Koninklijk Meteorologisch Instituut

Institut Royal Météorologique

Königliches Meteorologisches Institut

Royal Meteorological Institute

European Lightning Detection Workshop (ELDW)
Valencia, Spain, 15 November 2023

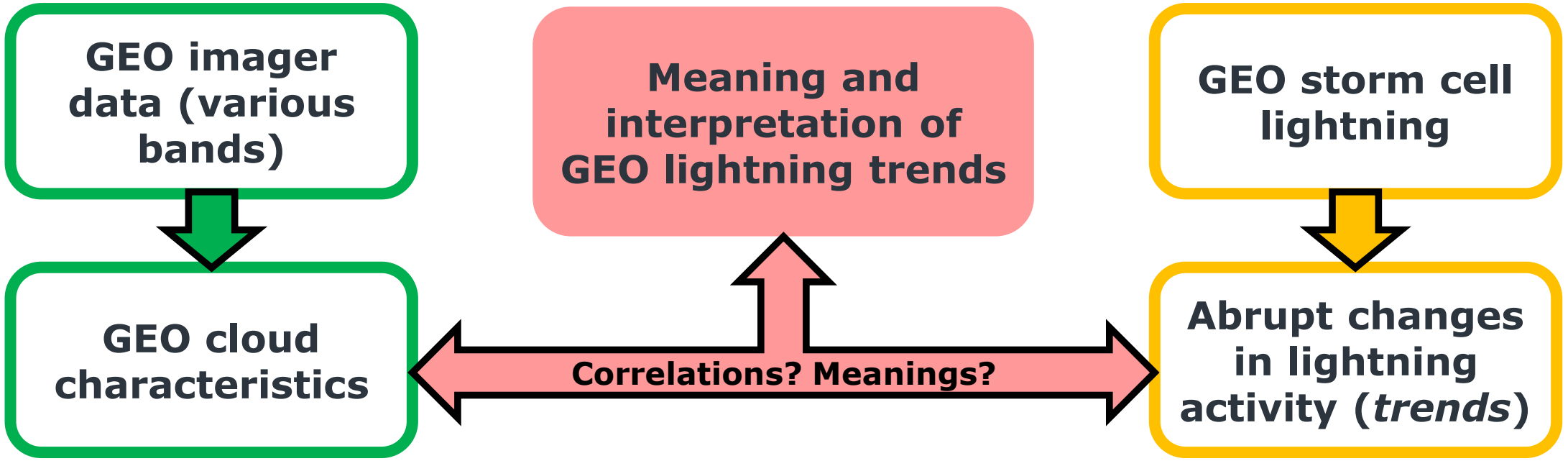
Lightning trends and related thunderstorm characteristics in satellite-based nowcasting

Felix Erdmann (EUMETSAT fellow)

Dieter Poelman

Introduction and Motivation

- **Meteosat Third Generation (MTG)** launched in December – Flexible Combined Imager (FCI) and Lightning Imager (LI)
- **Geostationary (GEO)** satellites (GOES-R series, Fengyun-4, MTG) for continuous **cloud characteristics** and **lightning locations**

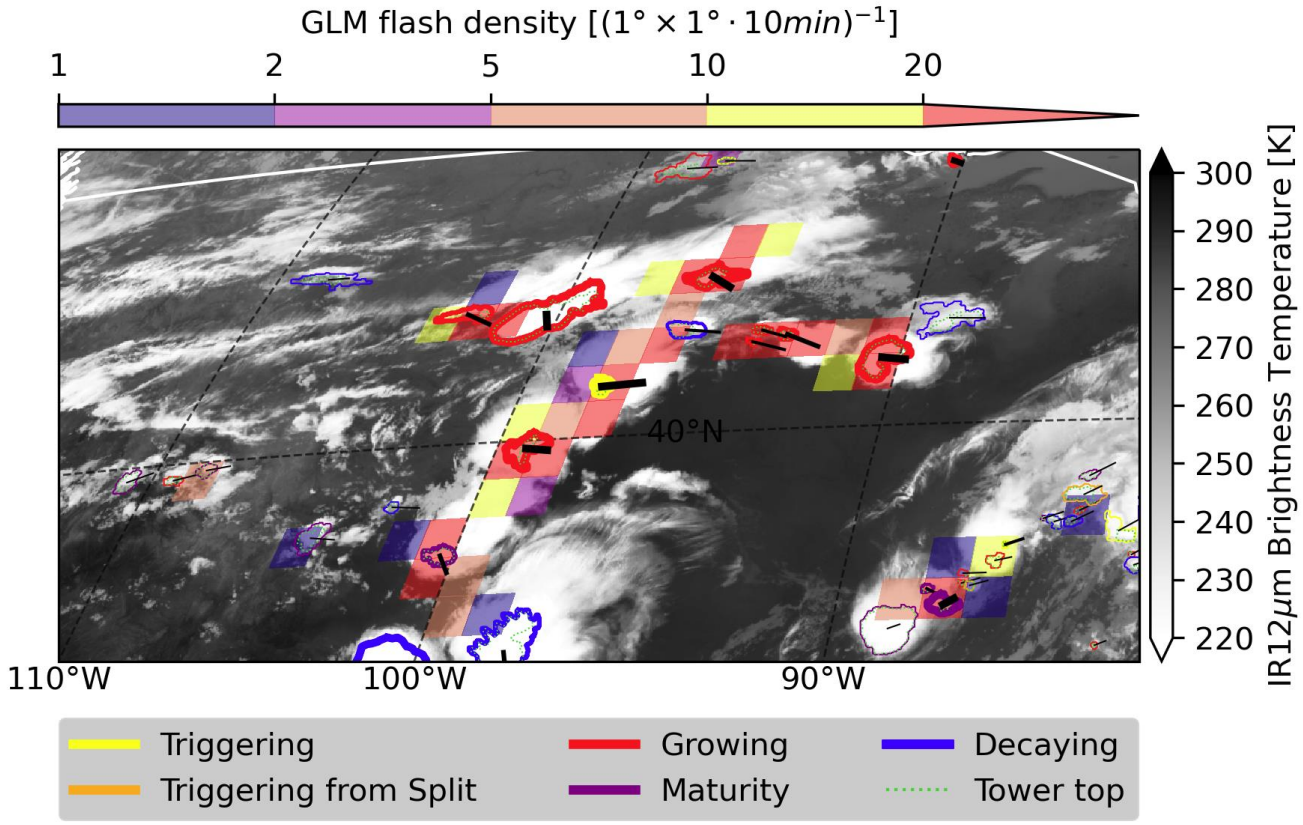


Methods

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 cloud cells
- **Cloud cell characteristics and GEO lightning**
- **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)



Contact: felix.erdmann@meteo.be

Data and methods

- 14 summer, 3 spring, 2 fall, and 10 winter days in 2020 and 2021 with **about 25,000 thunderstorms in the CONUS** analyzed
- **GOES-16** Advanced Baseline Imager (**ABI**) and Geostationary Lightning Mapper (**GLM**) observations
- ECMWF Numerical Weather Prediction (**NWP**) data and National Centers for Environmental Information (**NCEI**) **severe weather reports**
- Automated detection of **Lightning Jumps (LJs)** / **Lightning Dives (LDs)**
- **Cloud cell characteristics**: ABI channels and physical characteristics
- **Cloud cell categories**: distinguish cloud cells based on occurrence of GLM lightning (identify thunderstorms), NCEI reports, LJs, and LDs

