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Automated Severe Thunderstorm Outlooks from thundeR Package (ASTORP)

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Mateusz Taszarek[1,2], Patryk Matczak[1,2]

1 - Department of Meteorology and Climatology, Adam Mickiewicz University, Poznań, Poland
2 - Skywarn Poland, Warsaw, Poland

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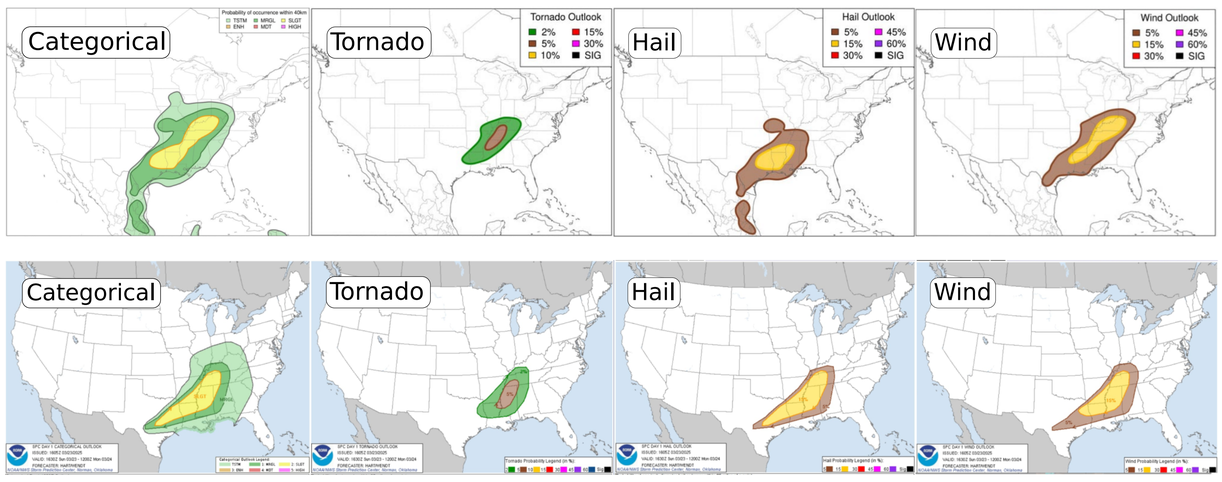
Main goal

Deliver automated convective outlooks using NOAA SPC and ESTOFEX risk categories to help forecasters identify the location and timing of potential severe weather outbreaks in medium-range forecast window.

Comparison of DAY 1 convective outlook between ASTORP (top) and NOAA SPC forecast (bottom) for 23 March 2025

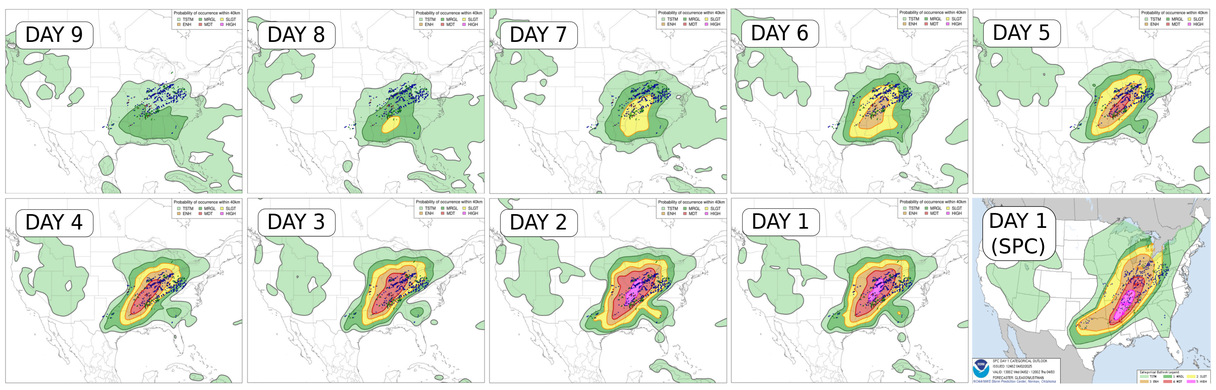


What is ASTORP?

