Koninklijk Meteorologisch Instituut

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European Conference on Severe Storms
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Space-based lightning observations in nowcasting severe weather and the impact of the flash detection efficiency

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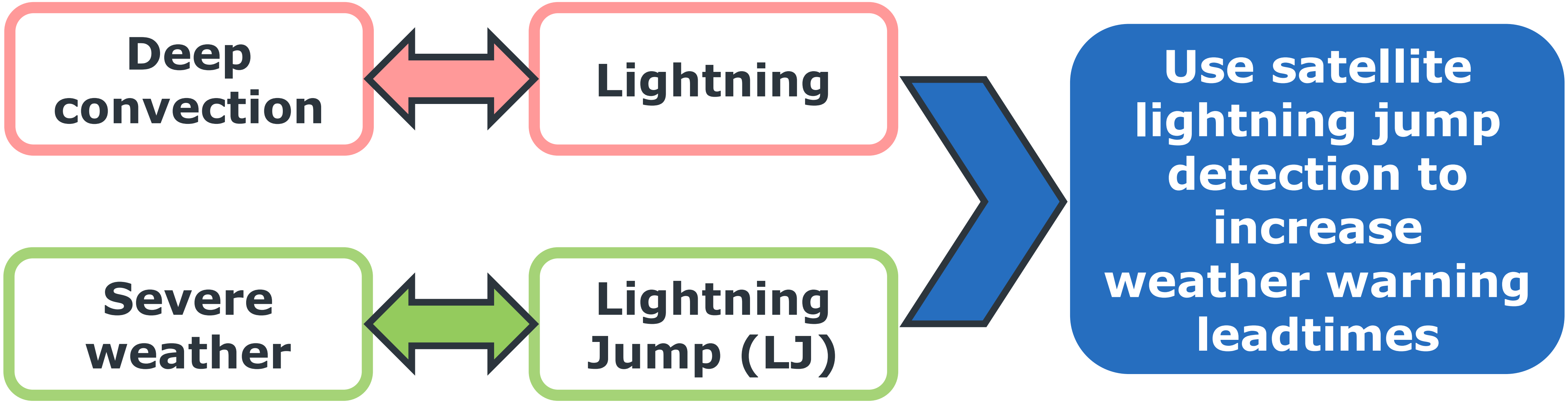
Introduction and Motivation

- Thunderstorms with **dangerous weather phenomena**
- **New generation satellites** (GOES-R series, Fengyun-4, Meteosat Third Generation [MTG]) carry new **lightning locating sensors**



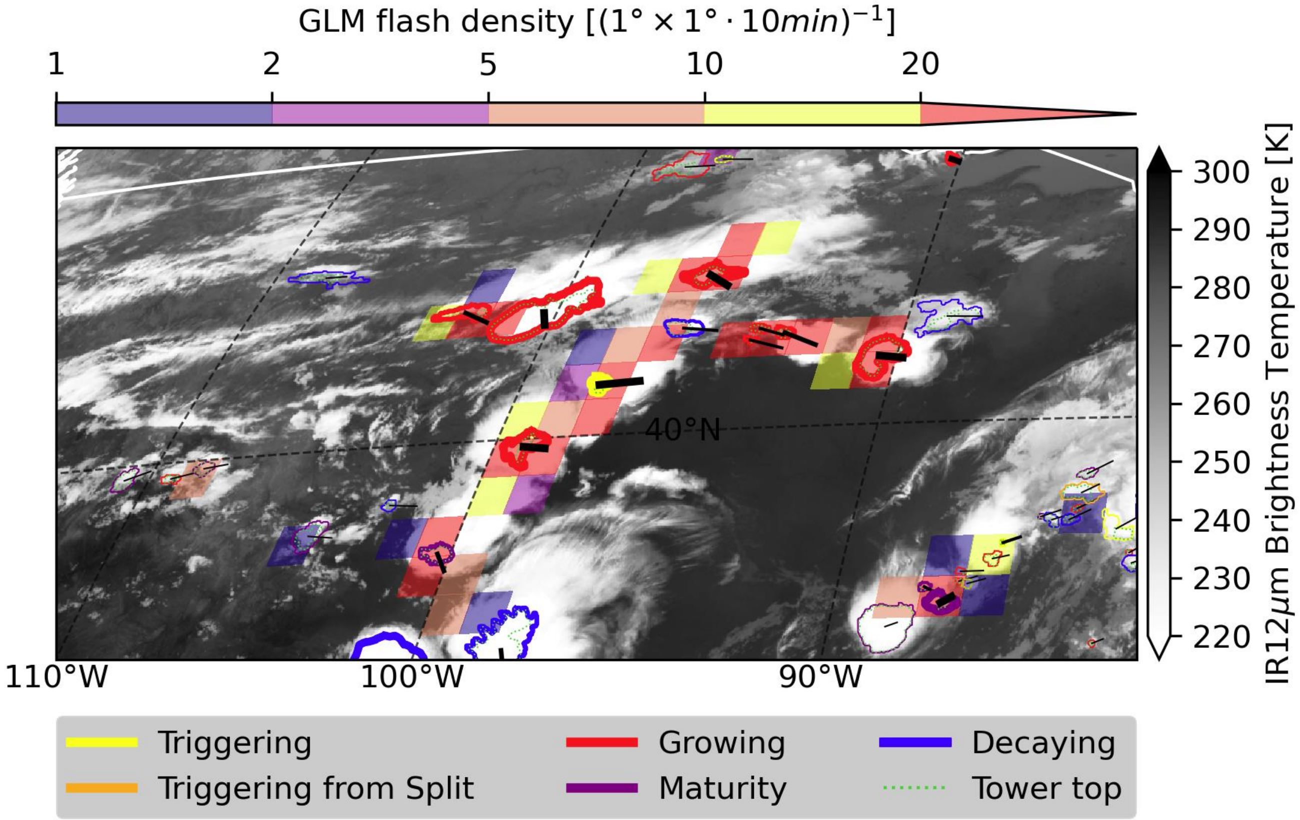
e.g., Williams et al., 1999, Goodman et al., 2005,
Gatlin and Goodman, 2010, Schultz et al., 2009, 2016

Methods

EUMETSAT NWCSAF nowcasting software

- **Nowcasting** based on satellite imagery (here GOES-16)
  - NWP data and observations, e.g., lightning records, as optional import
- Identification of (convective) cloud cells
- **Automated storm tracking**: Rapid Developing Thunderstorm Convective Warning (RDT-CW) package

RDT-CW significant cells on top IR12 background image and GLM flash density
(2020-06-05 03:10Z-03:20Z)

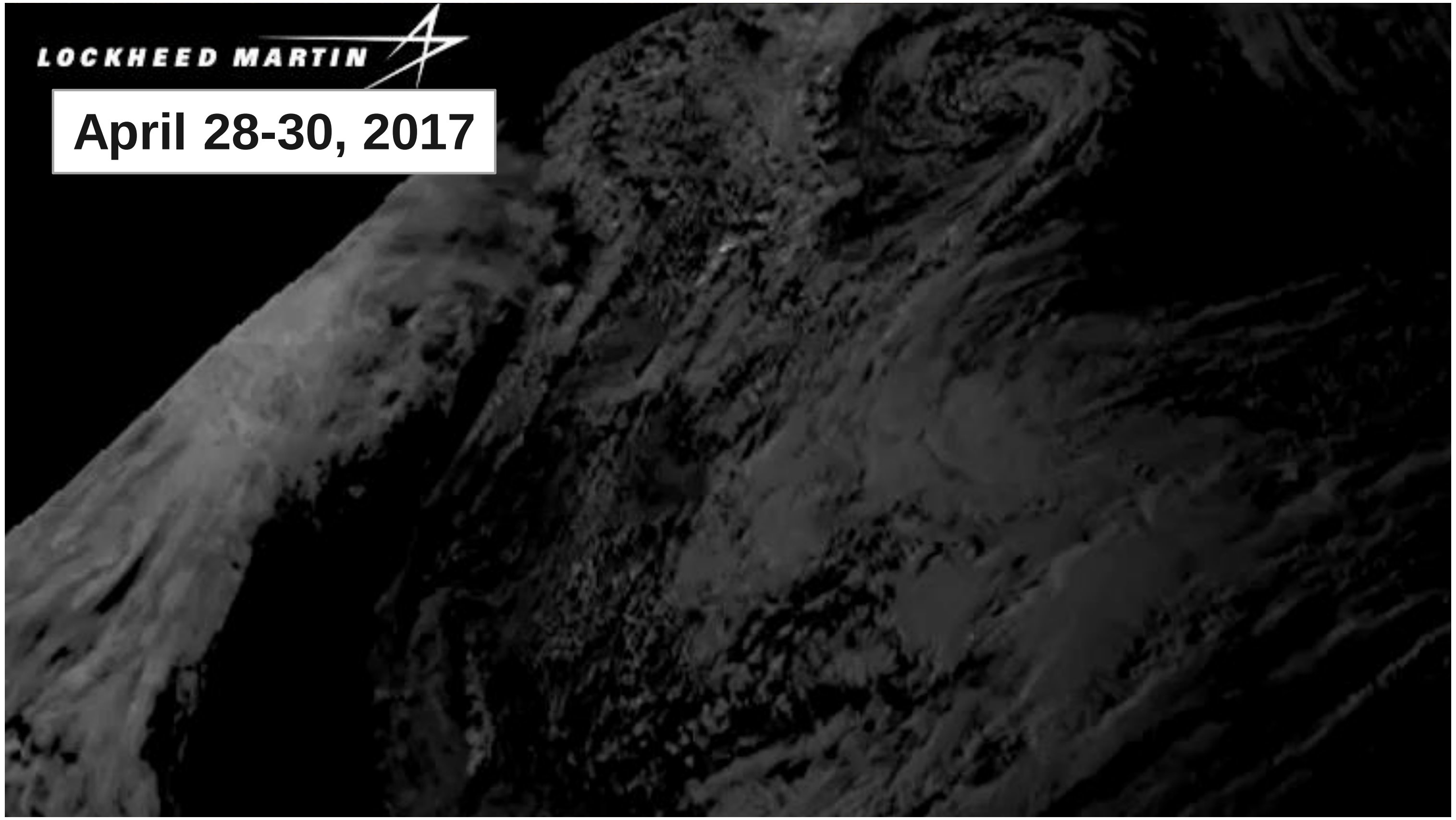


Geostationary Lightning Mapper (GLM)