Workflow

ABI data

NWP data

GLM lightning

NWCSAF cloud cells

Lightning jumps/dives

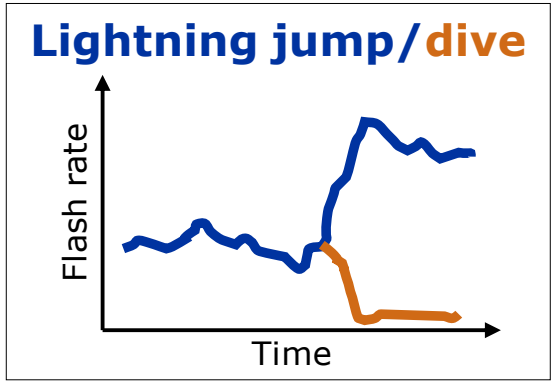
NCEI severe weather reports

Cloud cell characteristics

Evaluation

Cloud cell categories

Results



Contact: felix.erdmann@meteo.be

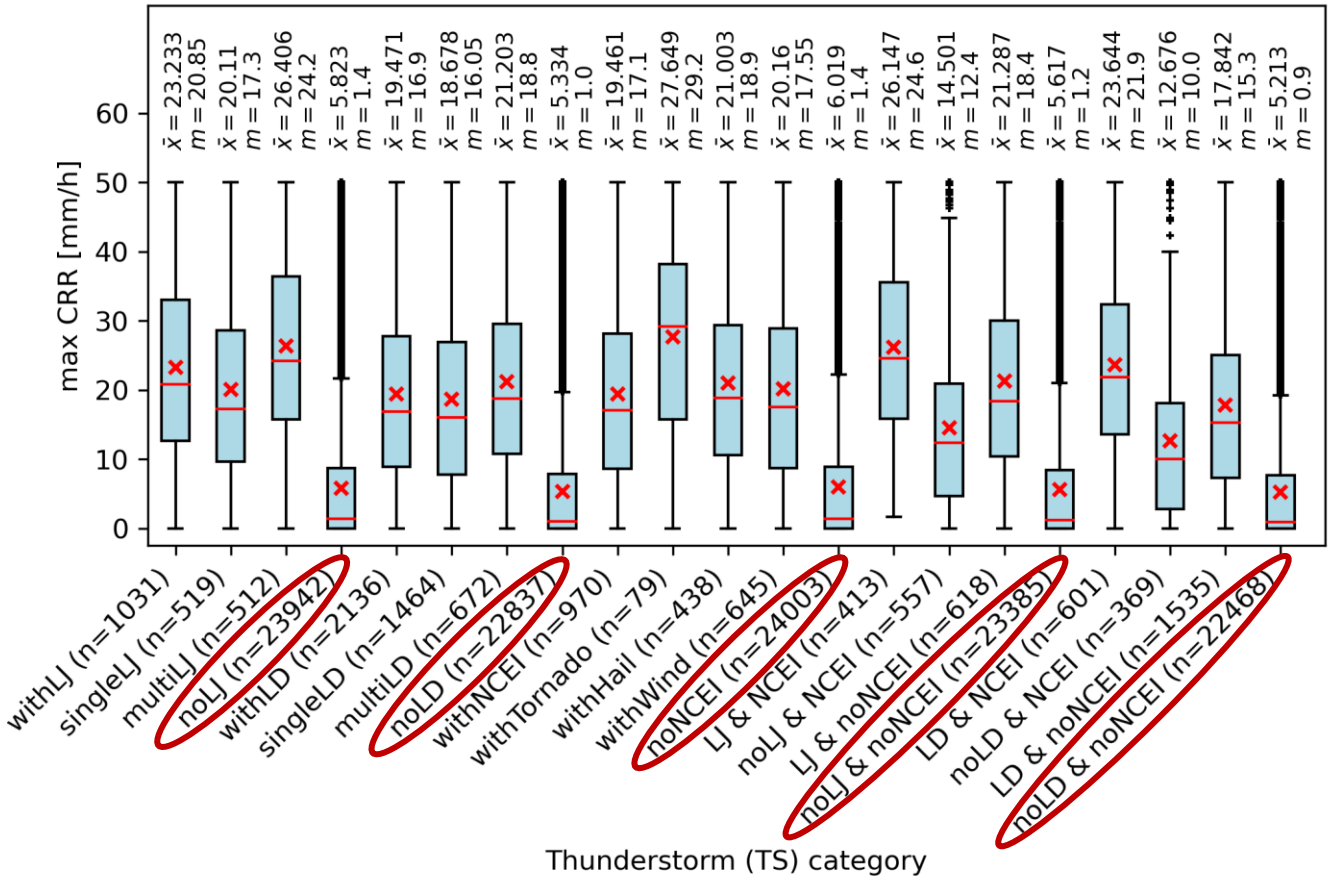
Results overall
- Storm categories

Contact: felix.erdmann@meteo.be

Ex.: Max convective rain rate (CRR)

- Comparison of **thunderstorm** categories
- **High CRR** most likely for cloud cells with **LJs, LDs and/or severe weather events (NCEI)**
- Multi LJ storms with higher CRR than single LJ storms
- LD count with low correlation to max CRR

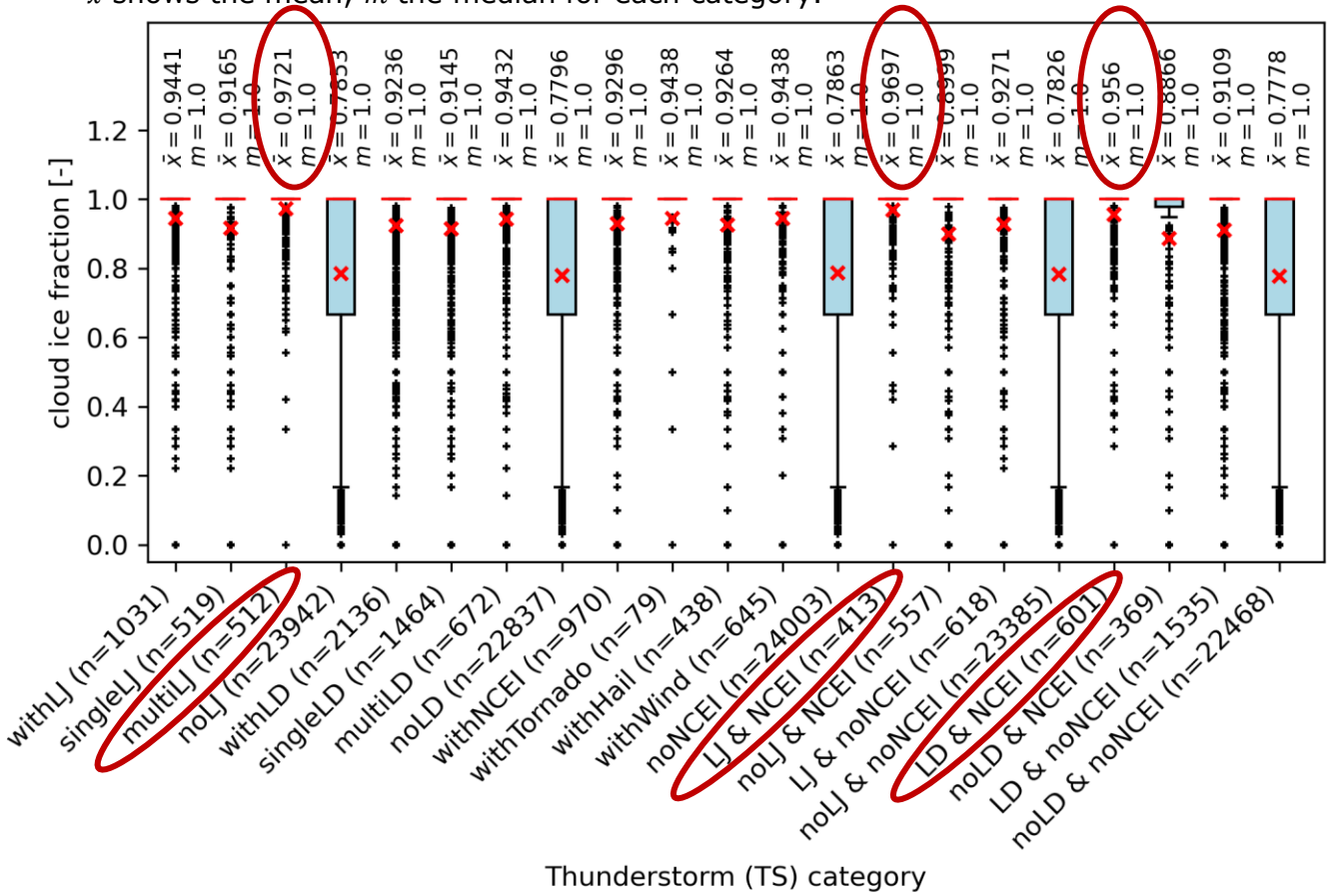
Fig.: Maximum estimated CRR during the cell lifecycle for thunderstorm cell categories. $\bar{x}$ shows the mean, m the median for each category.



Ex.: Cloud ice fraction

- Comparison of **thunderstorm** categories
- **Full ice cloud tops** most likely for cloud cells with **multiple LJs, and for LJ/LD with severe weather (NCEI)**
- Lowest cloud ice fractions for thunderstorms without LJ, LD, and/or severe weather

Fig.: Fraction of pure ice satellite pixels to mixed-phase and liquid water pixels. $\bar{x}$ shows the mean, m the median for each category.

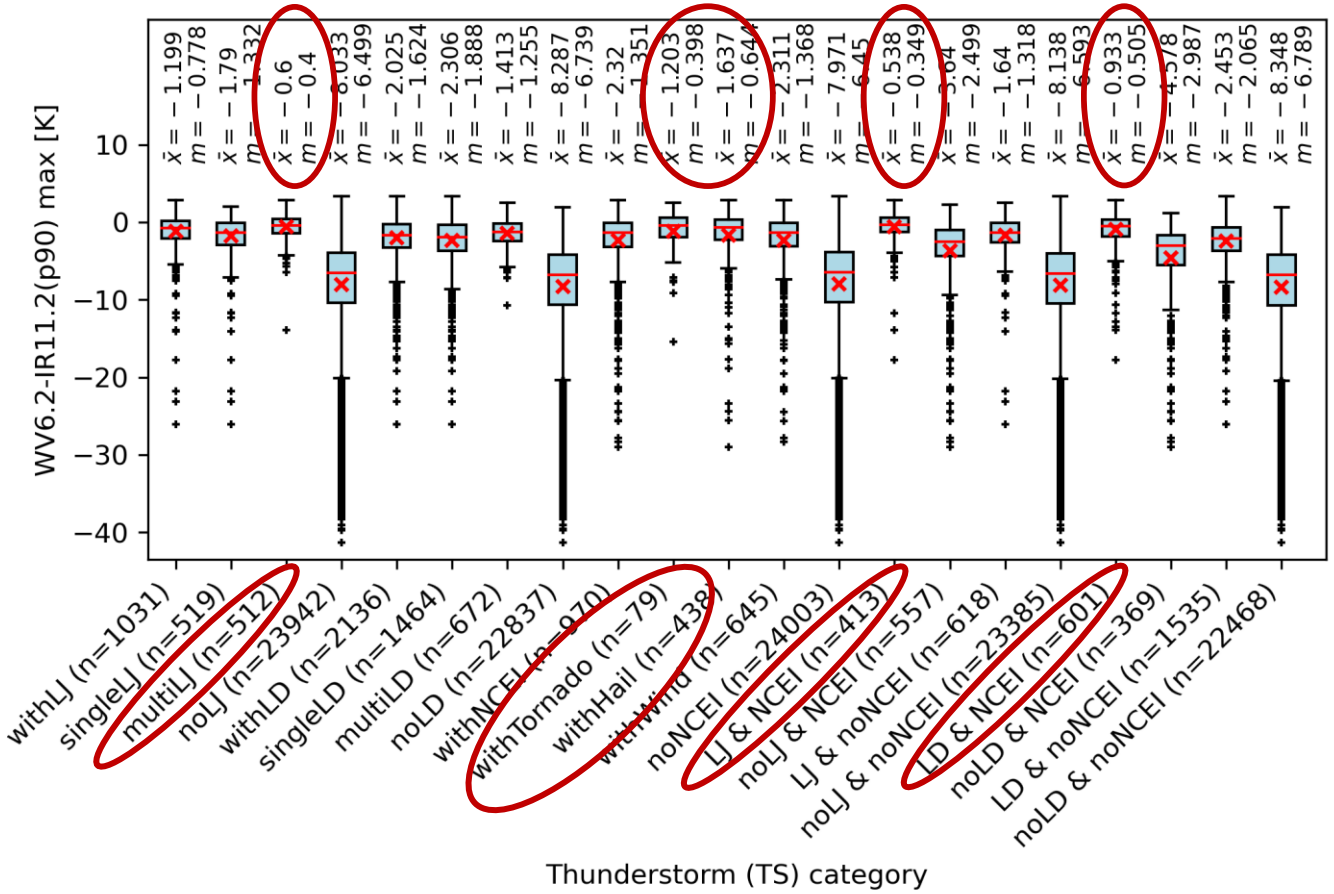


Contact: felix.erdmann@meteo.be

Ex.: WV6.2-IR11.2 (trajectory max of cell 90th percentiles)

