Physical and Dynamical Origins of Lightning Jumps

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The Lightning Jump

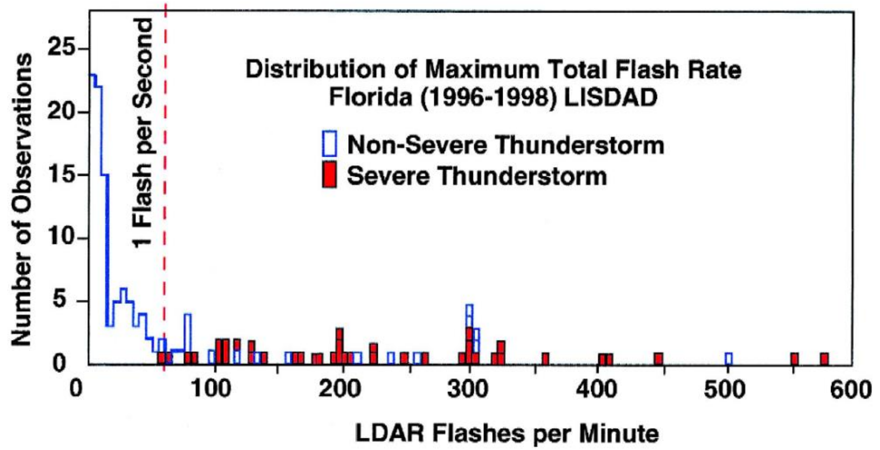
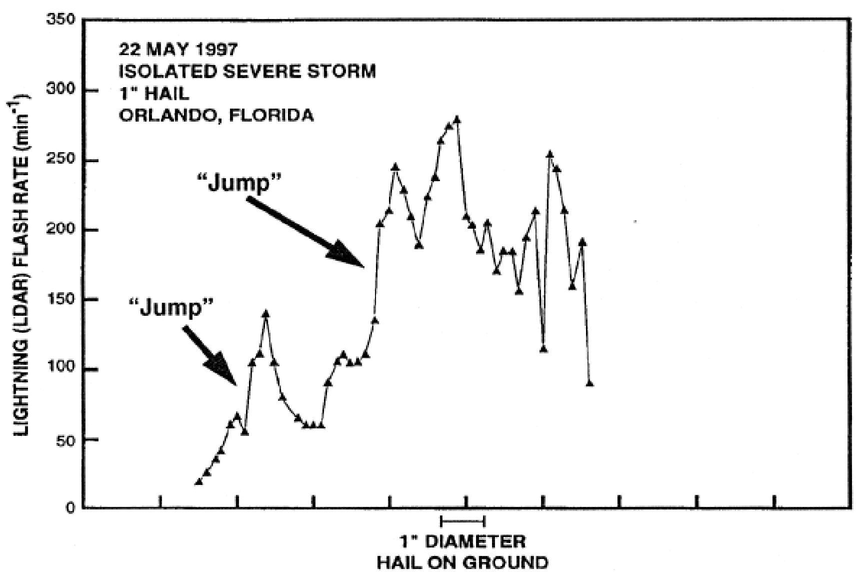


Fig. 3. Peak flash rates for Florida thunderstorms based on LDAR observations.



Williams et al. (1999)

- **Implicit transition from the magnitude of the total flash rate to the rate of change in the total flash rate**
  - Goodman et al. (1988)
  - Williams et al. (1989)
  - Williams et al. (1999)
  - Schultz et al. (2009)
  - Gatlin and Goodman (2010)
- **The presumption for the correlation was:**
  - Updraft strength modulates electrification.
  - Updraft strength directly contributes to the development of severe weather.

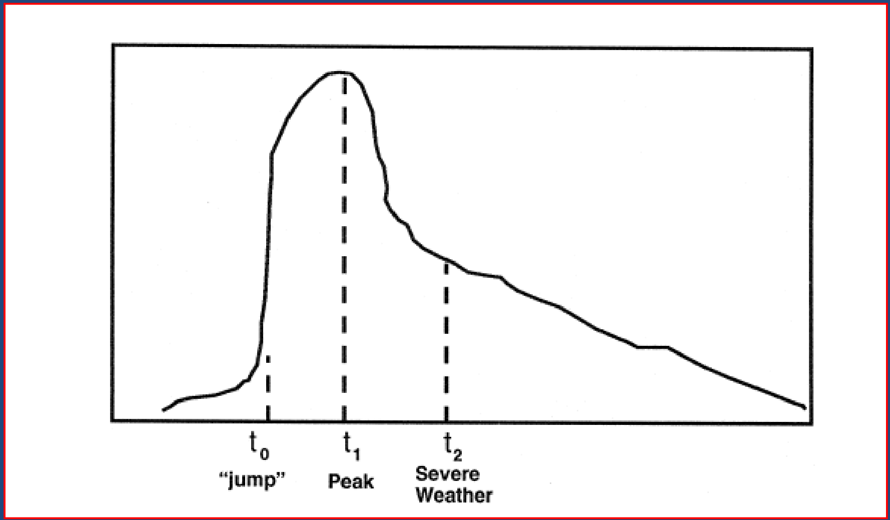


Figure credit : Williams et al. 1999, Atmos. Res.

