Lightning Jump Science and Applications

Lawrence Carey, University of Alabama in Huntsville (UAH)*

with significant contributions from Christopher Schultz (NASA MSFC and UAH), Kristin Calhoun (OU CIMMS and NOAA NSSL), Sarah Stough (UAH) and Brett Williams (UAH)

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Overview

- **Science Issue:** Severe warning operations and impacts-based decision support require early and frequent updates of convective updraft intensity
  - Currently a challenge from satellite
  - Total lightning trends can provide
- **Approach**: GOES-R GLM *Lightning Jump Algorithm (LJA)*
- **Conceptual model** of updraft, microphysics, total lightning and LJA
  - Dual-Doppler and dual-polarization radar case study of supercell and statistics prior to jump for 38 thunderstorms
- **Applications** and **fusion with operational radar data**
  - Tornadic supercell
  - Tornadic quasi-linear convective system (QLCS)
- **User Demonstrations** and near Future Plans
  - Hazardous Weather Testbed (HWT) 2014 examples
  - LJA in ProbSevere (NOAA CIMMS, CIMSS collaboration)
  - HWT 2015 and possible pathways to operations

GOES-R Geostationary Lightning Mapper (GLM)

Goodman et al. (2013)

GOES-R

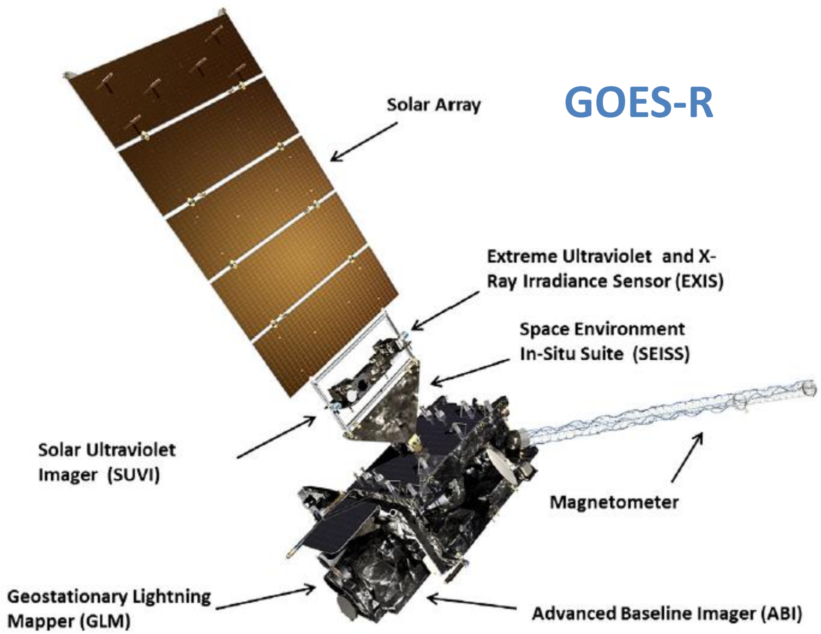
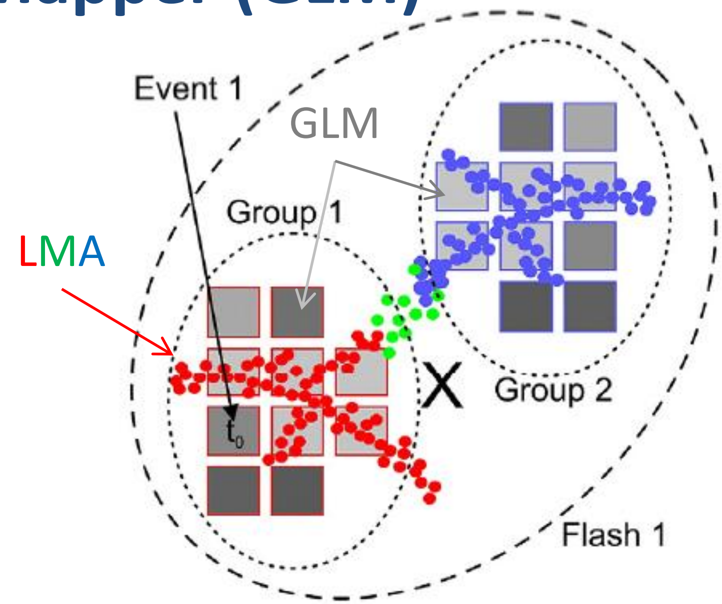


Fig. 1. The GOES-R spacecraft and instruments.



GLM

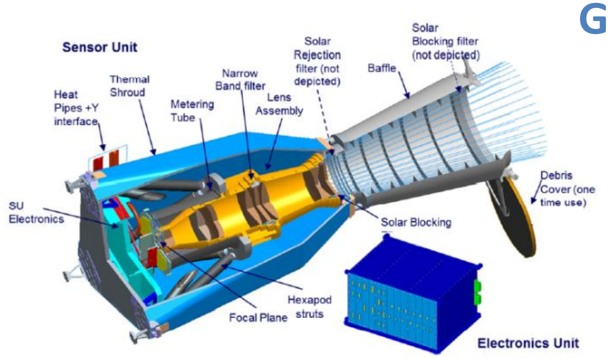


Fig. 3. The Geostationary Lightning Mapper (GLM) consists of a sensor unit (SU) and electronics unit (EU). An engineering development unit prototype was developed before the first production flight model (FM1) to reduce risk in the instrument development.

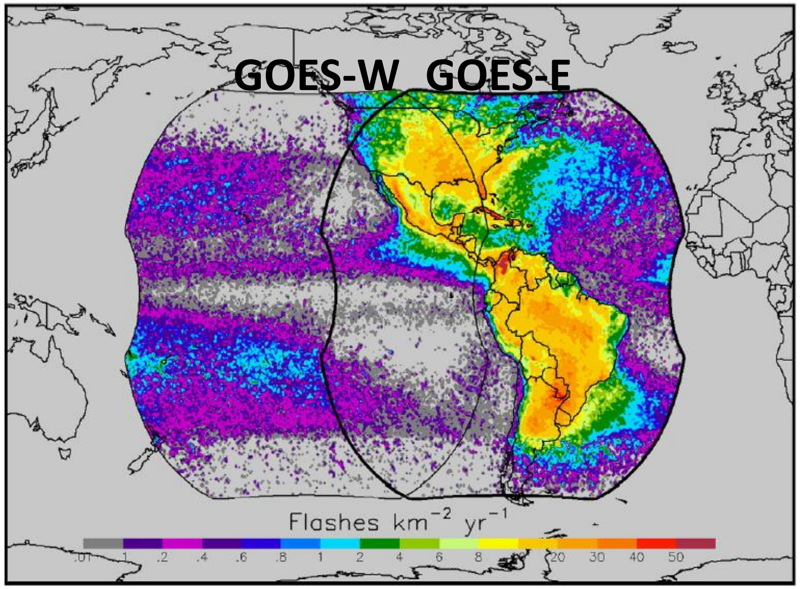


Fig. 2. Combined FOV view from the GOES-R series constellation (75 W, 137 W) superimposed on 10-yr of lightning observations from the NASA Lightning Imaging Sensor on board the Tropical Rainfall Measuring Mission (TRMM/LIS) and Optical Transient Detector (OTD) low earth-orbiting satellites (Cecil et al., 2012).

The Lightning Jump

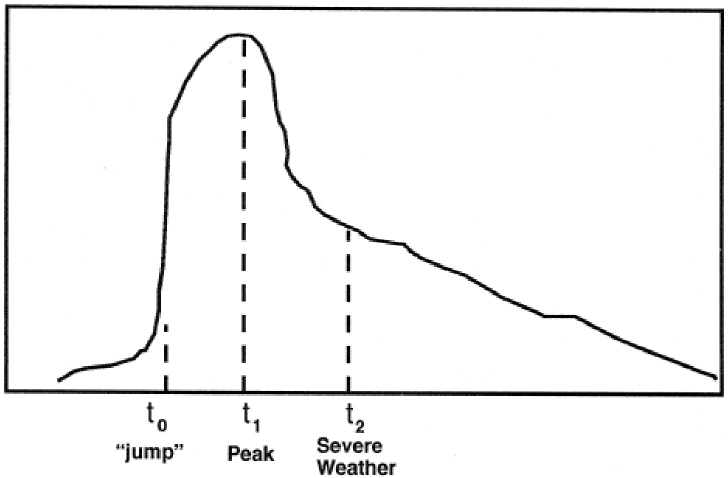


Figure credit : Williams et al. 1999, Atmos. Res.

