Deep Learning vs. Traditional Thunderstorm Nowcasting: A Preliminary Model Benchmark Study

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Motivation

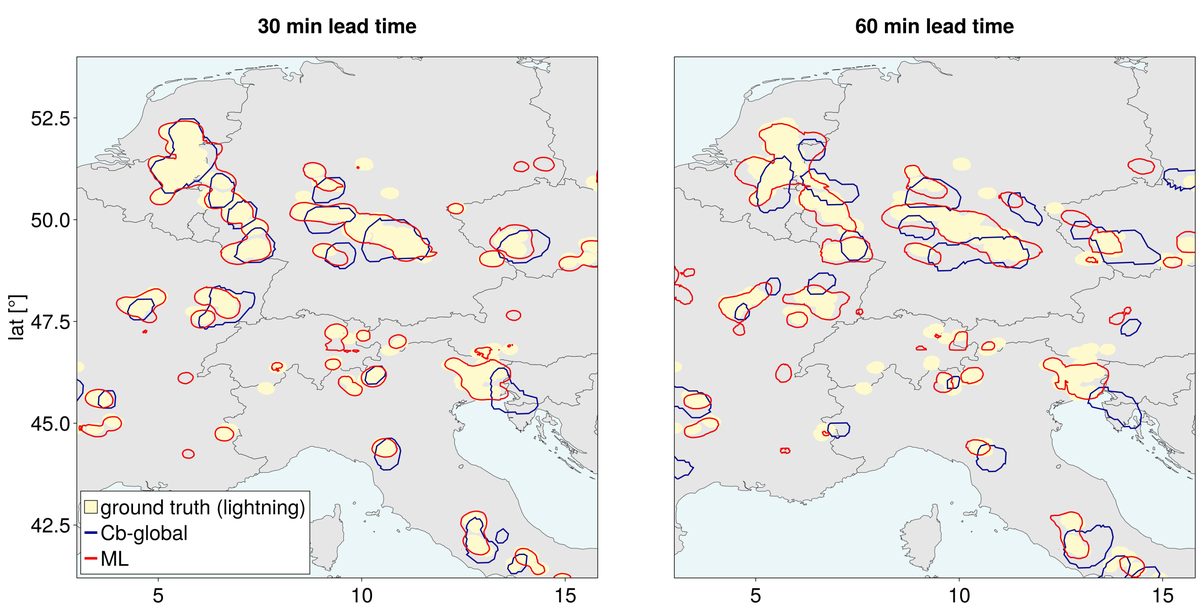
Traditional approaches to thunderstorm nowcasting employ deterministic, physics-based detection and optical flow algorithms. Recently, machine learning (ML) has emerged as an alternative and already shown promising results with ResUNet-inspired architectures proving to be a very robust baseline. ML-based methods currently represent an extremely active area of research and optimal approaches have yet to crystallise. Particularly for satellite-based thunderstorm nowcasting, the superiority of either traditional methods or a specific ML architecture has yet to be established by benchmark studies.

Setup

- Detection/prediction of lightning in 0/15/30/45/60 min based on satellite images (Cb-global, ML) and optionally lightning data (ML)
- Satellite data: MSG SEVIRI channels HRV, IR108, IR120, WV062
- Predictions are either deterministic (Cb-global) or pixelwise probabilities (ML)
- Ground truth: based on lightning data provided by LINET (at least 1 stroke within 15km, last 15min)
- Area of interest: central Europe (3° – 15.8° east, 41.2° – 54° north) with 1024x1024 grid for ML
- Evaluation period: summer (May – October) 2020
- Smaller, partially overlapping 256x256 patches from summers 2015 – 2018 are used for ML training

Models

- Cb-global (Cb-TRAM) [1]
- ResUNet-based probabilistic ML model [2]