- Brightness temperature difference (BTD)
- WV6.2: upper troposphere WV (~340mb)
- IR11.2: cloud top height
- **small negative values and positive values mean high cloud tops in moist upper troposphere**

Fig.: Brightness temperature difference (BTD) of WV6.2-IR11.2. The maximum of the 90th percentiles BTD for each time step during the cloud cell lifecycle for thunderstorm cell categories. $\bar{x}$ shows the mean, m the median for each category.

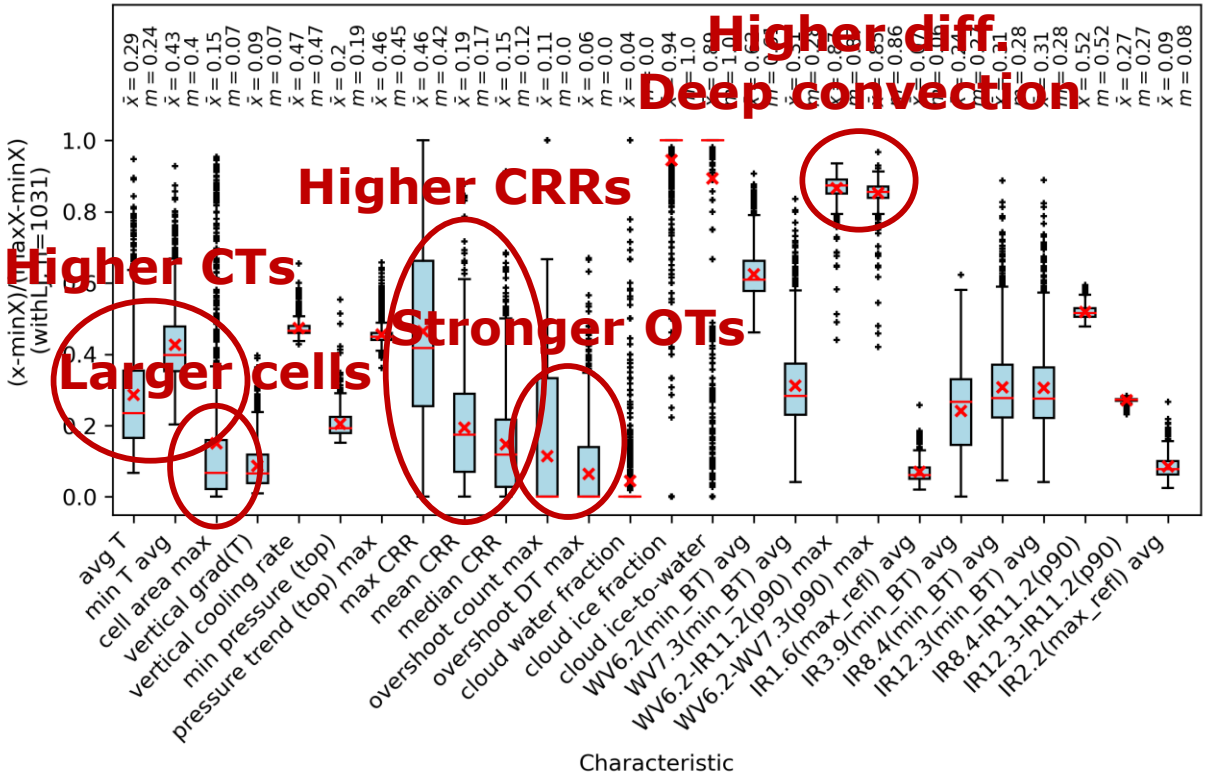


Results details – LJs

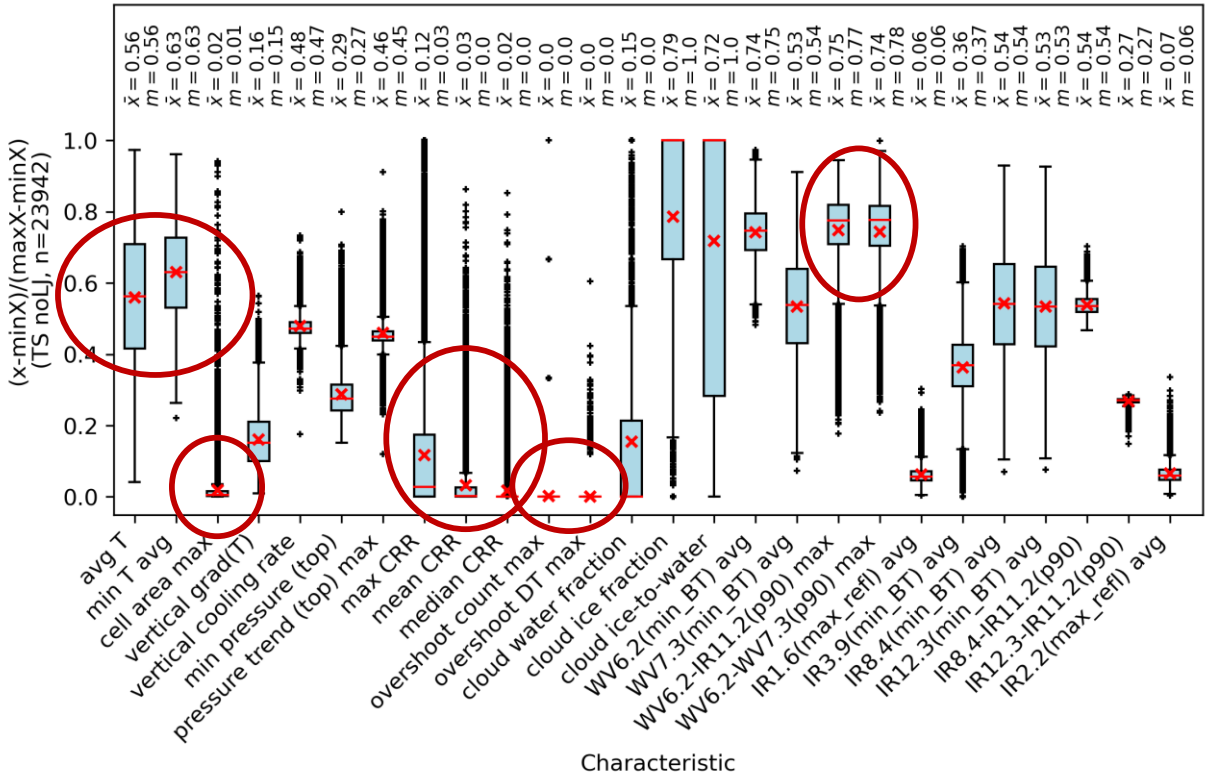
- Normalized characteristics: **range 0 to 1**
- Normalization based on overall minimum and maximum
  → **compare different categories**

