Describing long term seasonal and interannual variability of tornado frequency across the USA and Europe

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Tornadoes are extremely destructive atmospheric phenomena that can lead to significant damage and fatalities. Capturing their frequency in operational weather and climate models is challenging due to their short duration, limited spatial scale, and inherently chaotic nature. To address this, we employ an empirical statistical approach to examine their spatial and temporal patterns, presenting preliminary findings based on ERA5 meteorological variables.

The method is based on a two suitable meteorological variables:

✓ W_{MAX}: updraft maximum parcel vertical velocity, (CAPE)

$$CAPE = \int_{z_{lfc}}^{z_{eq}} B dz \approx \int_{z_{lfc}}^{z_{eq}} \frac{T_{v,parcel} - T_{v,env}}{\overline{T_v}} B dz \, \pi r^2$$

✓ **WS700**: mid-level wind shear

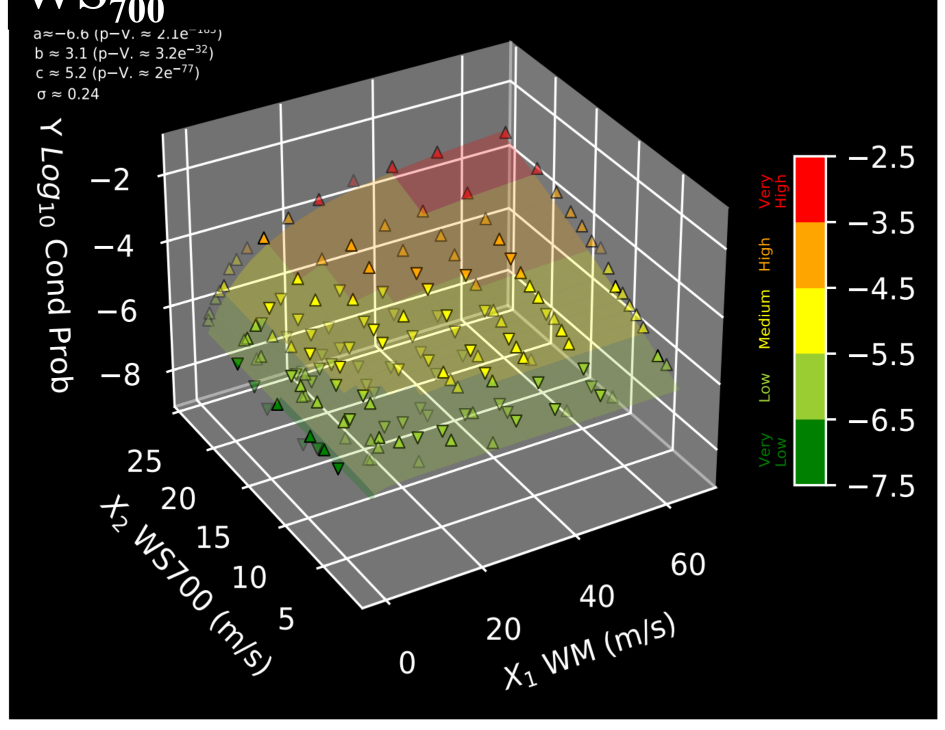
$$W_{MAX} = \sqrt{2CAPE}$$

$$WS_{700} = \|\vec{u}_{700hPa} - \vec{u}_{10m}\|$$

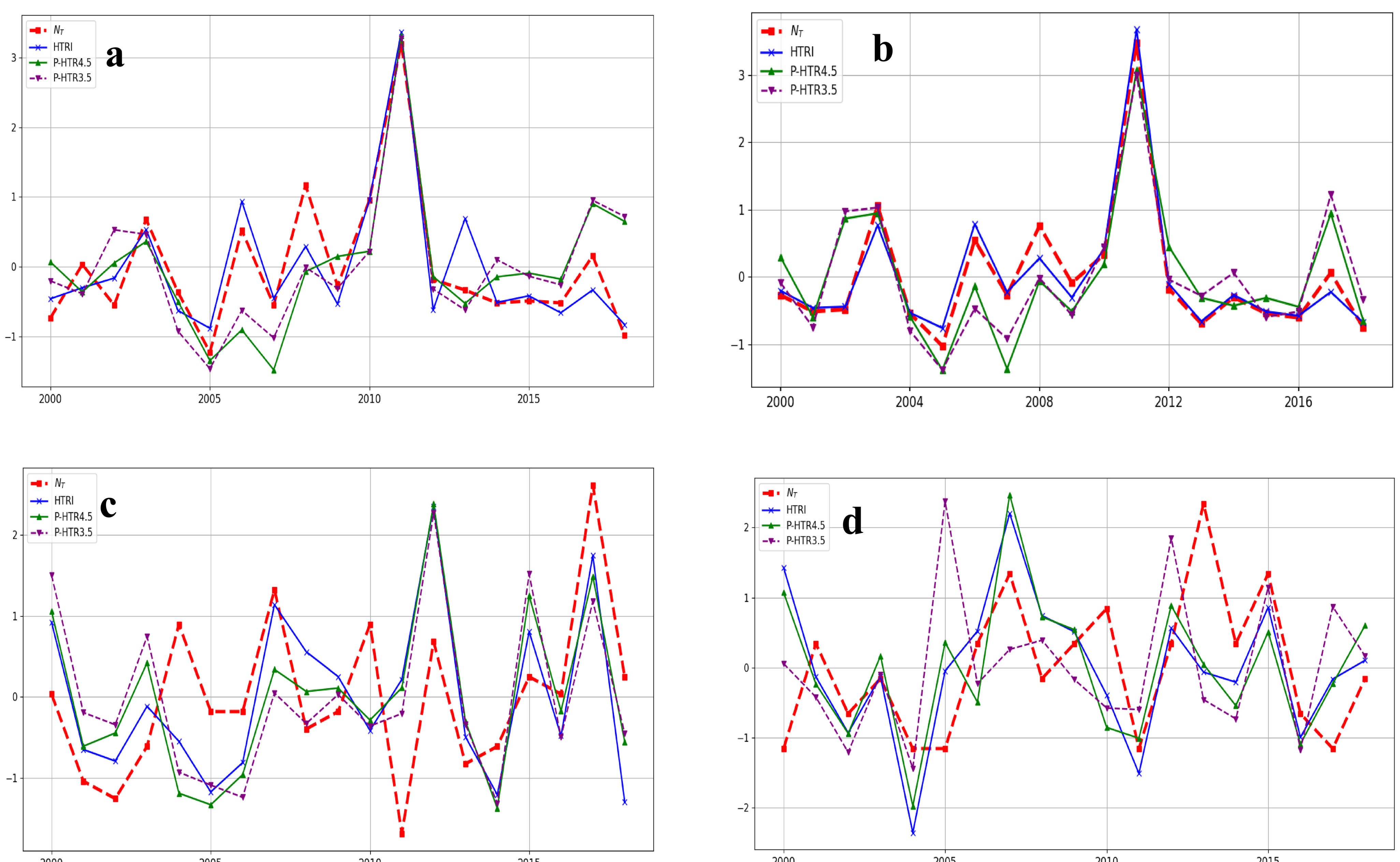
and an analytical formula describing the probability of tornadoes, whose parameters are tuned to reproduce observed EF2+ (stronger than category 2 in the Enhanced Fujita scale) tornado number in the period 2000-2018

✓ Bivariate probability P: $log_{10}P(W_{MAX}, WS_{700}) = -6.6 + \frac{W_{MAX}}{3.1+5.2^{W_{MAX}/WS_{700}}}$

Log_{10} probability of occurrence of tornadoes as a function of W_{MAX} and WS_{700}



Trends & Correlation between Tornadoes with Key Meteorological Variables 2000-2018