The Conceptual Model of a Lightning Jump

1) The flash rate increases rapidly (t_0)

2) A peak flash rate (i.e., intensity) is reached (t_1)

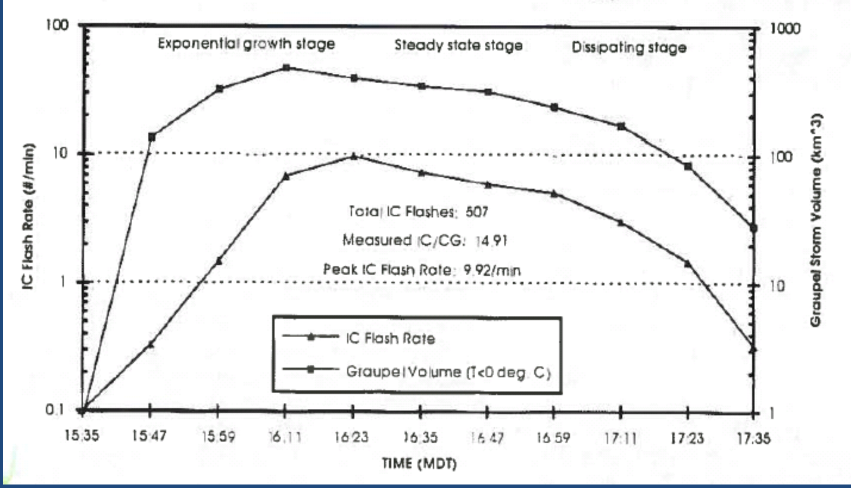
3) Severe weather occurs a short time later (t_2)

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 these studies
- Authors are not specific in which updraft properties govern the jump

Underlying Physical Basis Storm Intensification at the Time of a Jump

- **Current lightning jump studies have relied on observations from previous studies:**
  - **Strong correlation between mixed phase ice mass and flash rate**
    - **Non inductive charge mechanism dominant in electrification**
  - **Strong correlation between updraft volume and flash rate**
    - **Supply of cloud liquid water content for hydrometeor growth and charge separation**
  - **Weaker correlation between maximum updraft speed and total flash rate**



Carey and Rutledge (1996)

Table 3. Linear Fit of Mean Total Lightning Per Minute Averaged Over the Radar Volume Time Versus Updraft Volume (m^3) Above the $-5°C$ Level With Velocities $>5\ m\ s^{-1}$

	All Data Points	Data Points From Northern Alabama	Data Points From the Colorado/Kansas High Plains
Linear function	$f = 6.75 \times 10^{-11}\ w_5 - 13.9$	$f = 6.74 \times 10^{-11}\ w_5 - 14.3$	$f = 6.76 \times 10^{-11}\ w_5 - 13.7$
Correlation (r)	0.93	0.88	0.93

Table 4. Linear Fit of Mean Total Lightning Per Minute Averaged Over the Radar Volume Time Versus Maximum Updraft Velocity (m^3) Between the $-5°C$ and $-40°C$ Level

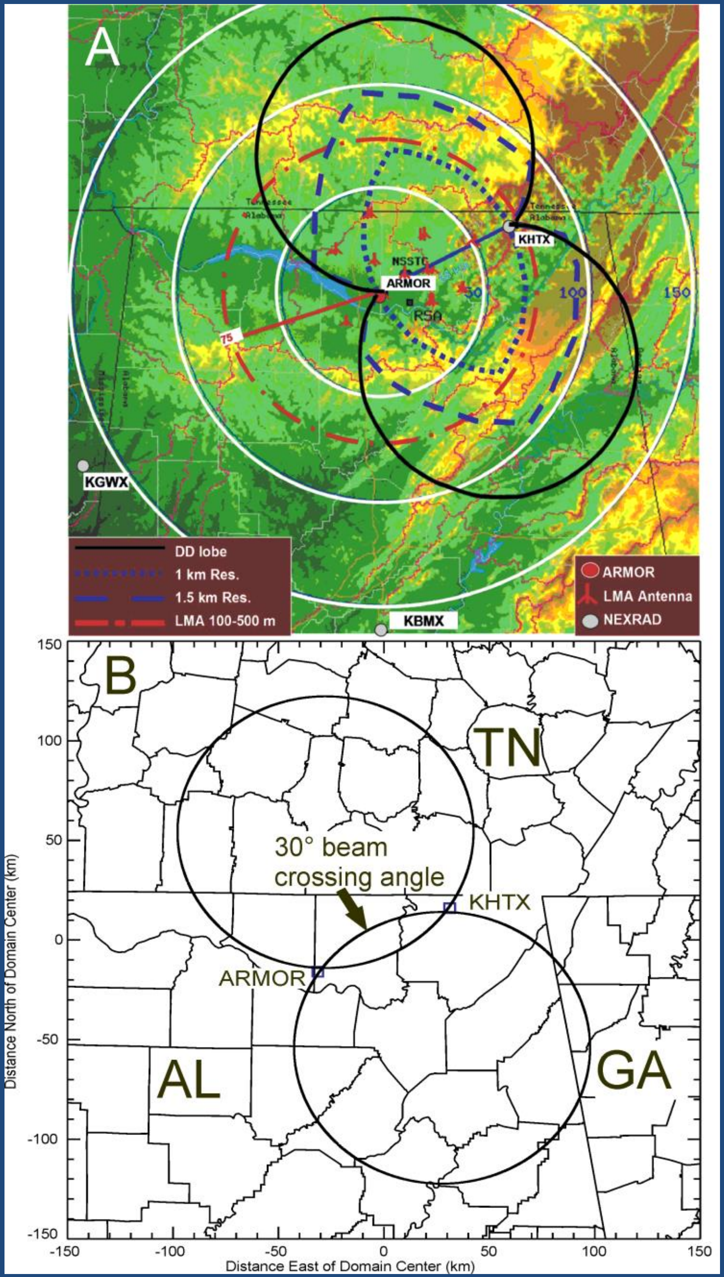
	All Data Points	Data Points From Northern Alabama	Data Points From the Colorado/Kansas High Plains
Linear function	$f = 5.73 w_{max} - 71.3$	$f = 4.4 w_{max} - 424$	$f = 6.05 w_{max} - 84.3$
Correlation (r)	0.8	0.68	0.8

Deierling et al. (2008)