Cloud cell characteristics – LJ vs no LJ

With LJ

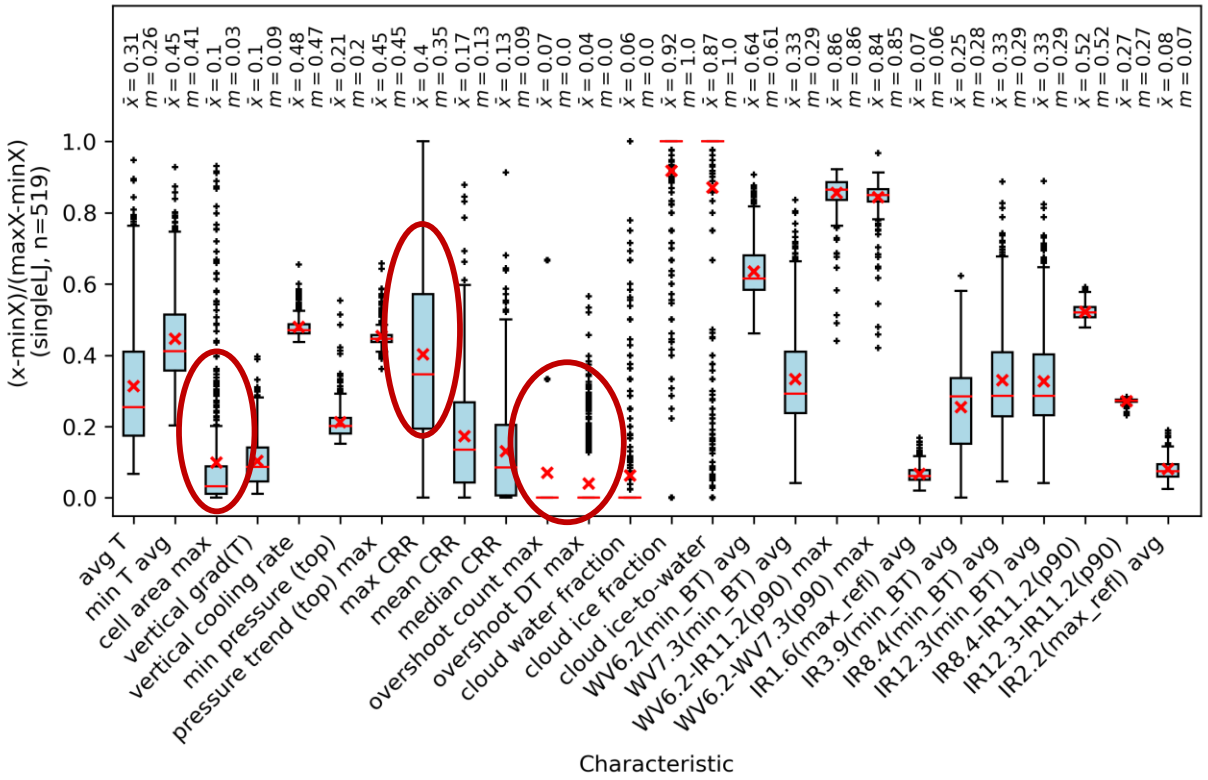


Thunderstorm no LJ

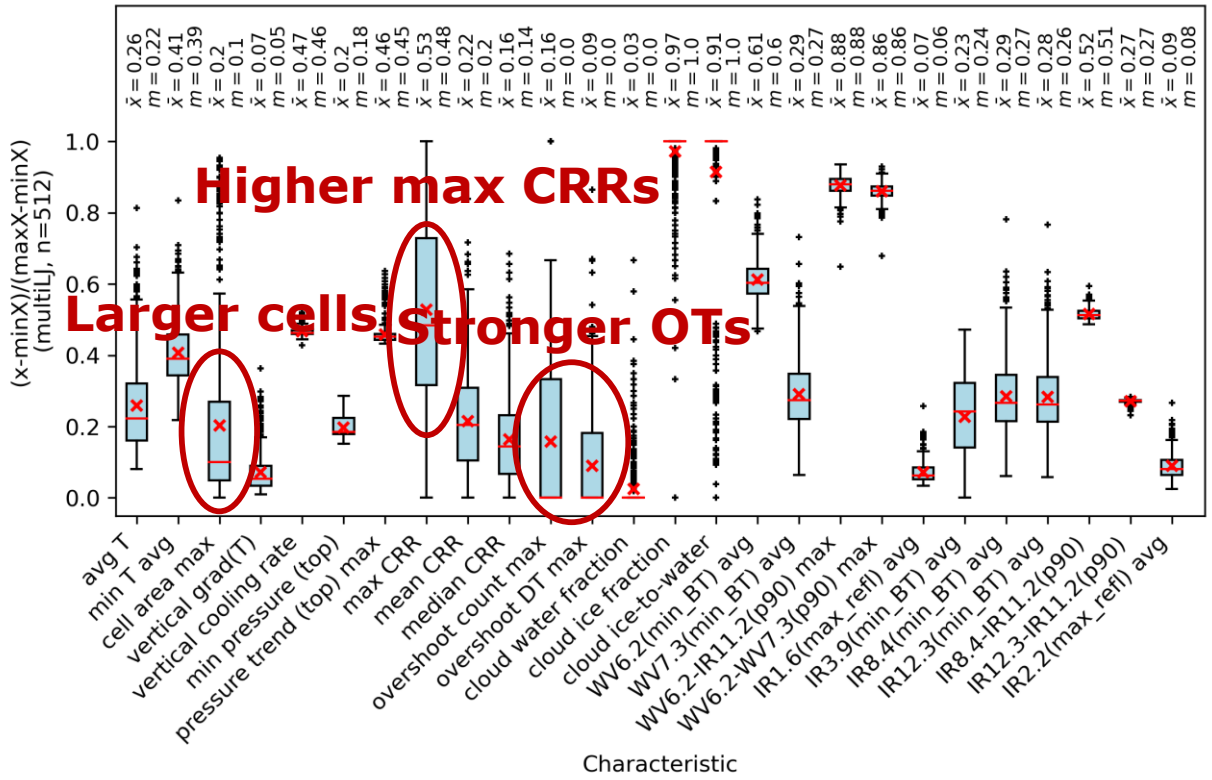


Single LJ vs multiple LJs

Single LJ



Multiple LJs



Summary

- Cloud cell categorization through GLM lightning trends (LJs, LDs) and NCEI severe weather reports
- Satellite-based physical cloud cell characteristics
- **LJs, LDs**: Indication of well organized, **deep convection, high rain rates**
- **Multiple LJs**: Above-average overshooting top count and strength → **correlation with updraft strength**
- Cloud cells with **LJs** and/or **LDs**: similar characteristics as cloud cells that produced **severe weather**
- **Next:** paper on recent results

Contact: felix.erdmann@meteo.be

THANK YOU

The Royal Meteorological Institute

Het Koninklijk Meteorologisch Instituut

L'Institut Royal Météorologique

Das Königliche Meteorologische Institut

The RMI provides reliable public service realized by empowered staff and based on research, innovation and continuity.

Het KMI verleent een betrouwbare dienstverlening aan het publiek en de overheid gebaseerd op onderzoek, innovatie en continuïteit.

L'IRM fournit un service fiable basé sur la recherche, l'innovation et la continuité au public et aux autorités.

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

Contact: felix.erdmann@meteo.be

References

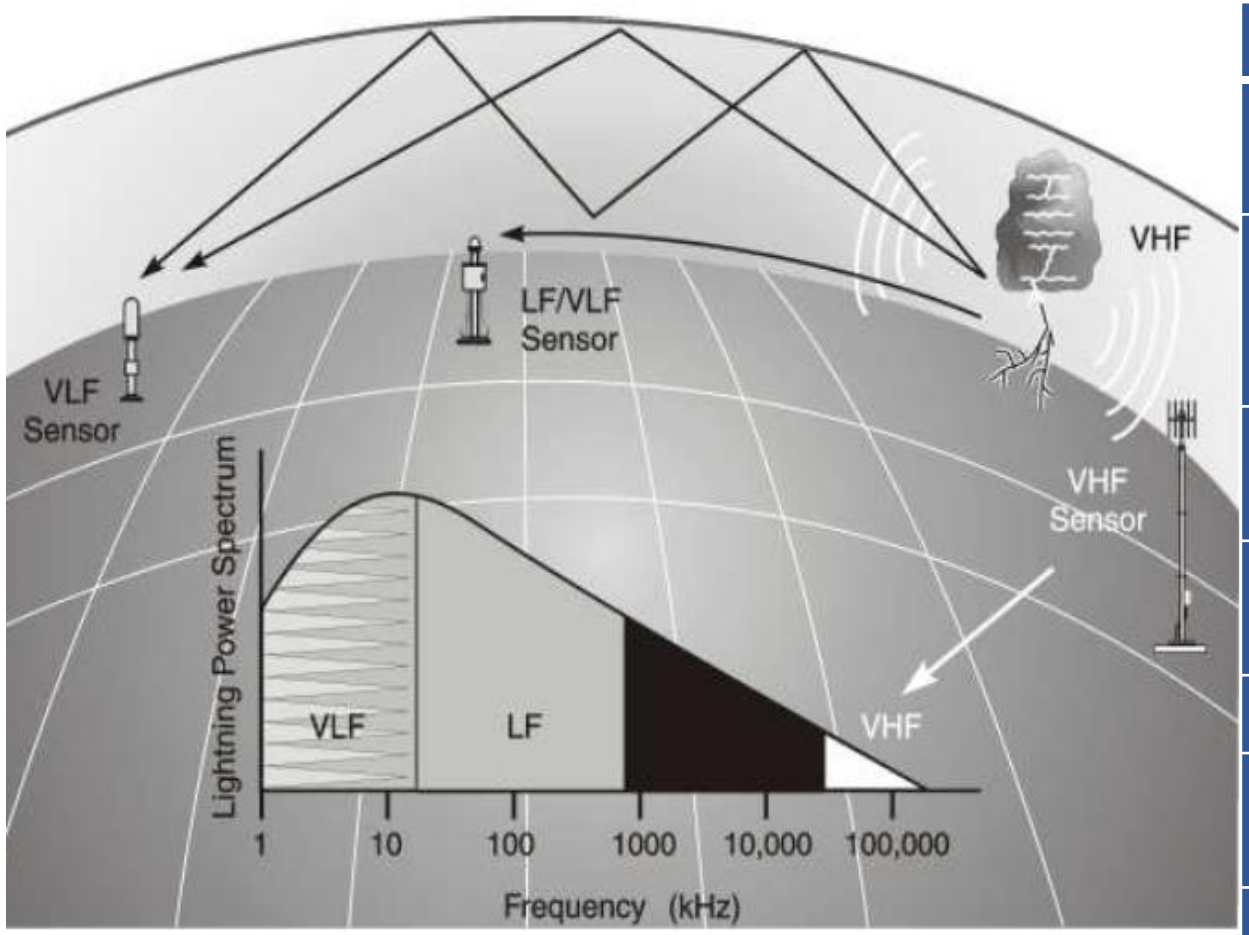
- Cummins, K. L. and M. J. Murphy, 2009: An overview of lightning locating systems: history, techniques, and uses, with an in-depth look at the U.S. NLDN. IEEE Trans. Electromag. Compat., 51(3), 499–518. doi: 10.1109/TEMC.2009.2023450 (cit. on pp. 3, 7, 35, 37, 39–40).
- Cummins, Kenneth L. (2021): On the spatial and temporal variation of GLM flash detection efficiency and how to manage it, AMS Annual Meeting 2021, extended abstract to poster 692.
- Erdmann, F., and D. R. Poelman, 2023: Automated Lightning Jump (LJ) detection from geostationary satellite data. J. Appl. Meteor. Climatol., https://doi.org/10.1175/JAMC-D-22-0144.1, in press.
- Gatlin, P. N., and S. J. Goodman (2010): A Total Lightning Trending Algorithm to Identify Severe Thunderstorms. *Journal of Atmospheric and Oceanic Technology*, *27*(1), 3-22. doi: 10.1175/2009JTECHA1286.1.
- Goodman, S. J., R. J. Blakeslee, W. J. Koshak, D. Mach, J. Bailey, D. Buechler, L. Carey, C. Schultz, M. Bateman, E. McCaul, and G. Stano (2013): The GOES-R Geostationary Lightning Mapper (GLM). Atmospheric Research, 125-126, 34 –49. issn: 0169-8095. doi: 10.1016/j.atmosres.2013.01.006.
- Goodman, S.J., R. Blakeslee, H. Christian, W. Koshak, J. Bailey, J. Hall, E. McCaul, D. Buechler, C. Darden, J. Burks, T. Bradshaw, P. Gatlin (2005): The North Alabama Lightning Mapping Array: Recent severe storm observations and future prospects, Atmospheric Research, 76(1–4), p. 423-437. ISSN 0169-8095. doi: 10.1016/j.atmosres.2004.11.035.
- Mach, D. M. (2020): Geostationary lightning mapper clustering algorithm stability. Journal of Geophysical Research: Atmospheres, 1255. doi: 10.1029/2019JD031900.
- Schultz, C. J., W. A. Petersen, and L.D. Carey (2009). Preliminary Development and Evaluation of Lightning Jump Algorithms for the Real-Time Detection of Severe Weather, *Journal of Applied Meteorology and Climatology*, *48*(12). doi:10.1175/2009JAMC2237.1.
- Schultz, E. V., Schultz, C. J., Carey, L. D., Cecil, D. J., & Bateman, M. (2016). Automated Storm Tracking and the Lightning Jump Algorithm Using GOES-R Geostationary Lightning Mapper (GLM) Proxy Data. *Journal of operational meteorology*, *4*(7), 92–107. doi: 10.15191/nwajom.2016.0407.
- Williams, E., B. Boldi, A. Matlin, M. Weber, S. Hodanish, D. Sharp, S. Goodman, R. Raghavan, and D. Buechler (1999): The behavior of total lightning activity in severe Florida thunderstorms. Atmospheric Research, 51(3–4), p. 245-265. ISSN 0169-8095. doi: 10.1016/S0169-8095(99)00011-3.