- **Total lightning** (CG + IC)
- Day- and nighttime
- Cloud top illumination
- **Optical lightning** observation at 777.4nm
- Narrow band of 1nm
- Platform: GOES-16, 17, 18*
  *only GOES-16 GLM used here

(e.g., Goodman et al. 2003, Mach 2020)

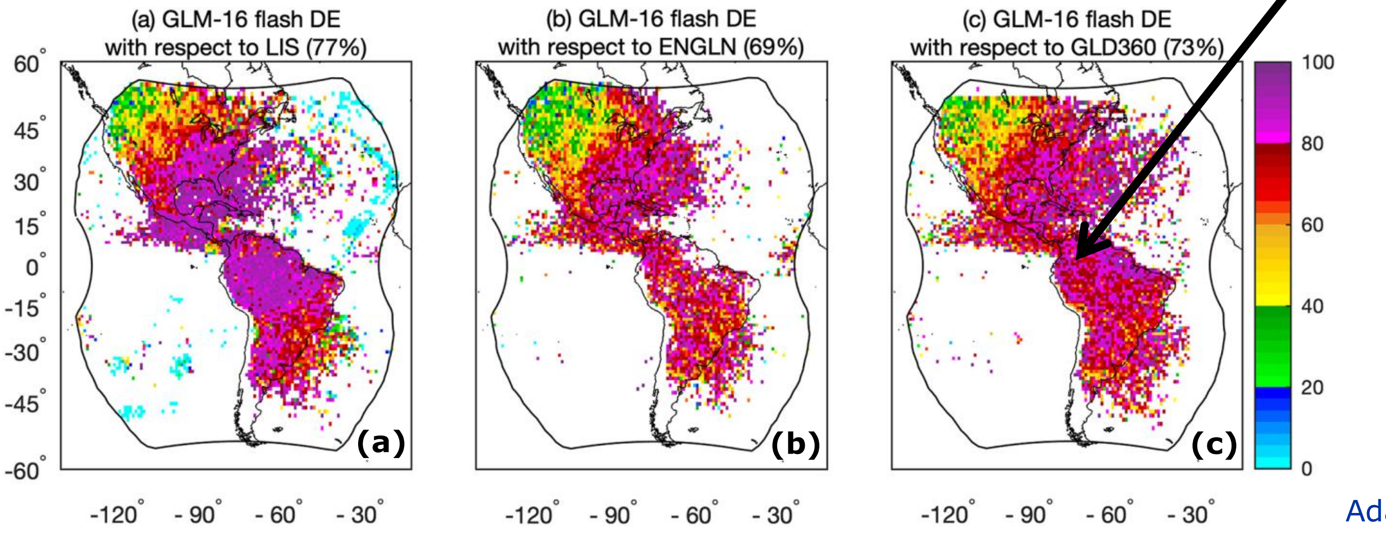
GOES-16 GLM lightning superimposed on GLM background



GLM flash detection efficiency (DE)

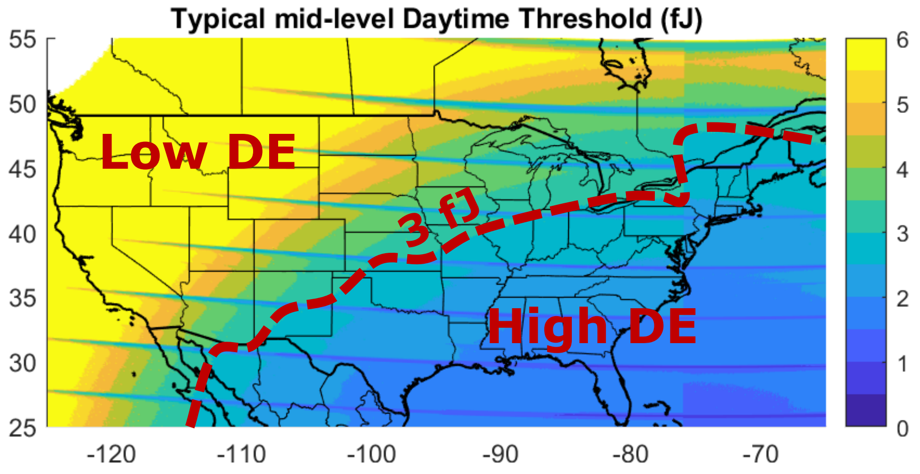
- GLM with a wide field of view (FoV)
- Position of storms in FoV influence the **flash detection efficiency (DE)**
- Higher DE close to the satellite nadir point (0° N/S, 75.2° W)

(1) Three Years of the Lightning Imaging Sensor Onboard the International Space Station: Expanded Global Coverage and Enhanced Applications



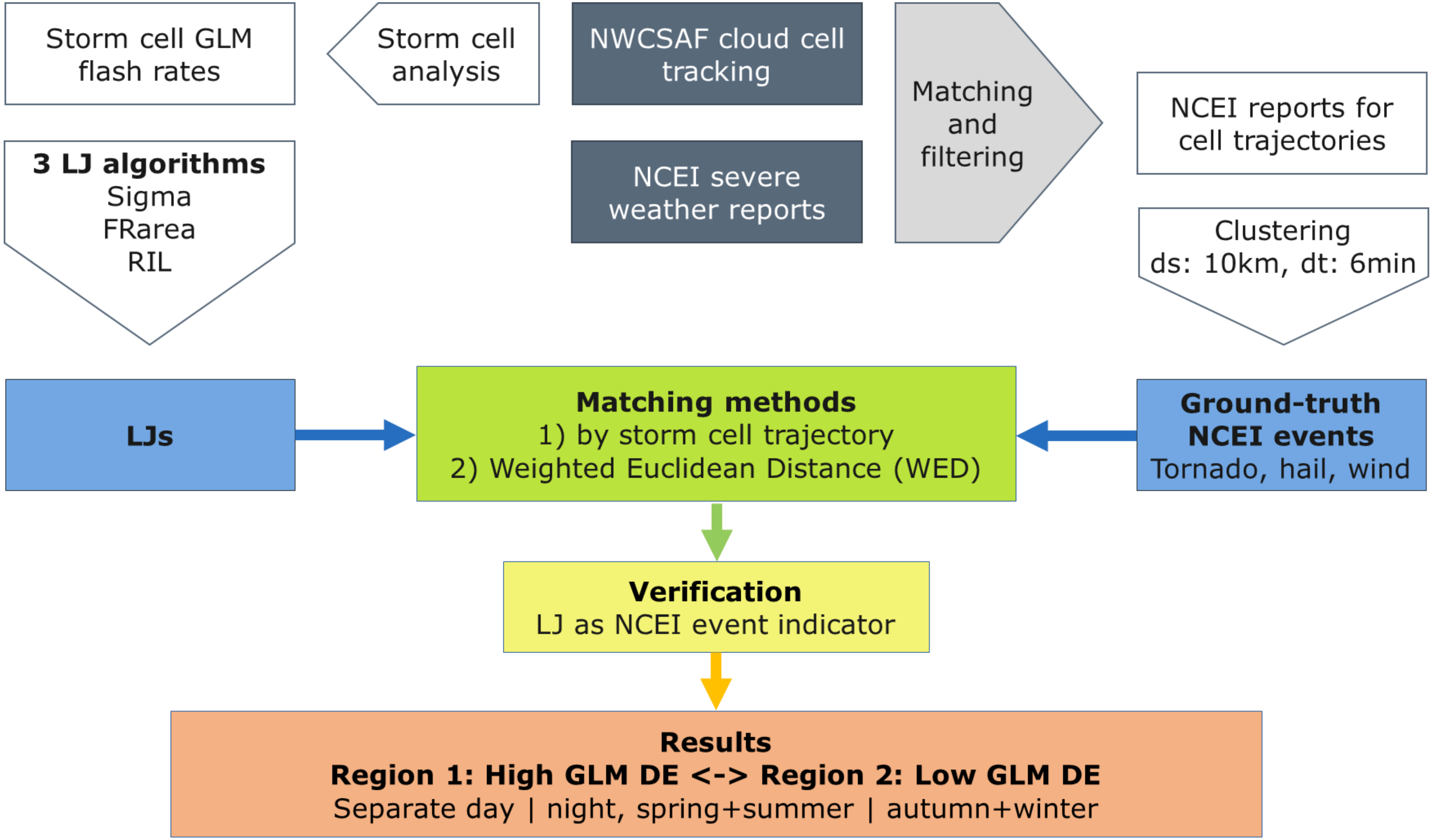
Source: Blakeslee et al. (2020), doi: 10.1029/2020JD03291

(2) GLM detection energy threshold – minimum required energy (daytime shown as more challenging than nighttime)