Multi-Doppler Analysis

- Use a combination of ARMOR and KHTX
  - Radar volumes must fall within 2 minutes of each other

- Variational integration technique used (O'Brien 1970)
  - 0 dBZ echo topped
  - Storm must be inside the 30° beam crossing angle and inside the 1.5 km resolution boundary



Graupel/Small Hail Mass Calculation

- Use a C-band tuned NCAR PID to identify regions of graupel (Deierling et al. 2008)

- Use a Z-M relationship empirically derived from Heymsfield and Miller (1988)

$$mass \quad (g \ m^{-3}) = 0.0052 * Z^{0.5},$$

Z in linear units ($mm^6 \ m^{-3}$)

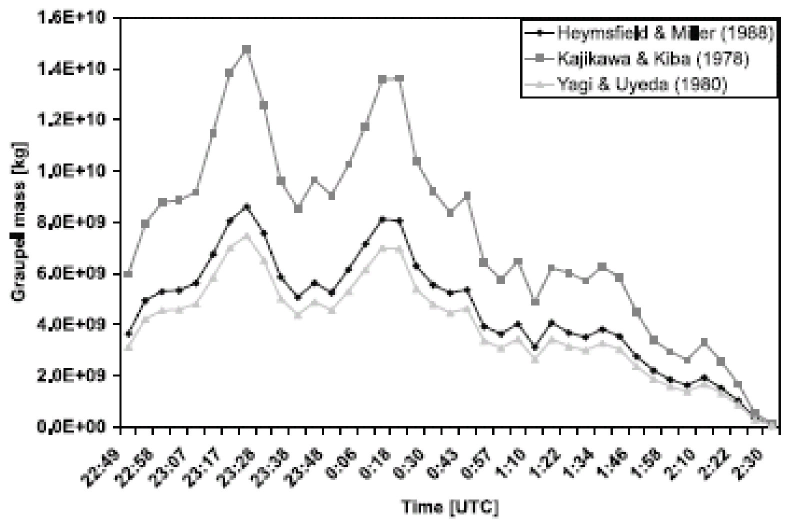


Figure 7. Time series of graupel mass above −5°C for the 10 July 1996 STERAO-A storm obtained from Z-M relationships from *Heymsfield and Miller* [1988], *Yagi and Uyeda* [1980], and *Kajikawa and Kiba* [1978], respectively. Calculations were performed in radar space. The correlation coefficients between combinations of two time series were above 0.99 in all three cases.

Deierling et al. (2008) showing trends in mass based on different Z-M relationships are the same.

Sigma-Level

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

$DFRDT_{t0} \geq 2*\sigma_{(DFRDT\_t-2...t-12)}$

- Yes/No Answer

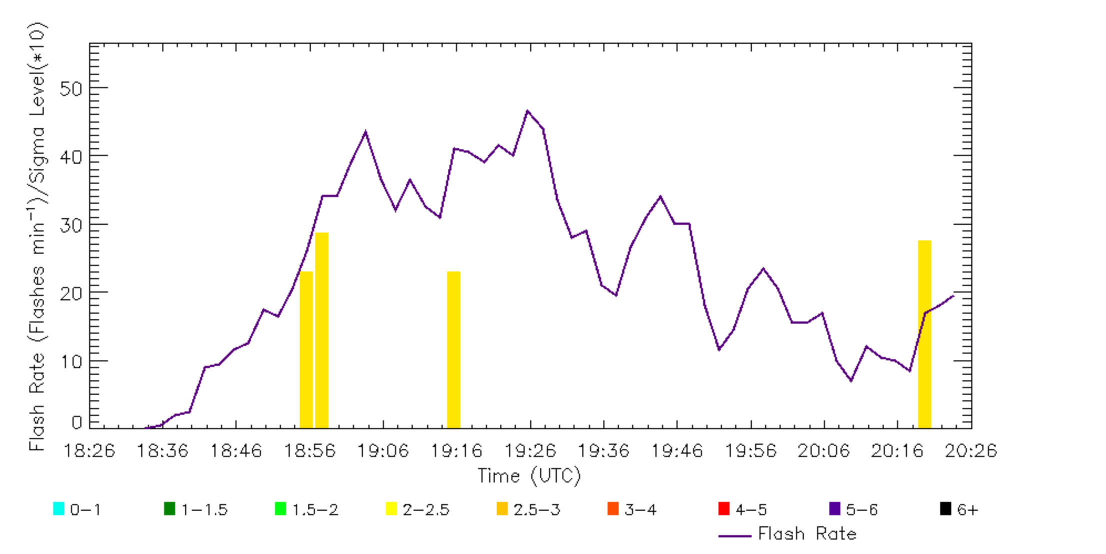
-No information on magnitude of the flash rate increase

The sigma-level is:

Sigma-level = $DFRDT_{to}/\sigma_{(DFRDT\_t-2...t-12)}$

Thus a sigma level of 2 is the same as a 2σ 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)
  - Chronis et al. (2015)

