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Nowcasting severe weather with automatically detected lightning jumps from Geostationary Lightning Mapper (GLM) observations

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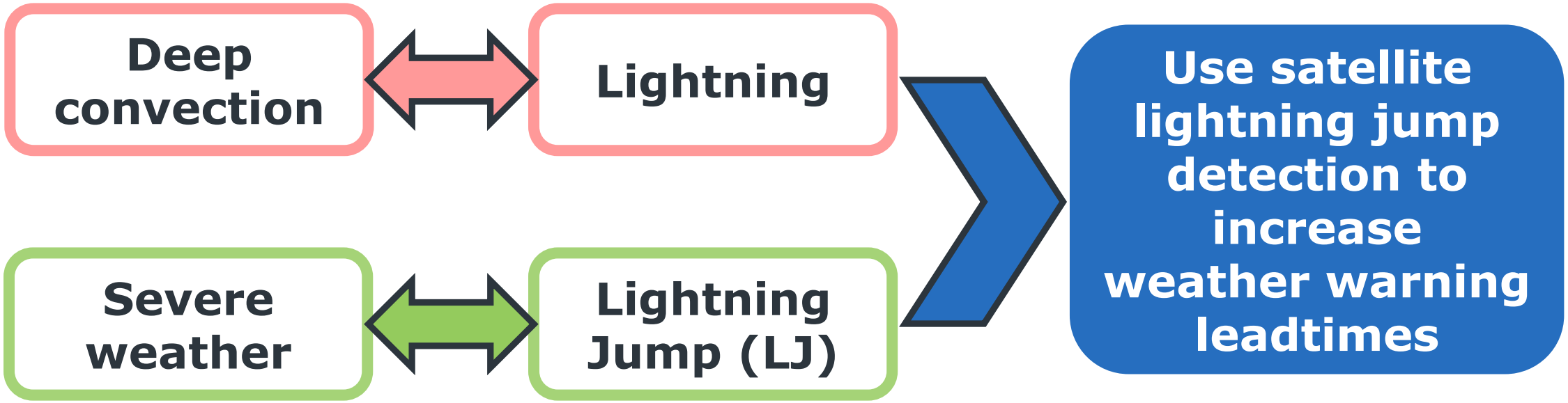
Introduction and Motivation

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



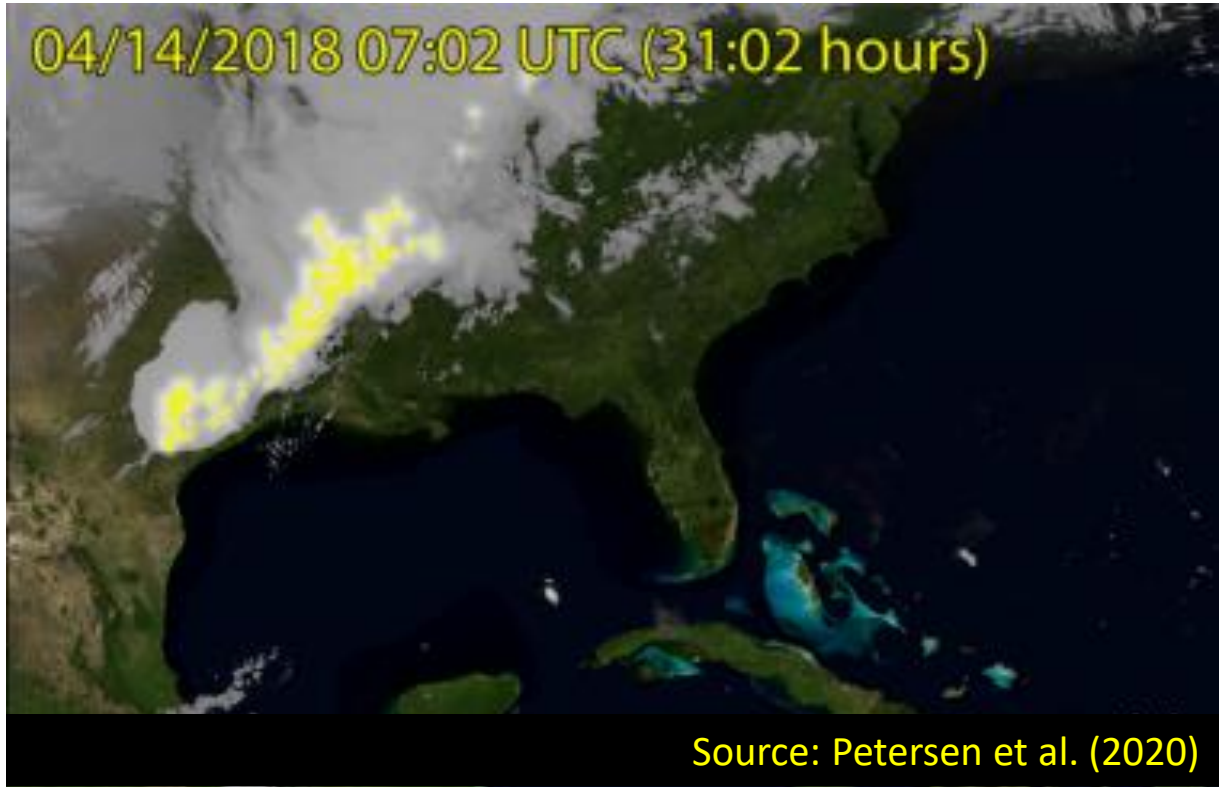
e.g., Williams et al., 1999, Goodman et al., 2005, Gatlin and Goodman, 2010, Schultz et al., 2009, 2016

GOES-GLM lightning observations

- **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

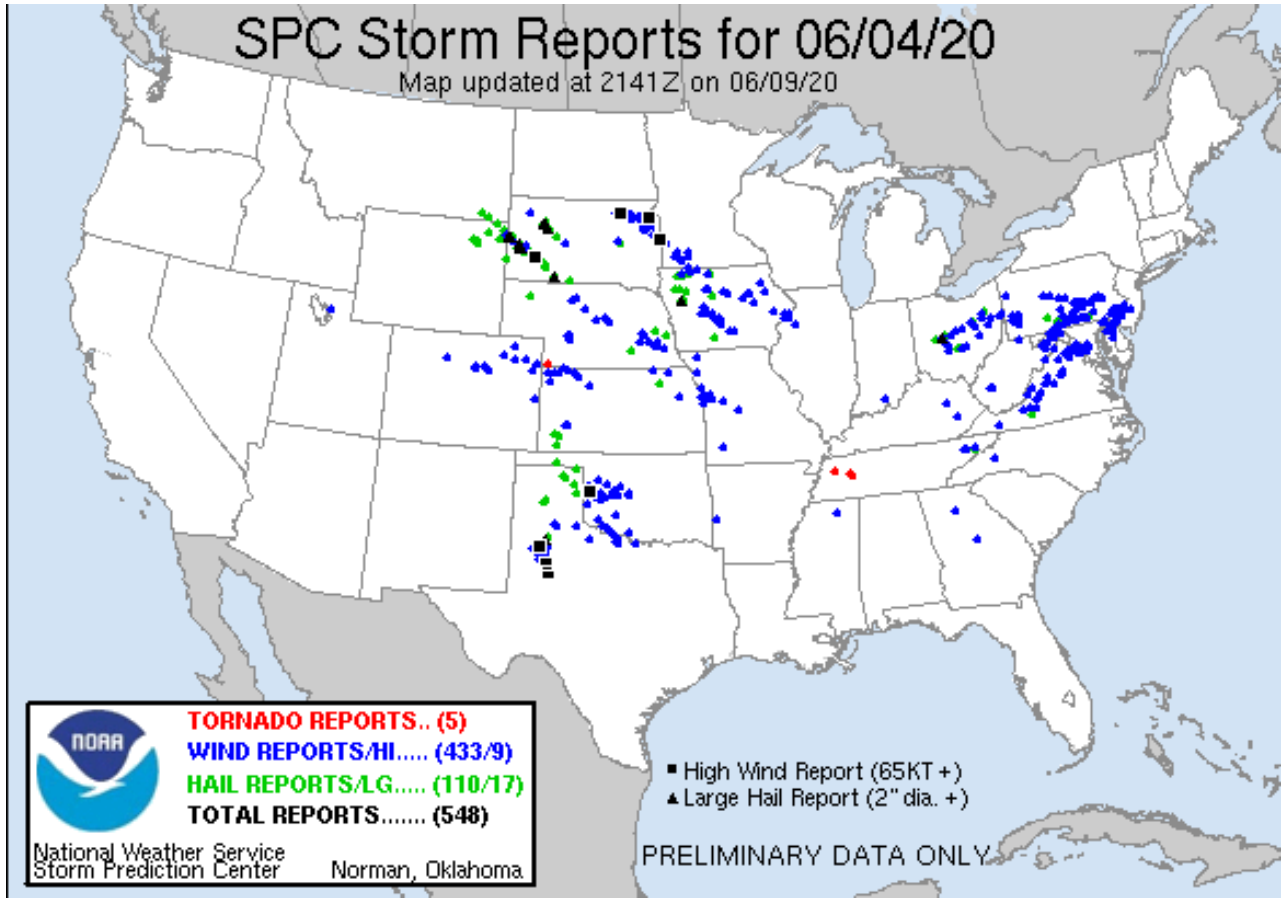
(e.g., Goodman et al. 2003, Mach 2020)