Adapted from: Cummins (2020), AMS Annul Meeting Poster 692

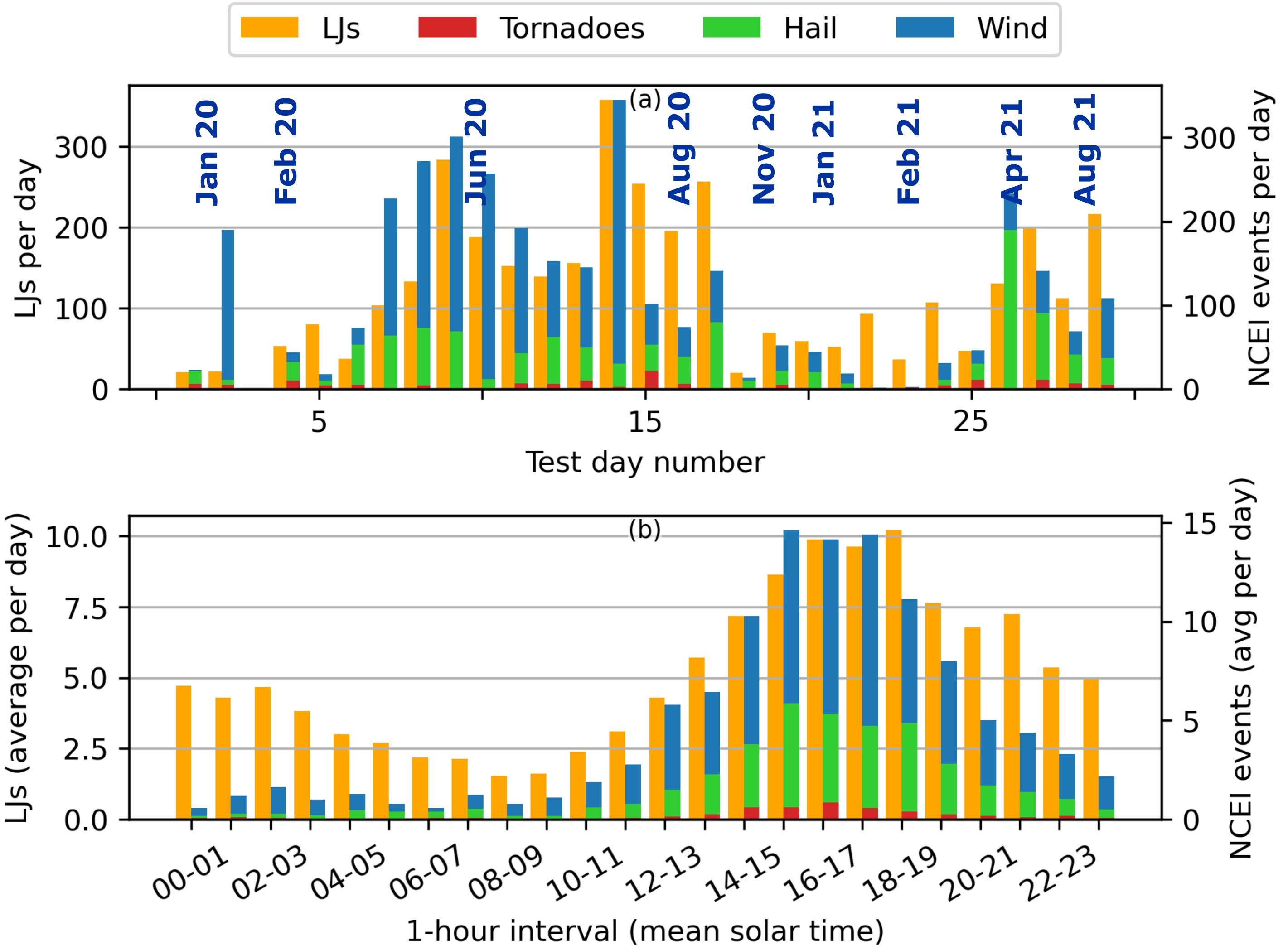
Workflow


Storm cell GLM flash rates
Storm cell analysis
NWCSAF cloud cell tracking
Matching and filtering
NCEI reports for cell trajectories
3 LJ algorithms
Sigma
FRarea
RIL
NCEI severe weather reports
Clustering
ds: 10km, dt: 6min
LJs
Matching methods
1) by storm cell trajectory
2) Weighted Euclidean Distance (WED)
Ground-truth
NCEI events
Tornado, hail, wind
Verification
LJ as NCEI event indicator
Results
Region 1: High GLM DE <-> Region 2: Low GLM DE
Separate day | night, spring+summer | autumn+winter

Main overall results

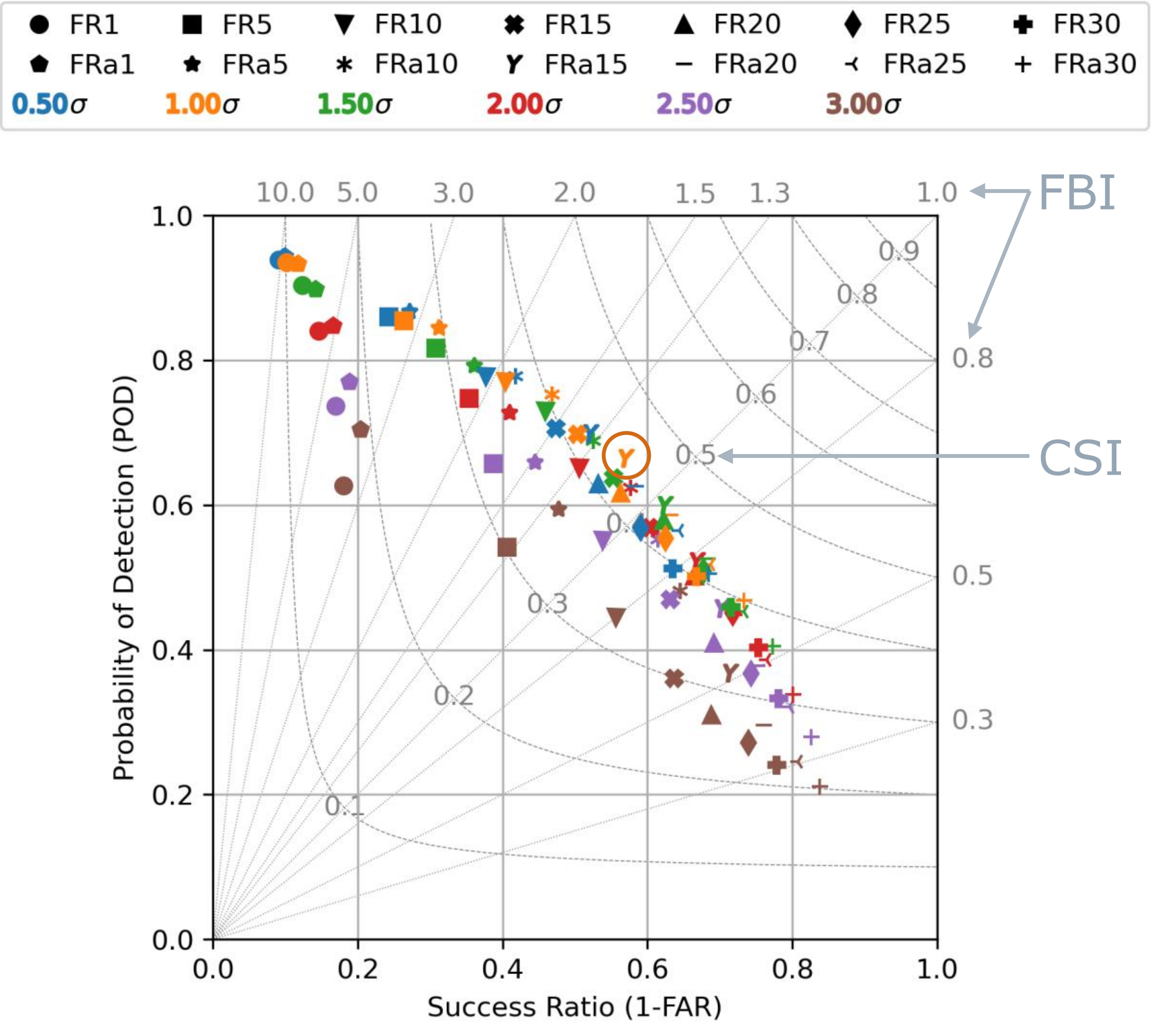
Analyzed LJs and severe weather events

- 29 test days
- Total LJs: 2913
- Total NCEI events: 3297
  (Tornado: 138, Hail: 1044, Wind: 2115)
- **Strong correlation** between LJs and severe weather occurrences
- LJ and NCEI event distribution **peak in local afternoon and evening**



Skill for LJs as severe weather indicator

- Results for various LJ algorithm configurations
- **FR | FRa (markers)** and **σ (color)** as variable algorithm thresholds
- Low σ and moderate FR thresholds yield most skill
- Best CSI all data: 0.44
- **Best CSI summer/spring and daytime: 0.52**



Additional conclusions (not presented)

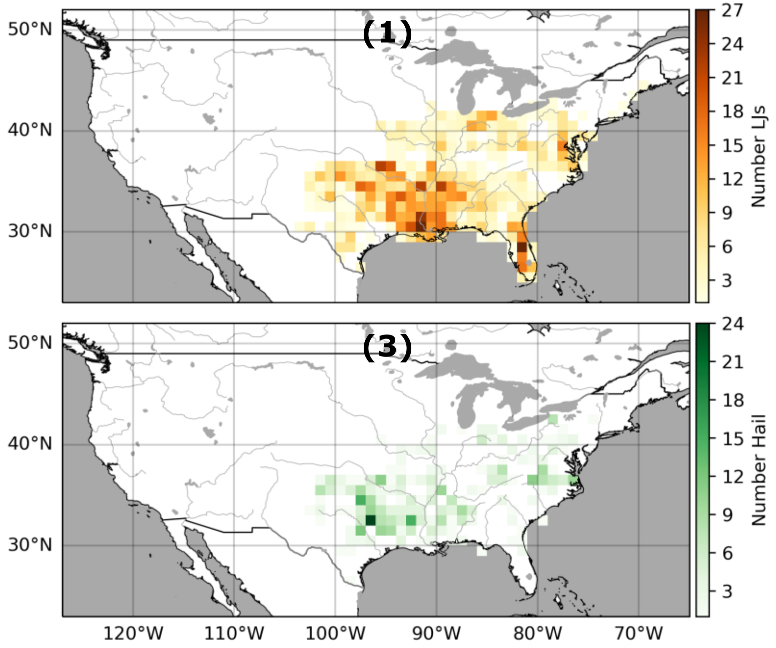
- **LJ to NCEI event leadtimes** from a few minutes to more than an hour
- **Recommended LJ algorithms*** based on CSI for LJ and severe weather
  (***** please see backup slides description of the LJ algorithms for more details**)**
- CSI-based skill: summer/spring > overall > winter
- CSI-based skill: daytime > overall > nighttime

