A Statistical Model to Forecast Tornadoes and Reconstruct Their Climatology and Trends Globally

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Introduction

Local climatologies of tornadoes exist across the USA, Europe, Australia, and China. **A global climatology is yet to be constructed**. In addition, **the relationship** of these events **with climate change has not been explored on a global scale yet**.

We have developed Additive Logistic Regression Models (**AR-CHaMo**) for tornadoes occurrence using:

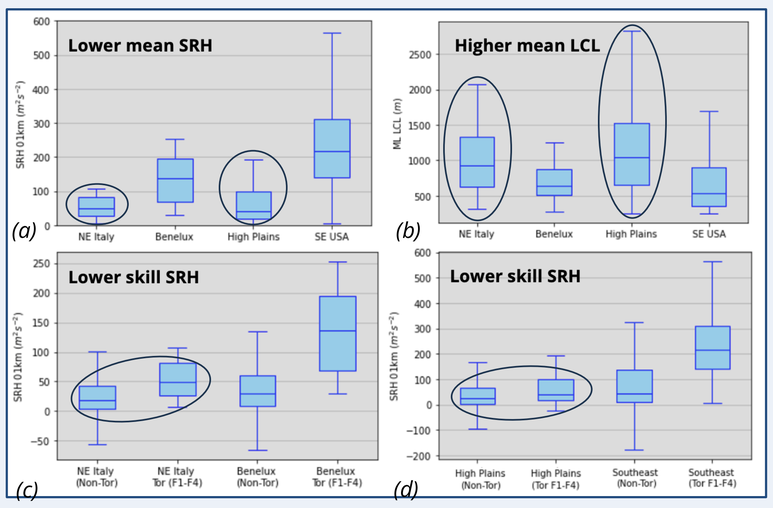
- Convective parameters from **ERA5 reanalysis** using the ThundeR package.
- **Tornado reports** from the European Severe Weather Database, the Storm Prediction Centre, and the Bureau of Meteorology.
- **Lightning observations** from the Arrival Time Difference Network (ATDnet), the National Lightning Detection Network (NLDN) and the Global Position and Tracking Systems (GPATS).

Methodology

The tornado model was developed by taking convective initiation explicitly into account:

$$P_{tornado} = P_{lightning} \cdot P_{tornado|lightning}$$

The model selection uses the **Deviance Explained** (the higher, the better) and the Bayesian Information Criterion (**BIC**; the lower, the better) scores.



Mean SRH (a) and LCL (b) associated with tornadoes ≥ (E)F1. Mean SRH for tornadic vs non-tornadic storms in Europe (c) and USA (d).

Lightning model

1. *MU Lifted Index*
2. *RH between 500-850 hPa*
3. *Convective Precipitation*
4. *MU Mixing Ratio*
5. *Land Sea Mask*

Tornado model

1. *SRH 0-500 m AGL*
2. *Lapse rates 0-1km*
3. *Vertical vorticity 10 m AGL*

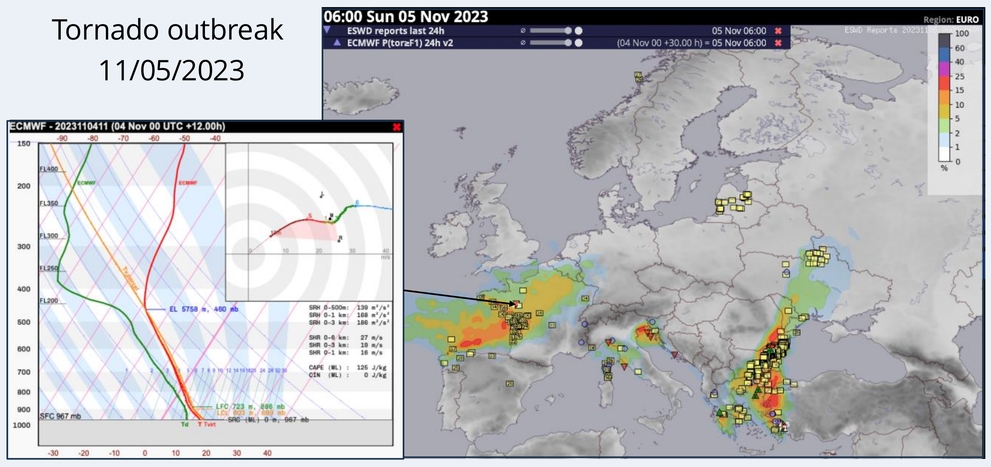
Heterogeneity of tornado environments complicates global model creation

Tornadoes in the USA **High Plains** and **N Italy** occur with low SRH and high LCLs. **SRH cannot discriminate** well between tornadic and non-tornadic storms, unlike in other parts of Europe/USA.

