Insight into the Physical and Dyna ical Processes that Control Rapid Incre ses in Total Flash Rate

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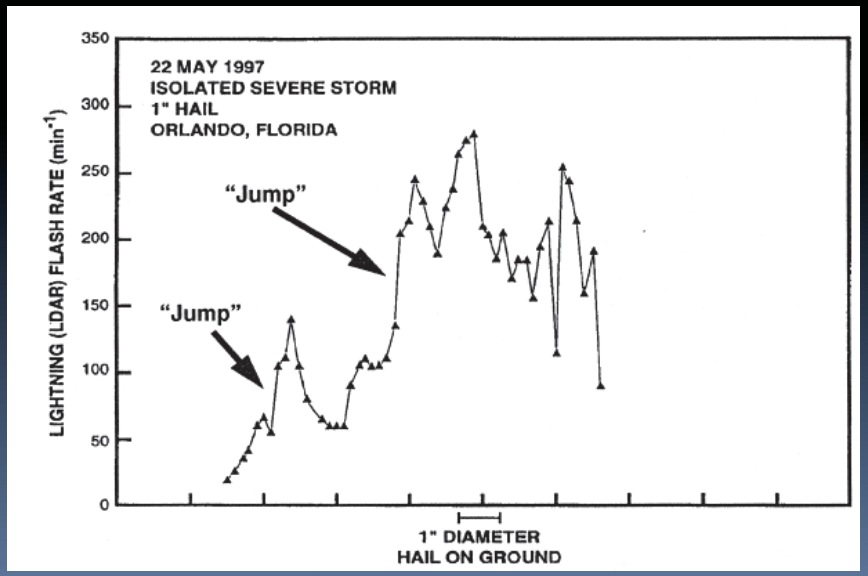


Figure credit above to Williams et al. 1999, Atmos. Res.

The Conceptual Model Behind a Lightning Jump

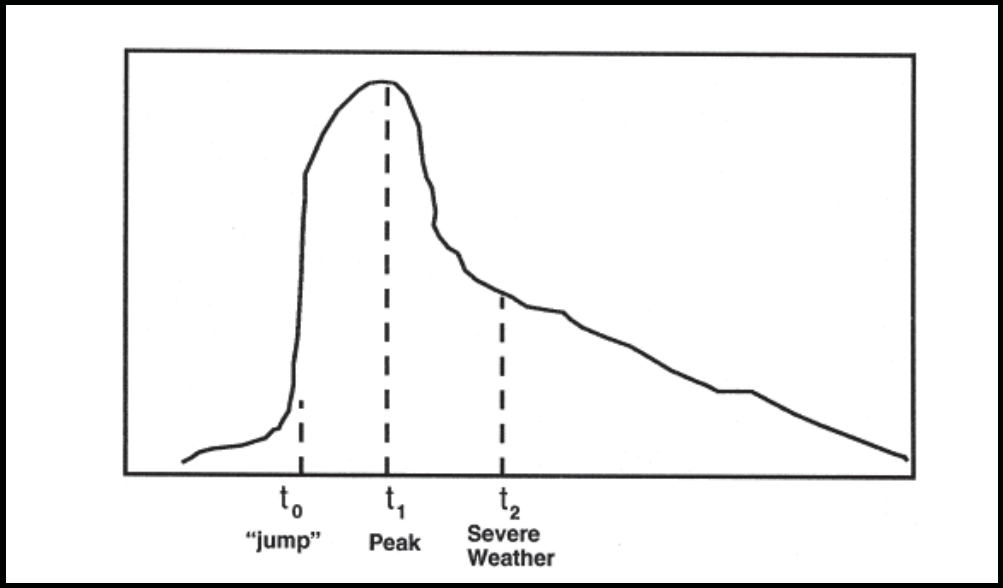


Figure credit : Williams et al. 1999, Atmos. Res.

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)

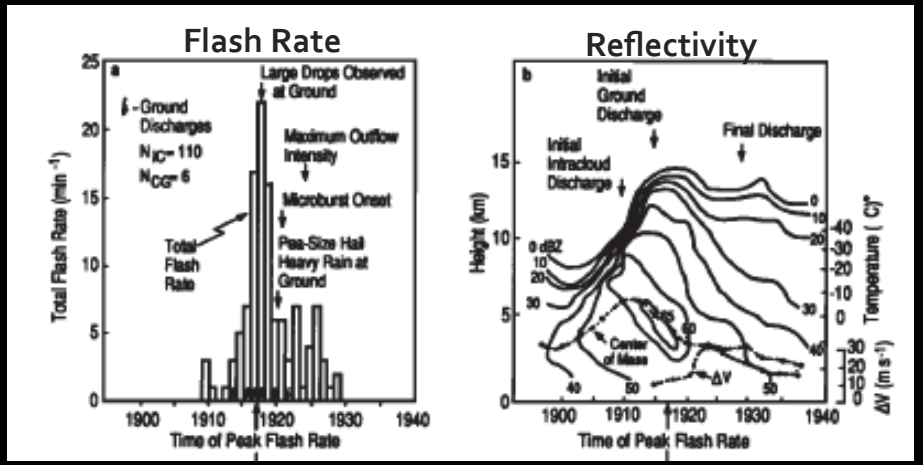
(Williams et al. 1999, Schultz et al. 2009; 2011, Gatlin and Goodman 2010, Rudlosky and Fuelberg 2013, Metzger and Nuss 2013).

