ERA5-Based Environmental Characteristics of F2 Tornadoes in Germany since 1950

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12th European Conference on Severe Storms, Utrecht, Netherlands - 17 to 21 November 2025

Background:

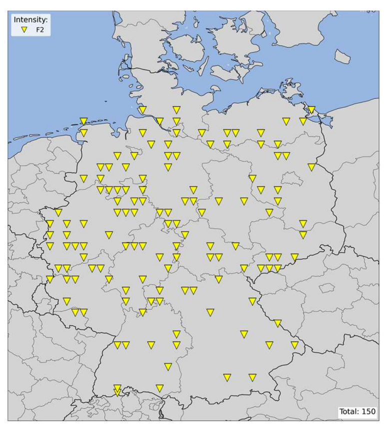

Fig. 1: All 150 Cases in Germany

To better understand tornadic environments in Germany, we used historical F2 tornados [2] and linked them to reanalysis data [1] via proximity soundings. These are historical tornadoes from all over Germany, as can be seen in **Fig. 1**. In order to better understand the atmospheric conditions shortly before tornado occurrence, we have divided the evaluation of the convective parameters by season. In this way, we hope to gain a better insight into the dynamic and thermodynamic nature of the atmosphere, which can improve operational decision making when forecasting tornadoes.

Data & Methodology:

ERA5-Reanalysis:

- Resolution: 0,25° × 0,25°
- Vertical: 27 Level
- Spatial coverage: Germany
- Spatial error: max. 0,768°
- Time period: 1950-2024
- Time error: 0-60 min before the event

Proximity-Soundings:

- Total: 150 Cases

Selection Criteria:

- Time: Occurrence of the event (UTC)
- Location: Lat-Lon-Coordinates (°)
- No duplicates

Climatology:

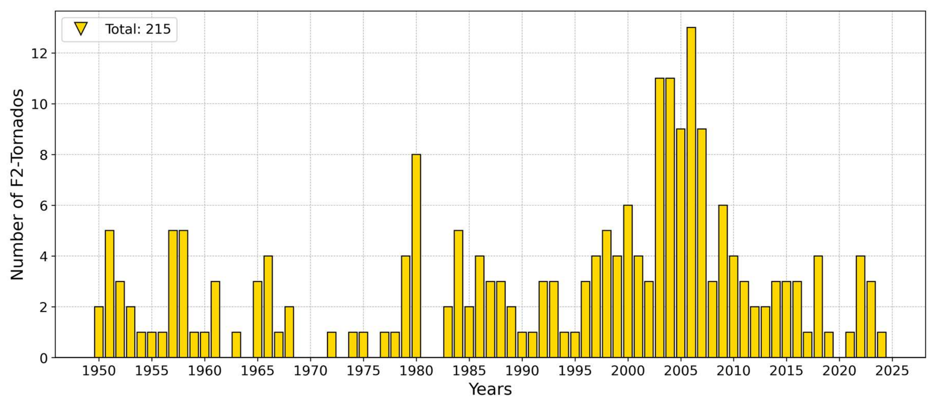

Fig. 2: Climatology of 215 documented F2-Tornados in Germany (1950-2024)

While there is a history of 215 documented F2 tornadoes in Germany since 1950, only a sample of 150 tornadoes meet the selection criteria and provide sufficient location and timing information. We have further analyzed this reliable sample, as shown in **Fig. 3-5**.

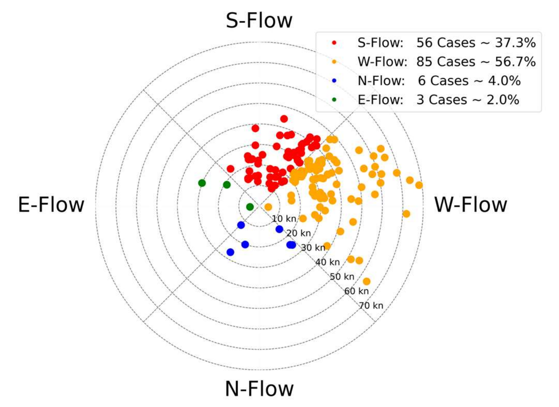

Fig. 6: Bunkers MW (Total: 150 Cases)

To determine the general synoptic flow regime, we have analyzed the bunkers mean wind [3] of each sounding. A classification by season can be found in **Fig. 7-9**.

Note: Storm Motion depends on the convective mode and may differ for each tornadic storm **(see Fig. 16)**.

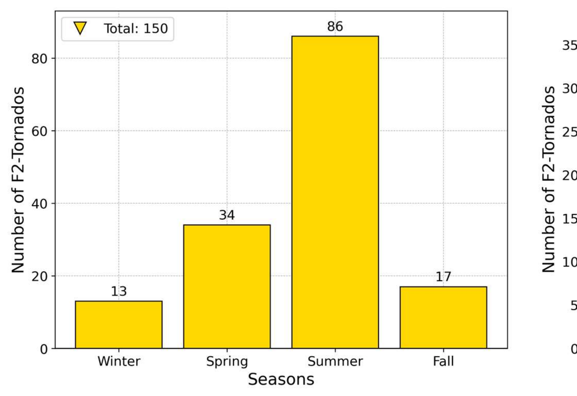

Fig. 3: Distribution by season (seasonal cycle)