Backup slides

Basics

Lightning electromagnetic spectrum

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



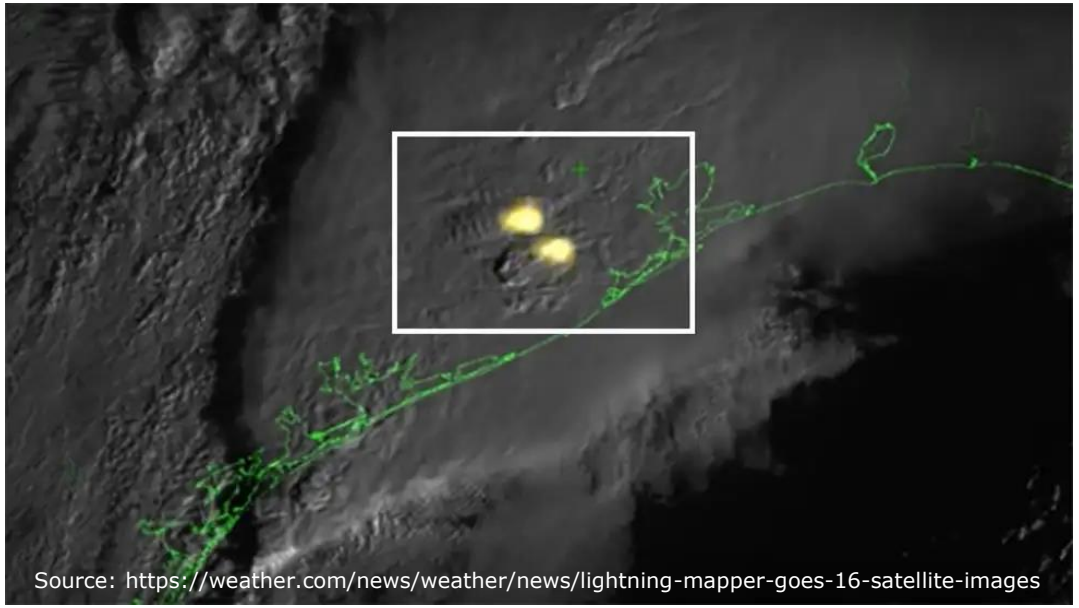
Adapted from Cummins et al. (2009)

	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

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)



Animation: https://youtu.be/Jcx7gv-LaKs

Contact: felix.erdmann@meteo.be

My previous work

Dataset

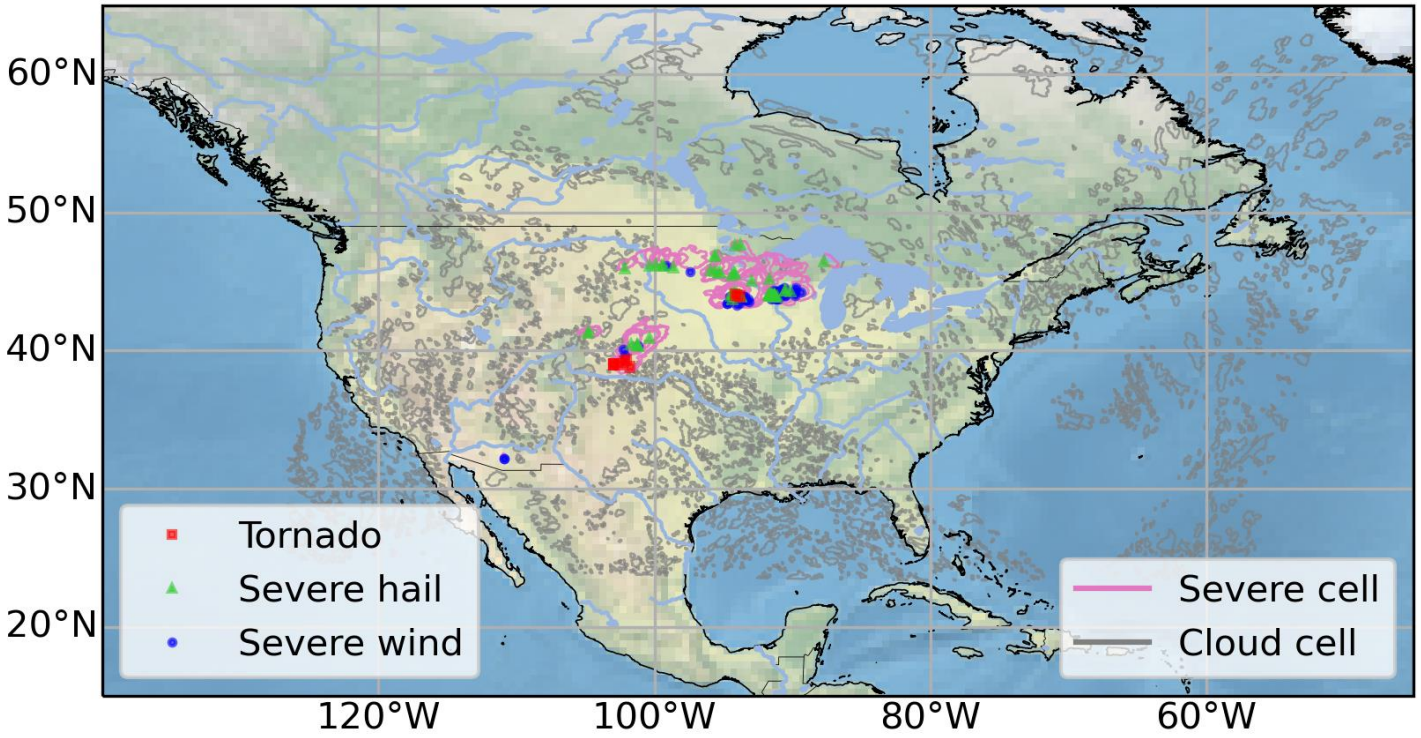
- GOES ABI and GLM imagery
- GOES-16 field of view limit to the CONUS
- National Centers for Environmental Information (NCEI) weather report archive → ground truth + verification of LJs
- 14 summer, 3 spring, 2 fall, and 10 winter days in 2020 and 2021
- 2.4 Million cells, **about 25,000 thunderstorms in CONUS** analyzed
- About 5% of the thunderstorms with LJ and/or NCEI severe weather report
- **Most comprehensive analysis of** satellite observed **LJs/LDs** known

Contact: felix.erdmann@meteo.be

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)