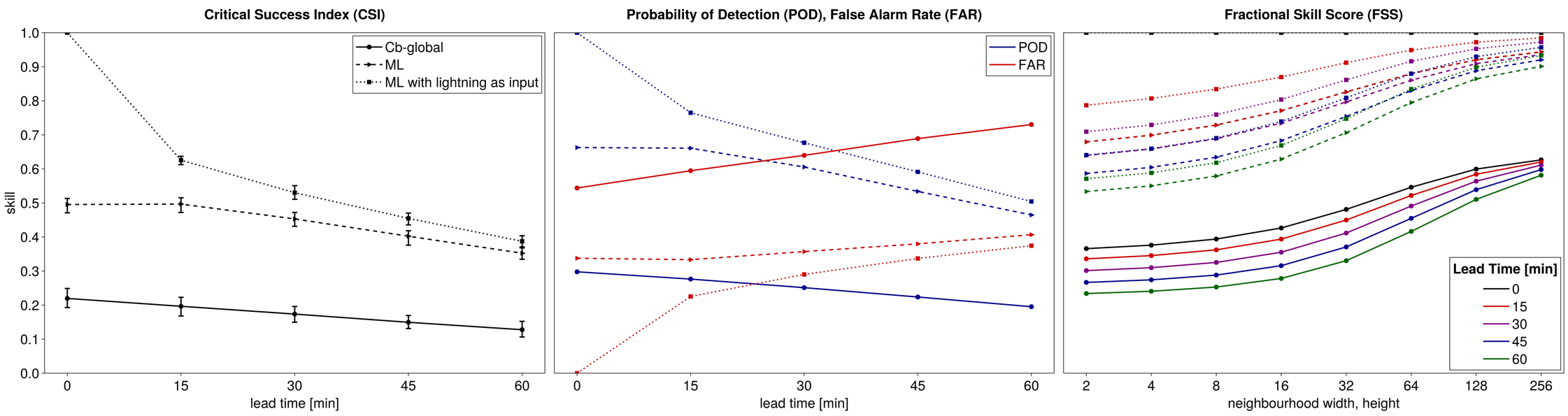
Evaluation

- Skill scores computed from accumulated binary predictions:
  - Critical Success Index (CSI)
  - Probability of Detection (POD)
  - False Alarm Rate (FAR)
  - Fractional Skill Score (FSS)
- The probabilistic ML model is evaluated by thresholding pixelwise probabilities at p = at 0.4
- Skill uncertainties are obtained by bootstrapping

$$\mathrm{CSI} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FP}+\mathrm{FN}}, \quad \mathrm{POD} = \frac{\mathrm{TP}}{\mathrm{TP}+\mathrm{FN}}, \quad \mathrm{FAR} = \frac{\mathrm{FP}}{\mathrm{TP}+\mathrm{FP}},$$

$$\mathrm{FSS} = 1 - \frac{\sum_{p\in\mathrm{grid}} \left(B_{\mathrm{prediction},p} - B_{\mathrm{ground\ truth},p}\right)^2}{\sum_{p\in\mathrm{grid}} \left(B^2_{\mathrm{prediction},p} + B^2_{\mathrm{ground\ truth},p}\right)}$$

$$\text{with } B_{a,p} = \langle b_a \rangle_{\mathrm{neighbourhood}(p)}$$



Conclusions and Outlook

- The traditional model Cb-global is consistently outperformed by ML
- Inclusion of lightning data significantly improves ML performance for short lead times
- FSS behaviour for large neighbourhoods shows that only ML reproduces the ground truth lightning climatology

➢ Follow-up study with additional models (NCS-A [3], NWCSAF RDT [4]) and significantly longer evaluation period

➢ Separate evaluation of qualitatively distinct scenarios (day/night, low/high lightning intensity)

➢ Integration of ML and benchmarking pipeline into community projects

References

[1] T. Zinner et al. "Validation of the Meteosat storm detection and nowcasting system Cb-TRAM with lightning network data - Europe and South Africa". In: *Atmospheric Measurement Techniques* 6.6 (2013), pp. 1567–1583. DOI: 10.5194/amt-6-1567-2013. URL: https://amt.copernicus.org/articles/6/1567/2013/.

[2] Christoph Metzl et al. "Physical Scales Matter: The Role of Receptive Fields and Advection in Satellite-Based Thunderstorm Nowcasting with Convolutional Neural Networks". In: *Artificial Intelligence for the Earth Systems*. ARTICLES 4.4 (Oct. 2025). Ed. by Corey Potvin, pp. 1–18. URL: https://elib.dlr.de/218180/.

[3] Richard Müller et al. "A Novel Approach for the Global Detection and Nowcasting of Deep Convection and Thunderstorms". In: *Remote Sensing* 14.14 (2022). ISSN: 2072-4292. DOI: 10.3390/rs14143372. URL: https://www.mdpi.com/2072-4292/14/14/3372.

[4] NWC SAF Guide. *Rapidly Developing Thunderstorm*. URL: https://www.nwcsaf.org/web/guest/practical-guide#RDT (visited on 11/06/2025).

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