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"

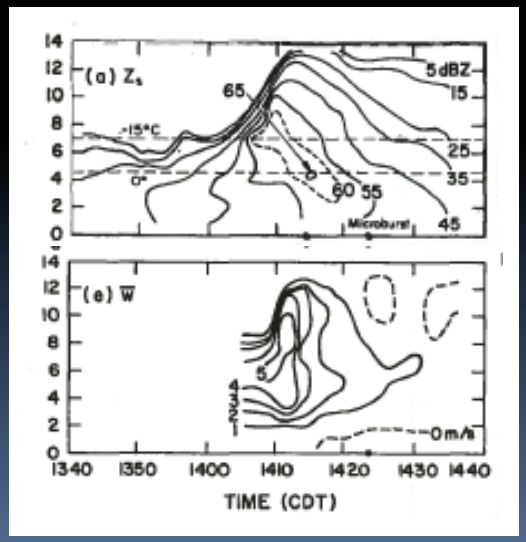
- Updraft properties were not directly measured in this study
- Authors are not specific in which updraft properties govern the jump

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



Goodman et al. 1988, GRL



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:

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

- **Yes/No Answer**

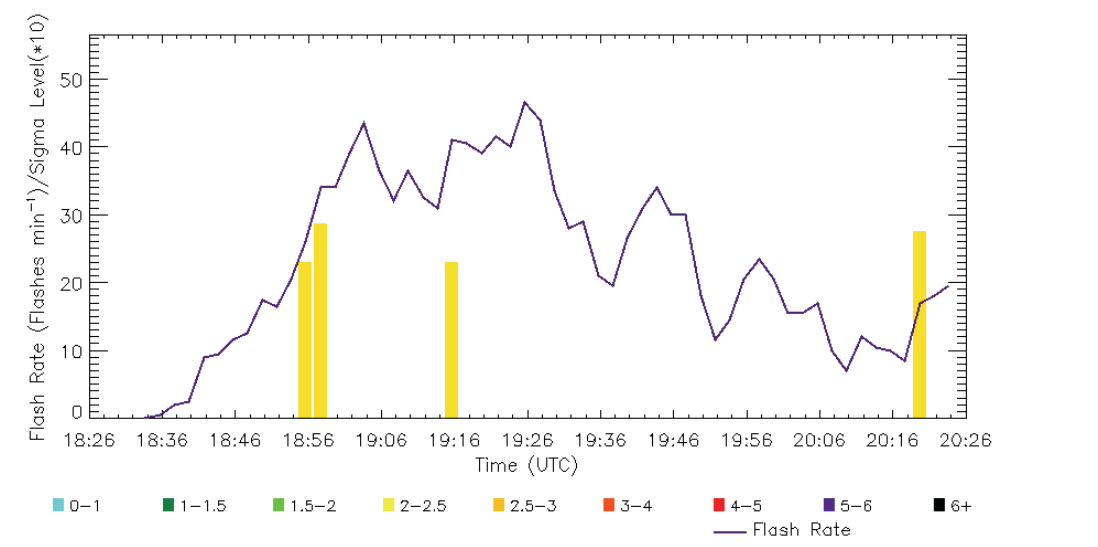
- **No information on magnitude of the flash rate increase**

The sigma level is:

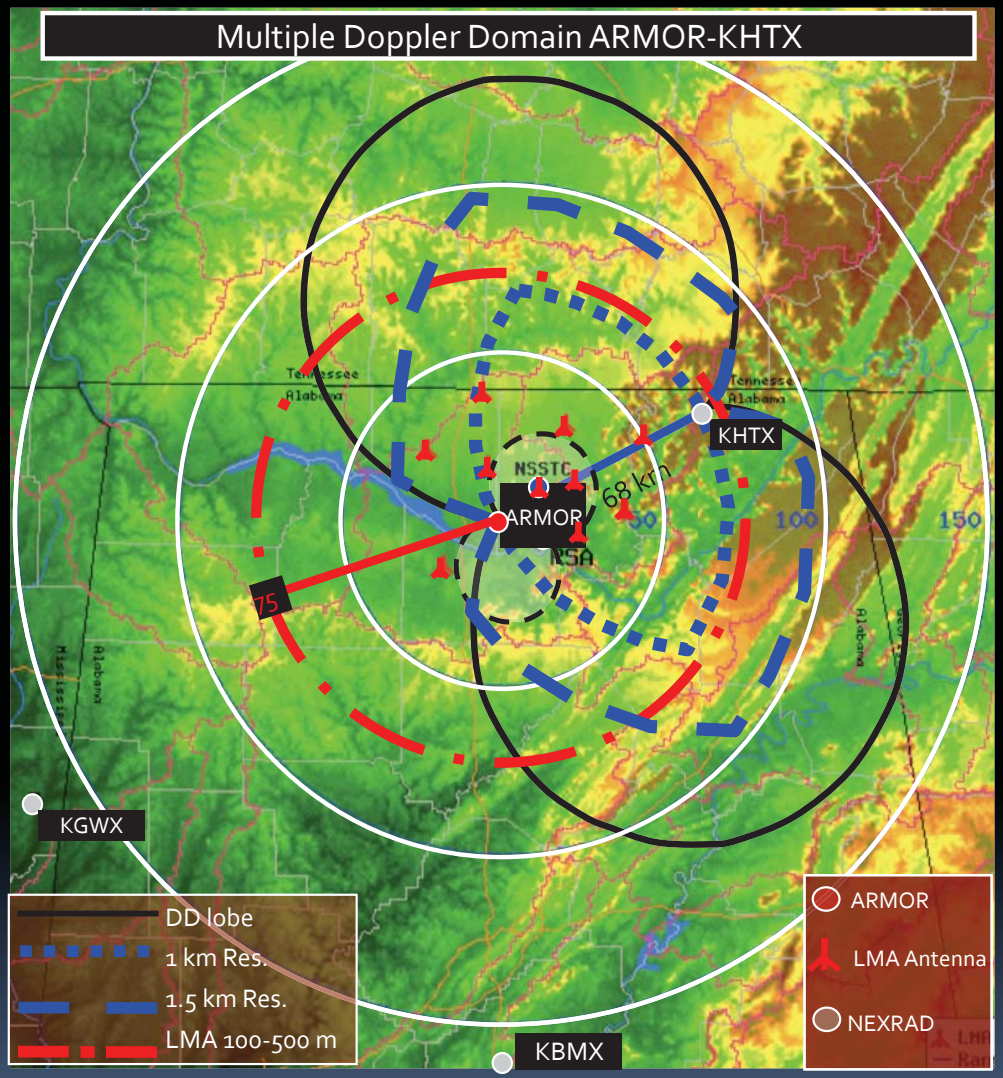
Sigma level = $DFRDT_{to} / \sigma_{(DFRDT\_t-2...t-12)}$