GLM observations over southeastern United States



Storm Prediction Center (SPC) reports

- SPC's **severe weather event** archive https://www.spc.noaa.gov/exper/archive/
- Reports: Tornadoes, Large hail (>1inch~2.54cm), Severe winds (damaging or >50kn)
- Time of occurrence, latitude, longitude (and location, county, state, comments)
- Here: grouped by 6min | 10km

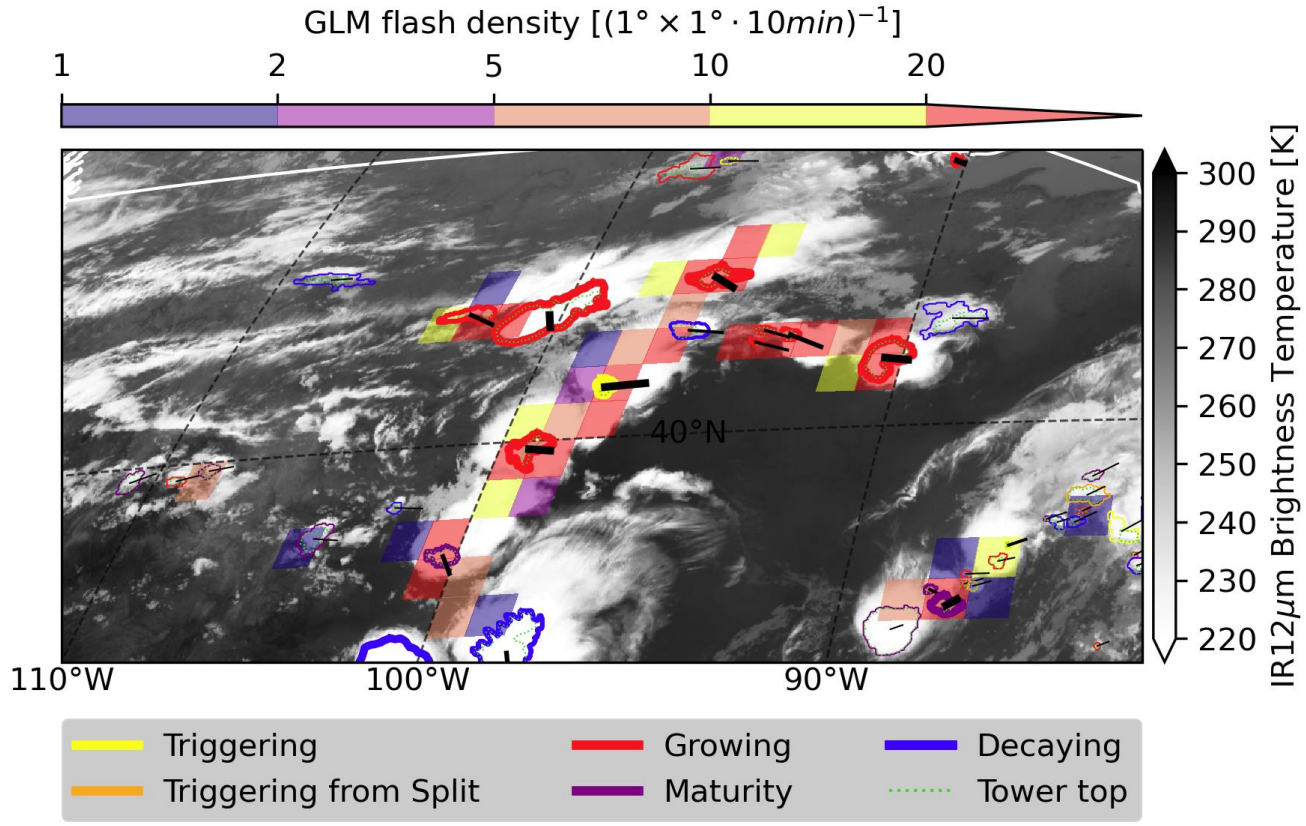


(2020-06-04 1200 UTC – 2020-06-05 1159 UTC)

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
- Other products, e.g., **convective rain rates (CRR)**, convective initiation, **overshooting tops (OT)**