1) The flash rate increases rapidly (t_0)

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

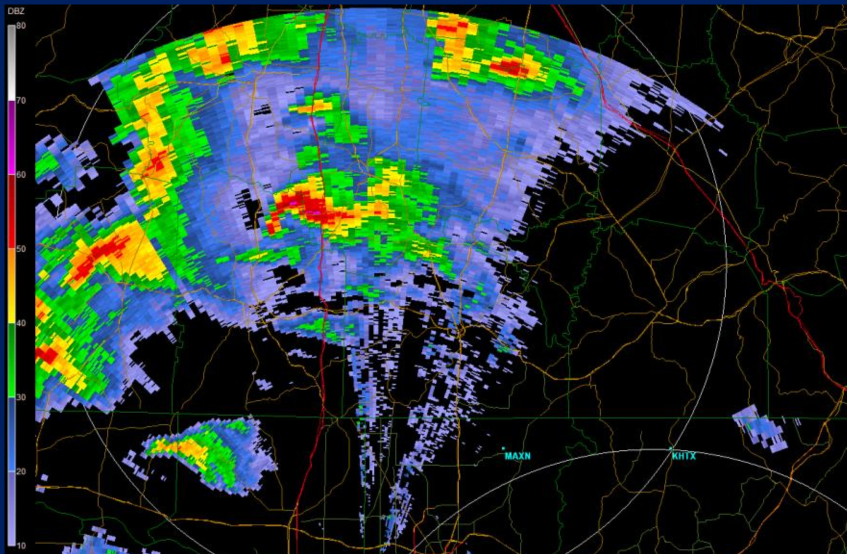
3) Severe weather occurs a short time later (t_2)

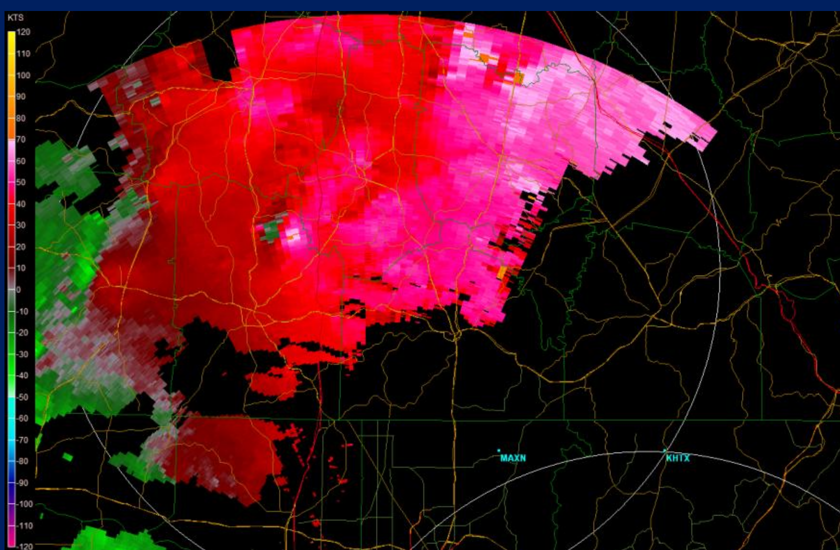
(Williams et al. 1999, Schultz et al. 2009; 2011, Gatlin and Goodman 2010, Rudlosky and Fuelberg 2013, Metzger and Nuss 2013, Chronis et al. 2015).

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"* (Williams et al. 1999)

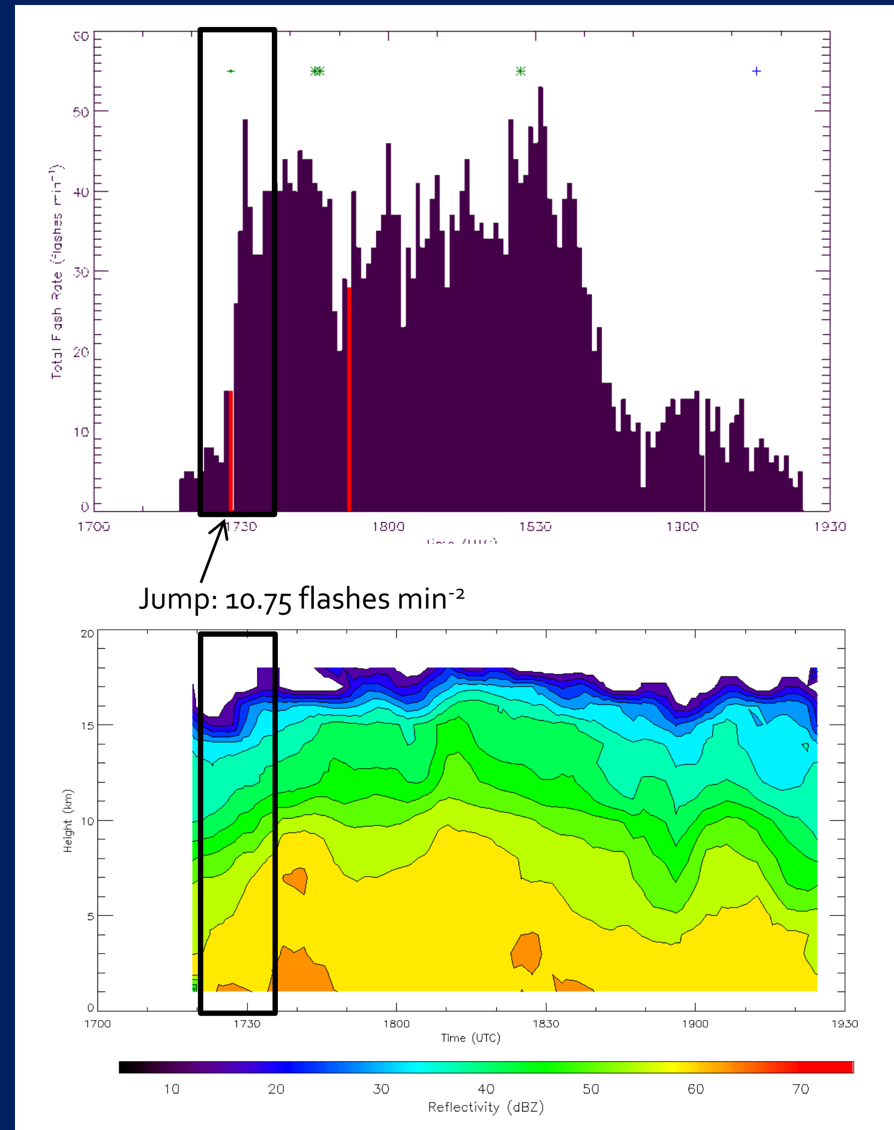
- Updraft properties were not directly measured in early jump studies
- Not specific which updraft properties govern the jump