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

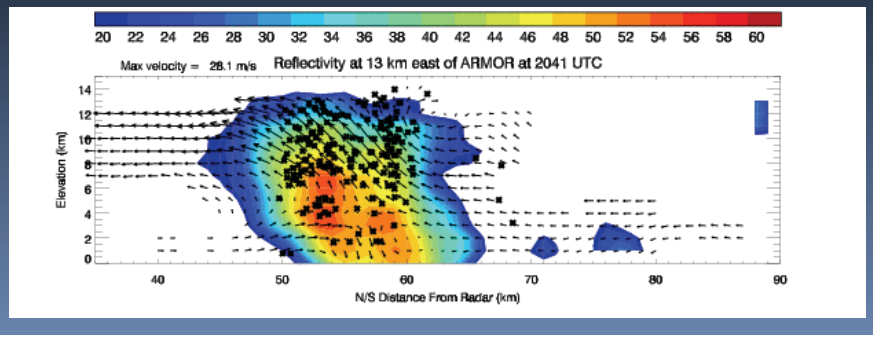
- This formulation provides continuous monitoring of increases in flash rate and the magnitude of that flash rate increase relative to the recent flash rate history.
  - Calhoun et al. 2015, this session
  - Chronis et al. (2014); WAF



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

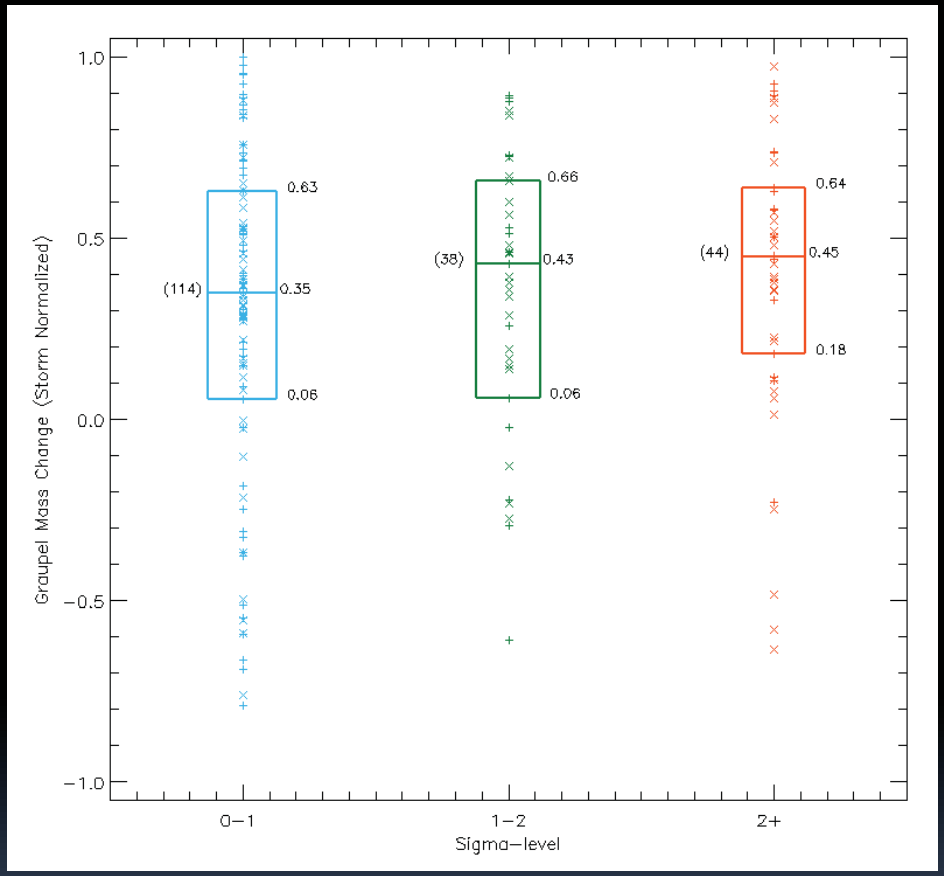


Sample Set

- 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



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

- 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+