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



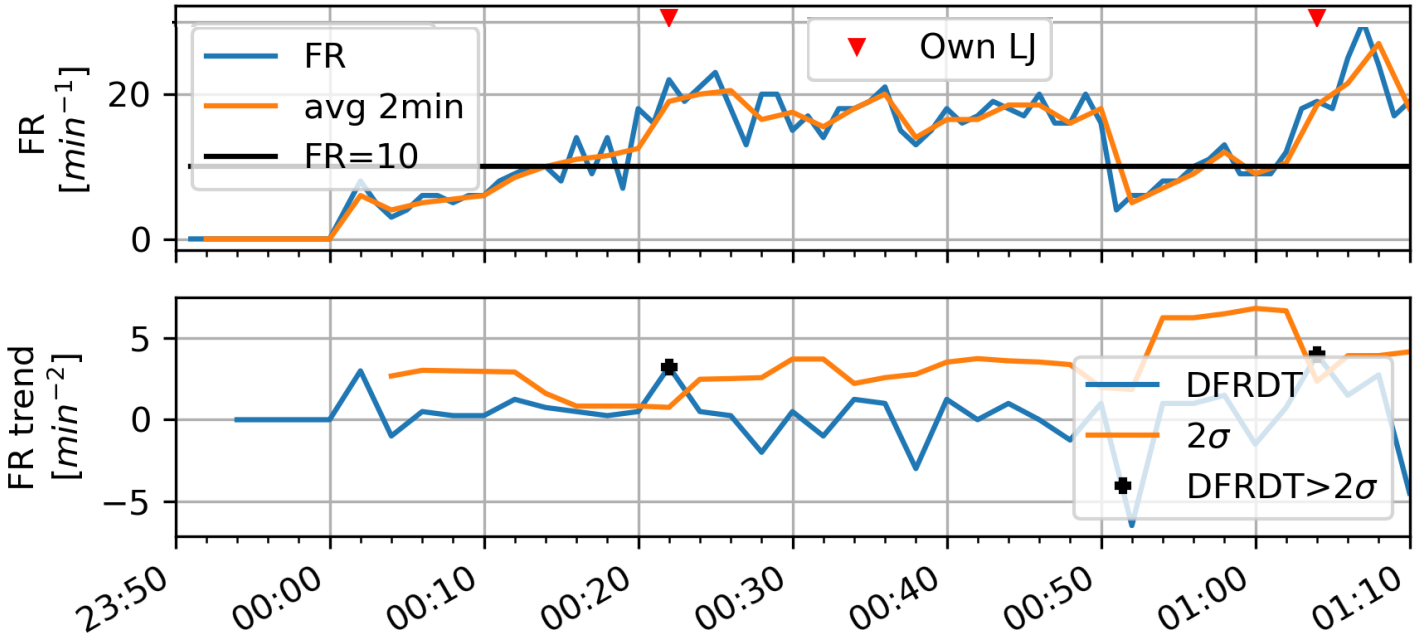
Automated Lightning Jump (LJ) detection

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

→ Test **LJ algorithms**

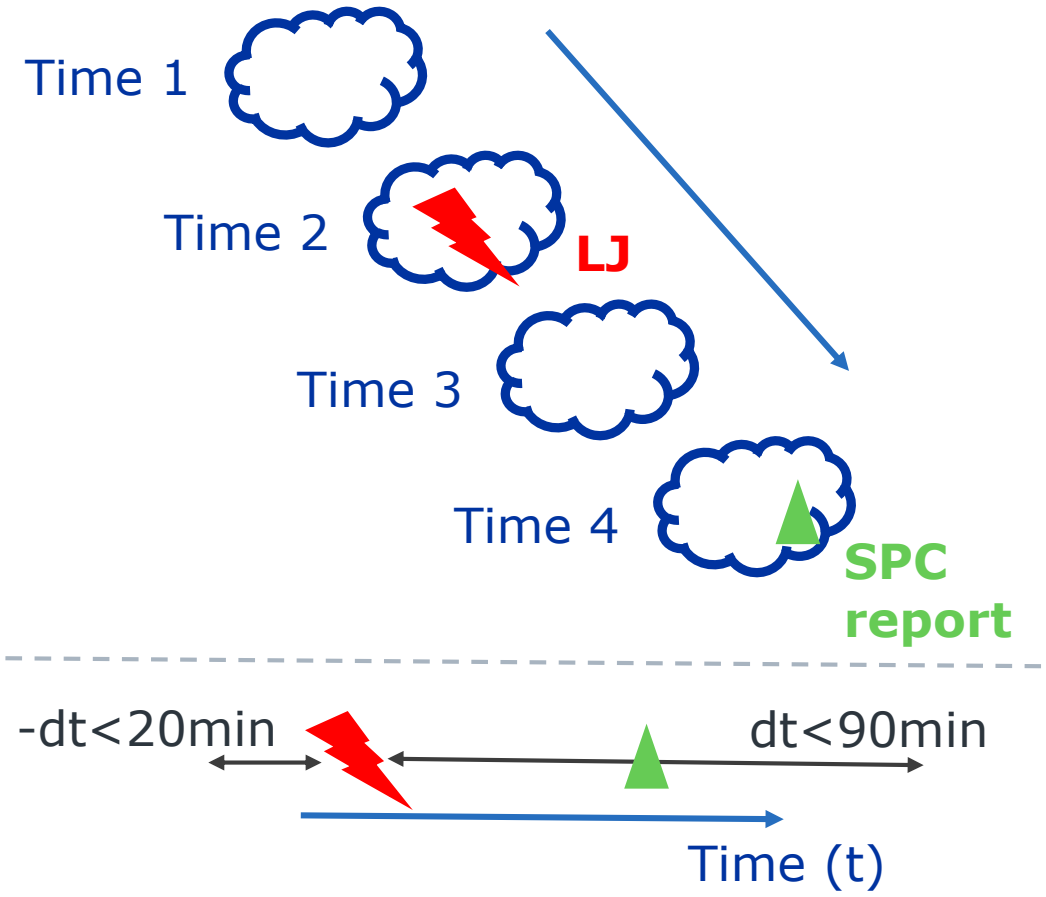
1. 2σ LJ algorithm (Schultz et al., 2009)
   - Flash rate (FR) threshold: 10 flashes per minute
   - σ-level threshold: 2
2. **Modification**: FR per cell area (**FRa**) in σ-calculation
3. **New:** FR/area relative increase level (**RIL**) LJ algorithm