Early work on ASTORP began in 2020 during Subseasonal-to-Seasonal (S2S) research activities using the GEFS model, alongside development of the thundeR package, compilation of intercontinental severe storm reports, and evaluation of convective parameters. ASTORP is an automated system that generates probabilistic forecasts of convective hazards using a family of algorithms trained on global lightning observations and severe weather reports from Europe, North America, South America, and Australia. More than 700 parameters were tested during development and calibration, incorporating:

- 20 years of **ERA5** reanalysis
- 3 years of operational **GEFS** (31-member ensemble)
- 10 years of NOAA Storm Prediction Center (**SPC**) outlooks
- 10 years of European Storm Forecast Experiment (**ESTOFEX**) outlooks

Progression of DAY 1-9 ASTORP outlooks for 02 Aprill and DAY 1 NOAA SPC forecast (points are severe storm reports)



How does it work?

The system consists of seven machine-learning models that forecast probabilities (within a 40 km radius) for non-severe, severe, and significant-severe thunderstorms. Specifically:

- **lightning** (at least 2 flashes)
- **severe hail**(≥ 2 cm) and **significant hail** (≥ 5 cm)
- **severe wind** (≥ 25 m s^{-1}) and **significant wind** (≥ 33 m s^{-1})
- **severe tornado** (≥ F0) and **significant tornado** (≥ F2)

Probabilities from all ensemble members are aggregated, calibrated, and mapped to the most likely risk scenario using SPC and ESTOFEX risk levels.

Definition of threat levels used by SPC

Probability	Lightning	Tornado	Wind	Hail
>10% lightning	TSTM	N/A	N/A	N/A
>2% severe	N/A	MRGL	N/A	N/A
>5% severe	N/A	SLGT	MRGL	MRGL
>10% severe	N/A	ENH	MRGL	MRGL
>15% severe	N/A	ENH	SLGT	SLGT
>15% severe >10% sig sev	N/A	MDT	SLGT	SLGT
>30% severe	N/A	MDT	ENH	ENH
>30% severe >10% sig sev	N/A	HIGH	ENH	ENH
>45% severe	N/A	HIGH	ENH	ENH
>45% severe >10% sig sev	N/A	HIGH	MDT	MDT
>60% severe	N/A	HIGH	MDT	MDT
>60% severe >10% sig sev	N/A	HIGH	HIGH	MDT

Definition of threat levels used by ESTOFEX*

Probability	Lightning	Tornado	Wind	Hail
>15% lightning	low thunder	N/A	N/A	N/A
>50% lightning	high thunder	N/A	N/A	N/A
>5% severe	N/A	Level 1	Level 1	Level 1
>15% severe	N/A	Level 2	Level 2	Level 2
>15% sig sev	N/A	Level 3	Level 3	Level 3

A complete outlook requires **36** parameters from the thundeR package. More than half of those are new or modified parameters, developed using global severe storm data.

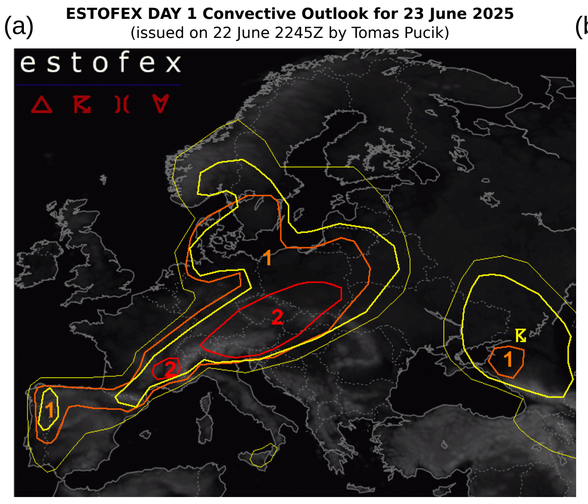
Concluding remarks

During a 9-month experimental forecasting period (Mar–Nov 2025) for the area of the United States and Europe (updated 4x daily), the system:

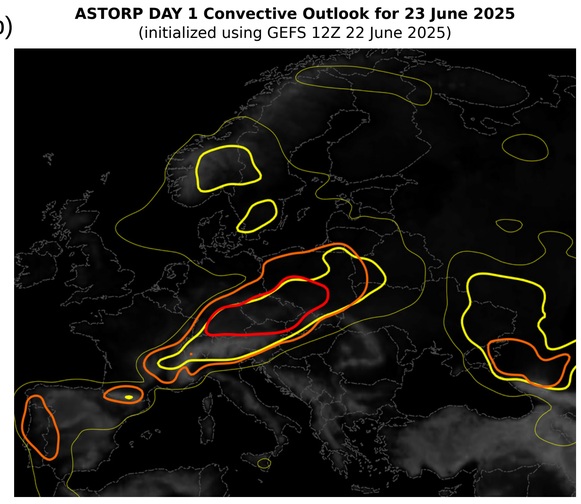
- Was capable of generating forecasts comparable to operational human-issued outlooks from NOAA SPC and ESTOFEX.
- Successfully highlighted the location of selected severe weather outbreaks 5–6 days ahead over Europe and 7–8 over the United States.
- Provided greatest utility in the medium-range window (2–8 days), while convective-allowing models were more skillful at short ranges (<48 h).
- Faced the greatest challenge in forecasting severe wind hazards.
- Achieved highest skill and robustness using models trained on parameters computed with effective layers rather than fixed layers.

Comparison of human-issued convective outlooks from ESTOFEX and NOAA SPC (left) with ASTORP (right)

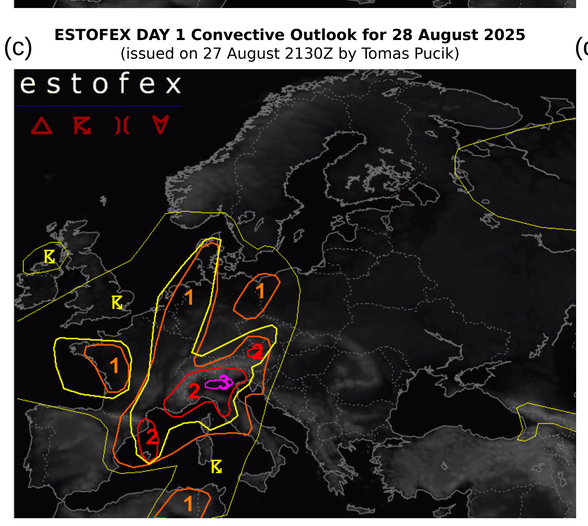
(a) **ESTOFEX DAY 1 Convective Outlook for 23 June 2025**
(issued on 22 June 2245Z by Tomas Pucik)



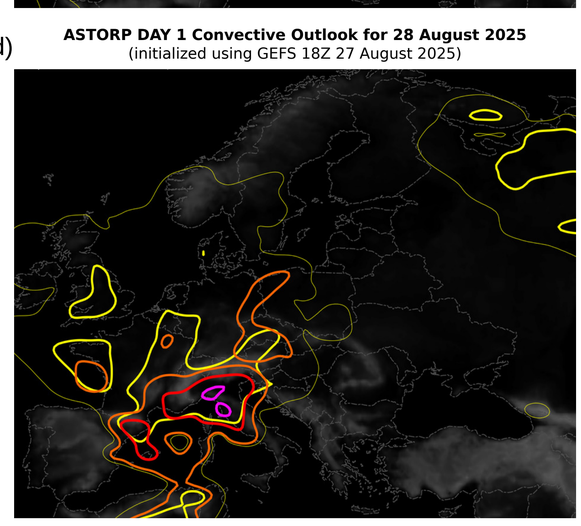
(b) **ASTORP DAY 1 Convective Outlook for 23 June 2025**
(initialized using GEFS 12Z 22 June 2025)