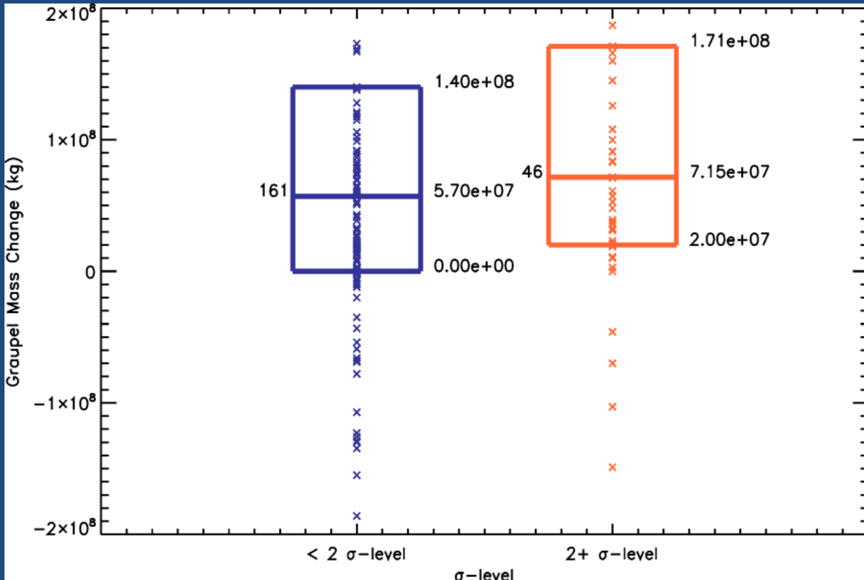


Distribution of Storm Types for Kinematic and Microphysical Analysis

Location	Number	Type	Jump	No Jump
3 May 2006	1	multicell	1	0
19 July 2006	2	multicell	2	0
3 April 2007	3	supercell	2	1
4 April 2007	1	QLCS	1	0
1 June 2007	4	multicell	0	4
7 July 2007	2	multicell	2	0
17 August 2007	6	multicell	5	1
14 September 2007	1	tropical	0	1
10 April 2009	3	supercell	3	0
13 April 2009	1	low topped	0	1
21 January 2010	2	low topped	1	1
12 March 2010	1	QLCS	1	0
26 October 2010	3	supercell	0	3
27 April 2011	1	supercell	1	0
18 May 2012	1	multicell	1	0
21 May 2012	1	multicell	0	1
11 June 2012	4	multicell	0	4
14 June 2012	2	multicell	0	2

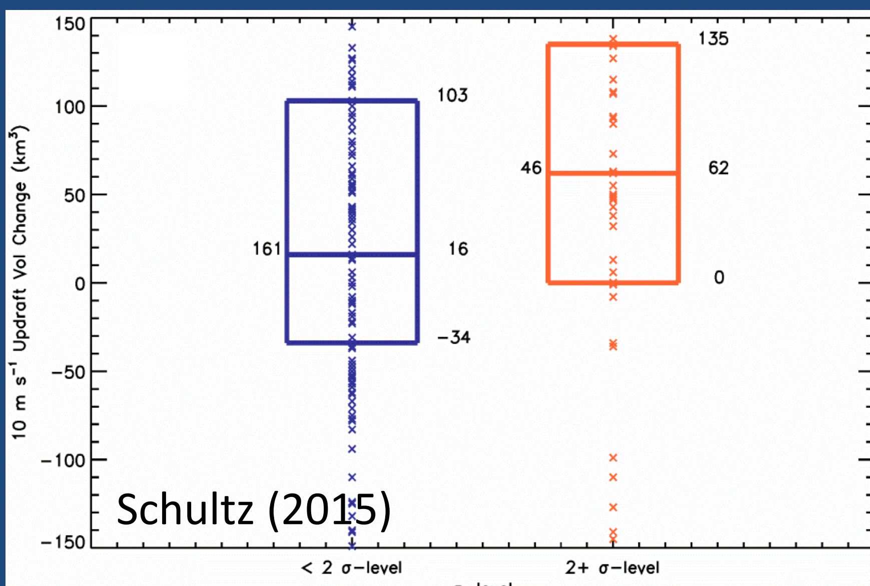
Table of storm types, number of storms on each day, and the jump of storms that contained 1 jump.

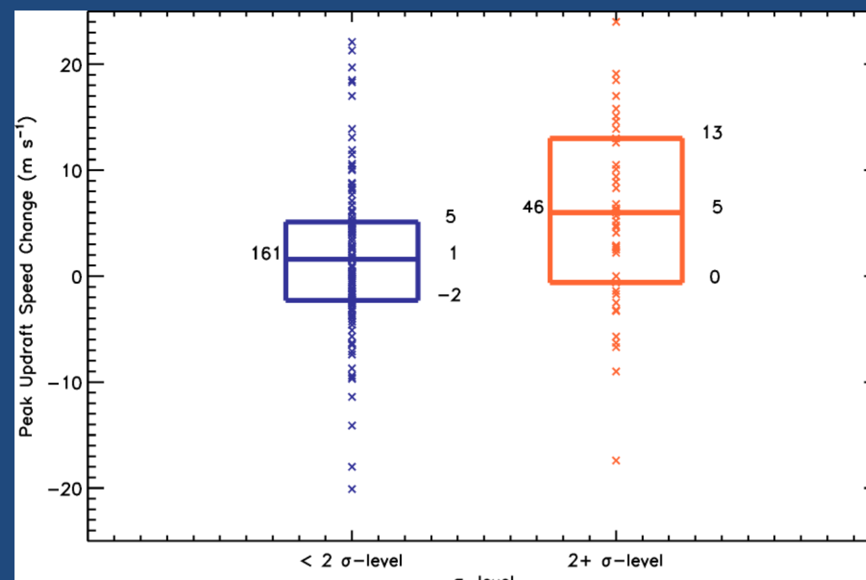
- 39 Thunderstorms examined with multi-Doppler, polarimetric and total lightning data
  - All storms found in the 1516 storm sample
- Individual detailed case study performed on 4 thunderstorms (blue boxes, left)
  - Only presenting severe multicell and supercell cases
- Overall analysis performed



Lightning jumps are controlled by increases in intense mixed phase updraft (> 10 m s^{-1}) less than 15 minutes prior to jump occurrence.

- 39 thunderstorms, 207 flash rate increases with multi-Doppler, polarimetric and total lightning measurements.
- Increases in mixed phase graupel mass and 5 m s^{-1} updraft also are observed, but the magnitude of the increase is not statistically significant at the 95th percentile.