Supercell Case: April 10, 2009

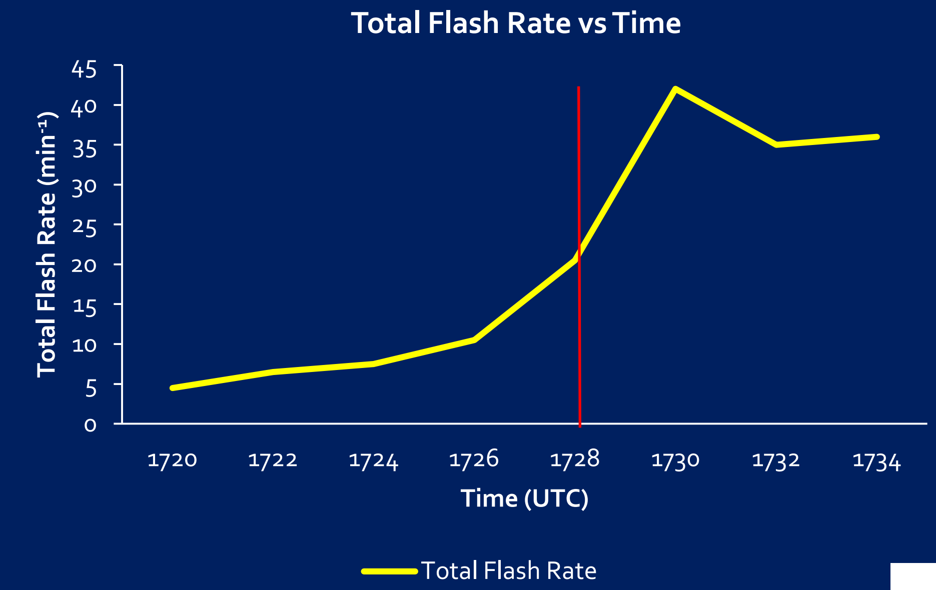


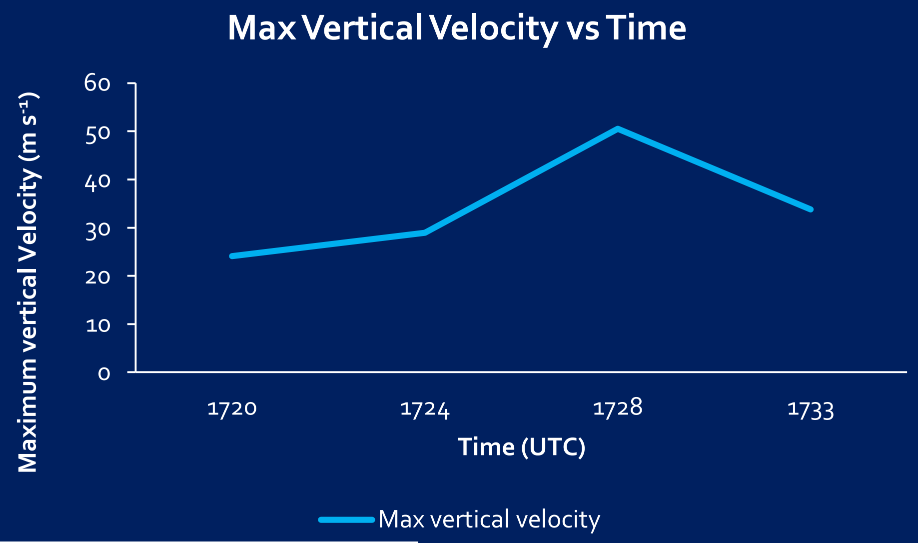


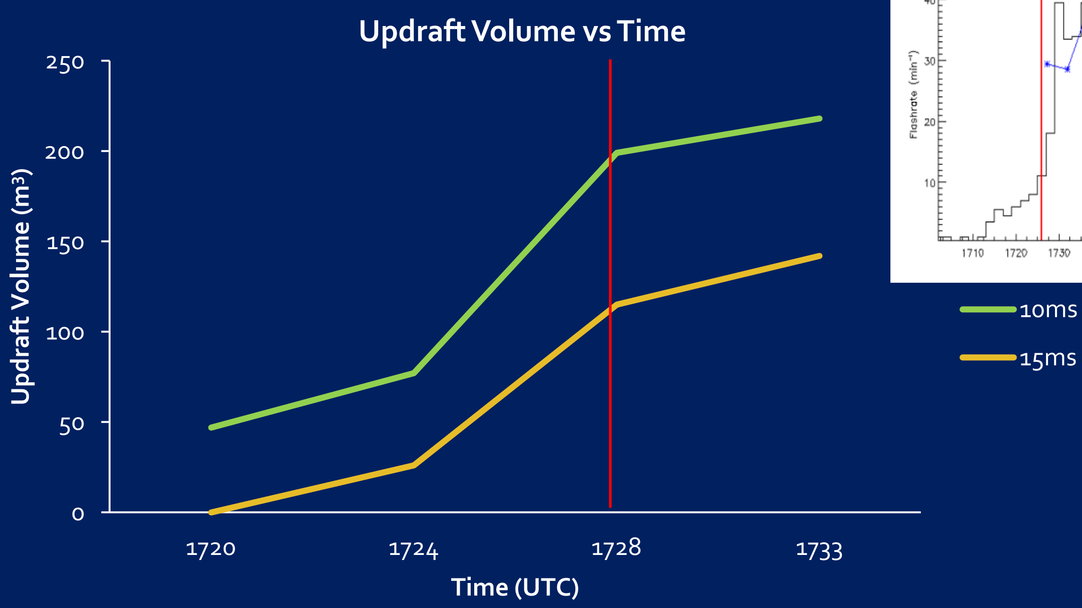
Above: Reflectivity and radial velocity at 1736 UTC

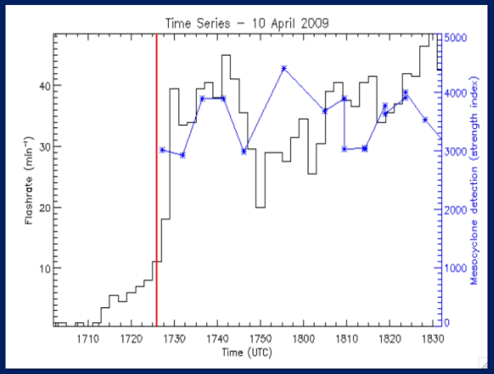


TOP: total flash rate (purple), lightning jump occurrences (red) and severe weather reports (hail, green; wind, blue)
BOTTOM: Time height of maximum reflectivity





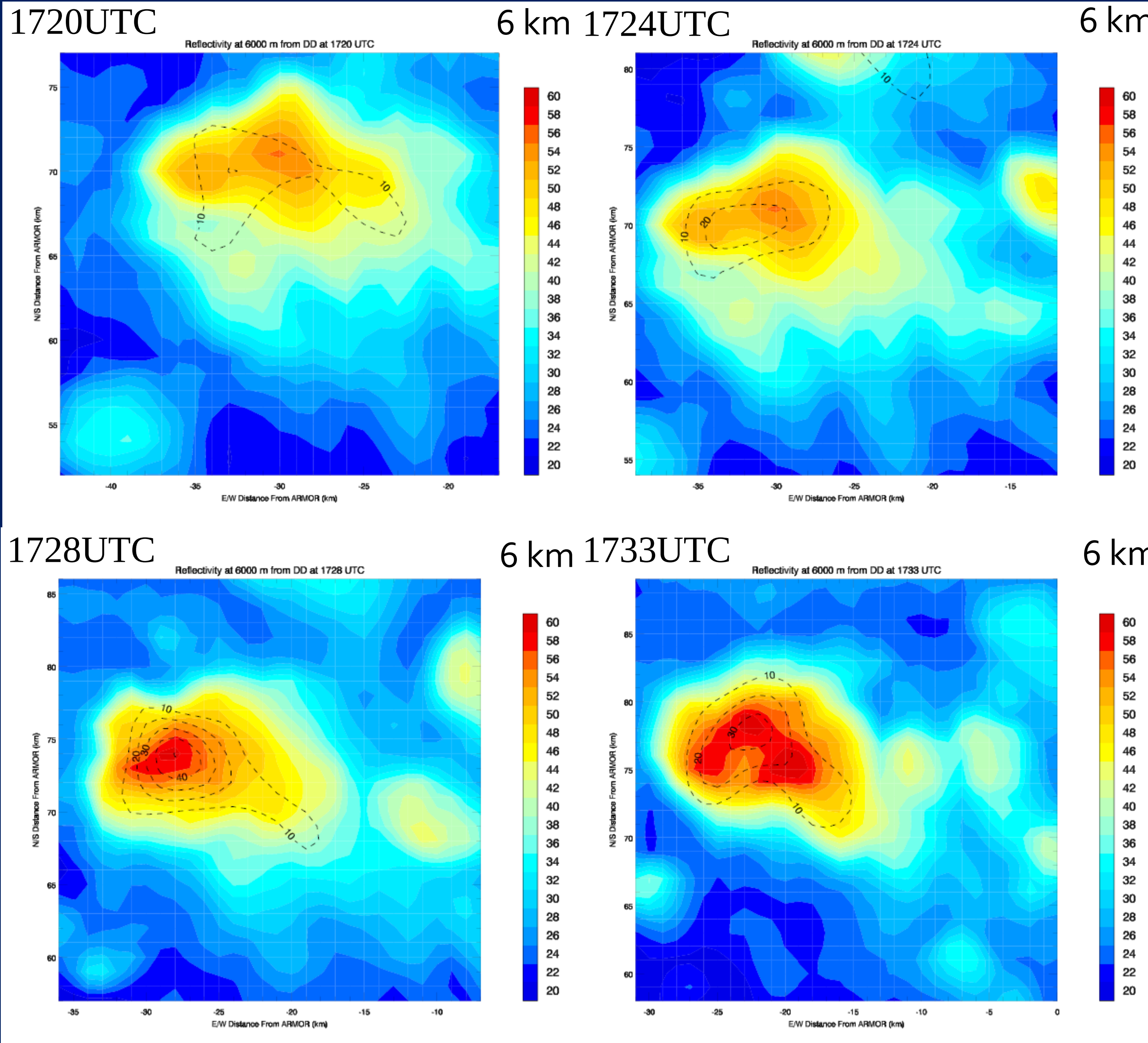




Take Homes:

1) Explosive growth in vertical velocity volume between -10°C and -40°C, just prior to lightning jump
2) Increase in maximum vertical velocity just prior to jump, followed by a decrease after jump time
3) NWS mesocyclone detection immediately after jump.