The figure 1 shows the timeseries of annual (a) for USA and (c) for Europe and spring (b) for USA and (d) for Europe between N_T total number of EF2+ tornadoes, and model derived indices; HTRI frequency high tornado-risk conditions, P-HTR4.5 and P-HTR3.5 frequency of hourly intervals with tornado probability exceeding $10^{-4.5}$ and $10^{-3.5}$, respectively (only large HTRI conditions are considered) Spring has been selected being the season with highest tornado frequency

a	Annual	Spring
HTRI	0.91	0.98
P-HTR4.5	0.72	0.82
P-HTR3.5	0.73	0.81

b	Annual	Spring
HTRI	0.5	0.45
P-HTR4.5	0.39	0.37
P-HTR3.5	0.33	0.03

Table 1: Correlation of N_T with indicators (only points with tornadoes occurrences are considered) a (USA) and b (Europe)

Results: In the USA the empirical model shows good correlation (figure 1 and table 1) with the actual number of tornadoes considering the valid tornado points.

However, when applied to the full spatio-temporal record (1950-2024), its performance is regionally dependent, the model maintains a high correlation in Dixie Alley, and weaker correlation in other Tornado Alleys (e.g., the Great Plains) indicates that the model may be missing key, region-specific processes necessary for tornadogenesis there (figure 2,3,and 4).

In Europe correlation is generally lower than in the USA, being significant only the training period on valid tornadoes point.

USA tornadoes considering the full record 1950-2024:

Figure 2: Trend between Actual tornado N_T and model derived indices HTRI, P-HTR4.5, P-HTR3.5, and N_E (model estimated tornadoes .