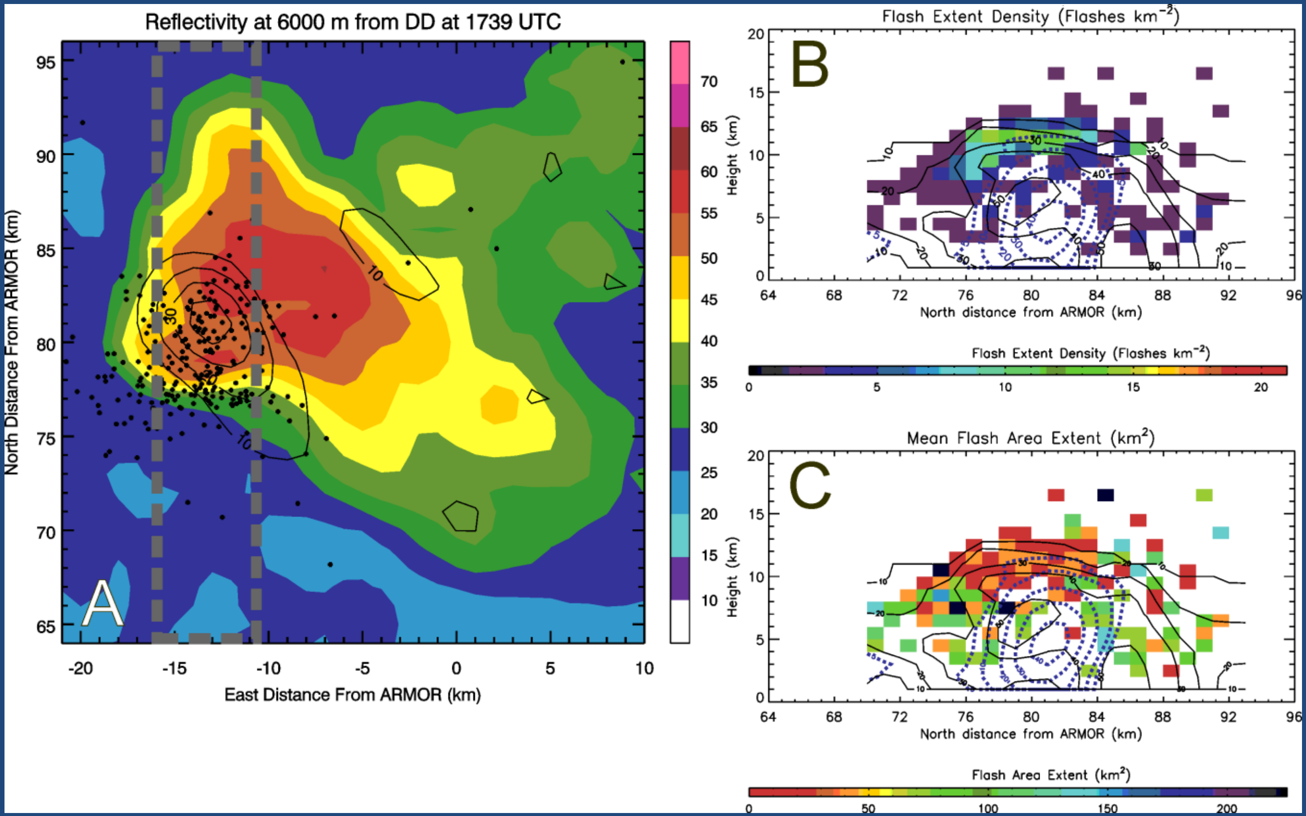
	Graupel Mass	Graupel Mass Density	5 m s^{-1}	10 m s^{-1}	MaxVV
Z-Score	1.065	1.304	1.323	1.987	3.286
P-value (one tailed)	0.096	0.143	0.093	0.0234	5.0×10^{-4}

Left- Rank sum significance testing of graupel mass and updraft change for jump and non-jump increases in lightning.

Importance of 10 m s^{-1} updraft

Why is the 10 m s^{-1} updraft so important when most lightning occurs outside of the intense updraft?

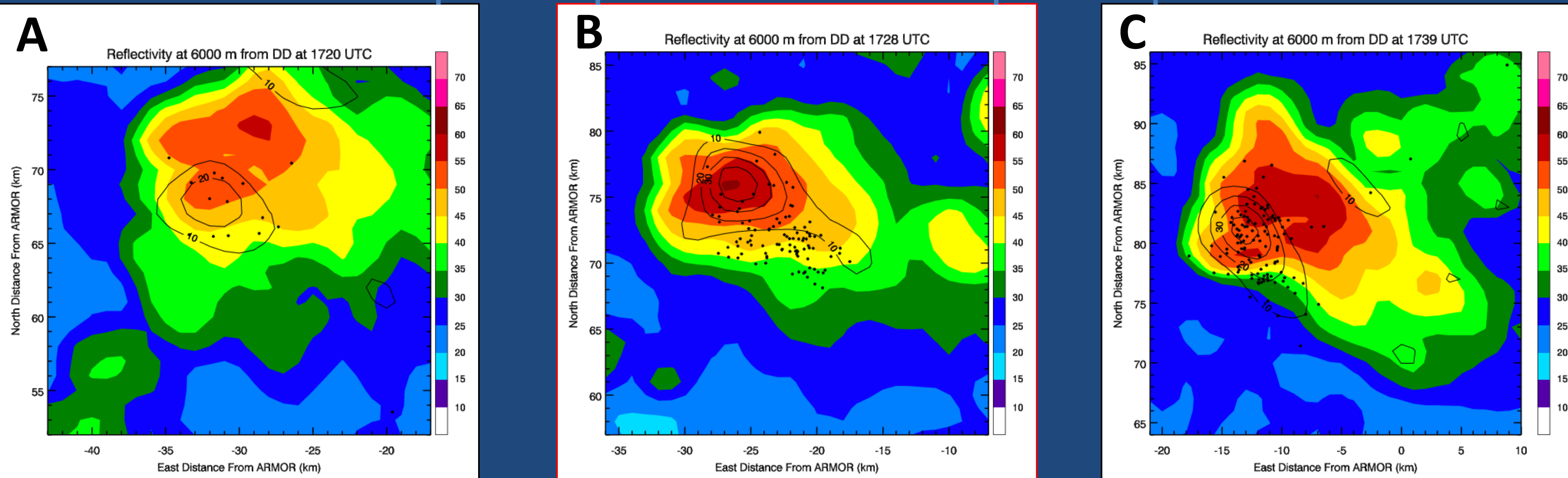
- Larger 3D volume of weaker updraft and updraft/downdraft interface
- These regions are preferred for **active charge separation, larger concentrations of ice, and an increase in the vertical flux of smaller charged ice** in the mixed phase region of the thunderstorm.