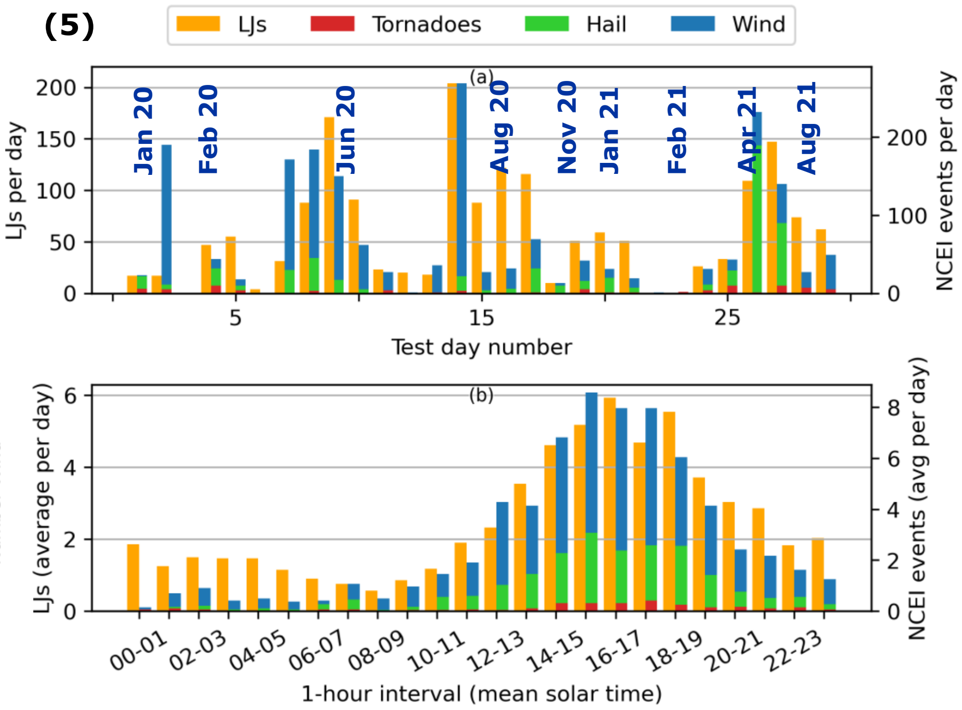
→ **Paper submitted to JAMC: "Automated Lightning Jump (LJ) detection from geostationary satellite data"**

GLM DE impact on results

LJs and NCEI events for high GLM DE

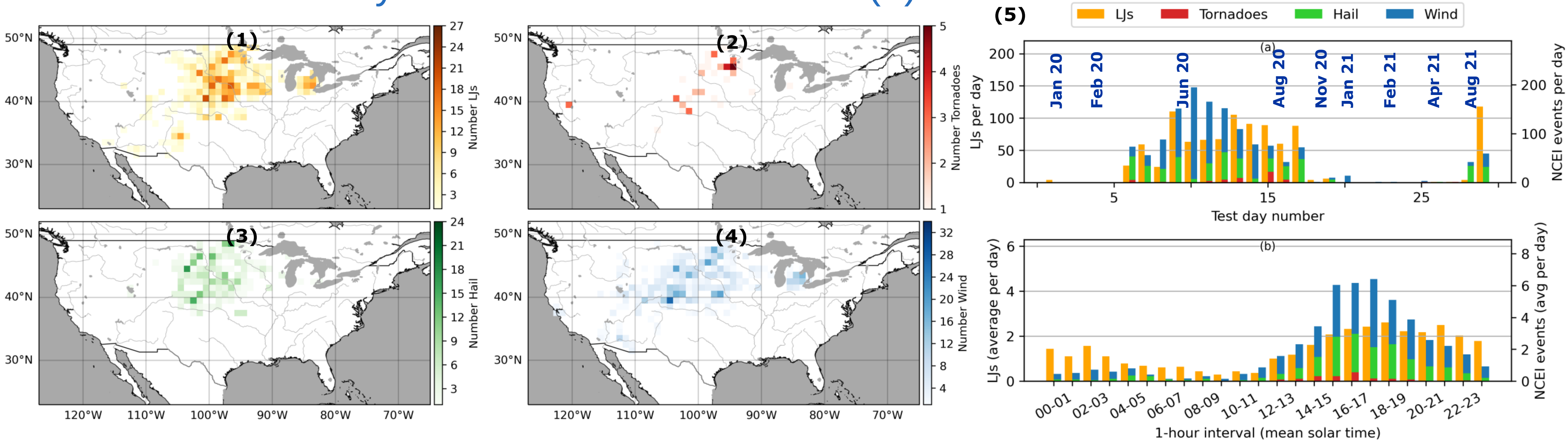
- Heatmaps (left) of LJs (1), Tornado (2), Hail (3), and wind (4) events with **significant amount** of cases in the high GLM DE region
- LJs and NCEI events on most test days (right, 5a) and average diurnal cycle (5b)





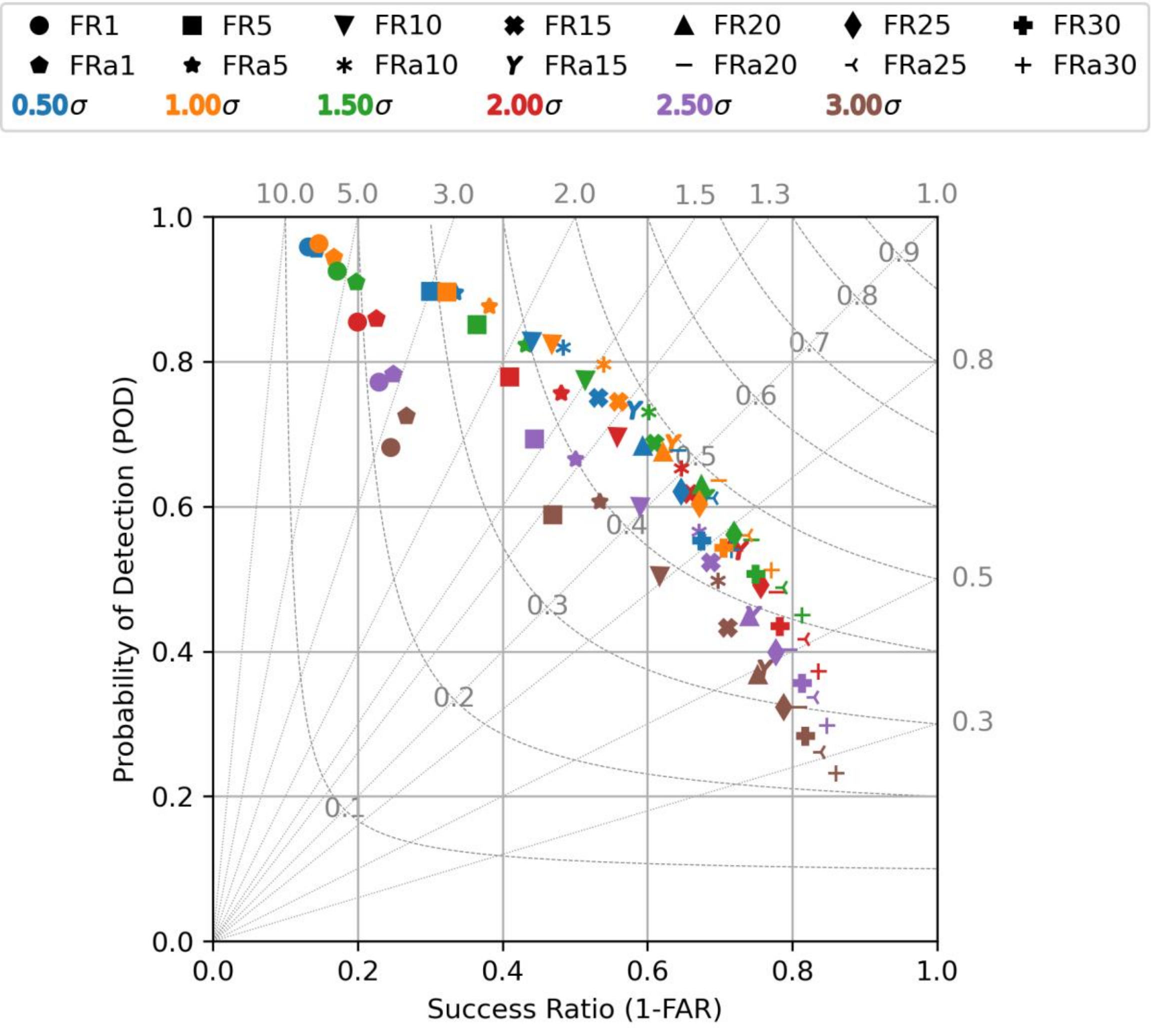
LJs and NCEI events for low GLM DE

- Heatmaps (left) of LJs (1), Tornado (2), Hail (3), and wind (4) events with **significant amount** of cases in the low GLM DE region
- LJs and NCEI events **mainly in June and August** (right, a), reduced number of daytime LJs and NCEI events (b)