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



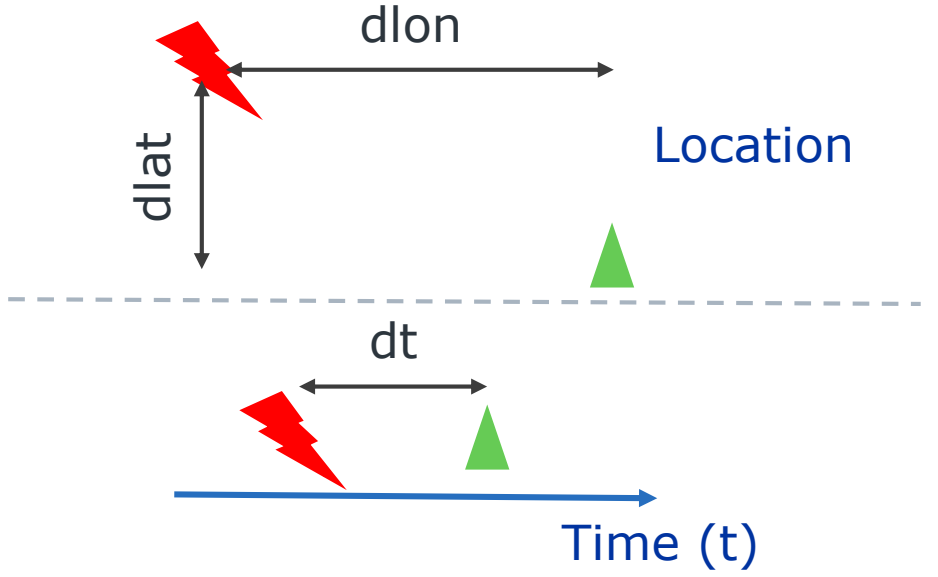
Matching of LJs and SPC reports

1) Cell trajectory based matching



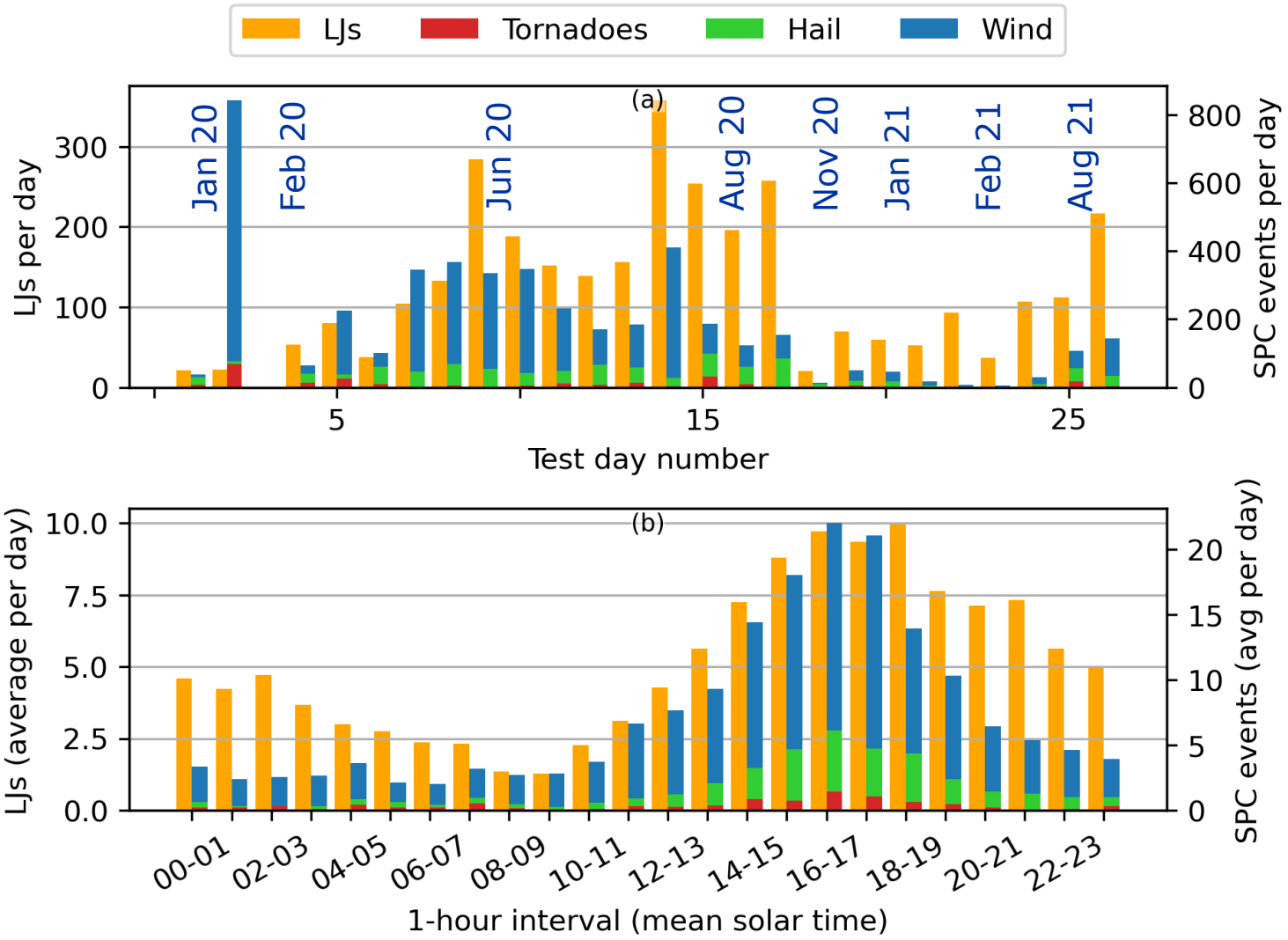
2) Weighted Euclidean Distance (WED) based matching

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



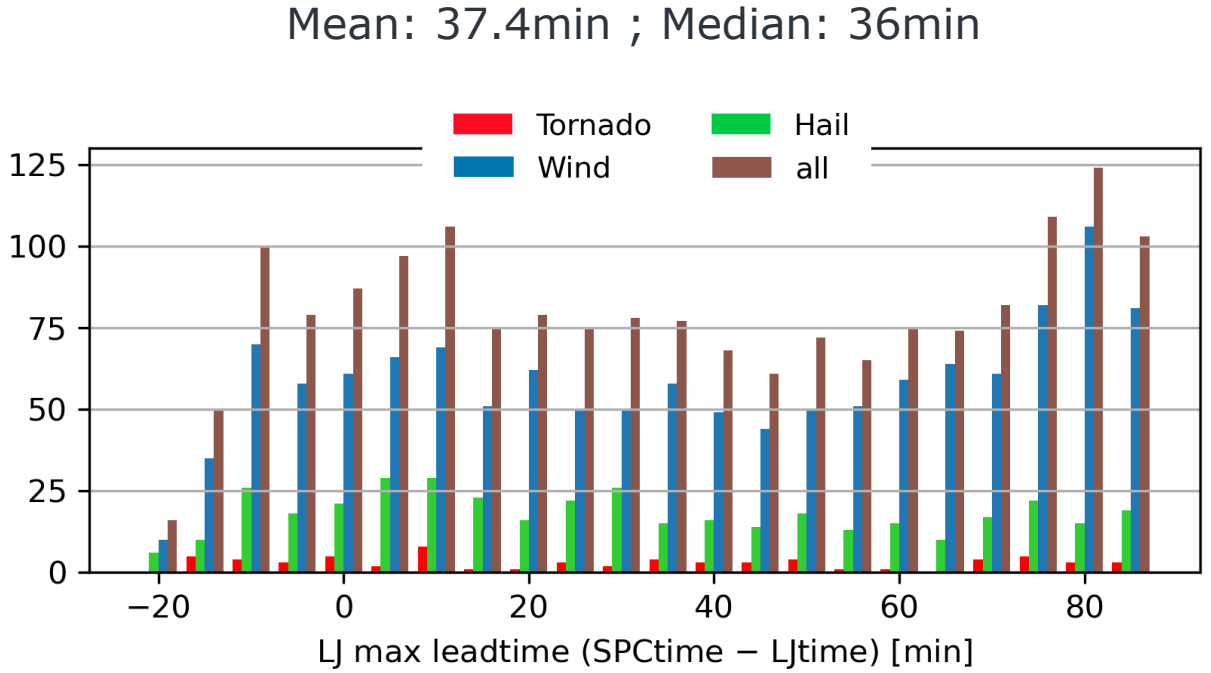
LJ and severe weather occurrences

- 26 test days (14 summer, 12 winter) in 2020/21
- Total LJs: 2913
- Total SPC events: 4552 (Tornado: 249, Hail: 798, Wind: 3505)
  with coincident RDT cell: 3554 (174, 776, 2604)
- LJ and SPC event distribution peak in local afternoon and evening



Leadtimes of LJs to matched SPC events

- **Thunderstorm trajectories**: 45,807; **1,876 with LJ and/or SPC report**
- LJ algorithm: FRa σ-algorithm with $FR \geq 15$ flashes/min and $\sigma \geq 1.0$
- Trajectory-based matching
- **Max. leadtimes** of LJ to SPC reports, i.e., the first LJ matched to a certain SPC report (positive = LJ before SPC report)



LJ-to-SPC events (Tornado, Hail, Wind) correlation

Quantitative measures (scores)