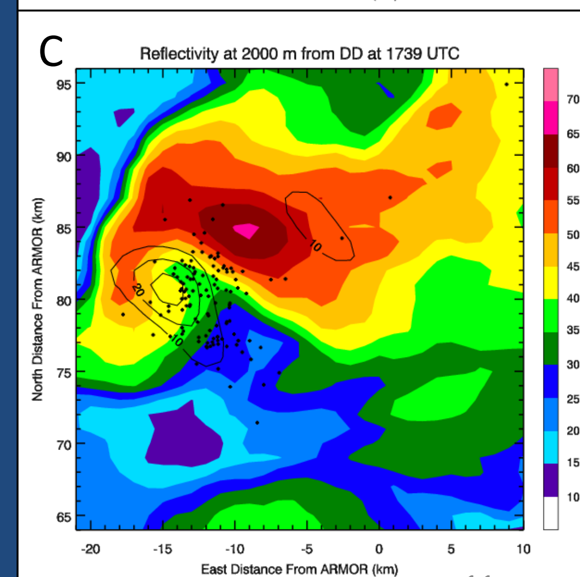


Schultz (2015)

Lightning Jump Conceptual Model

Δt Jump Time Δt





- LMA flash initiation

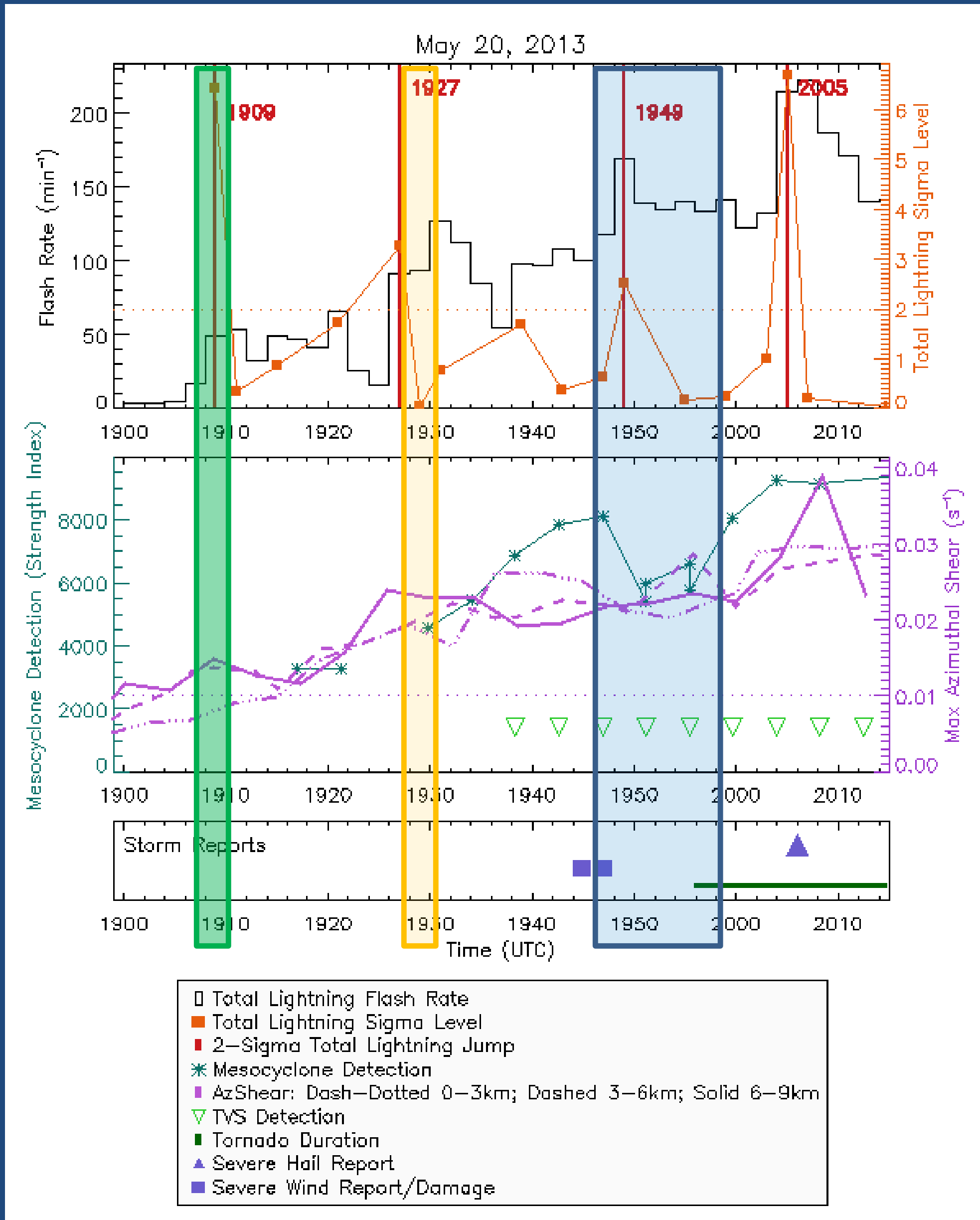
—— **W = 10, 20, 30, 40, 50 m s^{-1}**

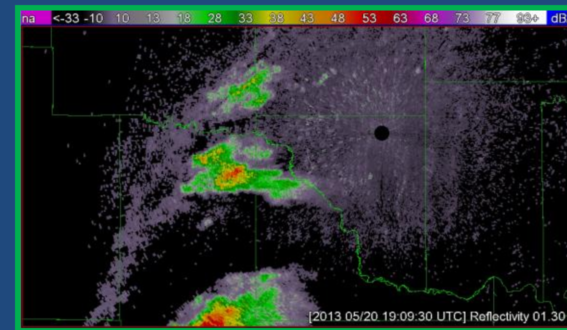
A to B – Mixed phase updraft volume, updraft speed and graupel mass increase and a lightning jump occurs

B to C – As flash rates continue to increase, increases in intensity metrics (e.g., MESH, azimuthal shear) are observed resulting in enhanced severe weather potential.