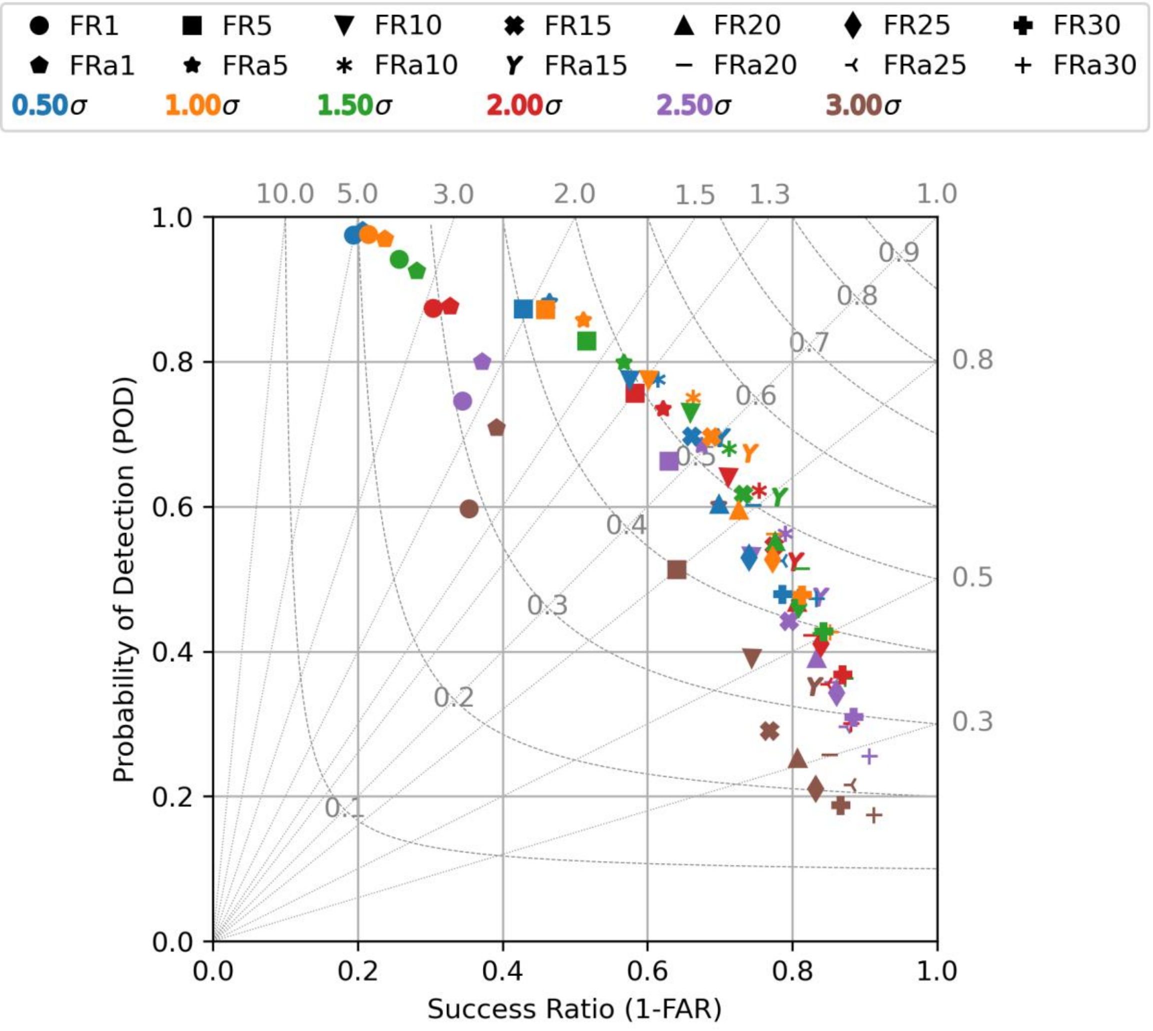
LJ algorithms for high GLM DE (spring,summer)

- FR | FRa (markers) and σ (color) as variable algorithm thresholds
- Similar algorithms with highest CSI than for full region
- **FR/FRa** thresholds with tendency to **higher optimal values** than overall (20 vs 15)
- Best CSI summer/spring data: 0.50



LJ algorithms for low GLM DE (spring,summer)

- FR | FRa (markers) and σ (color) as variable algorithm thresholds
- Similar algorithms with highest CSI than for full region
- **FR/FRa** thresholds with tendency to **lower optimal values** than overall (10 vs 15)
- Best CSI summer/spring data: 0.55
- **Higher CSI than in the high GLM DE region** → investigation!



Summary

- **Automated** storm-tracking and detection of Geostationary Lightning Mapper (**GLM**) lightning jumps (**LJ**)
- **GLM LJs** verified by **NCEI severe weather reports** (CSI up to 0.67)
- **GLM flash detection efficiency (DE)** without impact on max. CSI
- FR threshold for max. CSI in high DE region greater than in low DE region
- **Current research**:
  - Combine **satellite observed LJs with** other data, e.g., convective rain rates (CRRs) and overshooting tops (OTs)
  - Explain higher CSI in region of low GLM DE compared to region of high GLM DE
  - Study drops in the storm flash rate – so-called **lightning dives**

THANK YOU

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Vertrauenswürdige Dienstleistungen für Öffentlichkeit und Behörden begründet auf Forschung, Innovation und Kontinuität.

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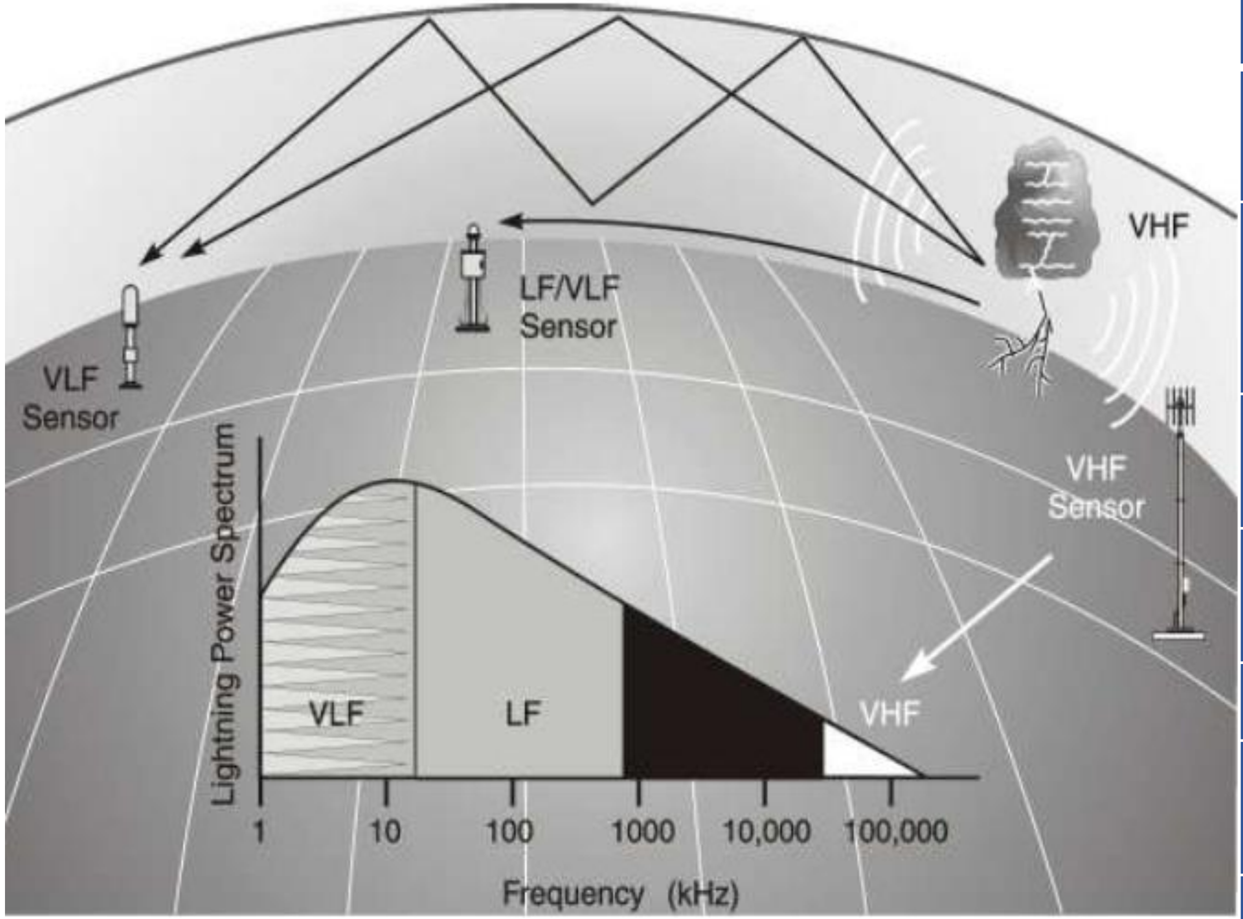
Backup slides