Total flash rate (top left), maximum updraft speed (top right), Updraft volume (lower left), mesocyclone detection algorithm (lower right) from Stough et al. (2014), 26th WAF

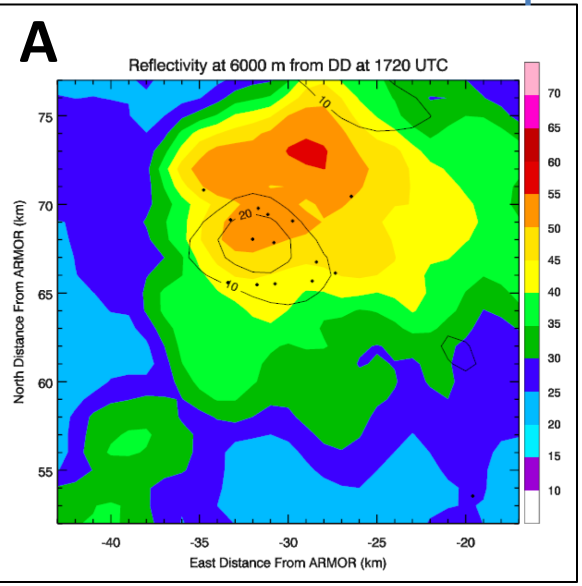


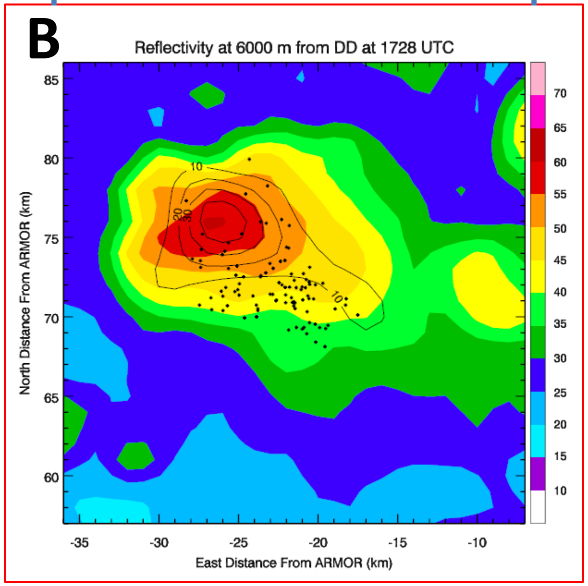
Left – radar reflectivity (shaded) and positive vertical velocity (dash contour; 10 m s^{-1}) at 1720 UTC, 1724 UTC, 1728 UTC and 1733 UTC at 6km.

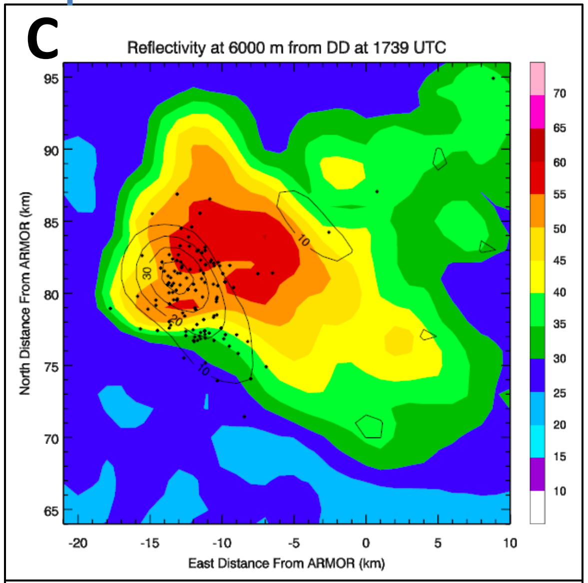
***Note explosive growth and increase in magnitude of vertical velocity and reflectivity leading up to and through the time of the lightning jump (1728 UTC).

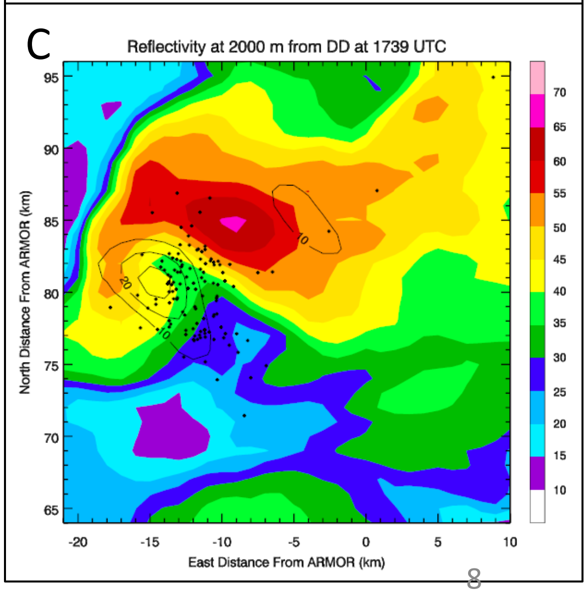
Lightning Jump Conceptual Model

Δt Jump Time Δt









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.

Larger Dual-Doppler and Dual-Polarization 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
- 203 distinct 30-minute windows centered at the time of each flash rate increase were examined
- Morphology
  - Multicell – 23 storms
  - 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. (2015; WAF) provided this temporal window
- Properties examined
  - Mixed phase Updraft Speed/Volume
    – Dual-Doppler radar
  - Mixed phase Graupel Mass
    – Dual-polarization radar

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

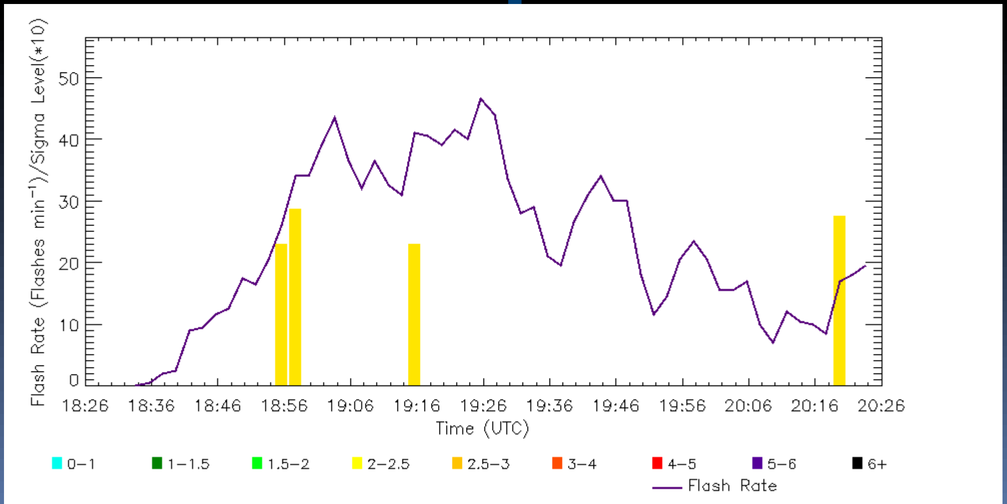
The sigma level is:

Sigma level =

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

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

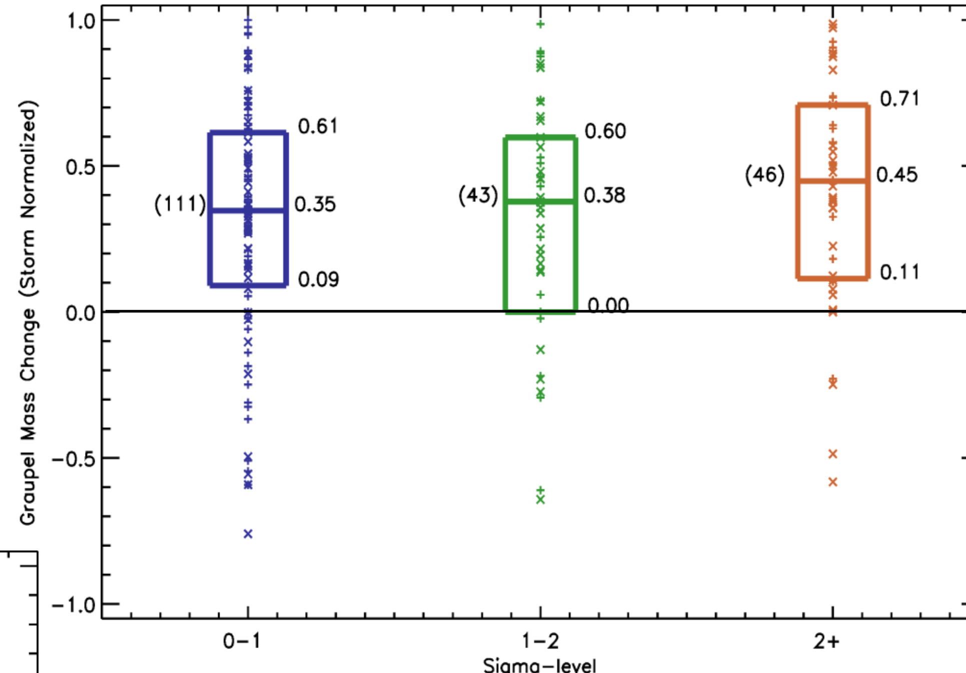


Kinematic and Microphysical Origins

During the time leading up to a lightning jump, kinematic and microphysical observations of storms display the following characteristics:

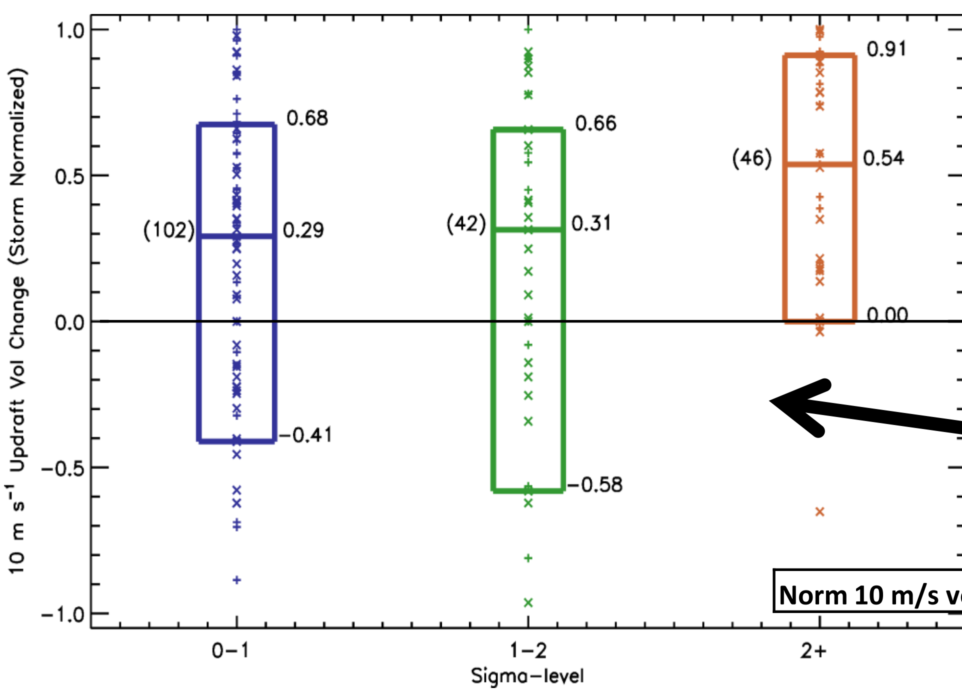
1) **There is a substantial increase in 10 m s^{-1} updraft volume (below) and peak updraft speed (not shown).**

Mixed phase graupel mass change (%)



2) **Mixed phase graupel mass also increases during this period (above).**

10 m s^{-1} updraft volume change (%)



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

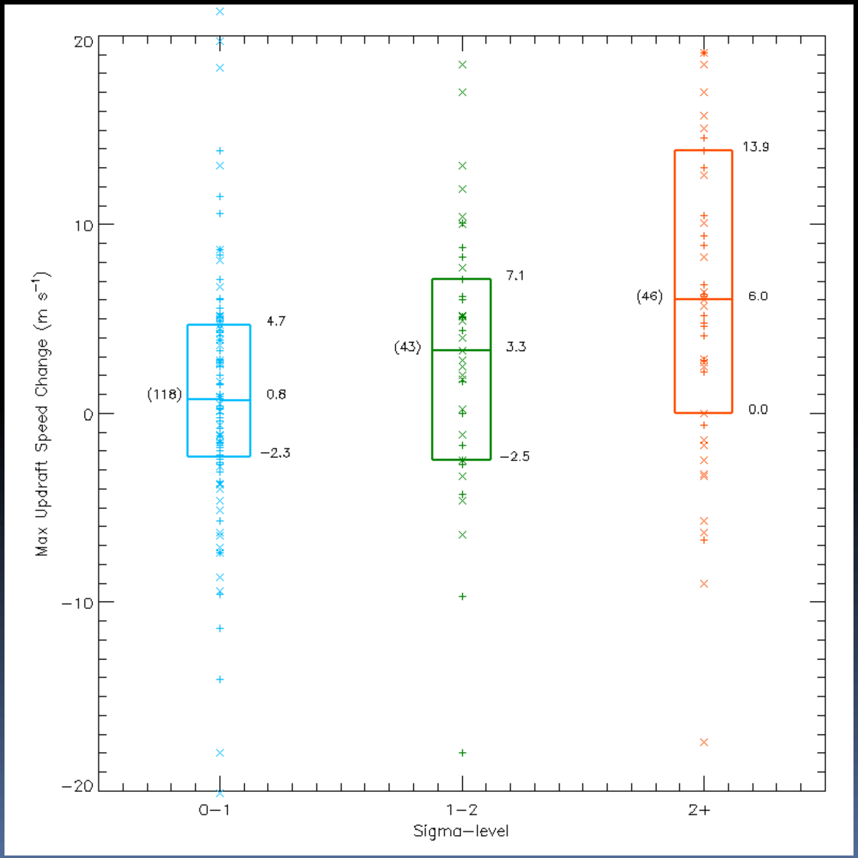
Maximum and 98th Percentile Updraft Speed Change

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

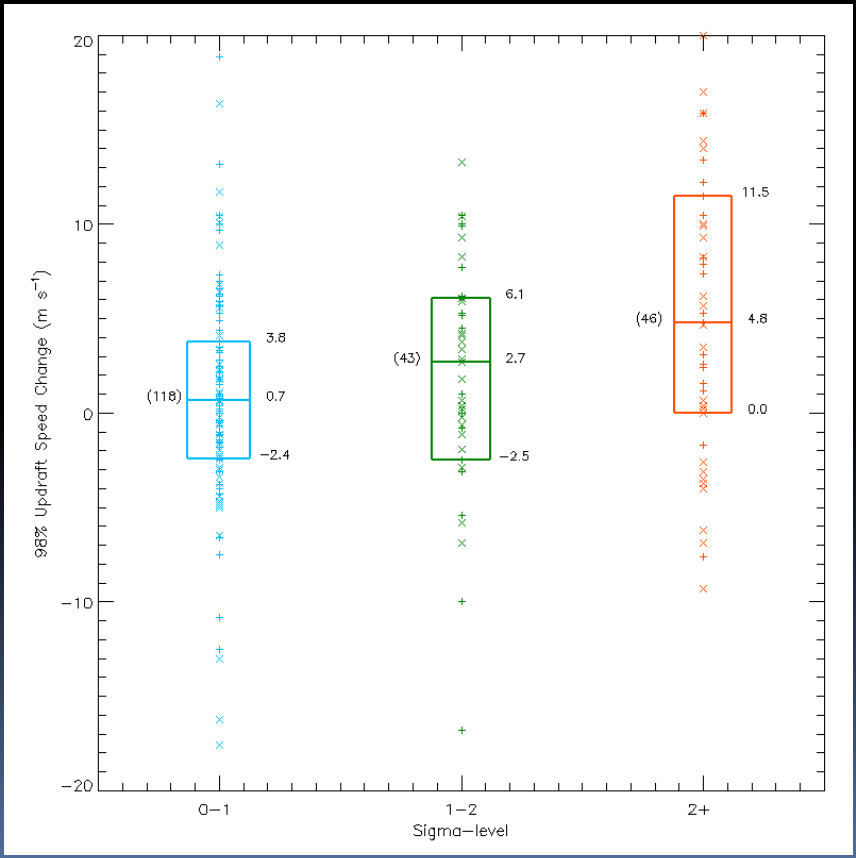
Rank Sum Testing

	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
Maximum w	1.72	1.71	3.55	0.04	0.04	0.00
98th w	1.32	1.74	3.27	0.09	0.04	0.00

MAX w



98th w

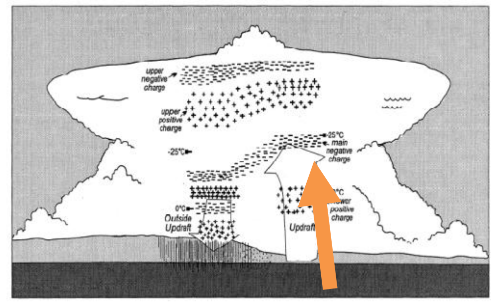


Supercell Applications: Conceptual Timeline

Given correct environment:

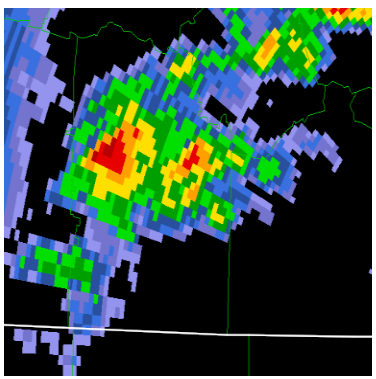
- ***Moderate-to-High Shear***
  (ex: 0-6km shear > 15 ms^{-1})
- **Moderate-to-High Instability**
  (ex: CAPE > 1000 J/kg)