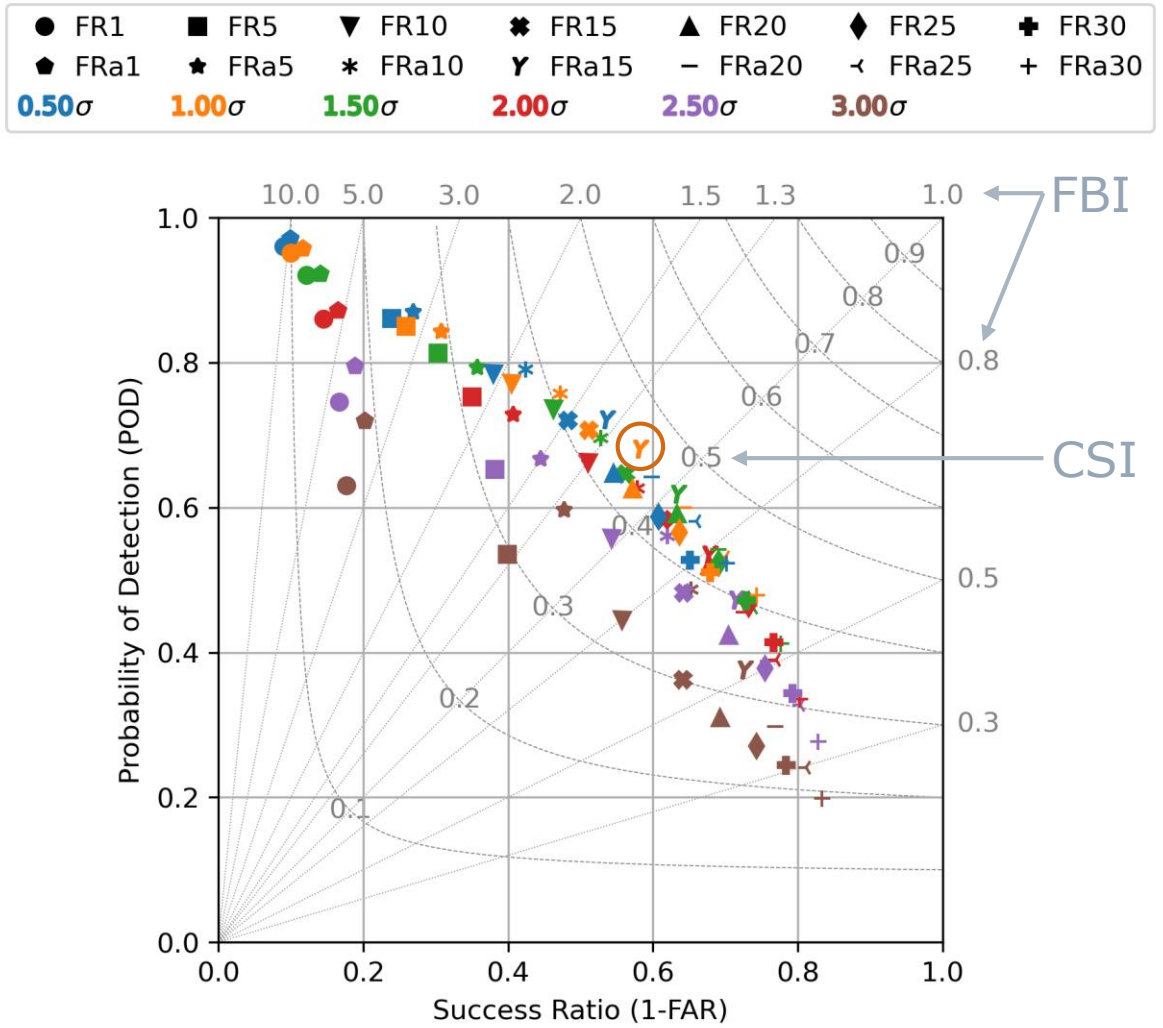
- Probability of Detection (POD) $= \frac{A}{A+C}$
- False Alarm Ratio (FAR) $= \frac{B}{B+A}$
- Frequency Bias Index (FBI) $= \frac{A+B}{A+C}$
- Critical Success Index (CSI) $= \frac{A}{A+B+C}$

LJs	SPC 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 SPC-LJ matching strategies (trajectory vs WED)

LJ algorithms for WED matching (1/3)

- FR | FRa and σ as variable algorithm thresholds
- Low σ and moderate FR thresholds yield most skill
- FRa more skill than FR (also seen for trajectory based matching)
- Overall higher skill than the trajectory based matching (CSI of 0.46 vs 0.39)

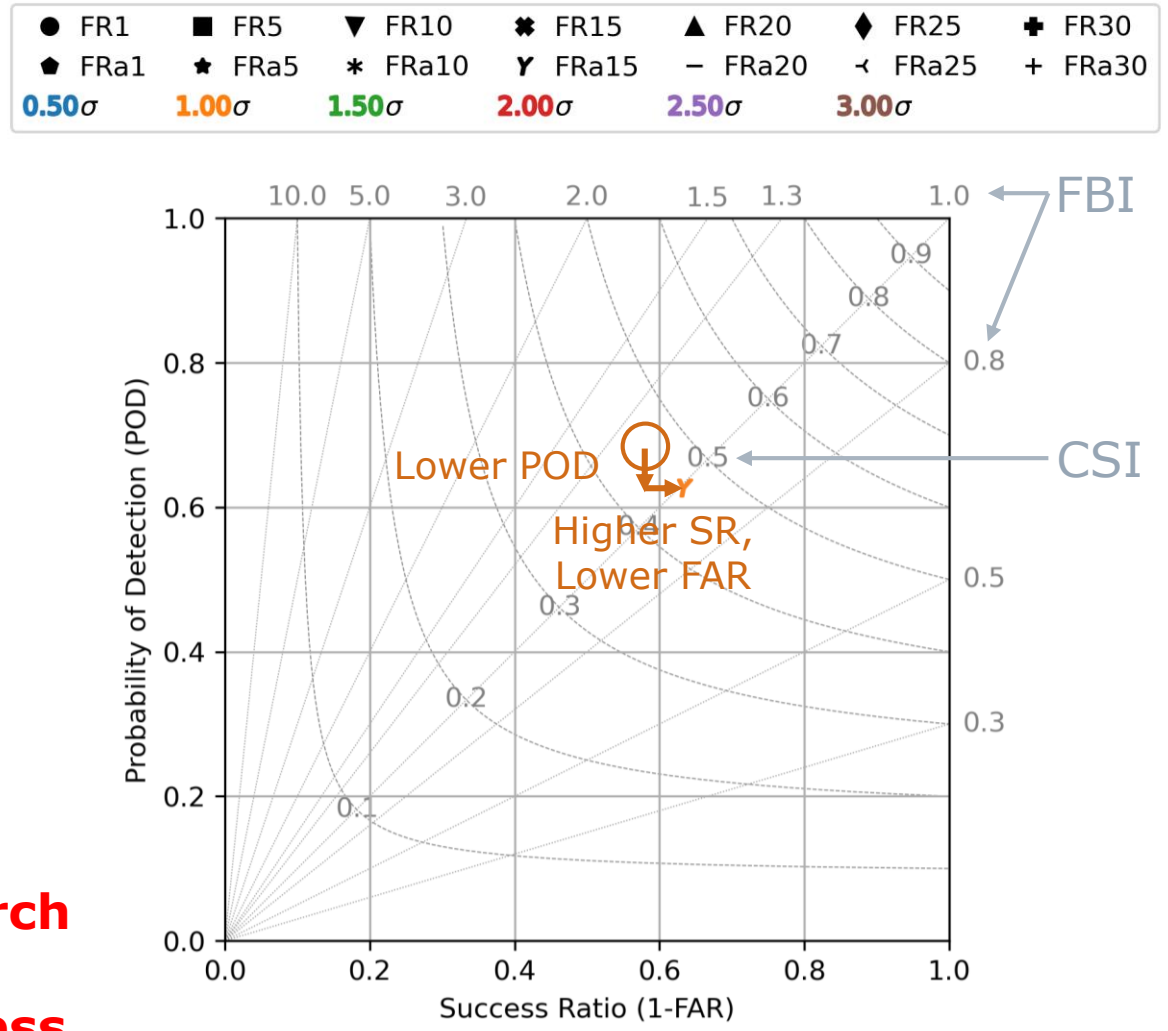


LJ algorithms for WED matching (2/3)

Adding Convective Rain Rate (CRR) and Overshooting Top (OT) thresholds

- FRa with FR 15, σ 1.0 threshold
- LJ filter: LJ needs CRR of at least 10mm or at least 1 OT (±20 min)
- Reduced POD: 0.68 to 0.63
- Reduced FAR: 0.42 to 0.37
- CSI remains the same: 0.46