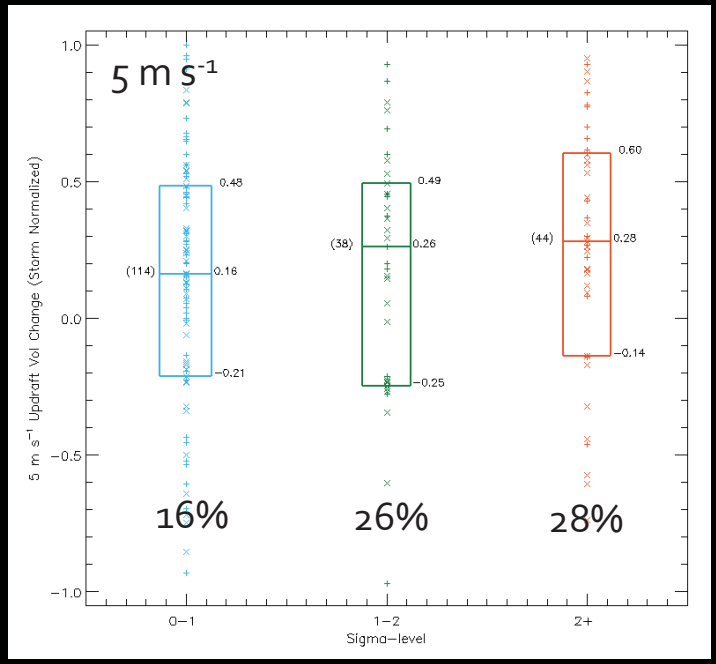
Rank Sum Testing

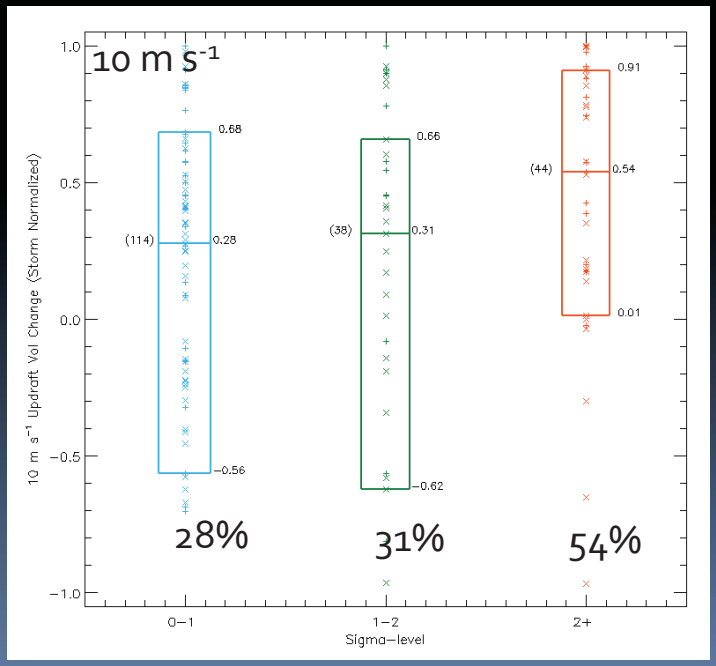
	Z Score			P_Level (one tailed)		
	0 and 1 σL	1 and 2 σL	0 and 2 σL	0 and 1 σL	1 and 2 σL	0 and 2 σL
Norm gmass	0.31	0.85	1.40	0.38	0.20	0.08

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

Updraft volume change normalized by storm size





Rank Sum Testing

	Z Score			P_Level (one tailed)		
	0 and 1 σL	1 and 2 σL	0 and 2 σL	0 and 1 σL	1 and 2 σL	0 and 2 σL
Norm 10 m/s vol	0.05	1.60	1.99	0.48	0.06	0.03

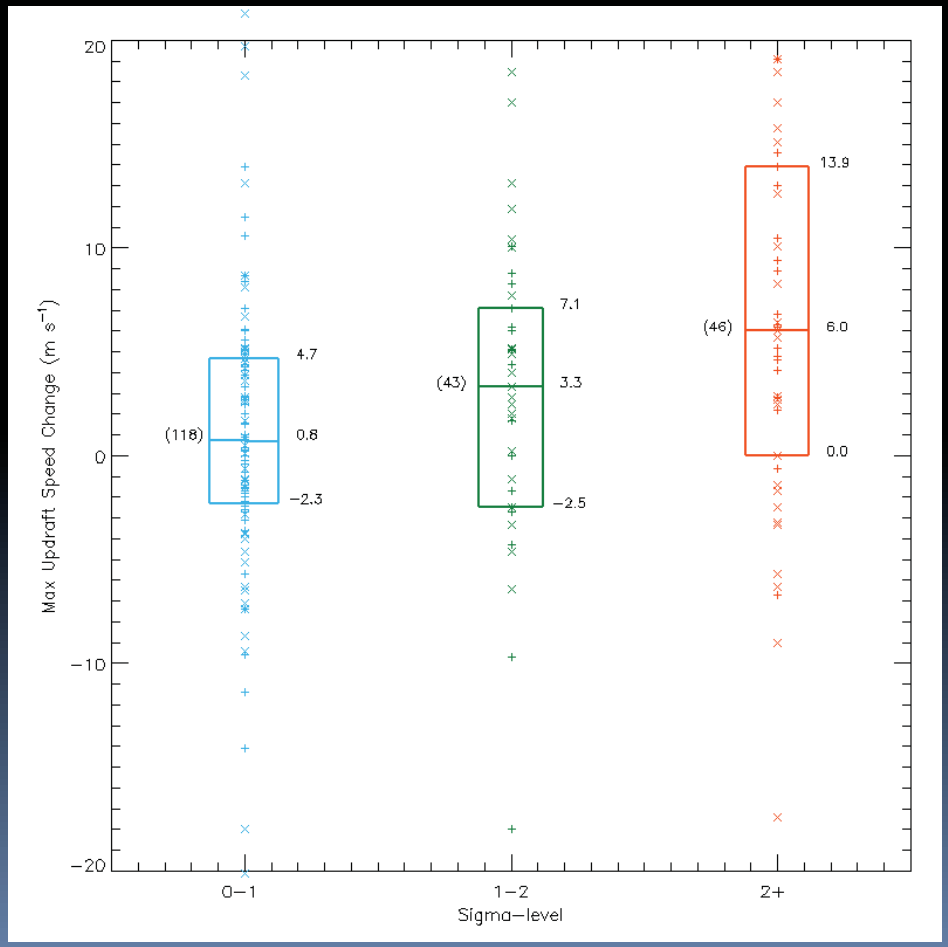
\+ - flash rate below 25 fpm
* - flash rate ge 25 fpm

