Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

Nowcasting of Thunderstorm Hazards with Deep Learning: Performance Report of the First Convective Season in Operations

Ulrich Hamann, Luca Nisi, Irina Mahlstein, Matteo Buzzi, Michele Cattaneo, Néstor Tarin Burriel, Przemyslaw Juda, Nathalie Rombeek, George Pacey, Ophélia Miralles, Jussi Leinonen

Introduction
Thunderstorms pose serious risks to life and property through hazards such as lightning, heavy rainfall, hail, and strong winds. These events develop rapidly and affect localized areas, making timely and accurate short-term forecasts essential for early warnings to the public, emergency services, and infrastructure operators. On the sub-hourly scale, nowcasting - statistical forecasting based on the most recent observations - offers high spatial and temporal precision. In particular, deep-learning has proven effective for nowcasting by rapidly learning patterns from diverse observational datasets.

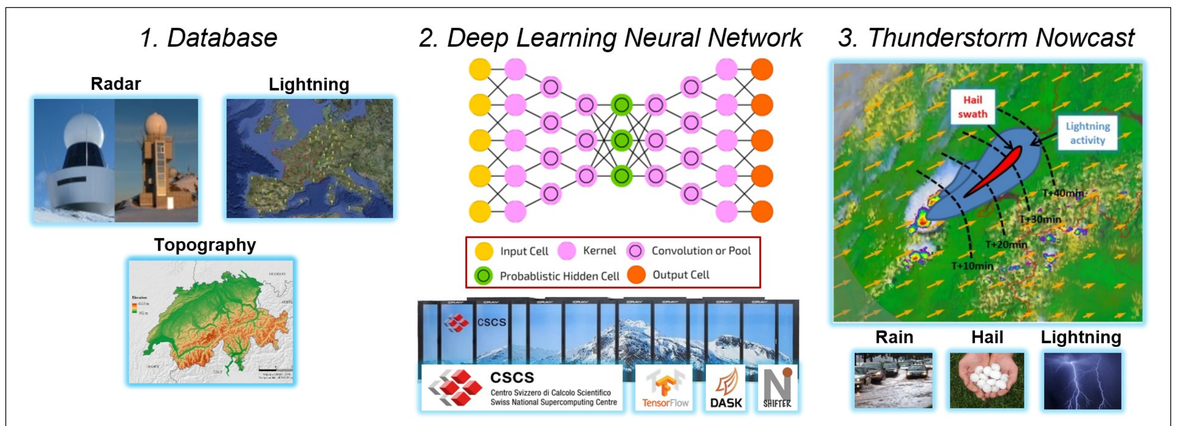

Figure 1: COALITION4 is a deep learning nowcasting algorithm utilizing an advanced encoder-forecaster model to nowcast thunderstorm-related hazards such as strong precipitation, lightning occurrence, and occurrence of different hail sizes with an update cycle of 5 min up to one hour in advance. It leverages recurrent-convolutional layers and integrates a range of predictor datasets, including radar observations from the Swiss dual-polarization radar network and Météorage lightning data.