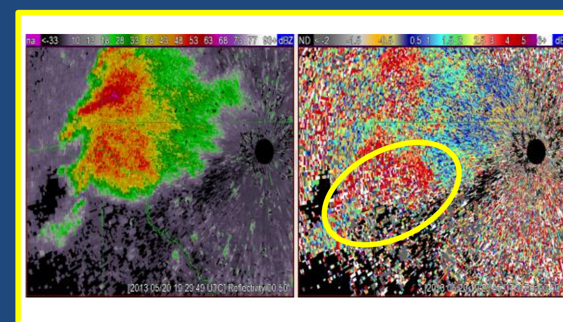
Schultz et al. (2015), WAF

Example Case: May 20, 2013; Oklahoma



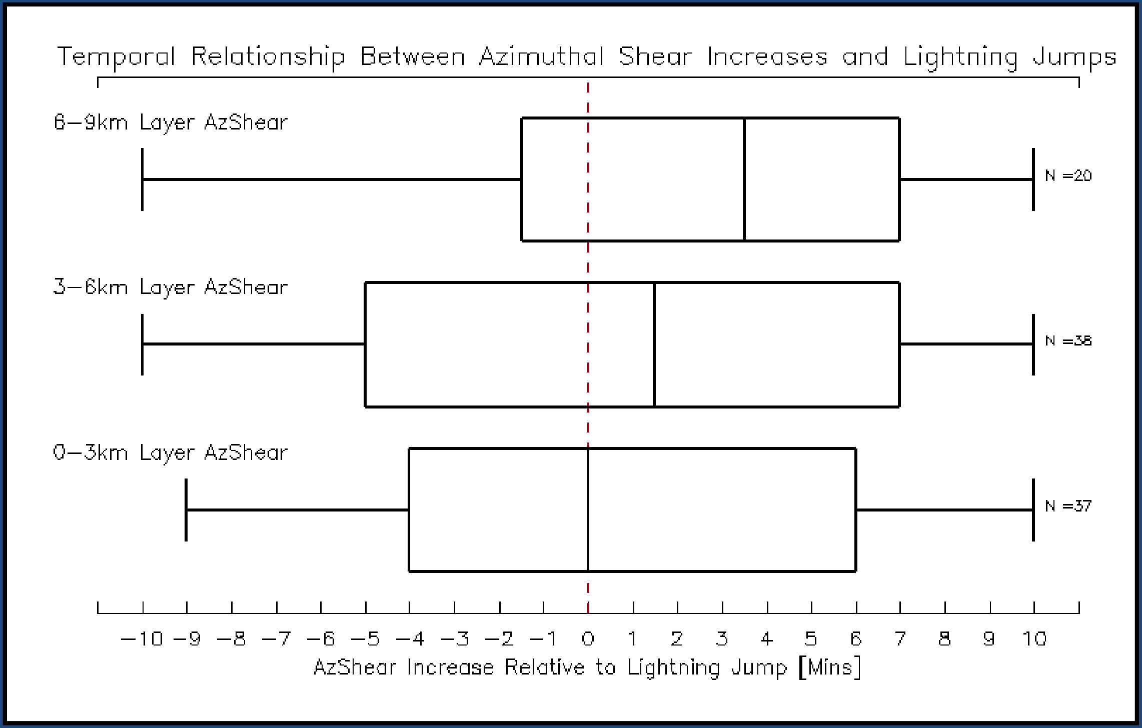


- Cell shown above at time of 1st jump, with evidence of BWER, no well-defined supercell structure



- Two minutes after the 2nd jump, ample supercell structure and strong Z_{DR} arc apparent; collocated AzShr maxima
- See third jump, relative maximum in 3-6 km azimuthal shear, and tornado in 7 minute period (imagery not shown)