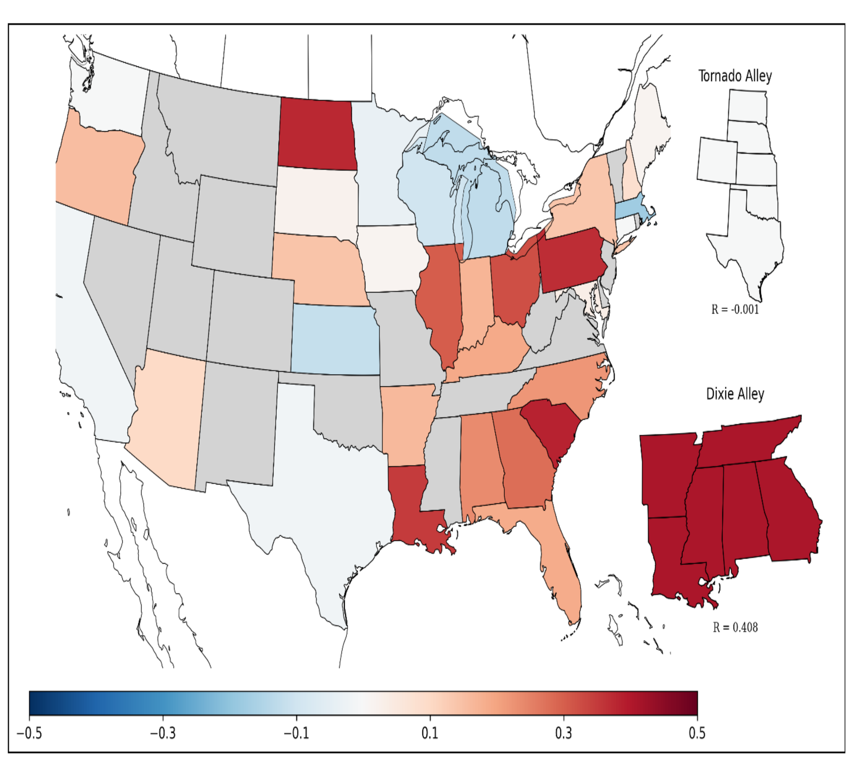


Figure 3: Spearman rank correlation between N_T and N_E

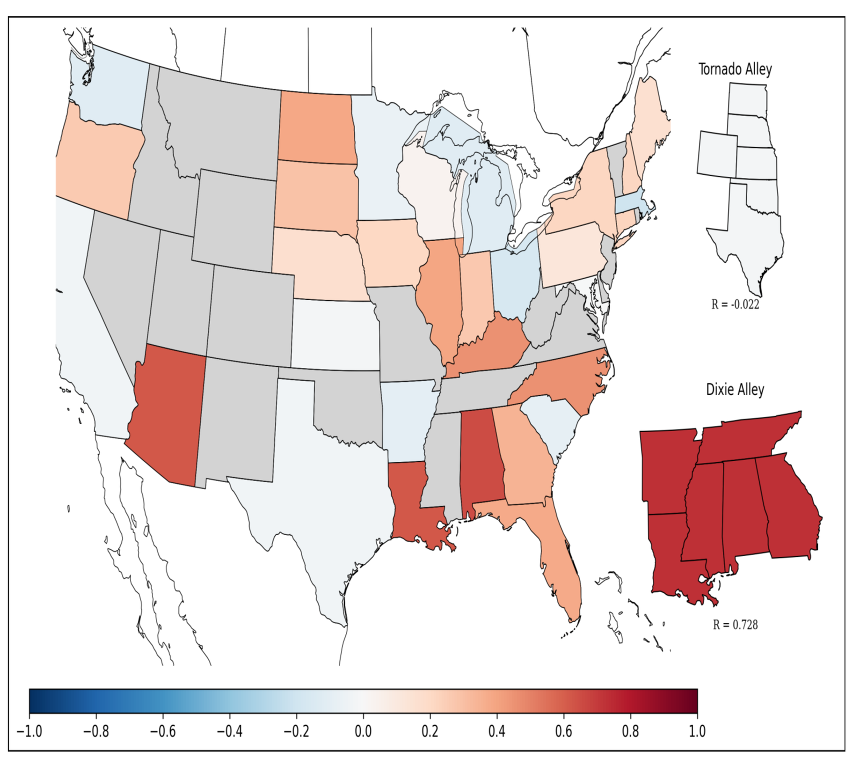


Figure 4: Spearman rank correlation between N_T and N_E in Active year, that is years when $N_T > \mu + 0.5\sigma$

Future Work:

- Refining the regional applicability of the method by developing region-specific parameters
- Incorporate additional critical meteorological variables, to better capture the complete physics of tornadogenesis
- Improve the model's performance including a verification of the observational data.

Reference:

Ingrosso, R. et al. Atmosphere 2020, 11, 301. 10.3390/atmos11030301