Research in Progress



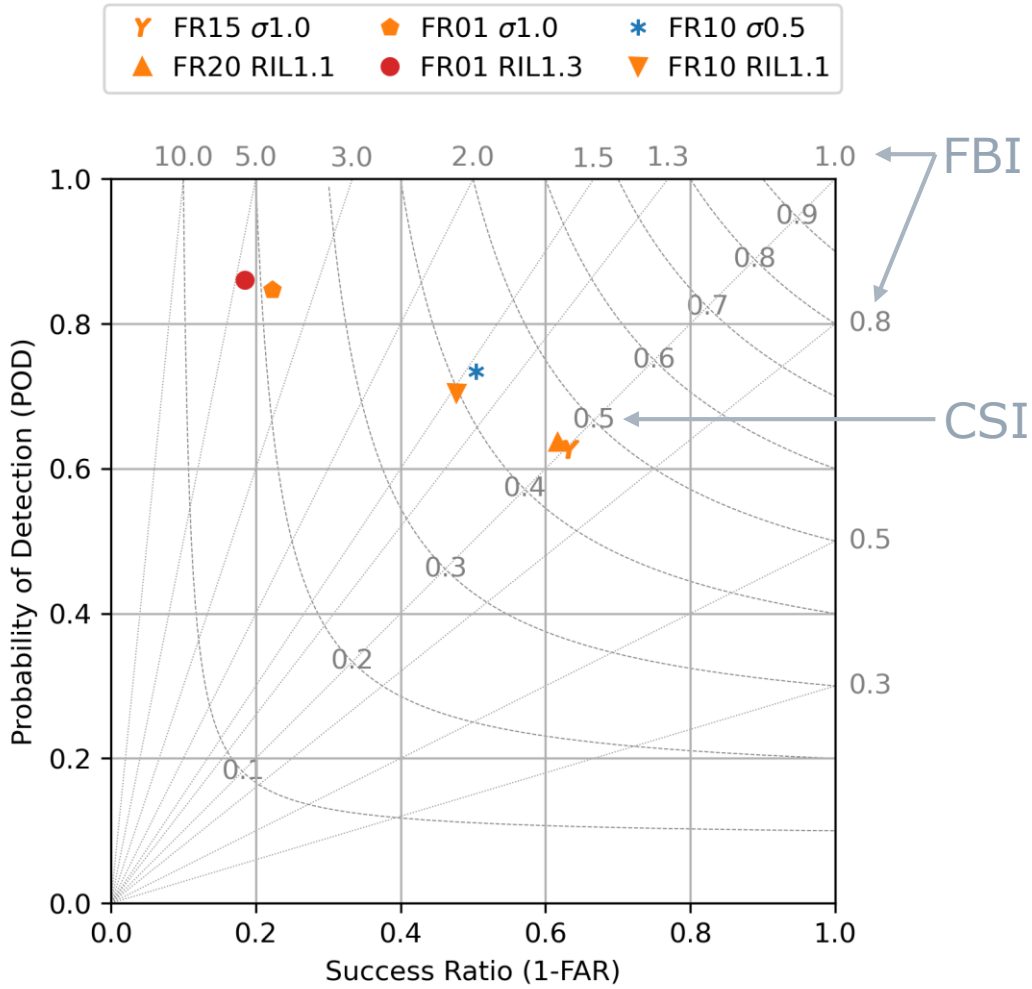
LJ algorithms for WED matching (3/3)

Adding CRR and OT thresholds

- LJ filter: LJ needs CRR of at least 10mm or at least 1 OT (±20 min)
- CSI for best LJ algorithms similar
- **Algorithms with low FR and low σ thresholds increased CSI**
- Research: higher CRR thresholds for LJ algorithms with relaxed criteria

→ Decrease FAR significantly while keeping higher POD

Research in Progress



Additional conclusions (not presented)

- Simple **Relative Increase Level (RIL) LJ algorithm with similar skill as the σ-based LJ algorithms**
- CSI skill: summer > overall > winter
- CSI skill: daytime > overall > nighttime

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

Summary

- **Automated** storm-tracking and detection of **GLM lightning jumps (LJs)**
- **LJ to SPC event leadtimes** from a few minutes to more than an hour
- **Flashes per cell area (FRa) approach** improves the original ***σ*-algorithm**
- **Recommended**: FRa σ-algorithm with thresholds for FR ≥ 15 flashes/min and $\sigma \geq 1.0$ OR RIL algorithm with FR ≥ 20 flashes/min and $\mathrm{RIL} \geq 1.1$
- **Current research**: Combine **satellite observed LJs with** other data, e.g., **convective rain rates (CRRs) and overshooting tops (OTs)**, to reduce FAR

THANK YOU

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

References

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Backup slides

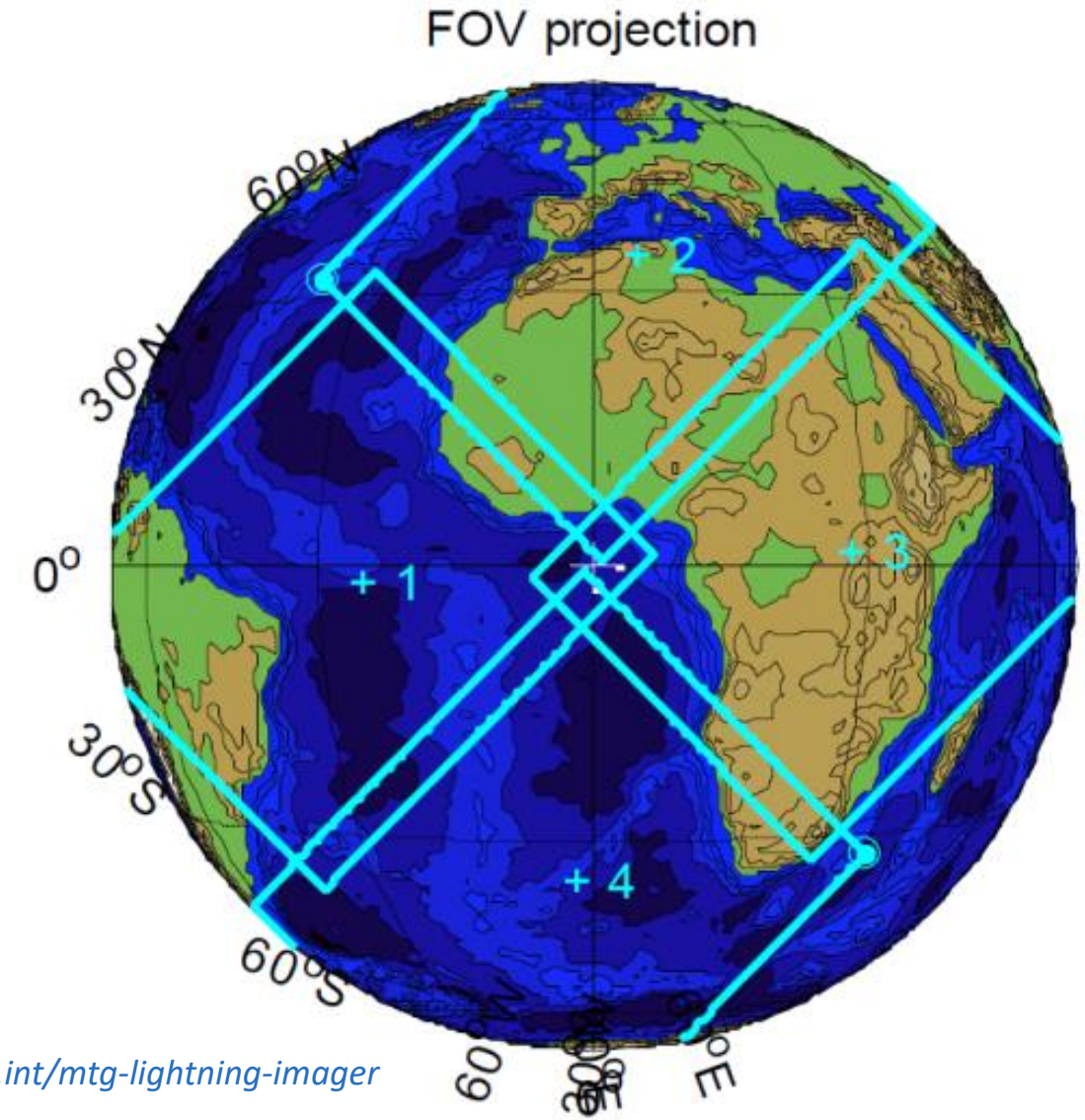
Geostationary satellite data

- GOES ABI and GLM imagery
- GOES-16 field of view limit to the CONUS
- 14 summer and 12 winter days in 2020 and 2021
- about 50,000 thunderstorms analyzed
- About 5% of the thunderstorm with LJ and/or SPC severe weather report
- **Most comprehensive analysis of** satellite observed **LJ algorithms** known

