume Change

- Largest difference between storms that contain a lightning jump and those that don’t, the 10 m s\(^{-1}\) updraft volume

**Rank Sum Testing**

<table>
<thead>
<tr>
<th>Norm 10 m/s vol</th>
<th>Z Score</th>
<th>P_Level (one tailed)</th>
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<tbody>
<tr>
<td>0 and 1 σL</td>
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<td>0.48</td>
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<tr>
<td>1 and 2 σL</td>
<td>1.60</td>
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<tr>
<td>0 and 2 σL</td>
<td>1.99</td>
<td>0.03</td>
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</table>

+ - flash rate below 25 fpm
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Updraft volume change normalized by storm size
Maximum and 98% Updraft Speed Change

Continuum of an increase in the maximum and 98% Updraft speed prior to jump occurrence.

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</thead>
<tbody>
<tr>
<td></td>
<td>0 and 1 σL</td>
<td>1 and 2 σL</td>
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<tr>
<td>max_vv</td>
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<td>98%_vv</td>
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</table>
Jumps and Development

- During early growth, 88% of jumps occur when both 10 m s$^{-1}$ updraft volume and mixed phase graupel mass growth occur.
Flash Rate and Size are Opposed

- An increase in the updraft -> more turbulence -> more flashes with smaller flash footprints

Drop in mean and median flash footprint size as lightning ramps up

Median size drops from 70 km² down to 14 km² during jump

Bruning et al. (2013), Fig 1.
Schultz et al. 2015, WAF in revision

Mean Flash Area Extent (km²)

Before Jump

Flash Extent Density (Flashes km²)

After Jump

E/W distance from ARMOR

BWER

E/W distance from ARMOR

BWER
Conclusions and Continuing Work

- Defining difference between lightning jumps and normal increases in total lightning:
  
  \[10 \text{ m s}^{-1} \text{ updraft volume and maximum updraft speed changes}\]
  
  - Graupel mass increases observed at times of jumps, but changes in mass are not distinct from ordinary increases in lightning

- Flash extent decreases observed at times of jump and correspond to updraft location/intensification

- Next step temporal analysis of lightning jumps and intensity metrics
  - Tie into future MRMS and other products forecasters regularly use in warning operations
    - **MESH**: Chronis et al. (2014), WAF
    - **Azimuthal Shear**: Stough et al., this conference, Wednesday Afternoon