Basics

Lightning electromagnetic spectrum

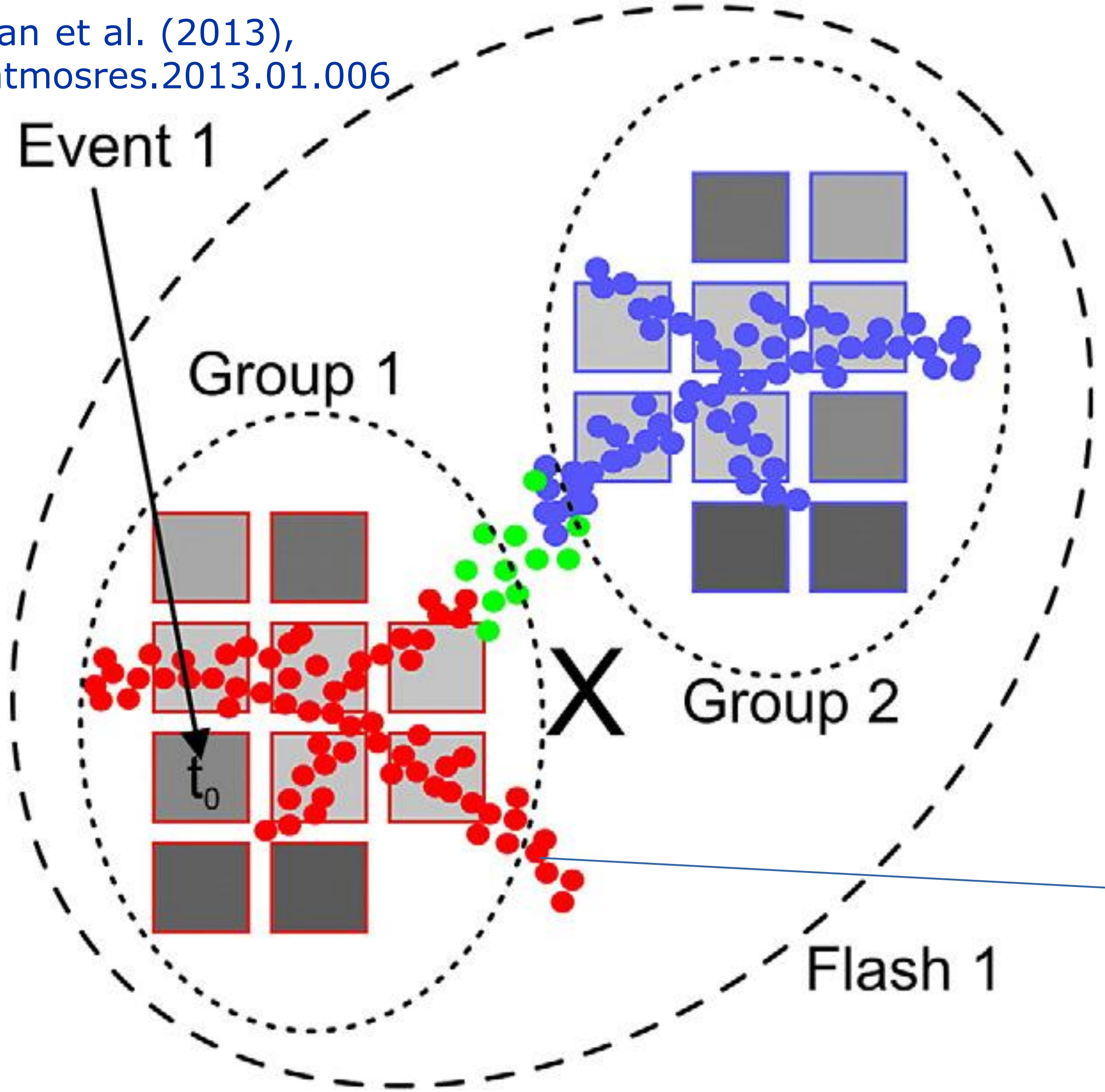
- Power spectrum of **radio frequency** range: Ground-based (V)LF and VHF networks



	LF networks	VHF networks
Frequency range	Few hertz to 30 kHz	3 MHz to 3 GHz
Most sensitive to	**Return strokes**, fast in-cloud components	**Leader** formation, stepped leaders
Signal propagation	Direct (line-of-sight), ground wave	Direct (line-of-sight)
Quantities	Time, location, LF current	Time, location, VHF amplitude
Measurement	Point locations	Mapping
Coverage	Global, nationwide, or regional	Regional
Example	NLDN, Meteorage	SAETTA LMA

Optical lightning obs. data scales/types

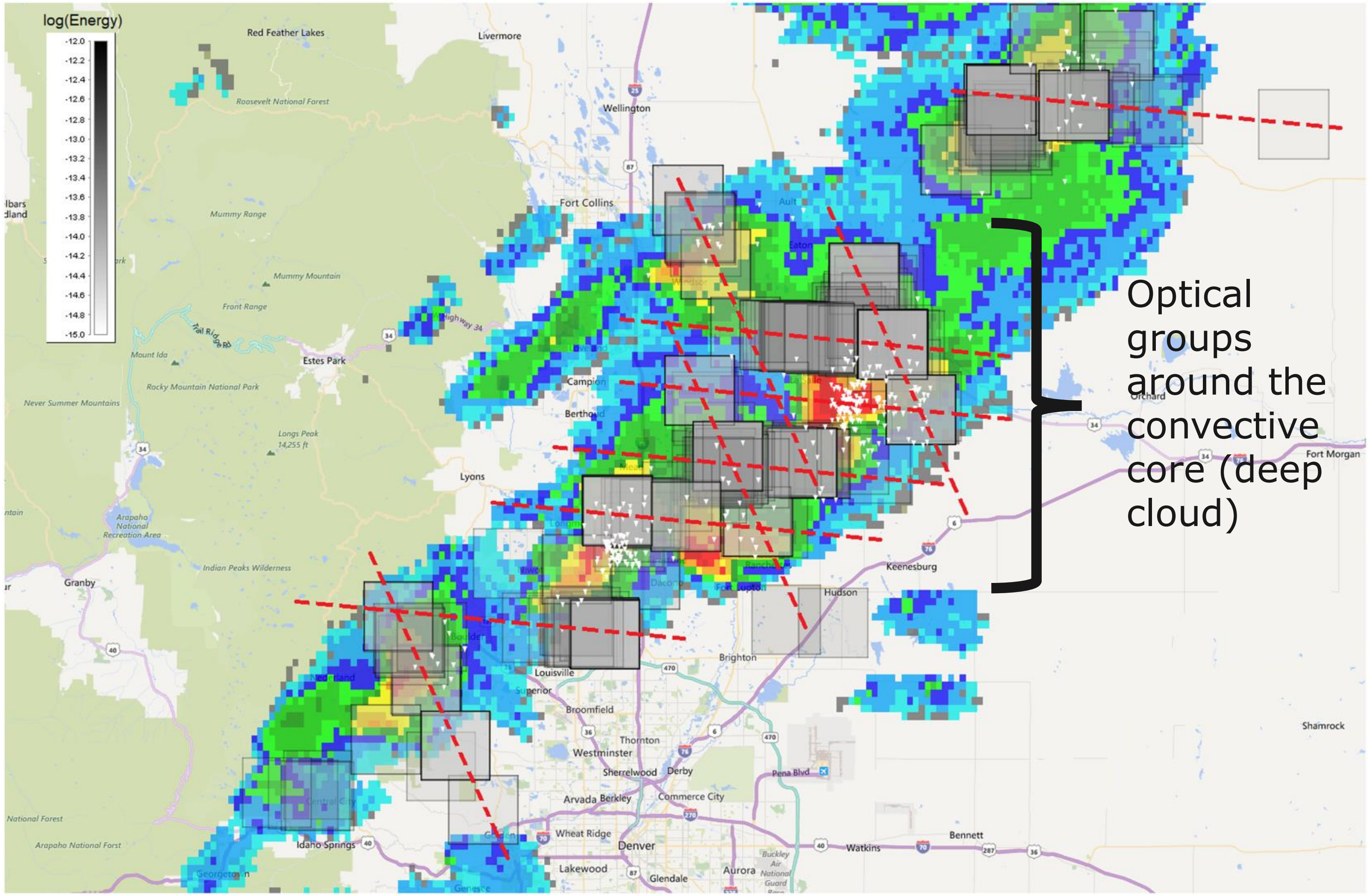
Fig. 5 of Goodman et al. (2013), doi: 10.1016/j.atmosres.2013.01.006



- **Event**: A single illuminated pixel that passes the detection threshold
- **Group**: Adjacent events of the same time frame
- **Flash**: Cluster of groups within 16.5km / 0.33s

Ground-based lightning observations

GLM lightning example vs. radar + NLDN



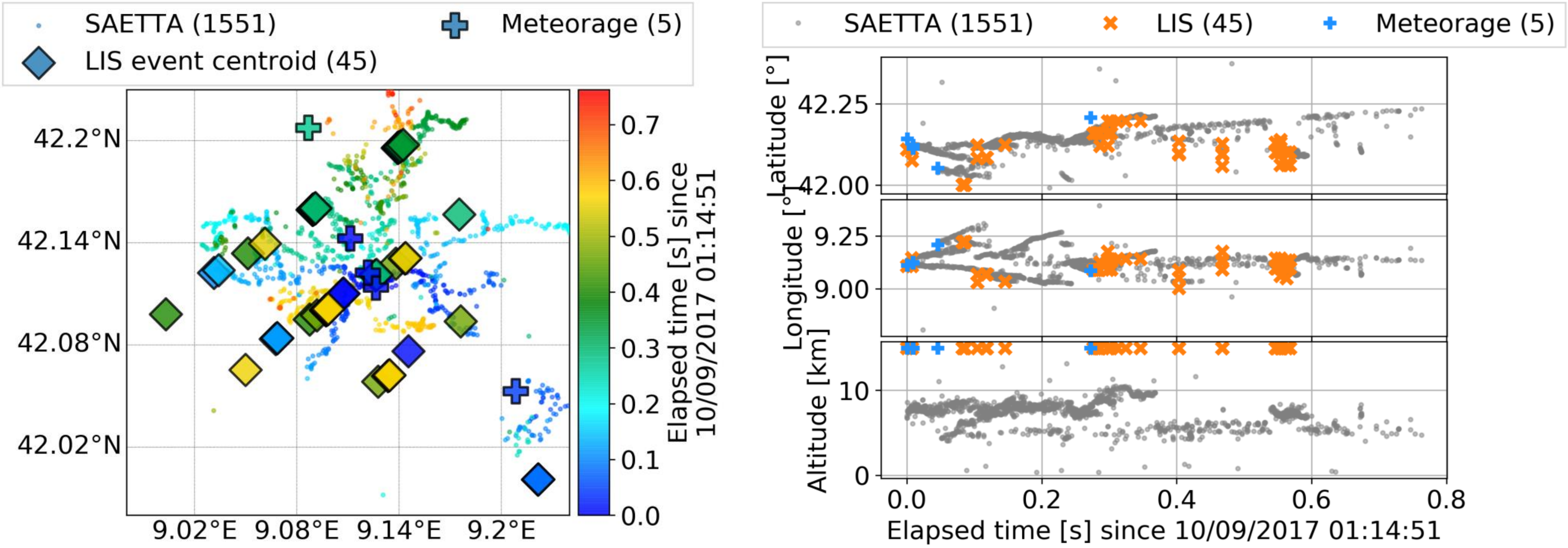
Radar (colors), GLM groups (10 × 10 km boxes, gray scale) and NLDN (small white dots) at 01:00 UTC on 2018-06-19 over northern Colorado. Notable observations are the alignment of most GLM group positions on a grid (red, dashed) and the relative lack of GLM observations directly over the storm cores that have the highest reflectivity. (adapted from Fig. 1 of Murphy and Said, 2020, doi: 10.1029/2019JD031172)