Excurse MTG-LI

MTG-LI key differences to GLM

- Field of View (FOV) includes Europe and Africa
- 4 camera images combined to final product
- 1ms time frames
- Spatial resolution 4.5km (nadir) [10km at 60° latitude]

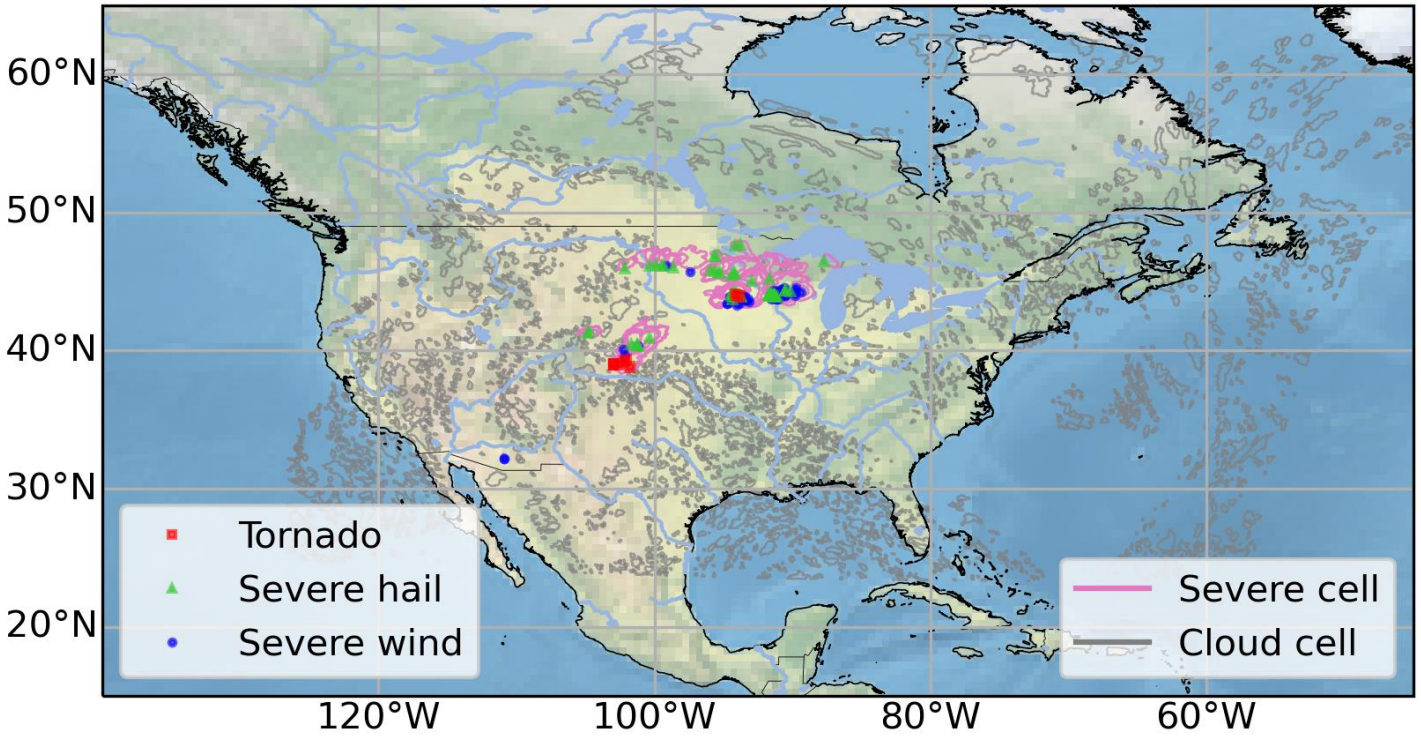


From https://www.eumetsat.int/mtg-lightning-imager

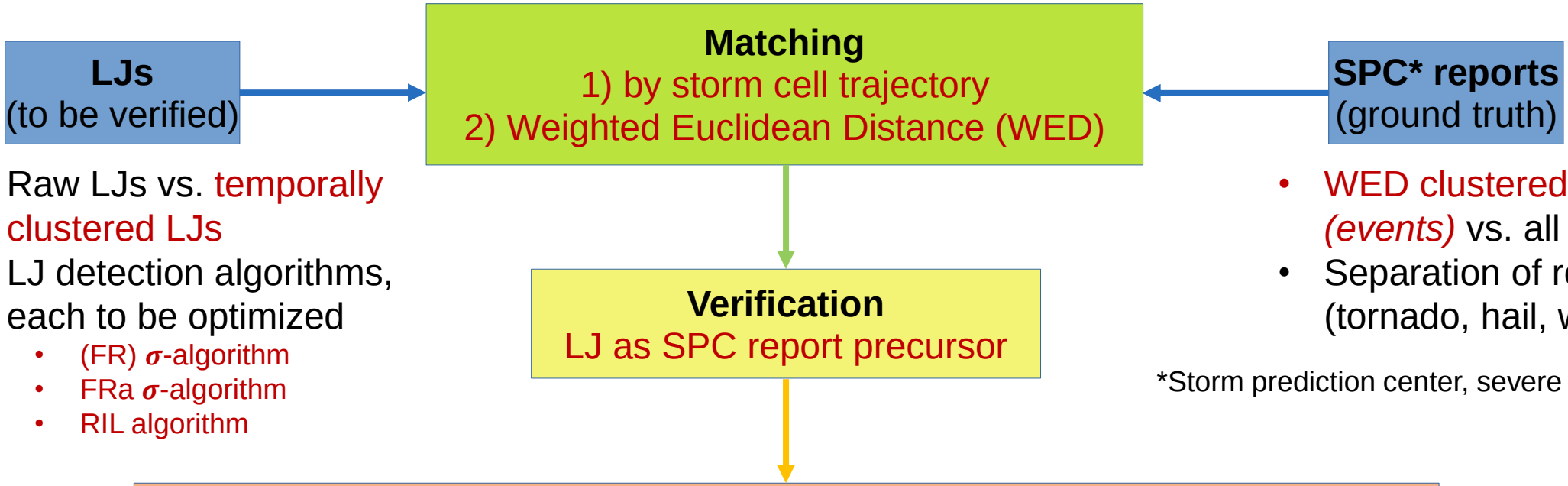
Matching of RDT cells and SPC reports

- SPC report within satellite scan interval (**10 minutes** for GOES-16) and **less than 50 km** from the cell contour matched to that cell
- 1 SPC report only matched to the closest cell at report time (often within the cell contour)
- SPC report not matched to any cloud = false report

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



Workflow and outcome variety



- Raw LJs vs. temporally clustered LJs
- LJ detection algorithms, each to be optimized
  - (FR) σ-algorithm
  - FRa σ-algorithm
  - RIL algorithm

- WED clustered reports *(events)* vs. all reports
- Separation of report types (tornado, hail, wind)