3a: More Particle Collisions → Increased Lightning

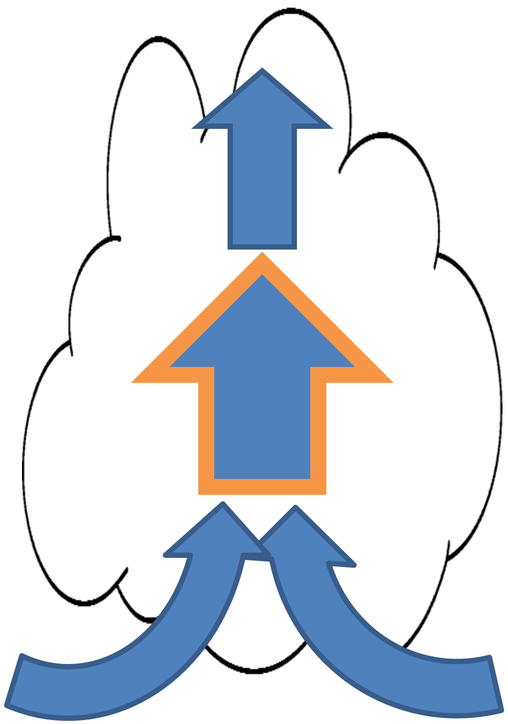


Stolzenburg *et al.* [1998] , Fig. 3

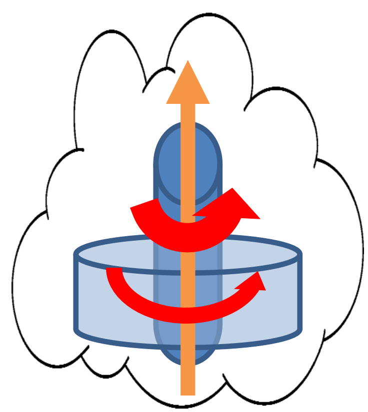
1: Ordinary Convection



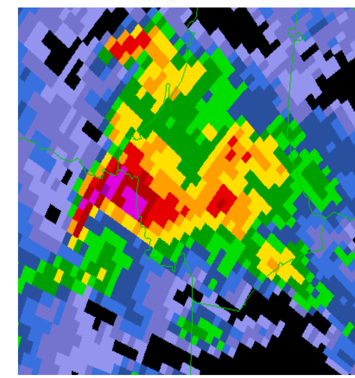
2: Updraft Pulse



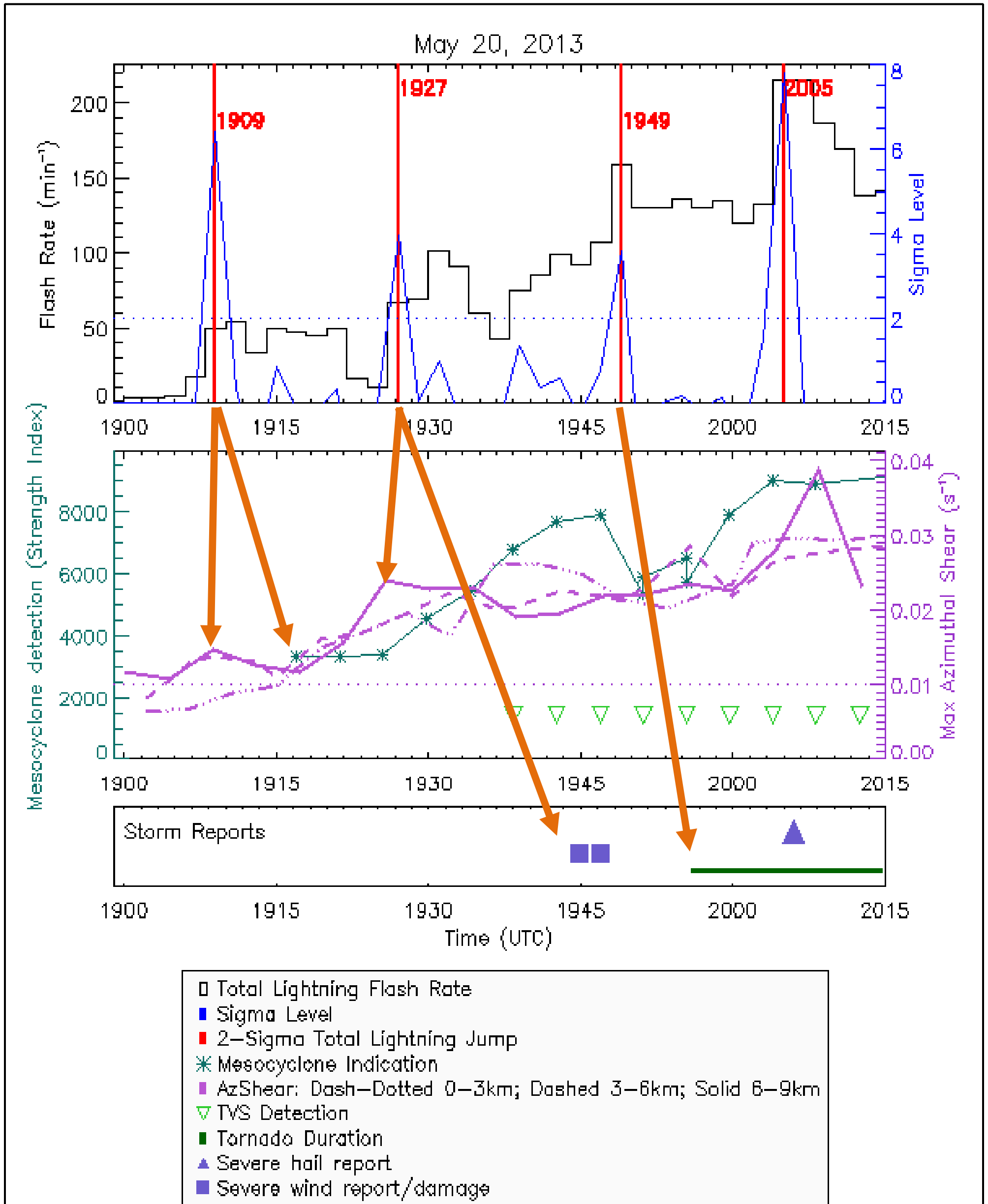
3b: Stretching of Vertical Vorticity → Mesocyclone

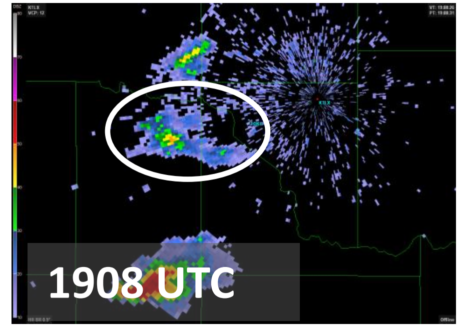


4: Supercell



Supercell Applications of the Lightning Jump

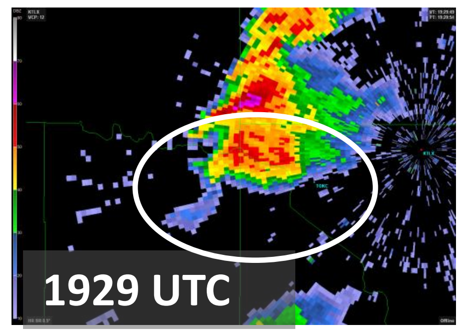




Developing cell

First jump :

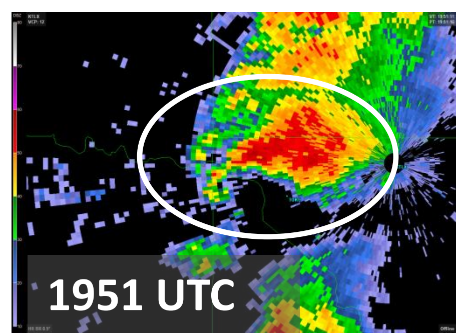
- coincident with peak in mesocyclonic rotation
- precedes first meso algorithm detection



Supercell

Second jump:

- occurs with second peak in mesocyclonic rotation
- precedes severe wind reports by 18-20 minutes



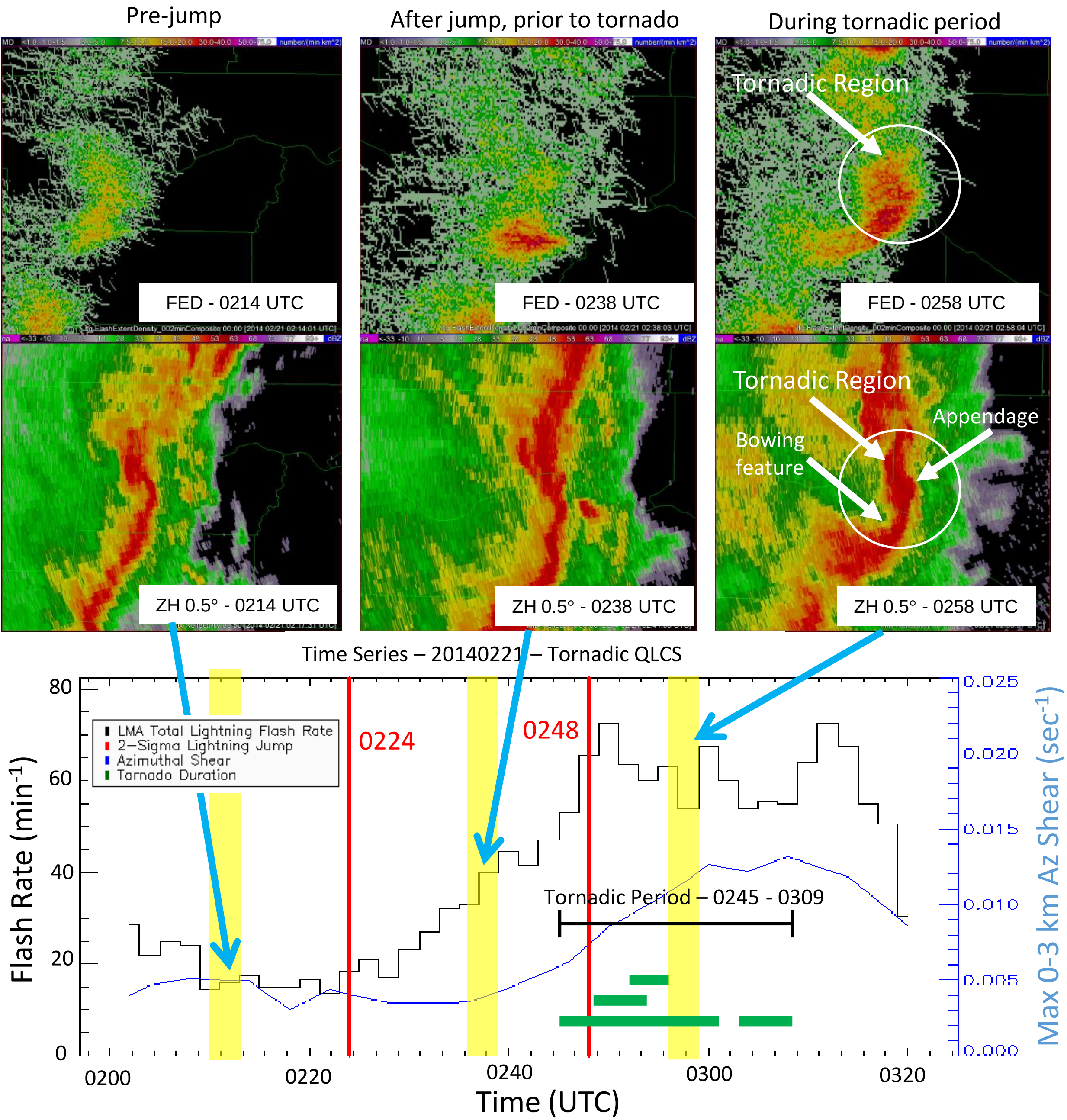
High flash rates along with sustained strong rotation