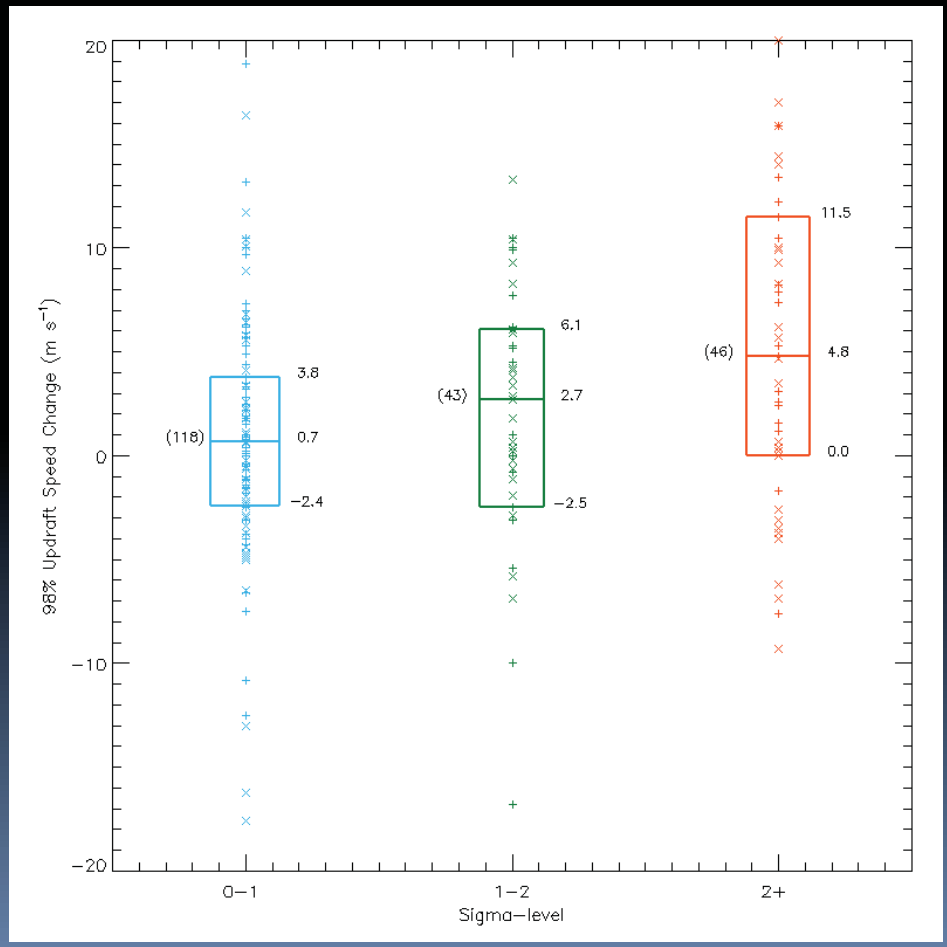
Maximum and 98% Updraft Speed Change

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

Rank Sum Testing

	Z Score			P_level (one tailed)		
	0 and 1 σL	1 and 2 σL	0 and 2 σL	0 and 1 σL	1 and 2 σL	0 and 2 σL
max_vv	1.72	1.71	3.55	0.04	0.04	0.00
98%_vv	1.32	1.74	3.27	0.09	0.04	0.00