One flash observed with different LLSs

- **ISS-LIS**: LEO on ISS, optical (777.4 nm), 2D mapping
- **Météorage**: NLDN France, low frequency (1 kHz – 350 kHz), 2D
- **SAETTA LMA**: LMA, very high frequency (60 MHz – 66 MHz), channel mapping in 3D

[Erdmann et al., 2020, doi: 10.5194/amt-13-853-2020]

One flash observed over Corsica island (NW Mediterranean Sea)



My recent work

Dataset

- GOES ABI and GLM imagery
- GOES-16 field of view limit to the CONUS
- National Centers for Environmental Information (NCEI) weather report archive → ground truth + verification of LJs
- 14 summer, 3 spring, and 12 winter days in 2020 and 2021
- **Almost 50,000 thunderstorms** analyzed
- About 5% of the thunderstorms with LJ and/or NCEI severe weather report
- **Most comprehensive analysis of** satellite observed **LJ algorithms** known

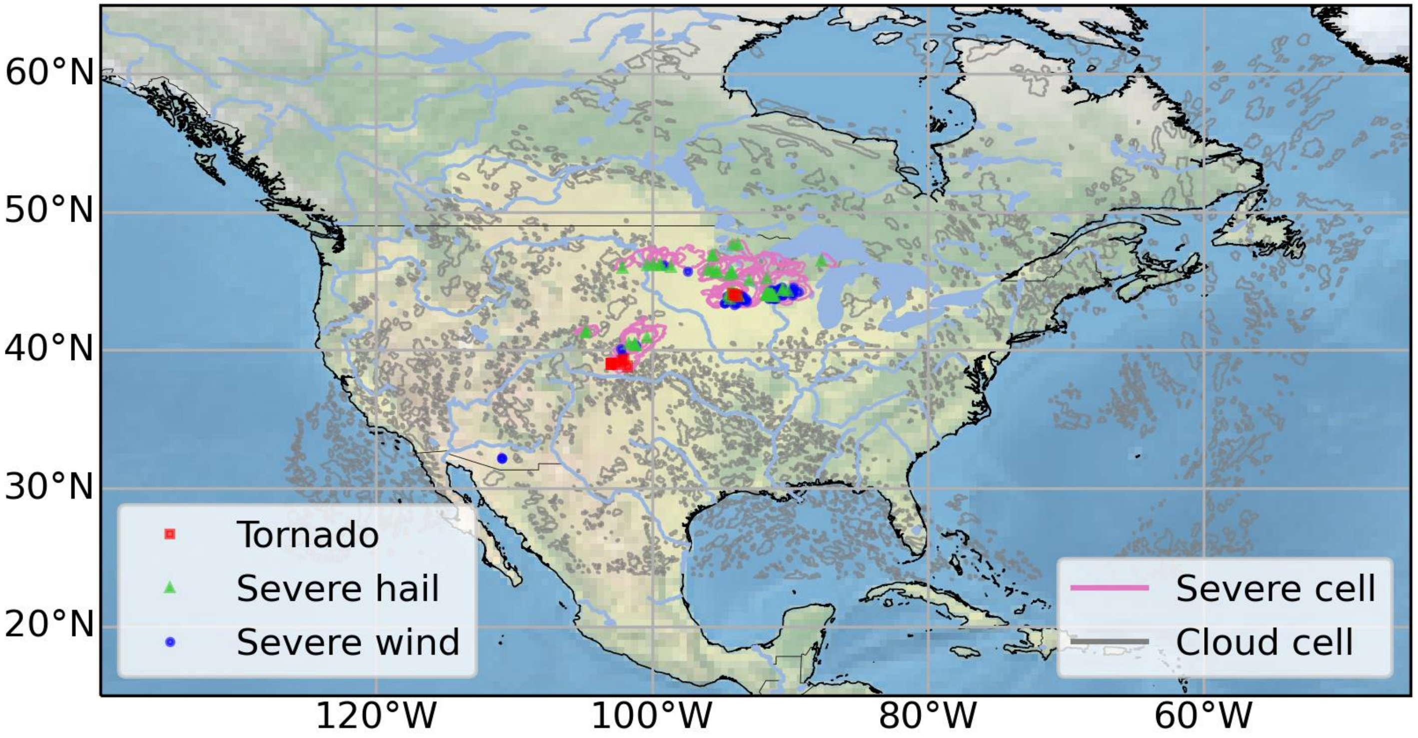
Matching of RDT cells and NCEI reports

- NCEI report within satellite scan interval (**10 minutes** for GOES-16) and **less than 50 km** from the cell contour matched to that cell

- 1 NCEI report only matched to the closest cell at report time (often within the cell contour)

- NCEI report not matched to any cloud = false report

Map NCEI reports and RDT-CW cells for 2020-06-02
(severe cells with NCEI report pink)



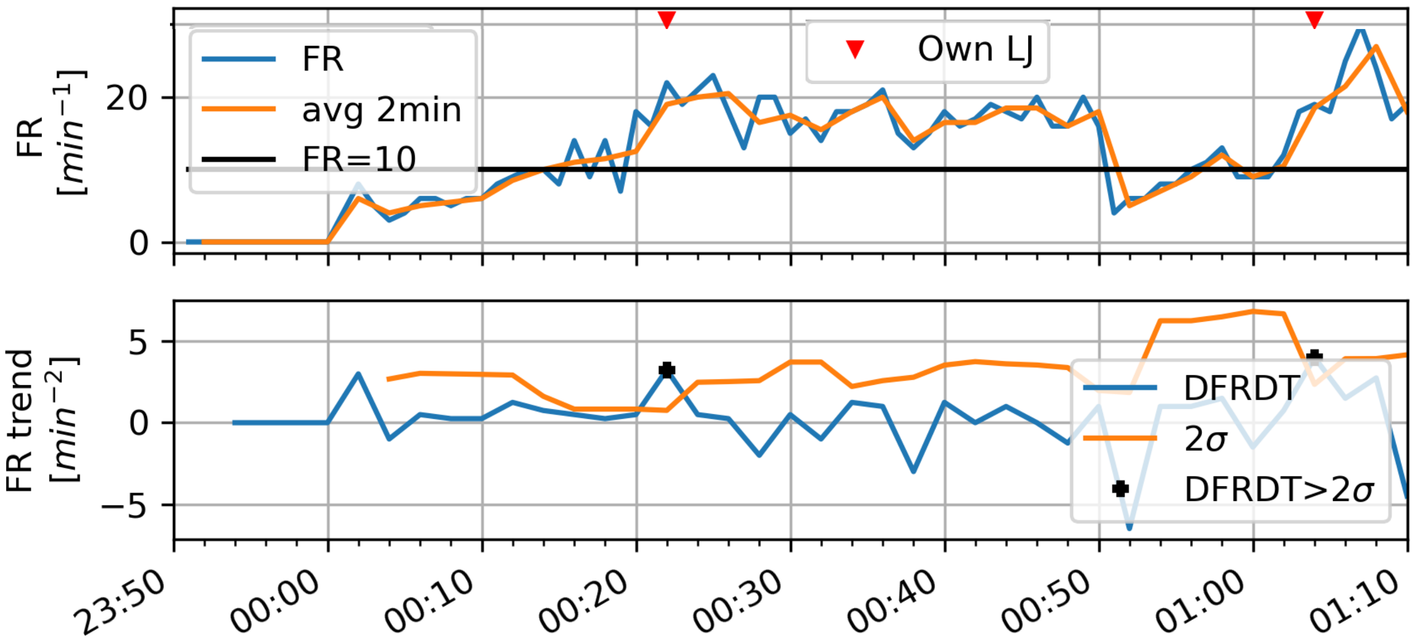
Automated Lightning Jump (LJ) detection

Lightning Jump (LJ): An abrupt increase in the total lightning flash rate (flashes per time) observed within a storm cell.

→ **3 LJ algorithms**

1. **2σ LJ algorithm** (Schultz et al., 2009)
   - Flash rate (FR) threshold: 10 flashes per minute
   - σ-level threshold: 2
2. **Modified σ algorithm**: FR per cell area (**FRa**) in σ-calculation
3. **New:** FR/area relative increase level (**RIL**) LJ algorithm

Example 2σ LJ algorithm: Cell trajectory with 2 LJs (2020-06-02 00:00Z-01:10Z)



LJ algorithms

Sigma LJ algorithm

Certain flash rate needed

Sigma (σ) as the standard deviation of DFRDT over the previous 10 min

Current $DFRDT > a \cdot \sigma$ means a LJ (factor a is called sigma level)

Modification: Uses the flash rate per cell area rather the raw flash rate of the storm