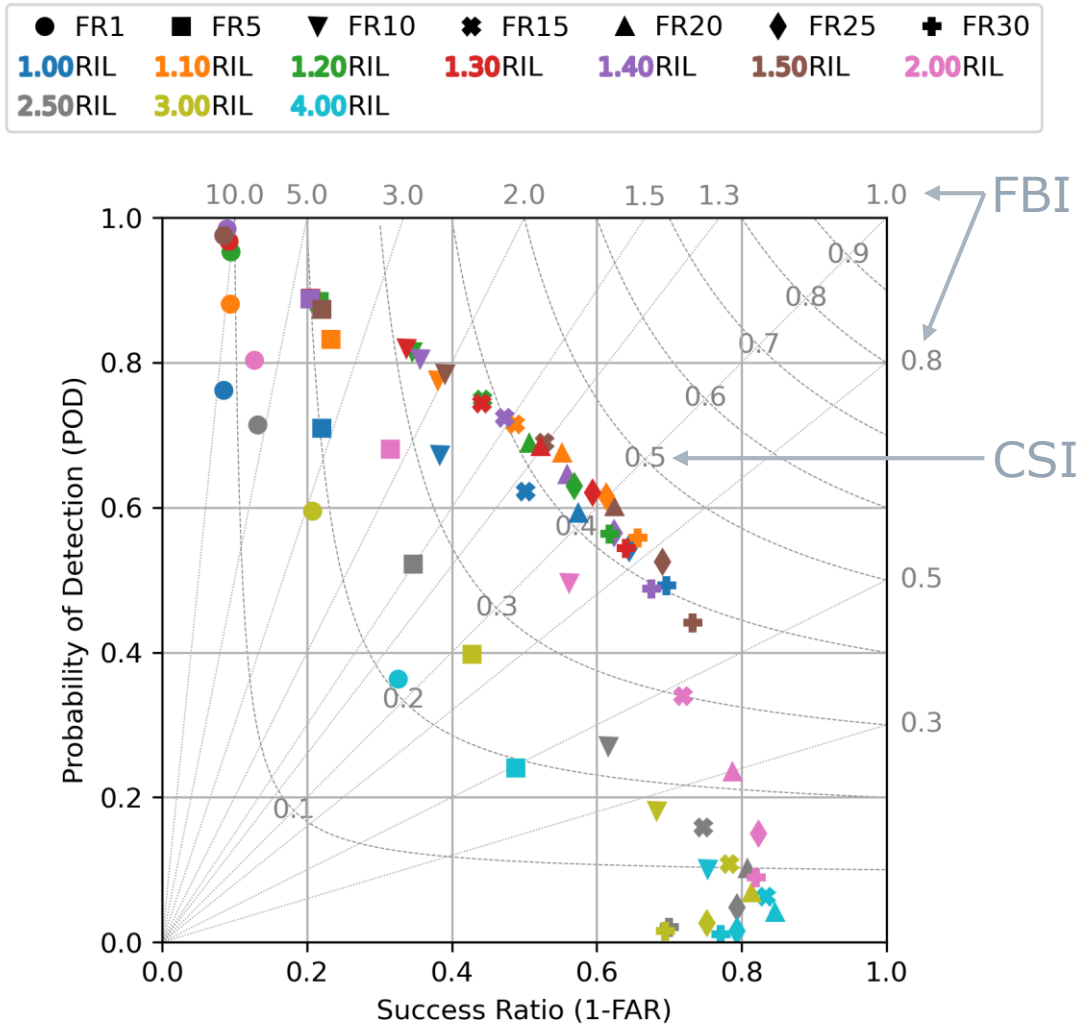
*Storm prediction center, severe weather archive

- Separate day | night
- Separate summer | winter

- False alarm (FA) assessment based on LJs or SPC reports

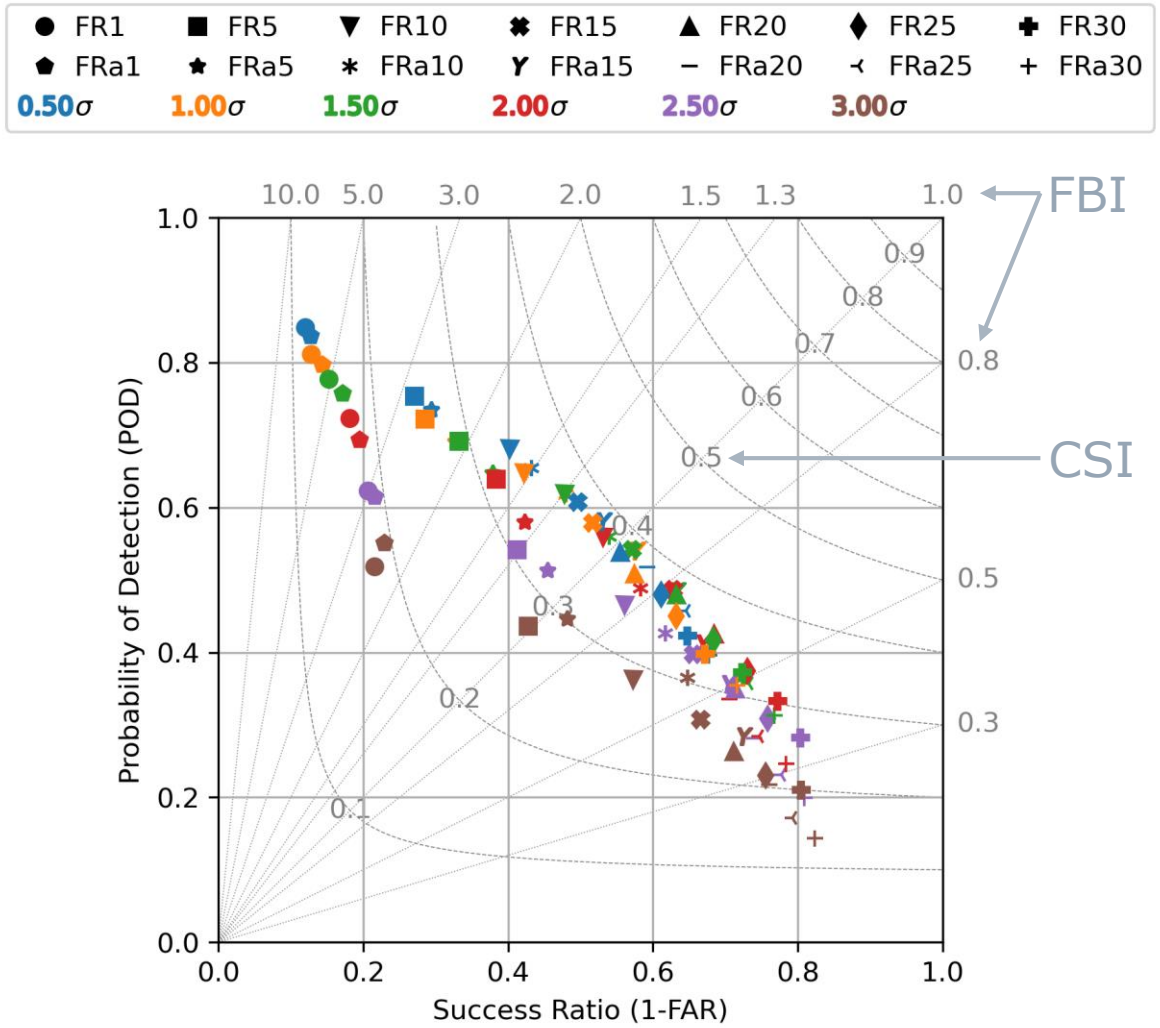
LJ algorithms for WED matching (4/3)

- FR and RIL as variable algorithm thresholds
- Low to medium RIL (1.1-1.5) and moderate FR thresholds of 20-25 yield most skill
- Best algorithms (CSI of 0.45) slightly better than for trajectory matching – consistent with σ-based LJ algorithms



LJ algorithms for trajectory matching (1/2)

- FR and σ as variable algorithm thresholds
- FR – original σ-algorithm
- FRa – flashes per cell area based σ-calculation
- Slight advantage, higher POD with lower FAR, higher CSI, for FRa
- Low σ with moderate FR threshold of 15 best (CSI of 0.39)



LJ algorithms for trajectory matching (2/2)

- FR and RIL as variable algorithm thresholds
- Best algorithm (CSI of 0.40) for low RIL (1.1) and moderate FR of 20
- Slightly better performance than both σ-based LJ algorithms (!)