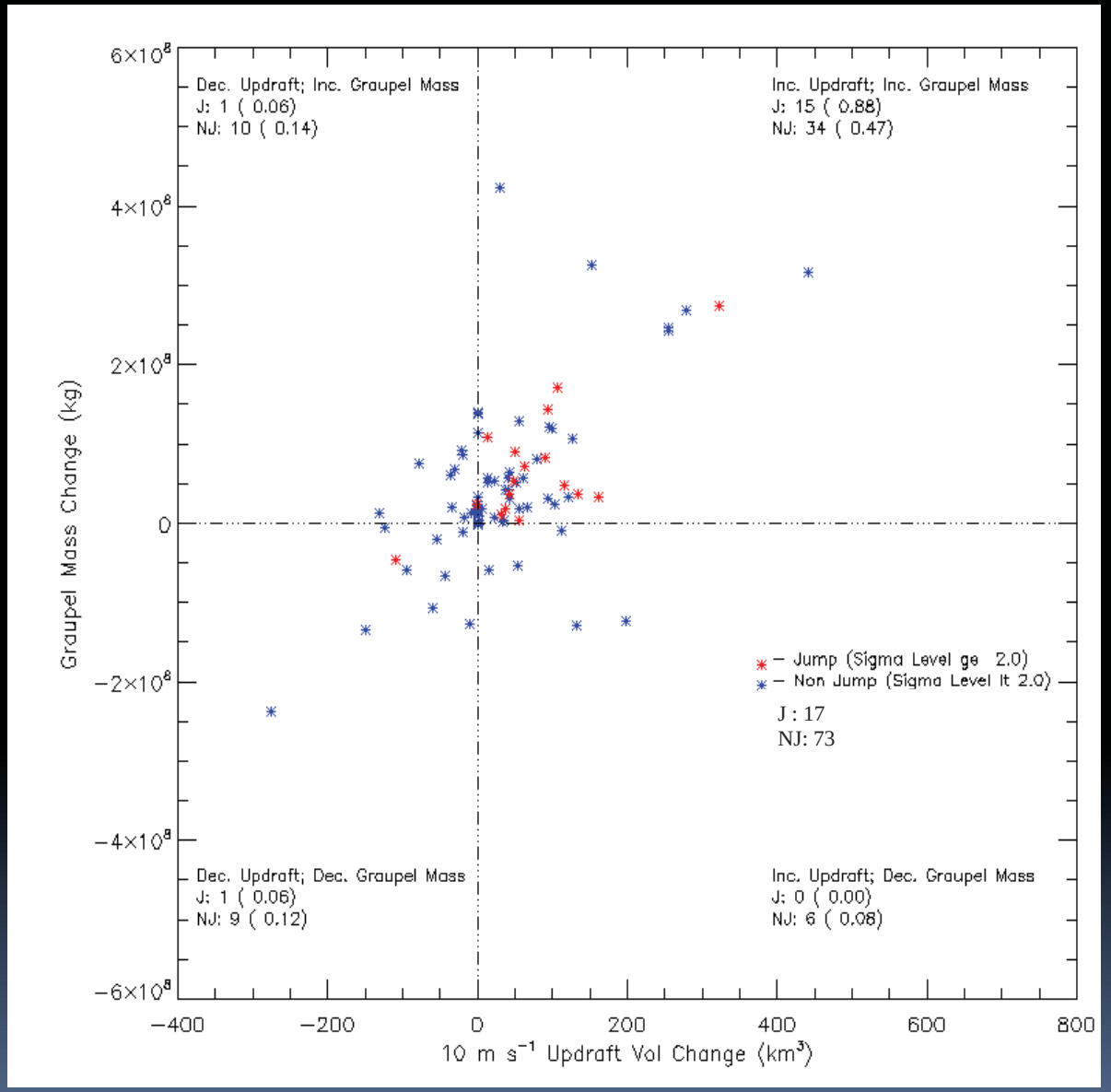




Jumps and *Development*

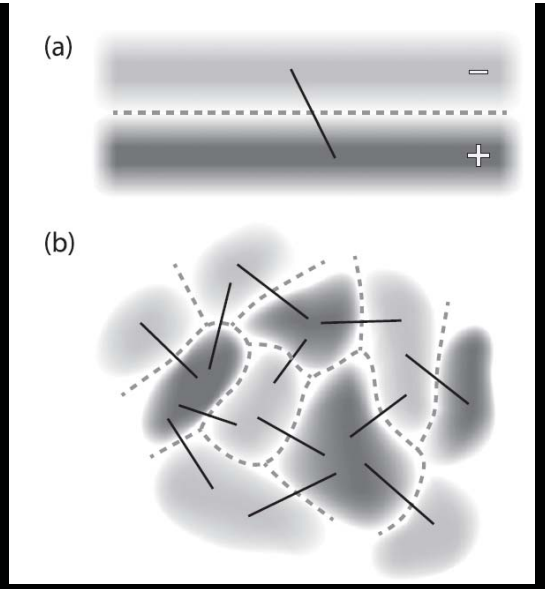
Growth Stage

- During early growth 88% of jumps occur when both 10 m s^{-1} updraft volume and mixed phase graupel mass growth occur