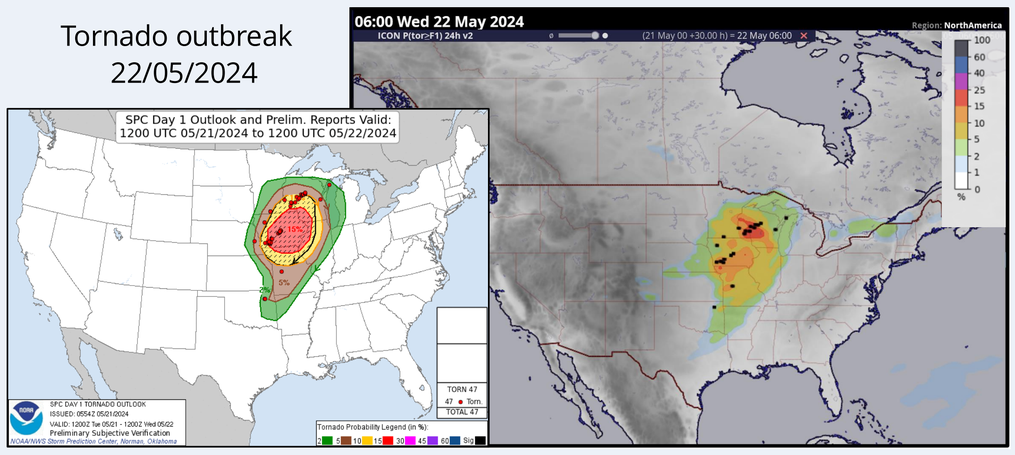
Medium-Range Forecasting

The **AR-CHaMo tornado ≥ (E)F1** model was applied to the deterministic run of the **ECMWF, GFS, and ICON**. The model was operationally tested at the **ESSL Testbed** during the summers of 2023 - 2025.

Tornado outbreak
11/05/2023



Tornado outbreak
22/05/2024

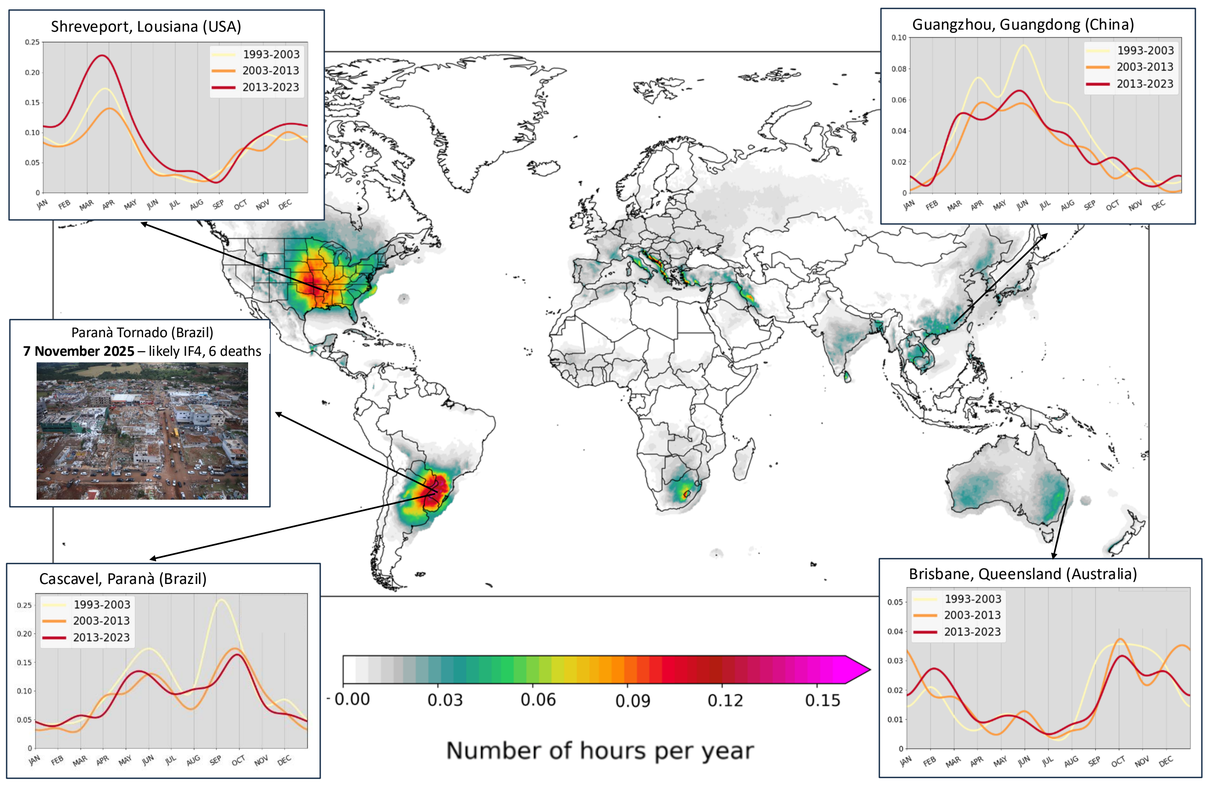


AR-CHaMo probabilistic forecast based on ECMWF (Europe) and ICON (North America). Forecasts are verified using ESWD data, SPC Day 1 categorical outlook and reports.