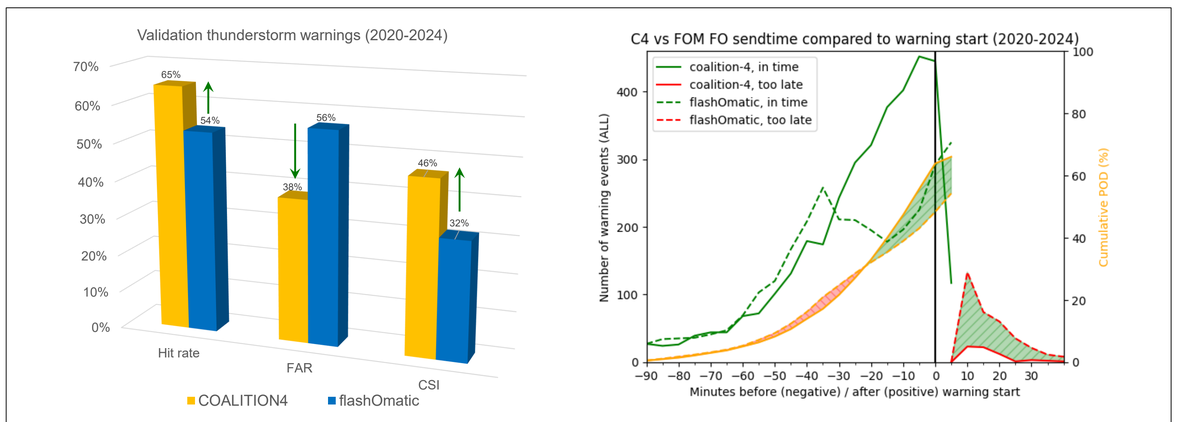

Figure 4: Left: Hit Rate, False Alarm Ratio (FAR) and Critical Success Index (CSI) could be improved by COALITION-4 in comparison to the operational algorithm flashOmatic. Right: The green lines show alert time of correct warnings with respect to the onset of the thunderstorm. COALITION4 raises more correct alerts starting 35 min before the event compared to flashOmatic resulting in a higher CSI of COALITION4 approximately 23 minutes before the event. Red lines show alarms after the onset, which were therefore issued too late. Green/red hatched area indicates improvements/deterioration.

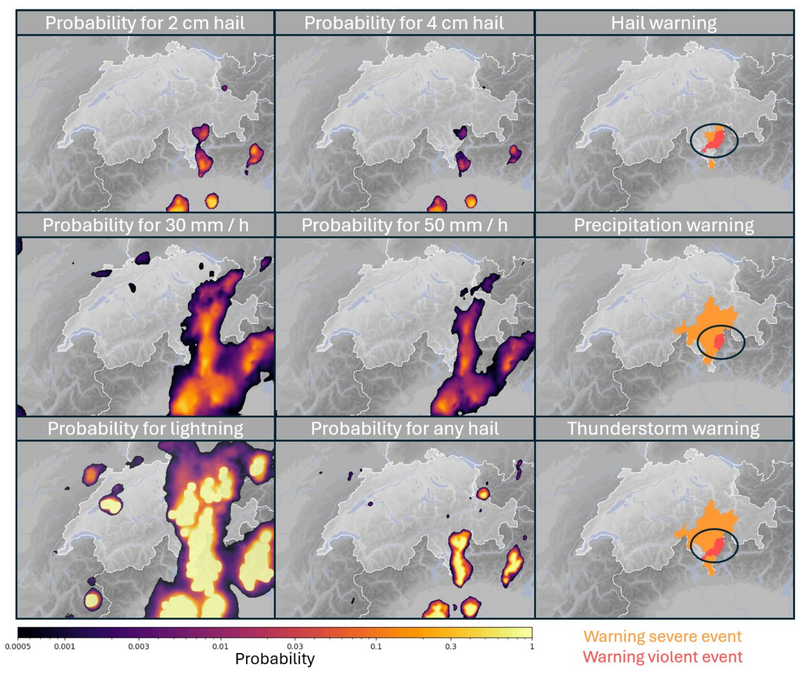

Figure 2: COALITION4 products for 21st of June 2024, 17:00 UTC, a catastrophic event in Misox, Grisons. In Switzerland, 2 cm hail and 30 mm / h indicate severe thunderstorm, 4 cm hail and 50 mm / h for violent ones. In Misox, warning level 4 for precipitation as well as for hail were raised well before the debris flow initiated.