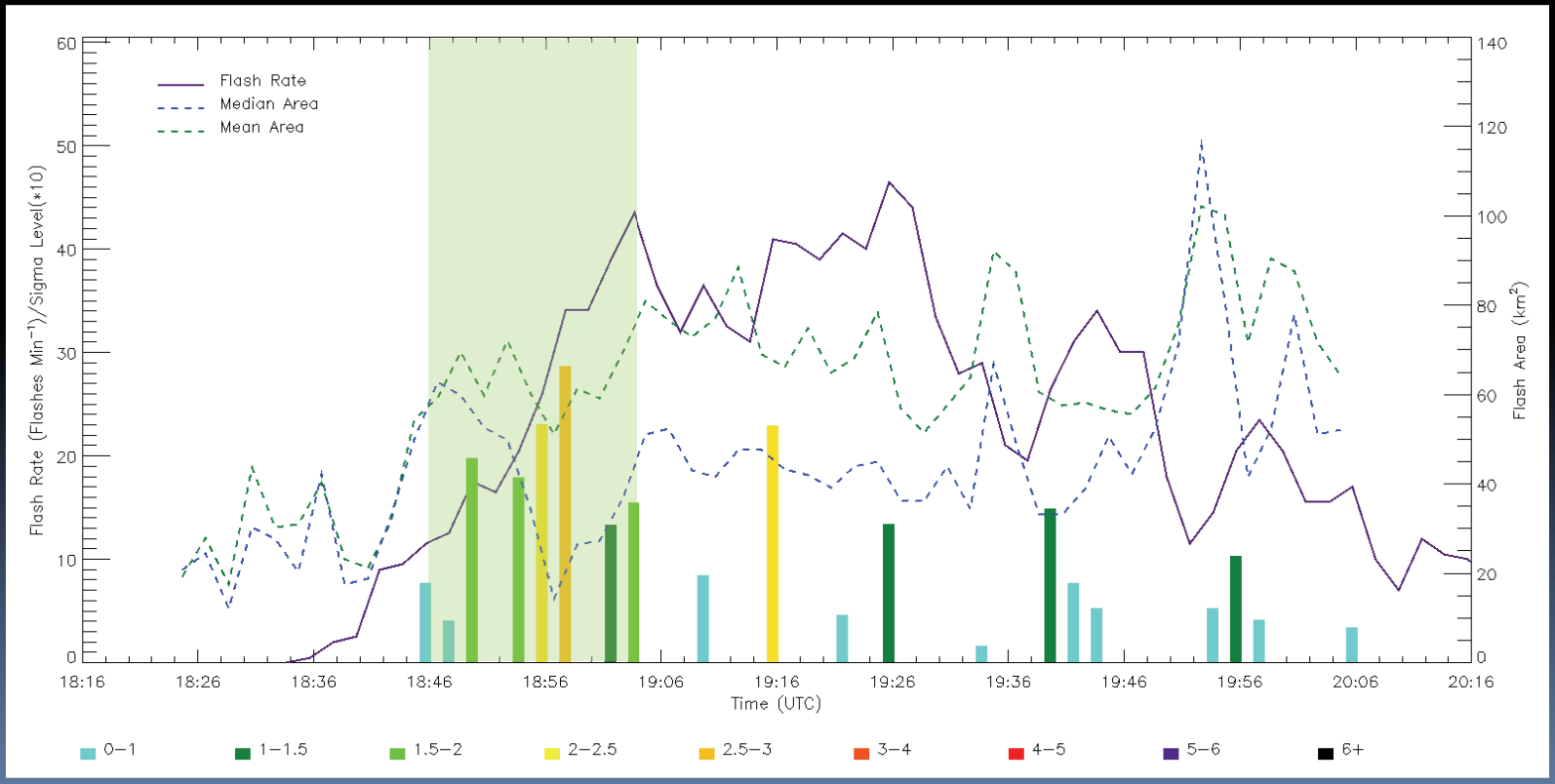


Flash Rate and Size are Opposed

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



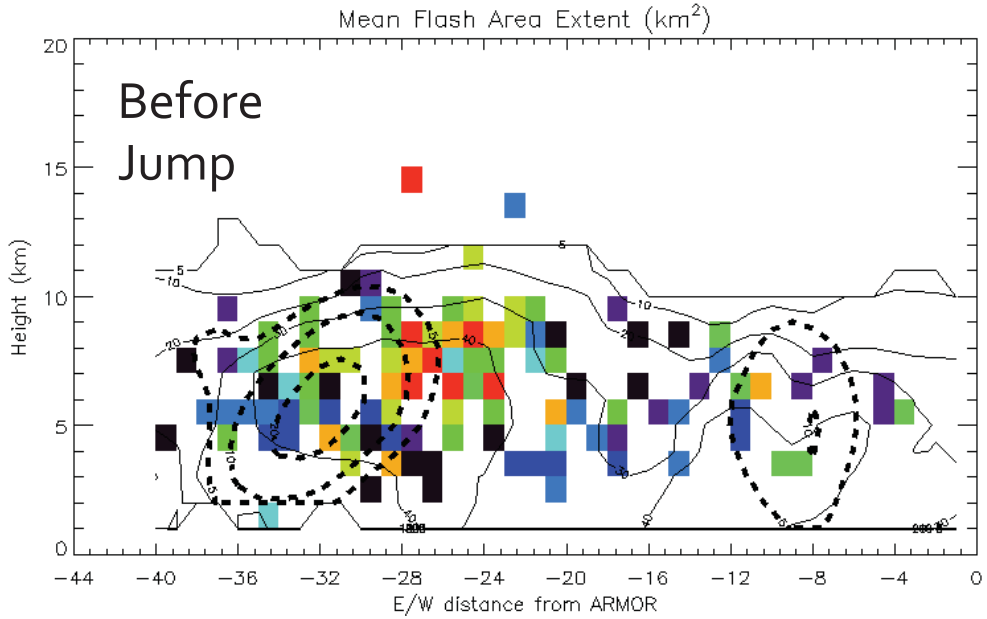
Bruning et al. (2013), Fig 1.