Third jump

- precedes tornado by 7 minutes

17Z OUN sounding: MLCAPE of 3120 Jkg^{-1}; 0-6 km shear of 26.8 ms^{-1}; 0-1 km SRH of 131 m^2s^{-2}

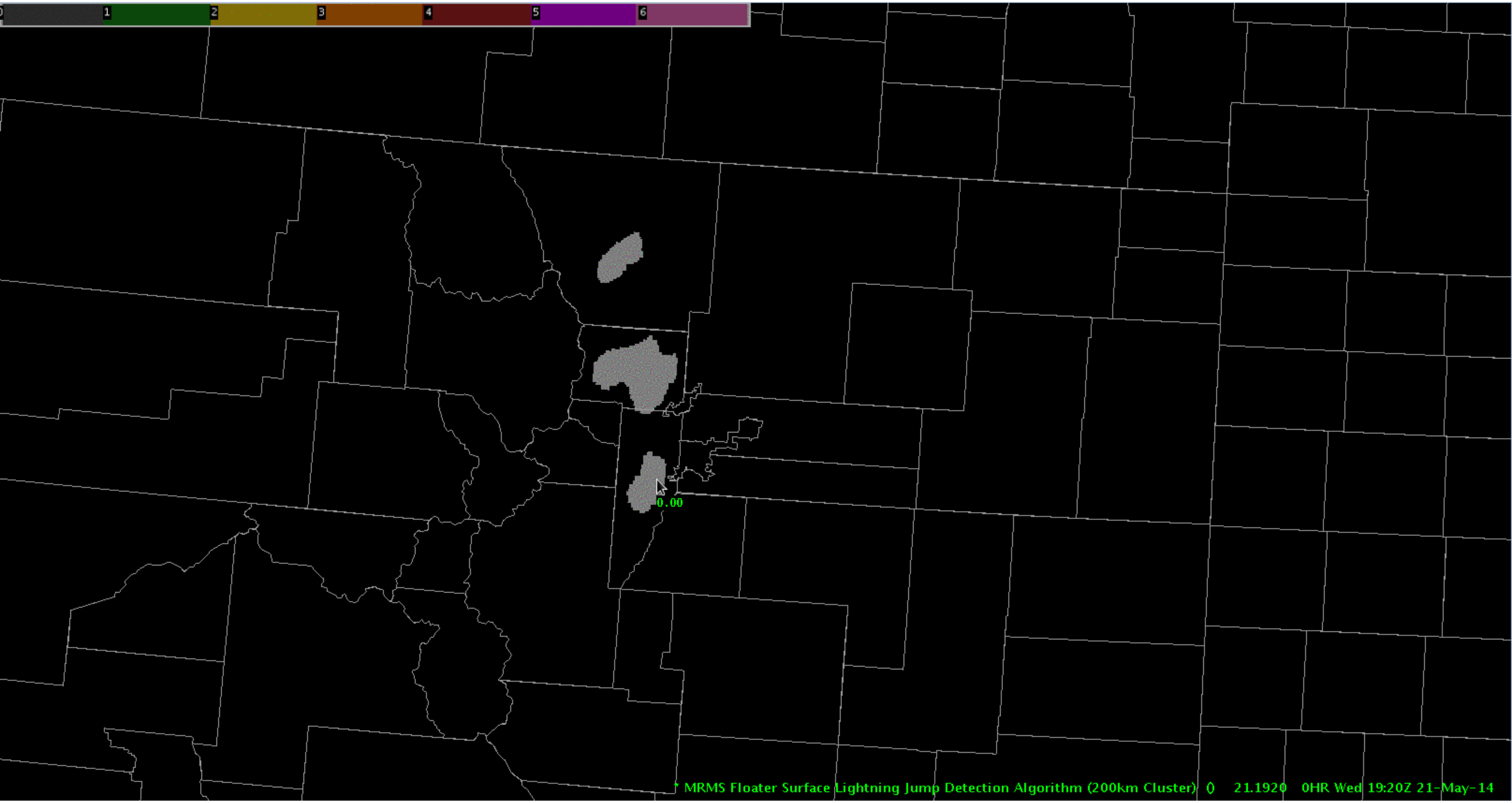
Lightning jump applications for QLCS tornadoes



The lightning jump can potentially help identify when and what part of the QLCS is becoming more favorable for mesovortex genesis

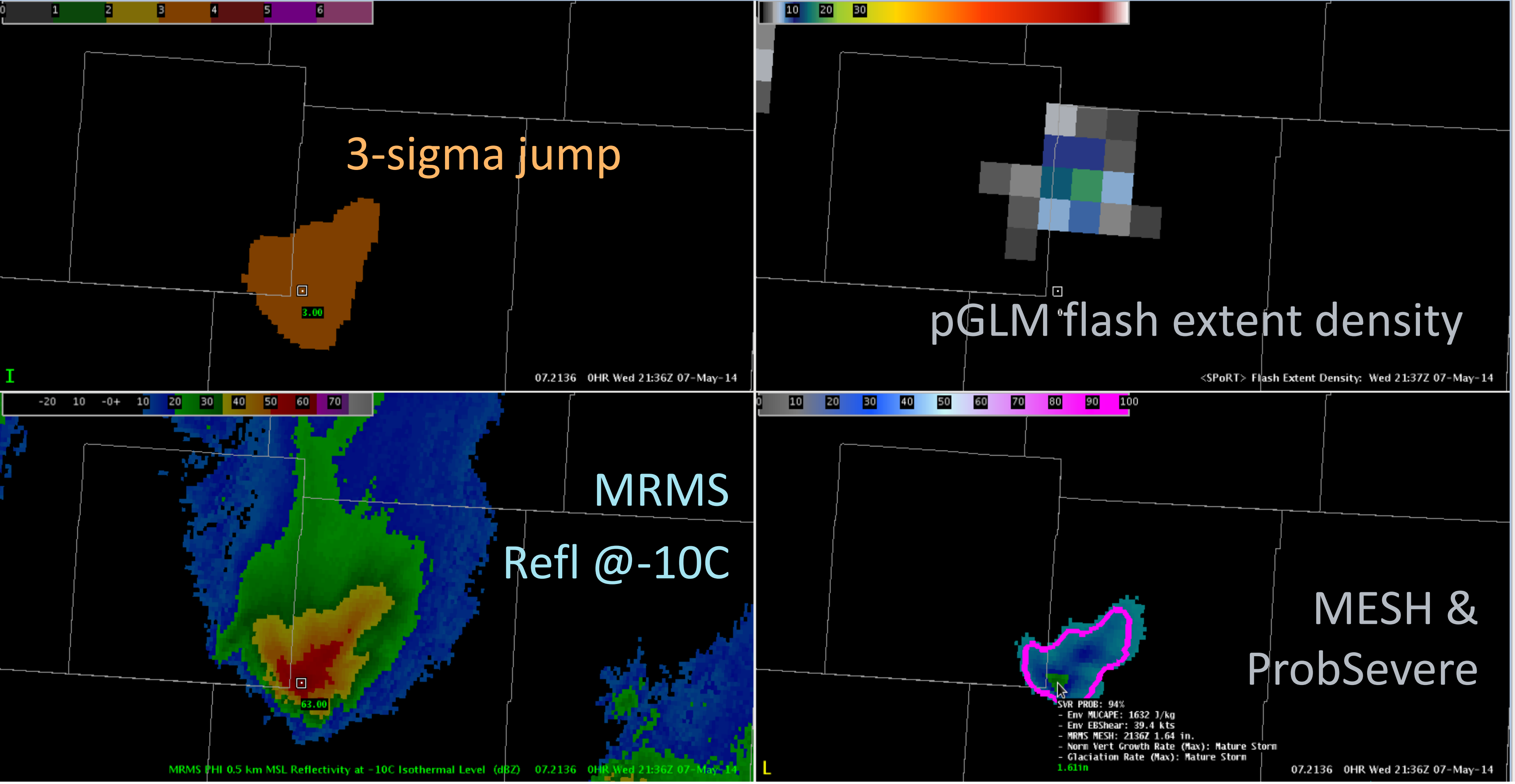
- Lightning jump is an indication that QLCS is strengthening, and precedes an increase in azimuthal shear, which signifies an increase in rotation
- Jumps precede formation of hooks & appendages in reflectivity, bowing segments, and velocity couplets
  - Potentially providing additional lead time over traditional radar only warning methodology
- If environment and radar characteristics suggest tornadic potential, the occurrence (or absence) of a lightning jump can add additional information to tip-the-scales in the warning decision process