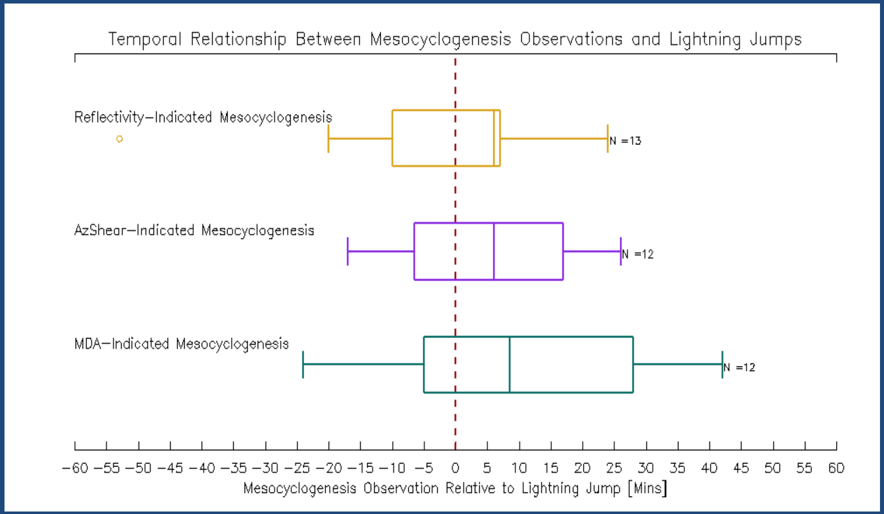
How the Lightning Jump Relates to Increases in Rotation in 19 Storms



Rapid increases in maximum azimuthal shear (MAS) through 0-3 km, 3-6 km, and 6-9 km layers are compared temporally with lightning jumps in 19 storms

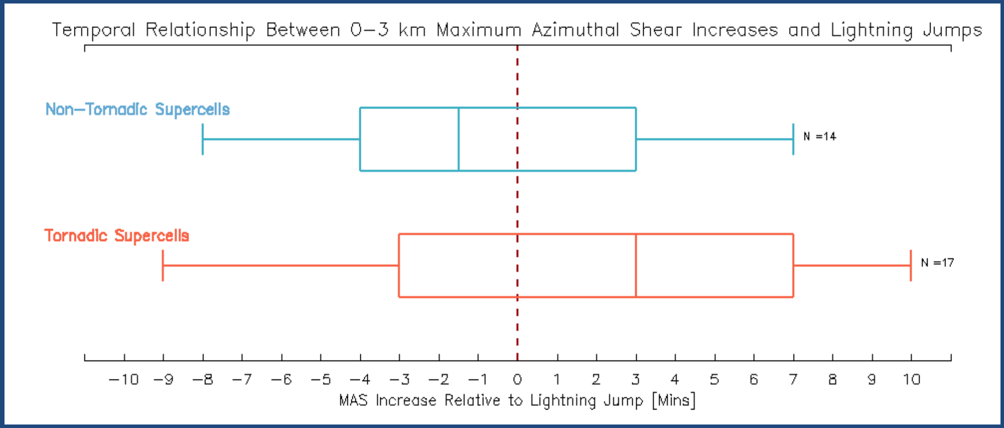
Generally, see a temporal shift in increase of azimuthal shear (rotation) later after the time of the lightning jump with height

1) Lightning jump related to observations of mesocyclogenesis



- Over 50% of the time, the 1st mesocyclone observation (by reflectivity, azimuthal shear, or meso detection algorithm) occurs 6.0-8.5 minutes after the 1st jump
- LJA shows most benefit against MDA

2) Lightning jump related to rotation in tornadic vs. non-tornadic storms

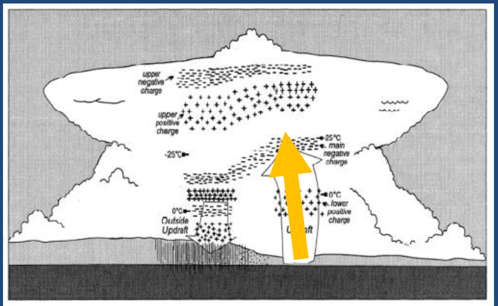


- Lightning jump signals updraft pulse that increases mixed-phase precipitation mass.
- Fallout of this precipitation results in downdraft and cold pool generation.
- Lightning jump, tied to updraft, may also signal onset of enhanced downdraft and potential for increased vorticity

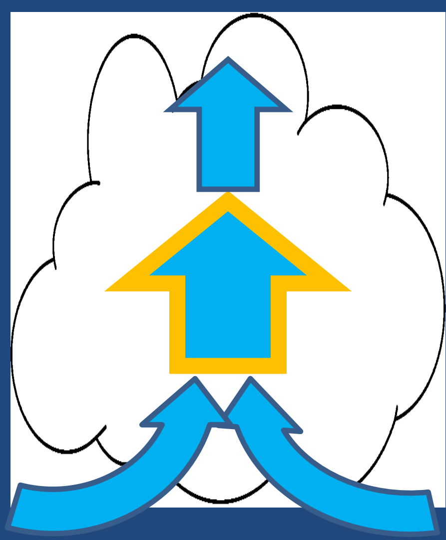
Hypothesized Conceptual Model

Total lightning and the supercell mesocyclone are physically linked by the updraft.

(Via Non-Inductive Charging)
More Particle Collisions
→ Increased Lightning

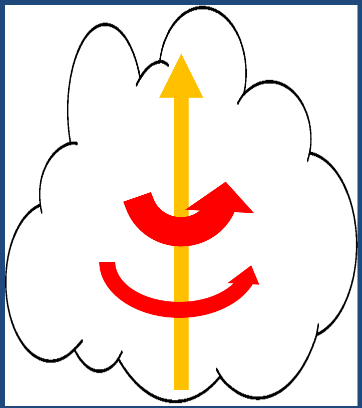


Stolzenburg *et al.* (1998) , Fig. 3



Updraft Pulse

Tilting to Vertical and
Stretching of Vorticity
→ Mesocyclone



Measurements Useful to Future Lightning Studies and Applications to Severe Weather

- The Geostationary Lightning Mapper, Fly's Eye GLM
  - Flash Rates
  - Energetics
  - Flash size
    - 8 km GLM vs 2 km FEG's resolution
- LMAs (when available)
- Radar observations
  - Multi-Doppler, polarimetric
  - Airborne
  - Higher resolution, the better (spatial and temporal)
- Higher resolution environmental context