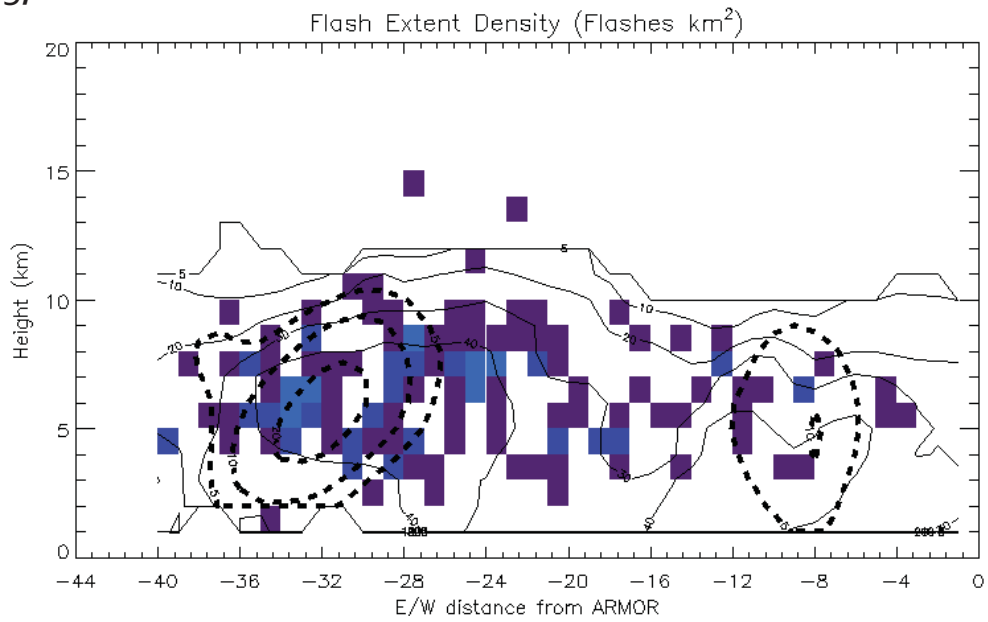


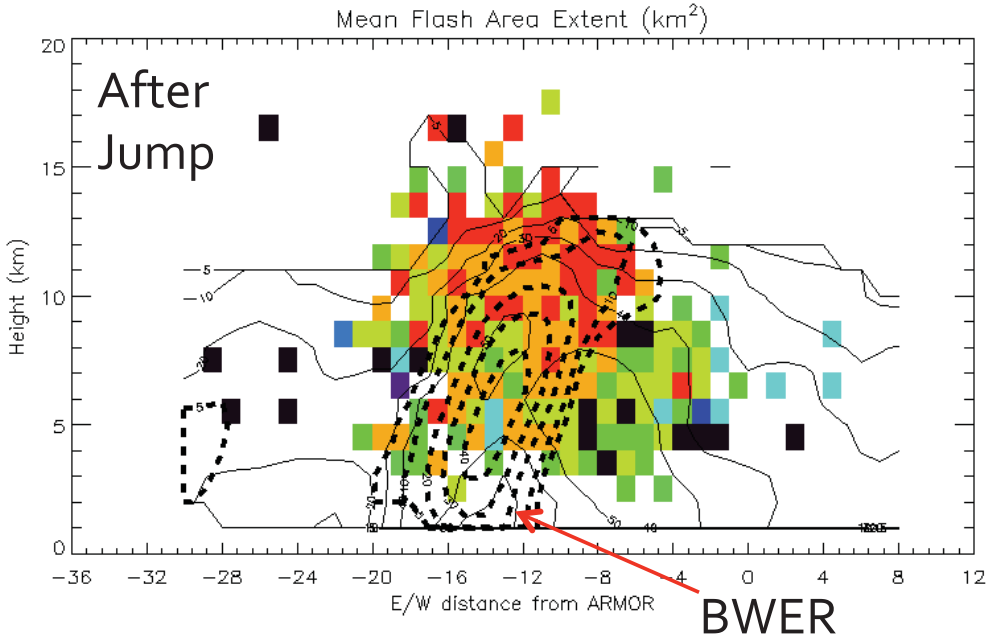
Drop in mean and median flash footprint size as lightning ramps up

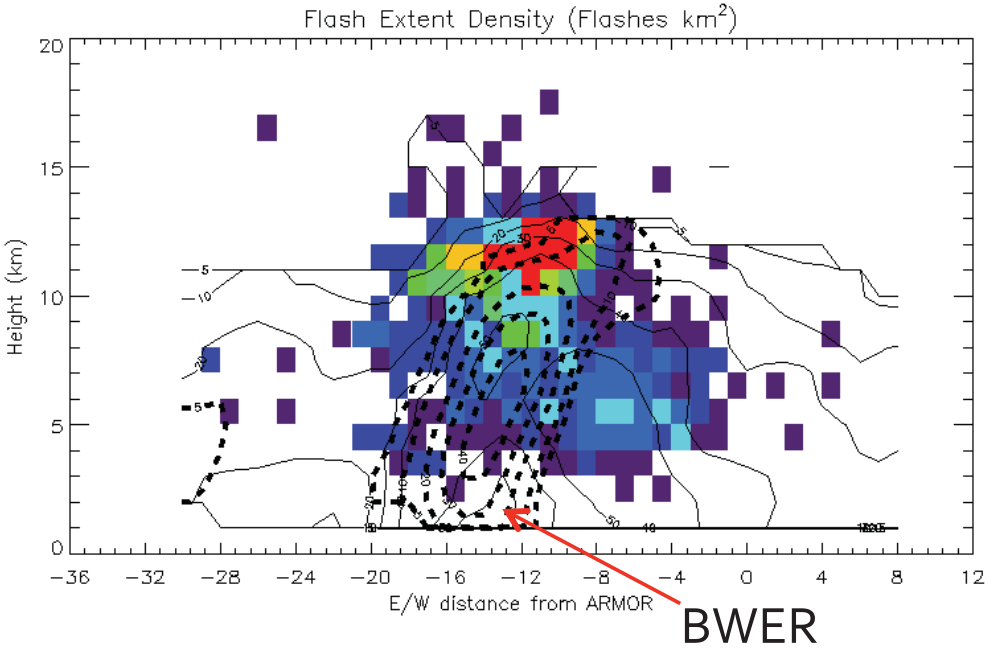
Median size drops from 70 km² down to 14 km² during jump

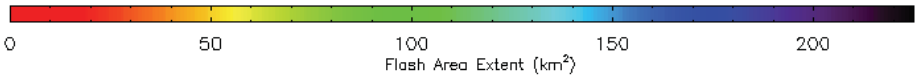
Schultz et al. 2015, WAF in revision











Conclusions and Continuing Work

- Defining difference between lightning jumps and normal increases in total lightning:

  10 m s^{-1} 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