2014 EWP: Lightning Jump Algorithm



"I really think this could be one of the most valuable tools in WFO operations. Once a jump - or more precisely a series of jumps occurred - there seem to be excellent correlation to an increase in storm intensity."

-NWS Forecaster, Post Event Survey, 2014 HWT



- (LMA-based) lightning data was heavily utilized in Warning Operations:
- 1 min update (filled in gaps in time / distance from radars)
- Jump provided view of rapid intensification in multiple storm environments
- Provided extra confidence in warning decision

"When I saw the jump and maybe a couple scans in a row, I was confident to issue a severe thunderstorm warning…."

-NWS Forecaster, Live Blog

"This information is a high temporal resolution (1-2 minutes) and provides additional data points that can fill gaps between radar volume times."

-NWS Forecasters (HWT blog)

"The jumps were very helpful in identifying quickly intensifying storms. … it provided valuable information that, to my knowledge, is not displayed elsewhere."

-NWS Forecaster, Post Event Survey

HWT 2014

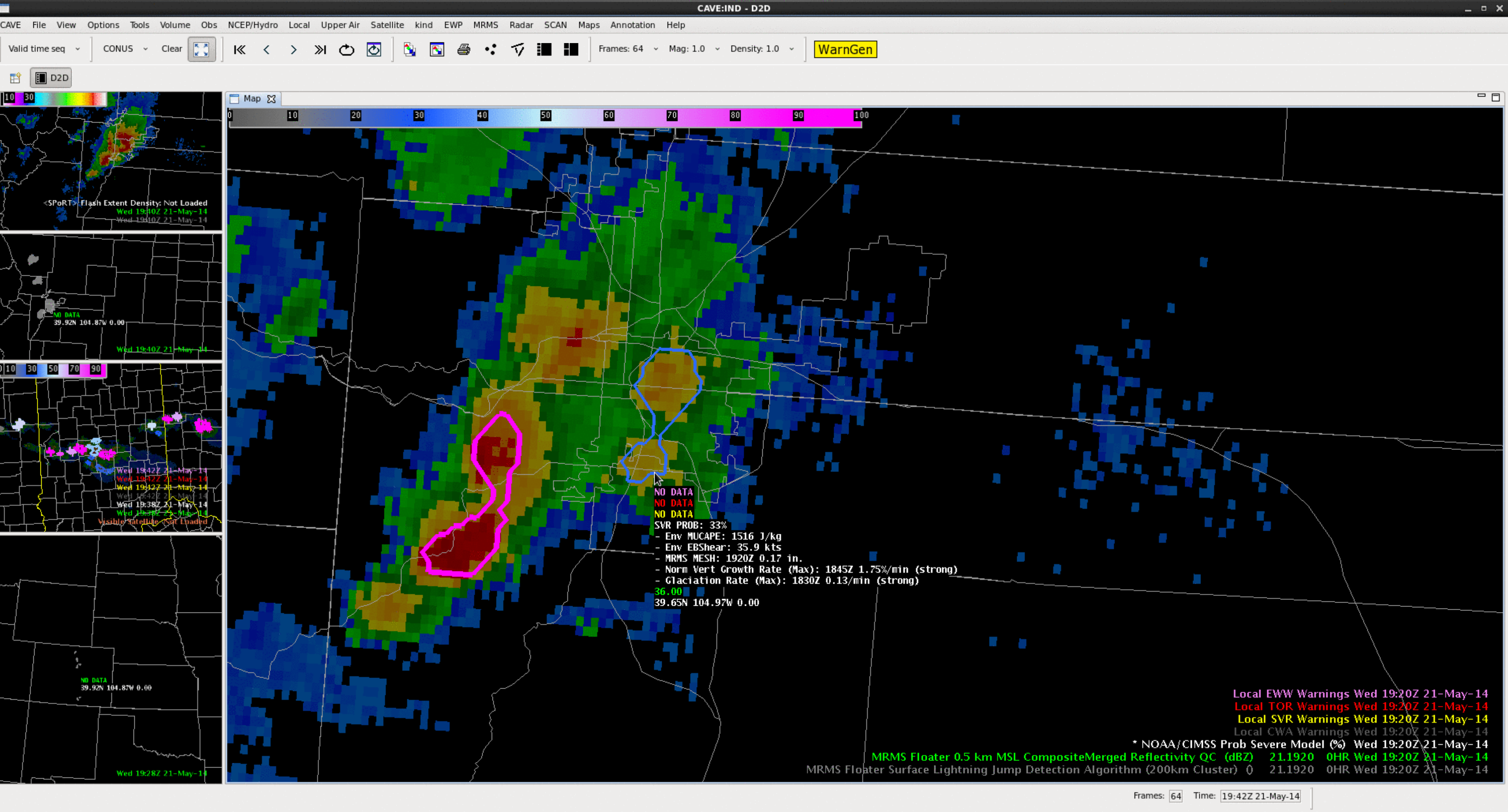
HWT Spring 2015 – Tales from the Testbed

NWS Forecaster Quotes regarding total lightning and jump

- "Lightning information was helpful in the QLCS environment. **Jumps and overall larger flash rates helped me identify where the strongest updrafts were located.** This perhaps can help identify where the greatest potential exists for a tornado associated with the leading line of the QLCS."

- "Using the time series of flash rates was a good way to **diagnose strengthening updrafts and provided useful situational awareness**. It definitely **added confidence to my warning decisions**."

- "Total lightning information is extremely useful because it has **higher temporal resolution than radar**. For storms that rapidly developed, the first hint of this came from the increase in flash rates and the lightning jump. **A number of warnings I issued were based largely off the lightning jump. I believe that the total lightning information and the jump has strong potential to increase lead times."**



In this case, ProbSevere and LJA both displayed the rapid intensification of the updraft, and could be especially useful in identifying the first severe storm of the day, and the maintenance of the ProbSevere and additional lightning jumps continued to highlight the threat of severe weather as the storm continued eastward as the storm propagated eastward.

Future work will include the integration of the LJA into ProbSevere as an additional input to the probability calculations (NOAA CIMMS working with NOAA CIMSS)

Summary

- GOES-R GLM total lightning and Lightning Jump Algorithm (LJA) provide early and frequent updates on updraft intensity and severe potential
  - Pre-GLM: LMA, pGLM (LMA based), ENTLN
- Conceptual model of updraft, microphysics, and total lightning – **demonstrated physical and statistical relationships**
  - Dual-Doppler case study of supercell
  - Dual-Doppler updraft statistics prior to jump for 38 thunderstorms
- Operational applications of LJA in tornadic supercell and QLCS
  - Fusion with radar (e.g., MESH, azimuthal shear, mesocyclone, TVS)
  - **maximum situational awareness and/or confidence to tip scale toward warning**

Summary

- Hazardous Weather Testbed (HWT) 2014 (LMA-based) Demonstration
  - **LJA color coded "sigma level"** (i.e., jump intensity) easiest to visualize along with pGLM, MESH, MRMS, Doppler velocity etc
  - **Positive forecaster feedback on operational utility**
- Ongoing and Future Operational Plans
  - HWT 2015: **near CONUS-wide demonstration of LJA using ENTLN**
  - Although not shown, recently added "negative sigma" (i.e., decreasing trend) grey shade contours in 2015 based on forecaster feedback
  - Integration of the **LJA (flash rate, sigma-level) into CIMSS ProbSevere**
    - ProbSevere: predicts the probability that a storm will **first** produce severe weather in the near-term (in the next 60 min)
    - ProbSevere currently based on model environmental, satellite, MRMS radar data
  - **Possible Pathway to Operations**: LJA could go into NWS AWIPS2 operations via multi-radar/multi-sensor processing at NCEP in summer of 2016 following GOES-R launch