Contact: felix.erdmann@meteo.be

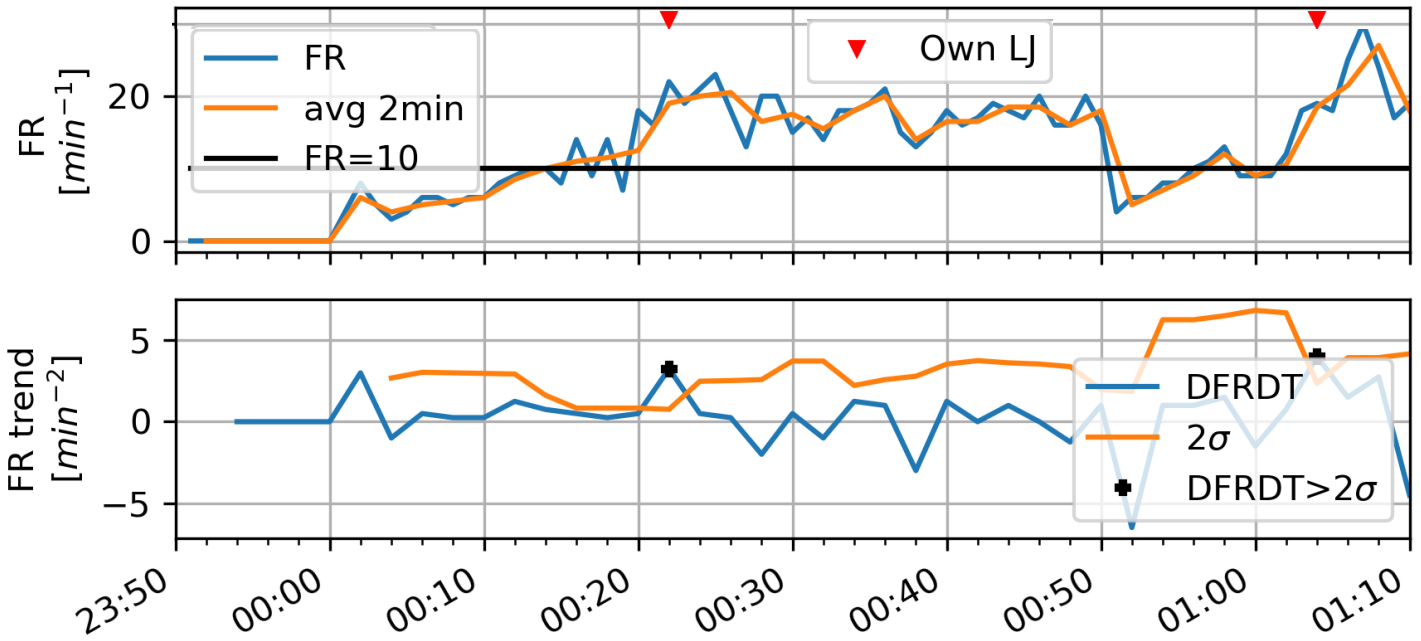
Automated Lightning Jump (LJ) detection

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)



Contact: felix.erdmann@meteo.be

LJ algorithms [Erdmann and Poelman (2023)]

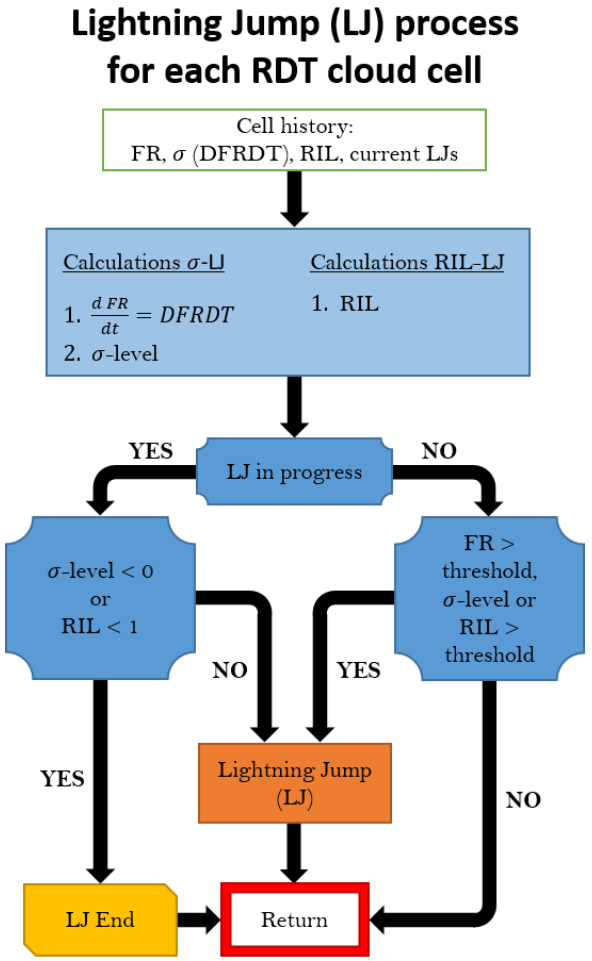
Sigma LJ algorithm

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



RIL LJ algorithm

Certain flash rate needed

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

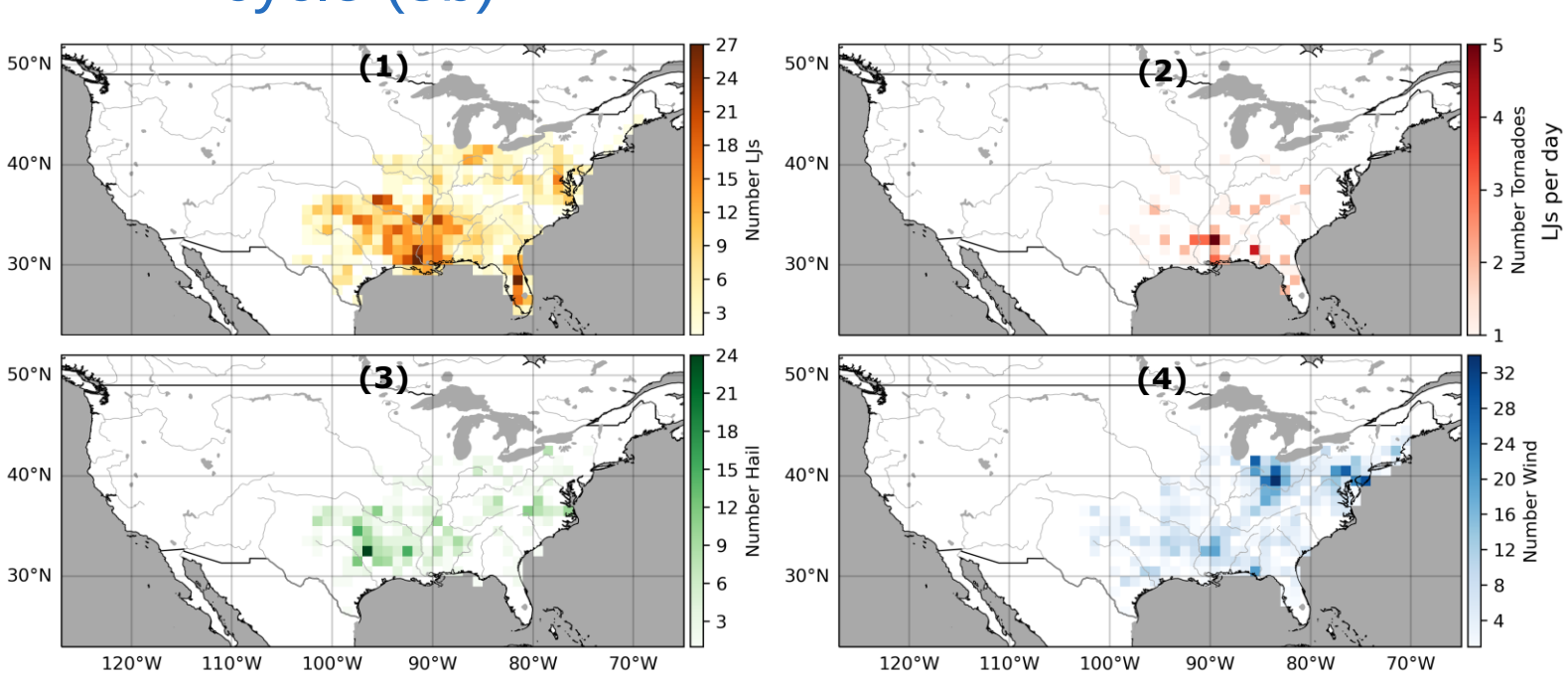
with the Relative Increase Level (RIL), and the Flash Rate (FR) as a function of time

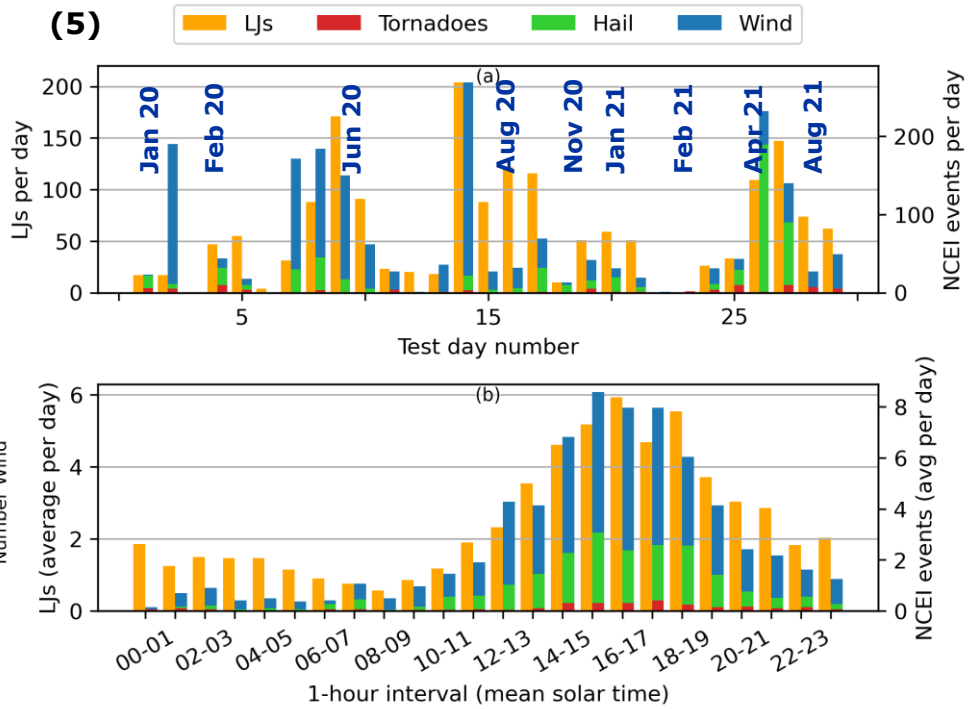
Current RIL $> x$ means a LJ (x is a threshold)