Lightning Jump Process for each cluster

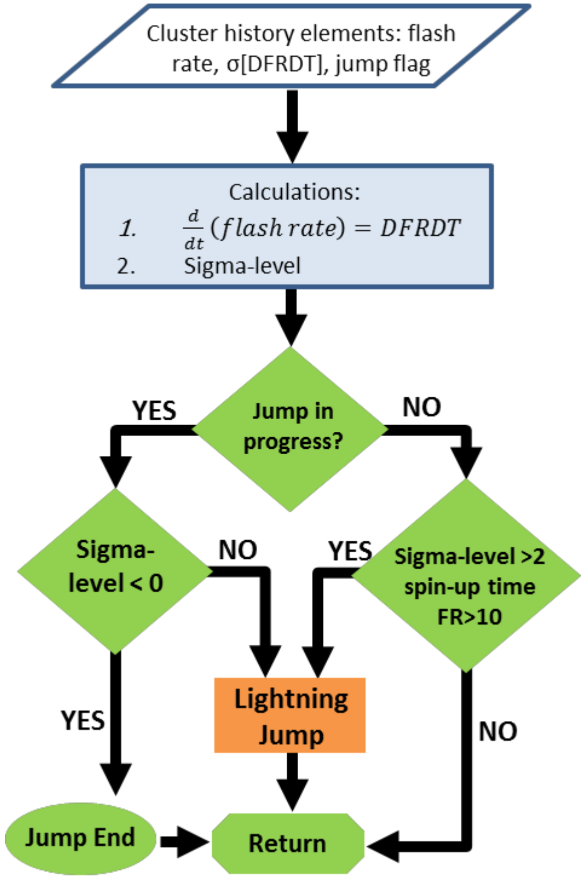


Fig. 5, Schultz et al. (2016), doi: 10.15191/nwajom.2016.0407

RIL LJ algorithm

Certain flash rate needed

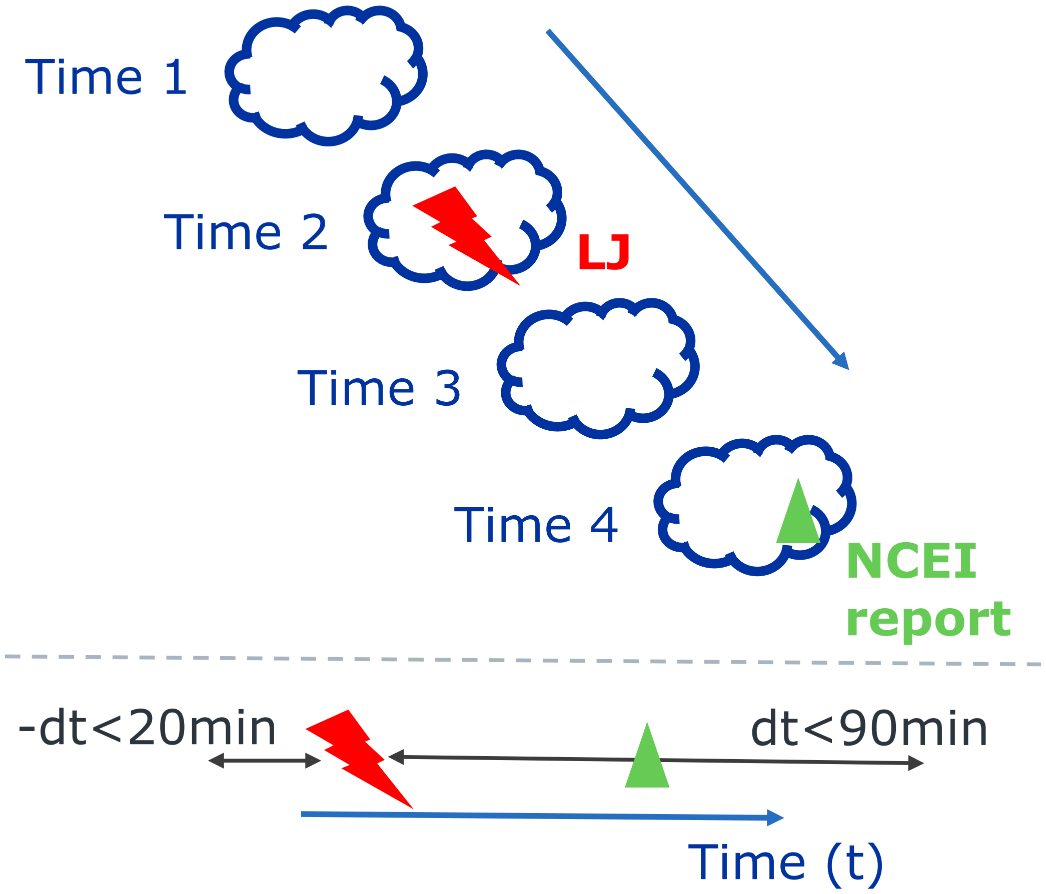
$$\mathbf{RIL} = \frac{\mathrm{FR}(t_0)}{\mathrm{FR}(t_0 - 1\,min)}$$

with the Relative Increase Level (RIL), and the Flash Rate (FR) as a function of time

Current RIL $> x$ means a LJ (x is a threshold)

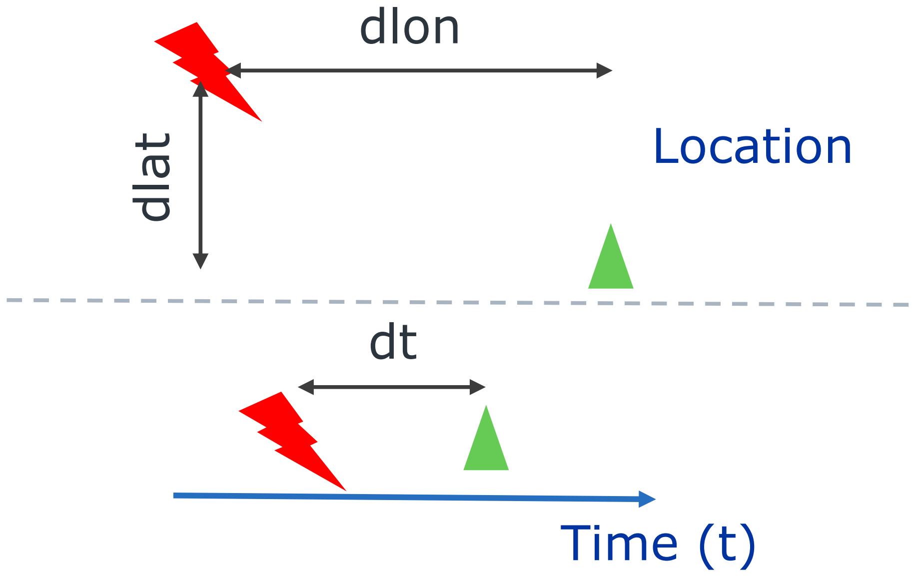
Matching of LJs and NCEI reports

1) Cell trajectory based matching



2) Weighted Euclidean Distance (WED) based matching

$$WED = \frac{dlat}{50km + R_{cell}} + \frac{dlon}{50km + R_{cell}} + \frac{dt}{90min|_{\text{LJ before NCEI}} \text{ or } -20min|_{\text{LJ after NCEI}}} < 1$$

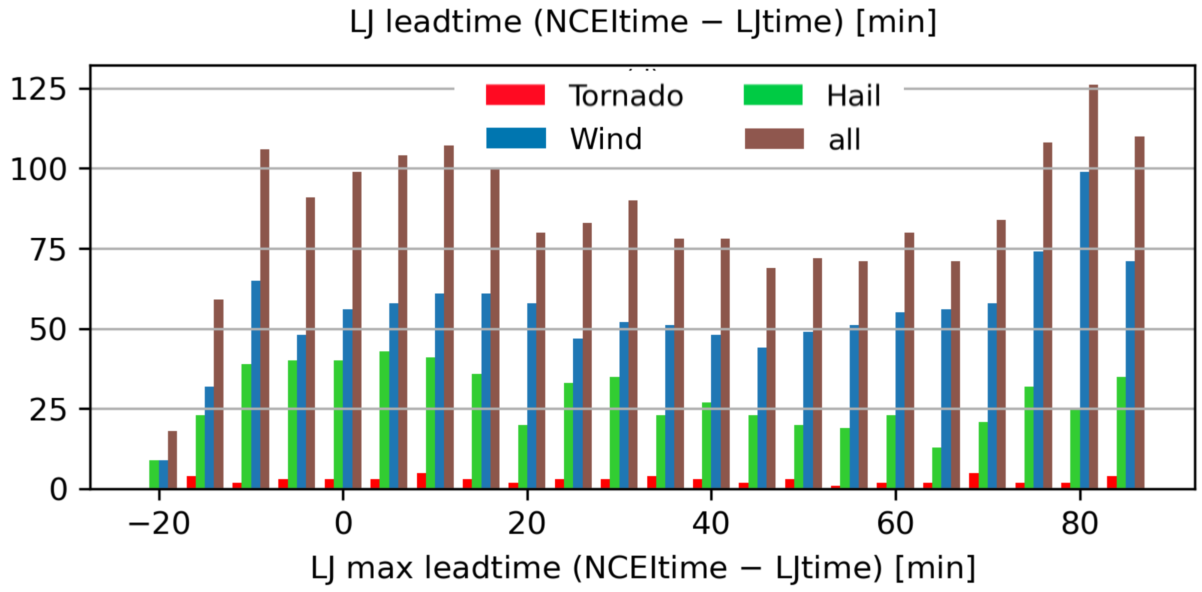


48,273
48,273

Leadtimes of LJs to matched NCEI events

- **Thunderstorm trajectories**: 48 273; **2163 with LJ and/or NCEI report**
- LJ algorithm: FRarea LJ algorithm with $FR \geq 15$ flashes/min and $\sigma \geq 1.0$
- Trajectory-based matching
- **Max. leadtimes** of LJ to NCEI reports (the first LJ matched to a certain NCEI event) [positive = LJ before NCEI event]

Mean: 36.1min ; Median: 34min



LJ-NCEI events (Tornado, Hail, Wind) correlation

Quantitative measures (scores)

- Probability of Detection (POD) $= \frac{A}{A+C}$
- False Alarm Ratio (FAR) $= \frac{B}{B+A}$
- Frequency Bias Index (FBI) $= \frac{A+B}{A+C}$
- Critical Success Index (CSI) $= \frac{A}{A+B+C}$

LJs	NCEI events (Tornado, Hail, Wind)	
	Yes	**no**
yes	A -hit-	B -false alarm-
no	C -miss-	D -correct no-

- 3 LJ algorithms (σ, σ with FR per area, RIL) and 2 NCEI-LJ matching strategies (trajectory vs WED)