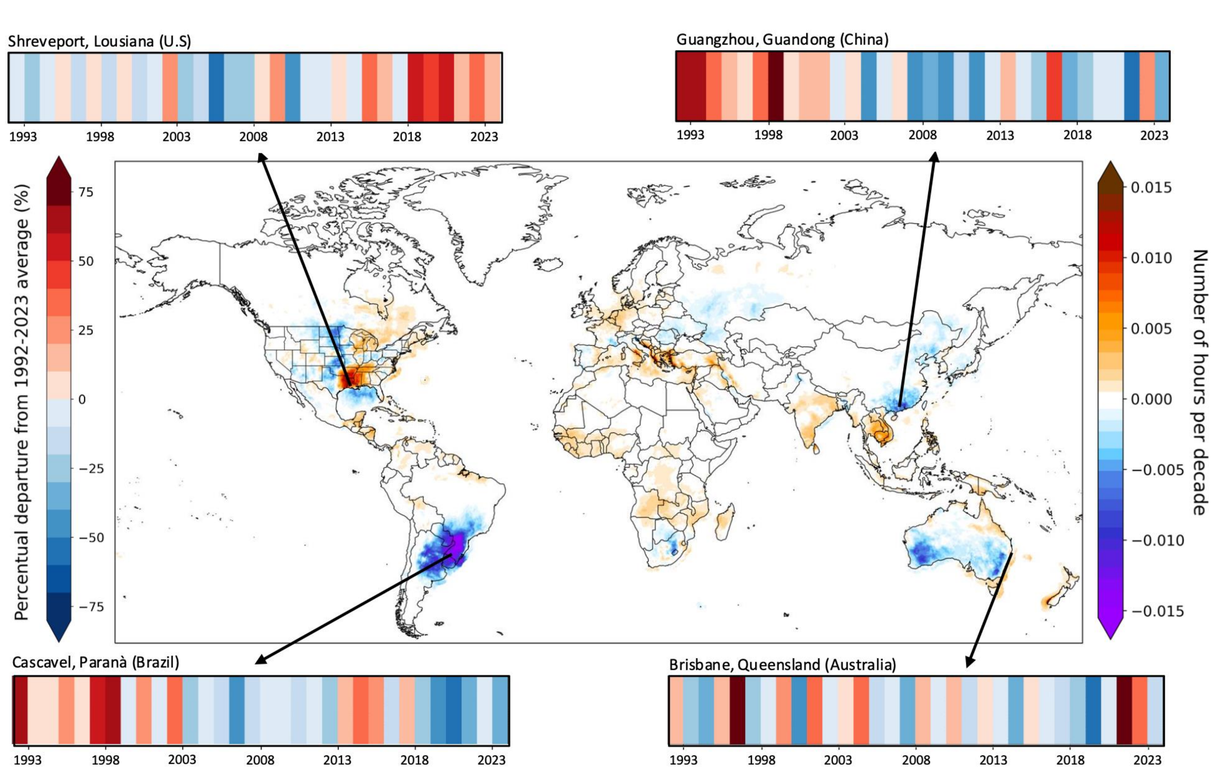
From forecasting to climate timescales

The AR-CHaMo models can be used to evaluate climatological patterns and reconstruct the long-term climate trends (see below). **2024 was a record year for tornadoes in the USA,** standing out in the Top 5 in the whole timeseries (+16.8%, 1992-2023), while **2025** returned **close to the long-term average** (+3.5%).

Tornado ≥ (E)F1 climatology (1992-2023)



Tornado ≥ (E)F1 trends (1992-2023)



Conclusions

- **Modeled tornadoes ≥ (E)F1** are most common across the **SE US** and the tri-border region between **Argentina, Paraguay, and Brazil**.
- Modeled tornadoes ≥ (E)F1 have **increased in frequency across the SE US**. while they have **decreased in the High Plains**. Decreases are also present in **S America**, **S China,** and **Continental Australia**.
- **AR-CHaMo can be used for operational forecasting**. Successful case studies in **Europe and the USA.**

Acknowledgements

ESSL acknowledge the ClimXtreme II project funded by the German Federal Ministry of Research , Technology and Space (BMFTR) under grant 01LP2324F. Environmental features were derived from ERA5 (Hersbach et al. 2020) and calculated using the ThundeR package (Czernecki et al. 2025) We are very thankful to all volunteers collecting severe weather reports for the ESWD.

The **European Severe Storms Laboratory** is a non-profit organization located in Germany (Wessling) and Austria (Wiener Neustadt). It supports research by operating the European Severe Weather Database, organizing the ESSL Testbed and scientific meetings. It studies the climatology, impacts and forecasting of severe storms and provides forecaster training. Its members include 30 European weather services, research centers and research departments as well as 39 commercial supporting members. For more information, visit: **www.essl.org**