Contact: felix.erdmann@meteo.be

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)

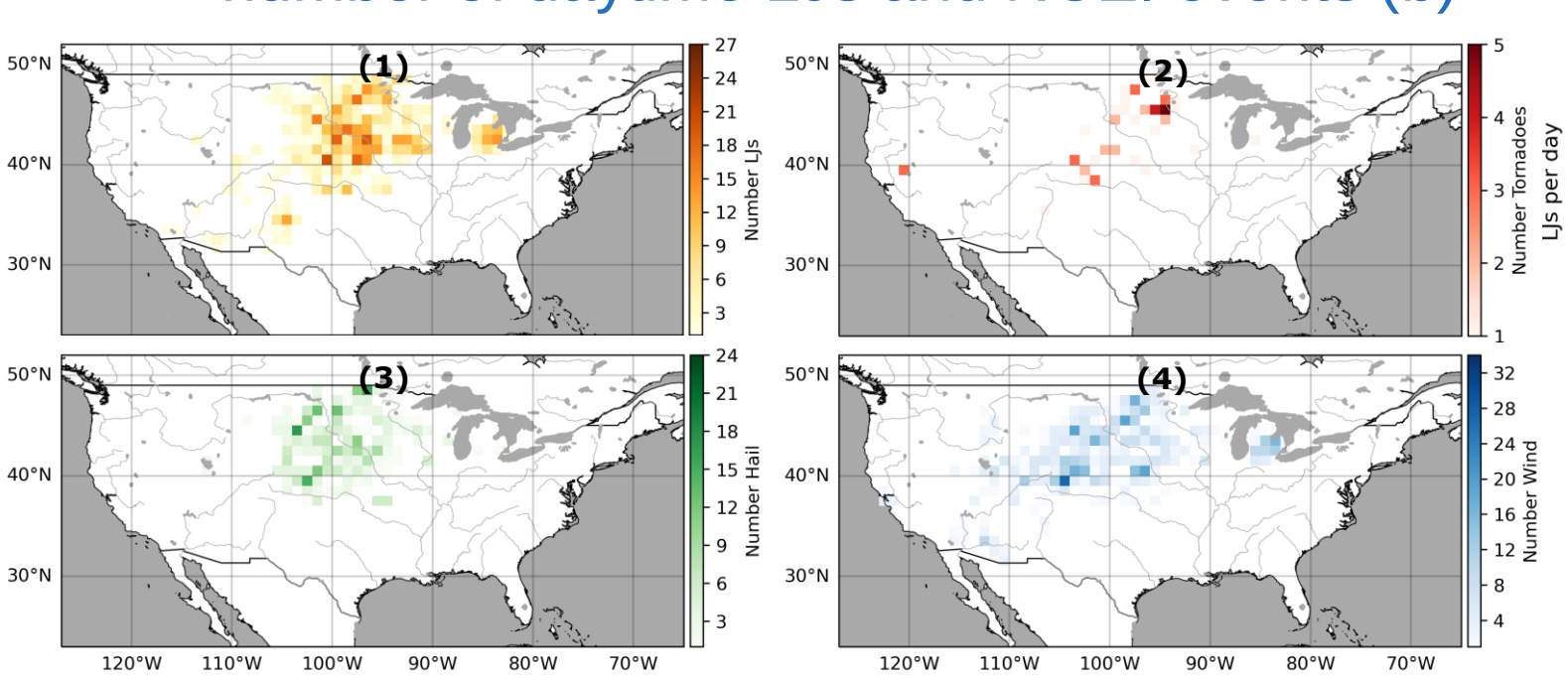


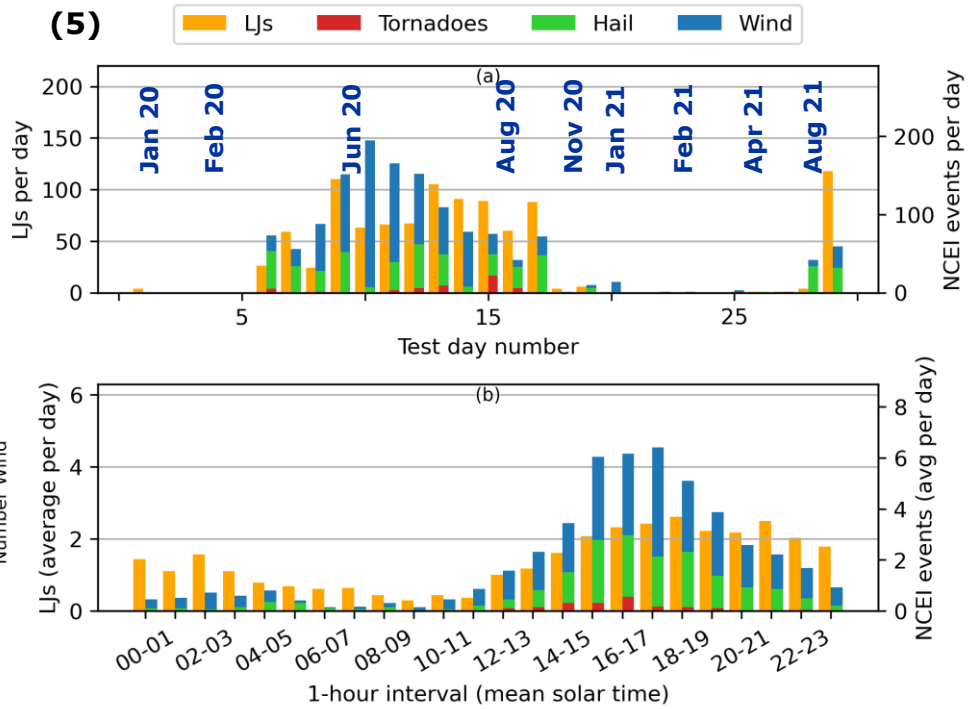


Contact: felix.erdmann@meteo.be

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)