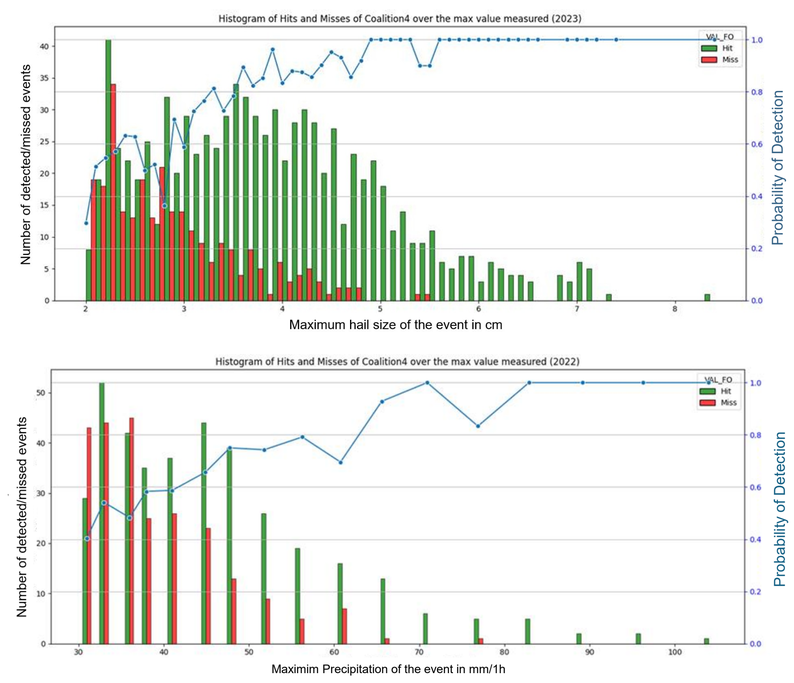

Figure 5: The figures show how many thunderstorms were correctly detected or missed as function of the strength of the event: Upper figure for hail, lower for precipitation. Around the limit for warnings (2 cm hail size and precipitation of 30 mm in 1 hour), the probability of detection is around 50% and increases steadily with the strength of the event.