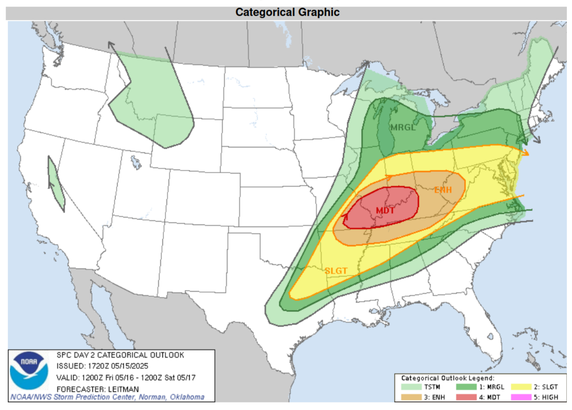
(c) **ESTOFEX DAY 1 Convective Outlook for 28 August 2025**
(issued on 27 August 2130Z by Tomas Pucik)



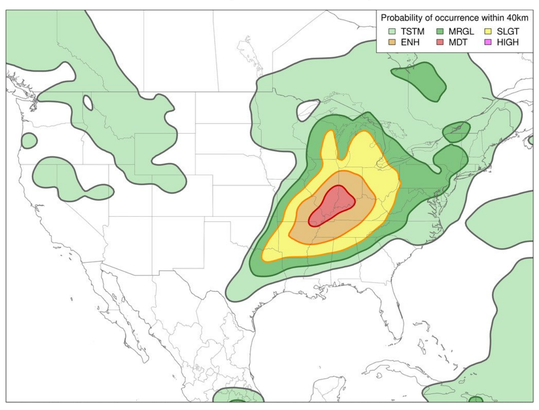
(d) **ASTORP DAY 1 Convective Outlook for 28 August 2025**
(initialized using GEFS 18Z 27 August 2025)



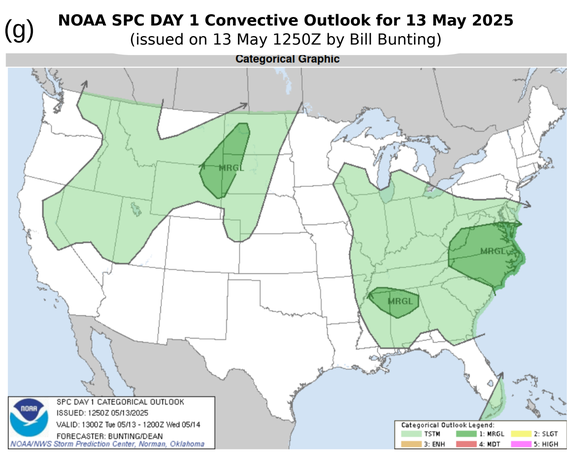
(e) **NOAA SPC DAY 2 Convective Outlook for 15 May 2025**
(issued on 15 May 1720Z by Liz Leitman)



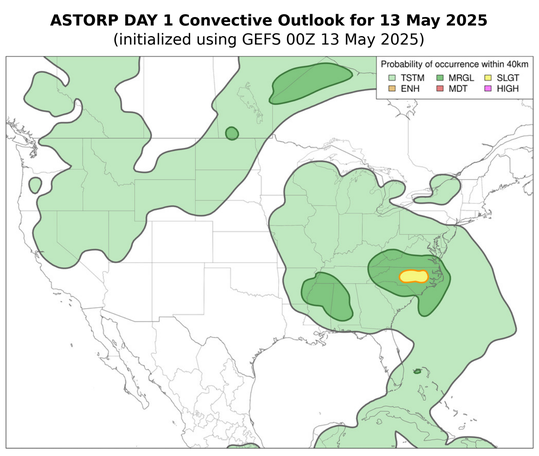
(f) **ASTORP DAY 2 Convective Outlook for 16 May 2025**
(initialized using GEFS 18Z 14 May 2025)



(g) **NOAA SPC DAY 1 Convective Outlook for 13 May 2025**
(issued on 13 May 1250Z by Bill Bunting)



(h) **ASTORP DAY 1 Convective Outlook for 13 May 2025**
(initialized using GEFS 00Z 13 May 2025)



Future plans

(1) Develop an automated forecast verification routine, **(2)** expand convective outlooks to Australia and South America, **(3)** integrate the ECMWF ensemble, **(4)** reduce FAR, increase POD.