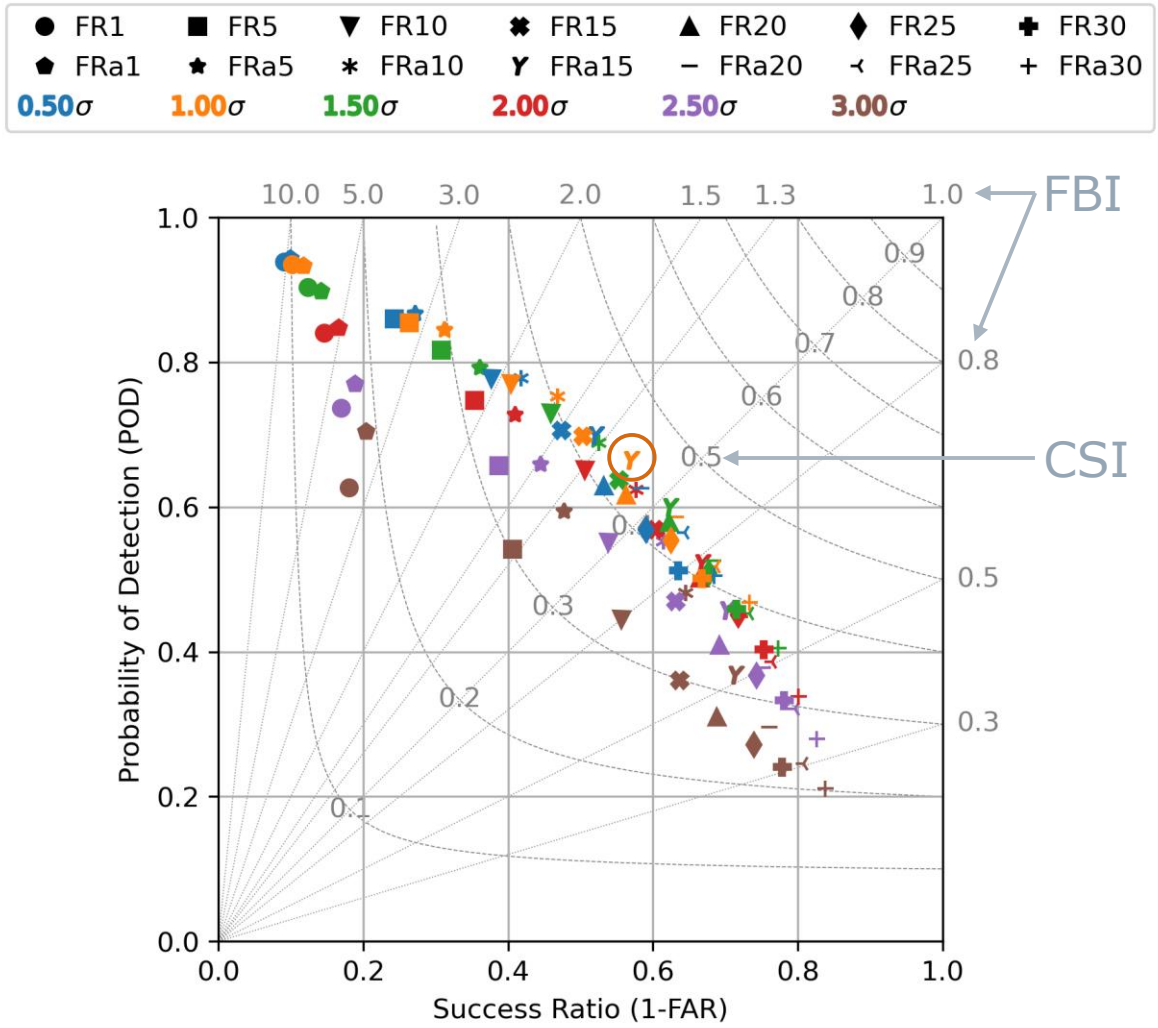




Contact: felix.erdmann@meteo.be

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**

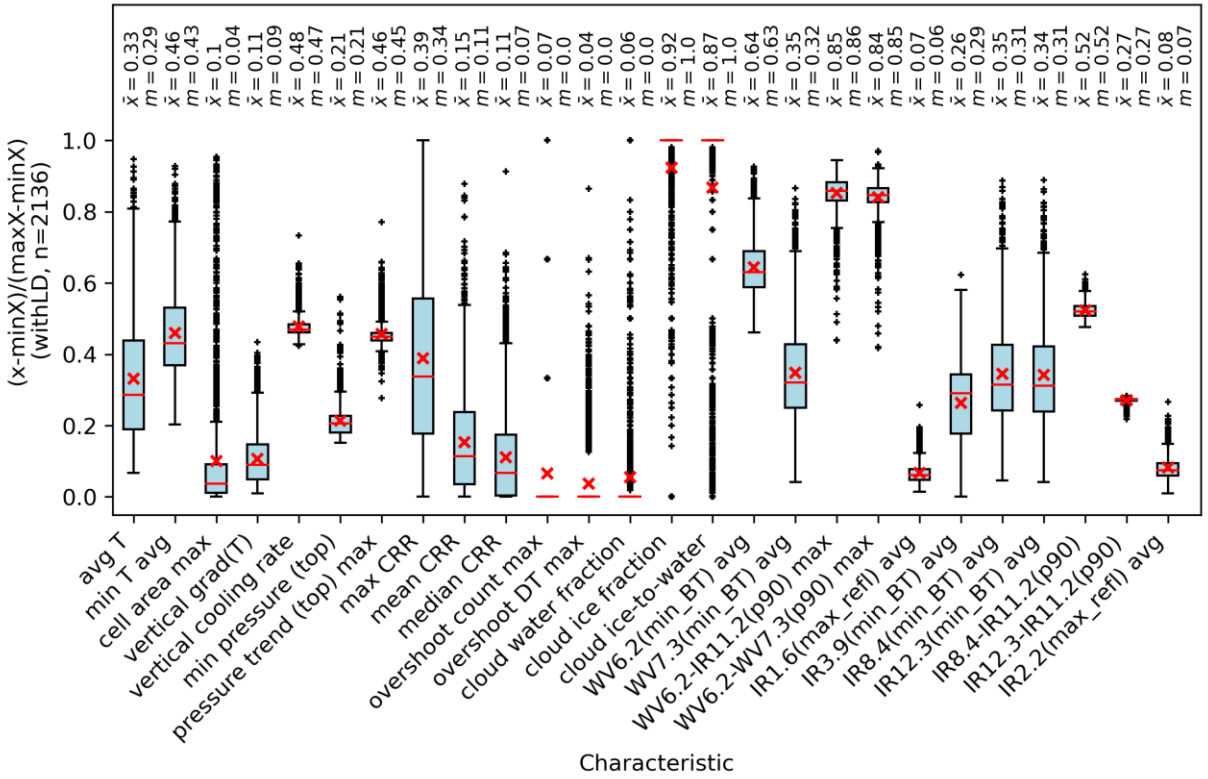


Results details – LDs

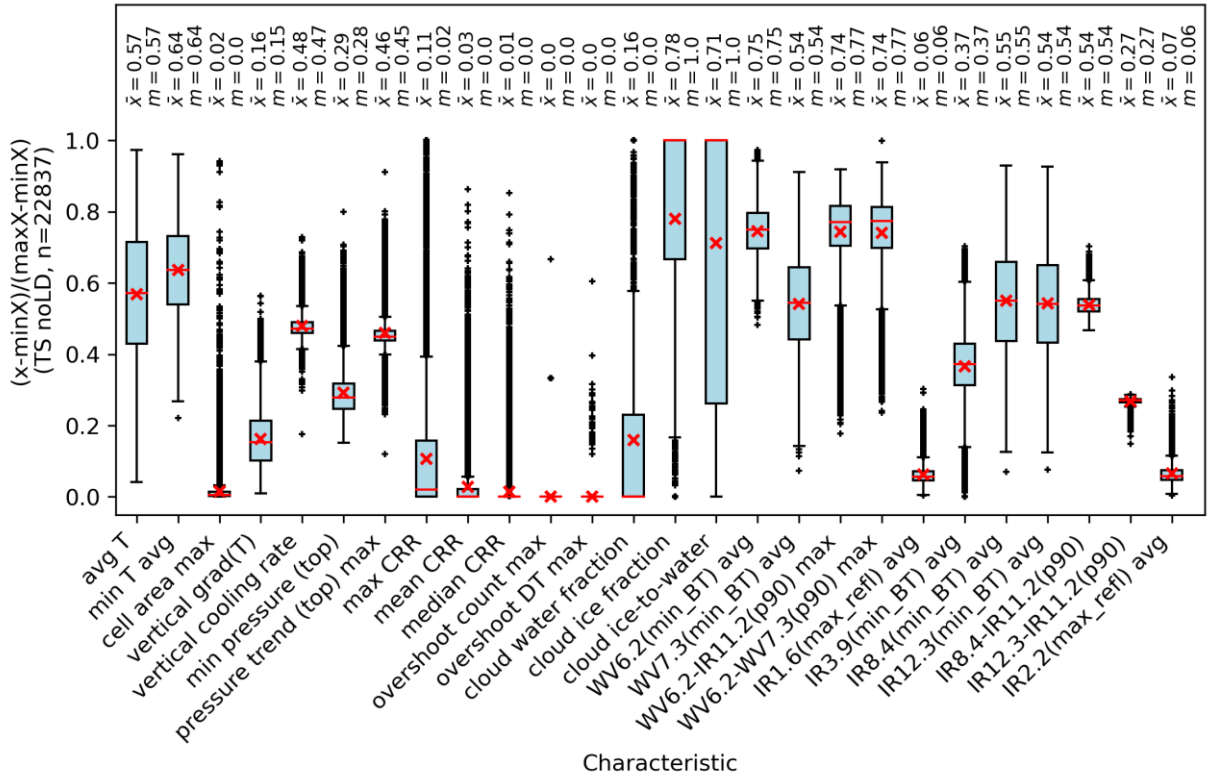
Contact: felix.erdmann@meteo.be

Cloud cell characteristics – LD vs no LD

With LD



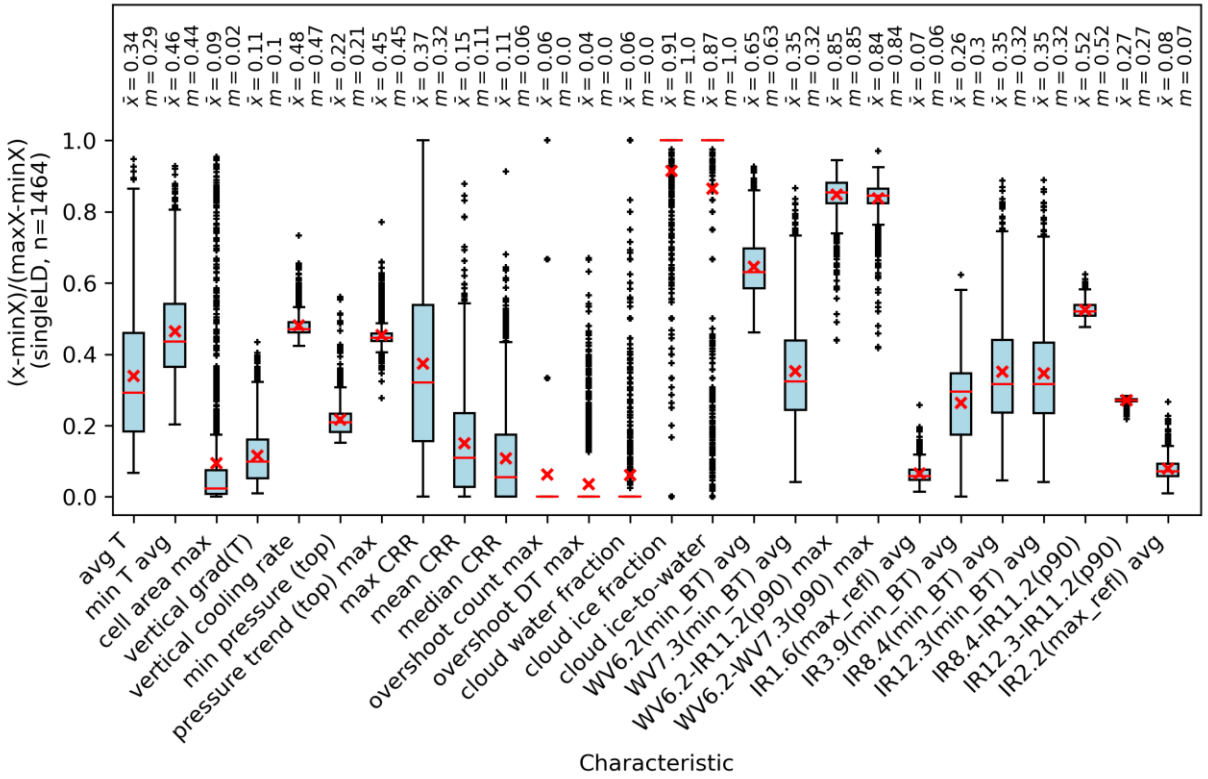
Thunderstorm no LD



Contact: felix.erdmann@meteo.be

Single LD vs multiple LDs

Single LD



Multiple LDs