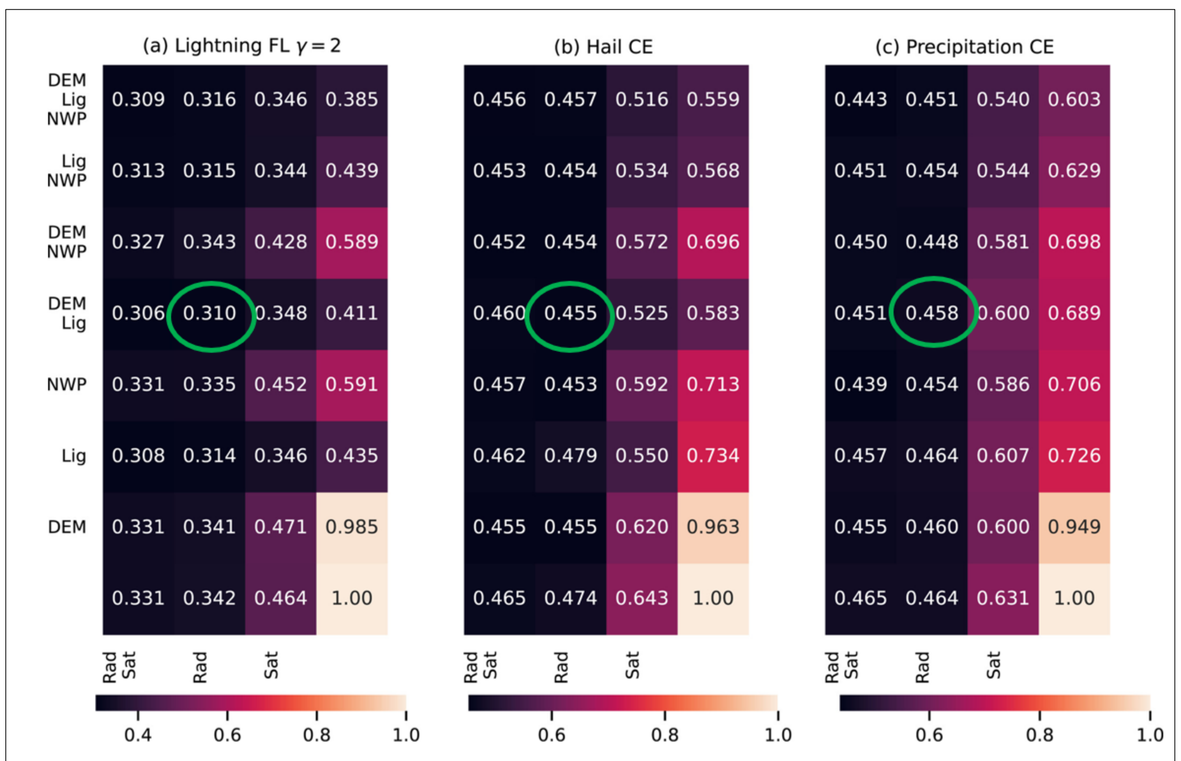

Figure 3: We trained COALITION4 model versions with different combination of input datasets: DEM (digital elevation model), NWP (Numerical Weather Prediction variables e.g. CAPE and CIN), Lig (lightning observations, i.e. location, current), Rad (Radar observations e.g. reflectivity), and Sat (MSG SEVIRI visible and infrared channels). Each square represents the minimal loss of the ML model with the input datasets indicated by row and column. The smaller, the better. This study allows to estimate the trade off between better forecast quality against higher implementation costs and greater susceptibility to faults due to missing input data during operational use. The green circle mark the model chosen for operational implementation.

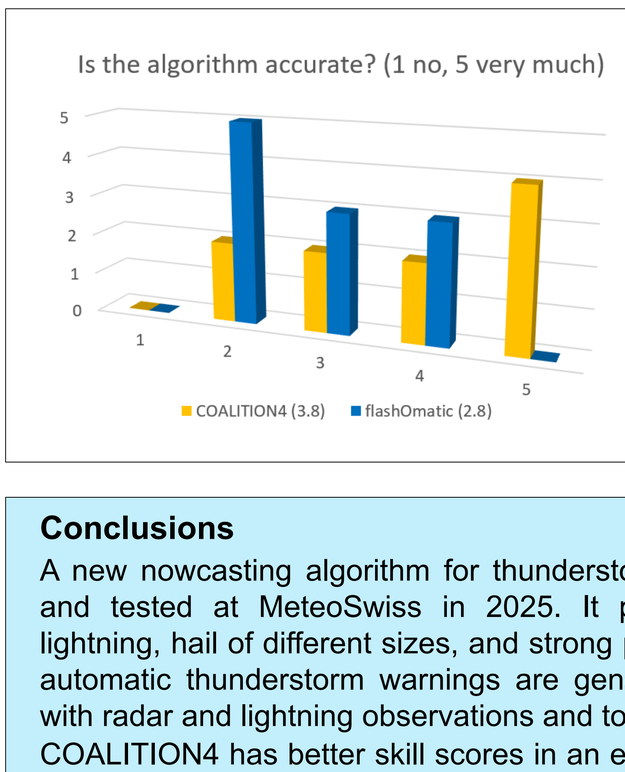

Figure 6: We conducted a survey with the forecasters in the convective season 2025 comparing the new thunderstorm algorithm Coalition-4 (yellow) with the current operational system flashOmatic (blue). We ask for both algorithms, if the forecaster considers them accurate. COALITION4 was rated four times as very accurate.

Conclusions

A new nowcasting algorithm for thunderstorm warning Coalition-4 was validated and tested at MeteoSwiss in 2025. It produces occurrence probabilities for lightning, hail of different sizes, and strong precipitation. Based on these products, automatic thunderstorm warnings are generated. For implementation, a version with radar and lightning observations and topography as input was chosen.
COALITION4 has better skill scores in an evaluation from 2020 to 2024 compared to the operational algorithm. In particular, strong thunderstorm events are detected with high accuracy. Also the forecasters concluded that COALITION4 is more accurate than the current operational algorithm. MeteoSwiss plans to use COALITION4 for thunderstorm warnings in the MeteoSwiss App in summer 2026.

Poster P63 show progress in COALITION4 model development.

For **publication,** have a look at the link or scan the QR code.

https://www.meteoswiss.admin.ch/about-us/research-and-cooperation/projects/2020/coalition-4-thunderstorm-forecasting-with-artificial-intelligence.html