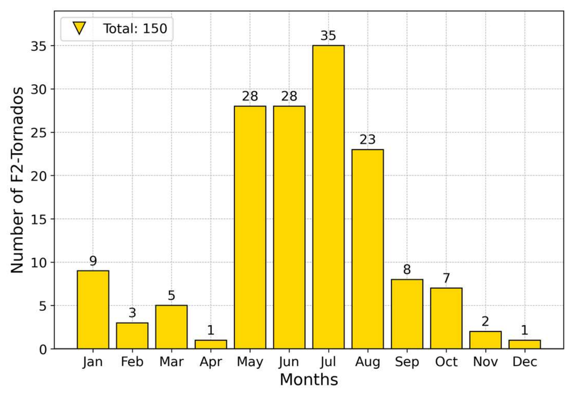

Fig. 4: Distribution by month (annual cycle)

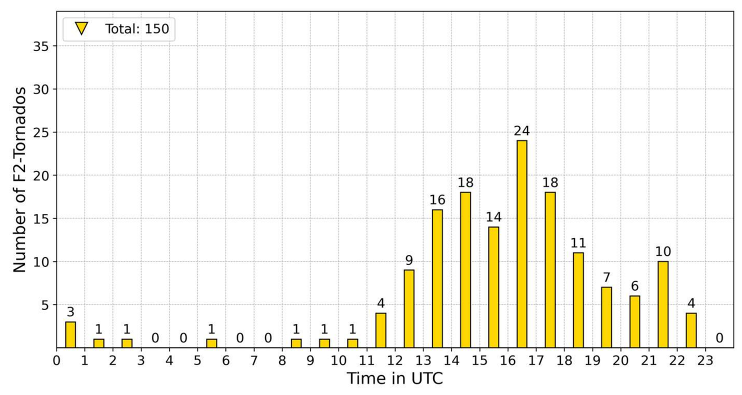

Fig. 5: Distribution by daytime (diurnal cycle)

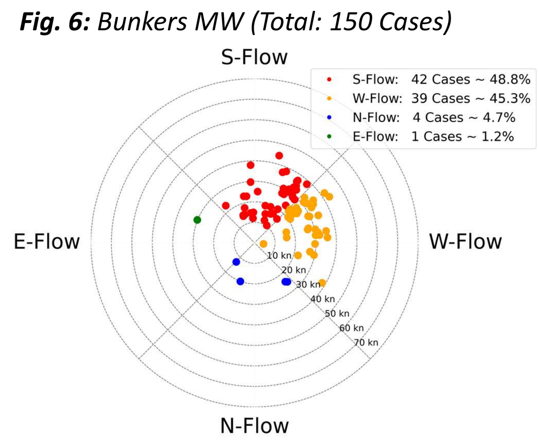

Fig. 7: Bunkers MW (Summer: 86 Cases)

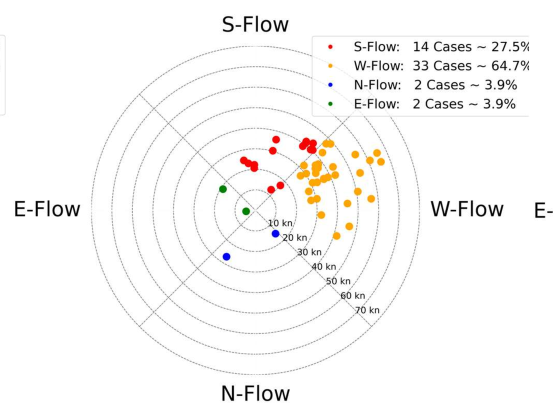

Fig. 8: Bunkers MW (Fall/Spring: 51 Cases)

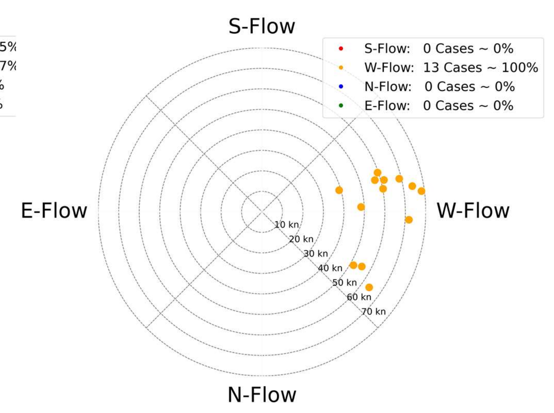

Fig. 9: Bunkers MW (Winter: 13 Cases)

Kinematics:

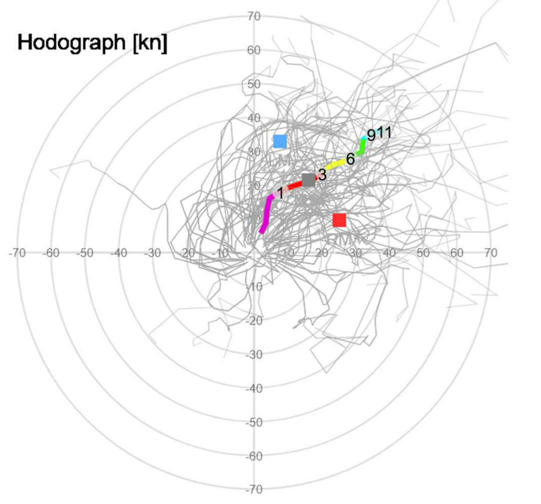

Fig. 10: Given is the mean hodograph from all 86 summer cases.

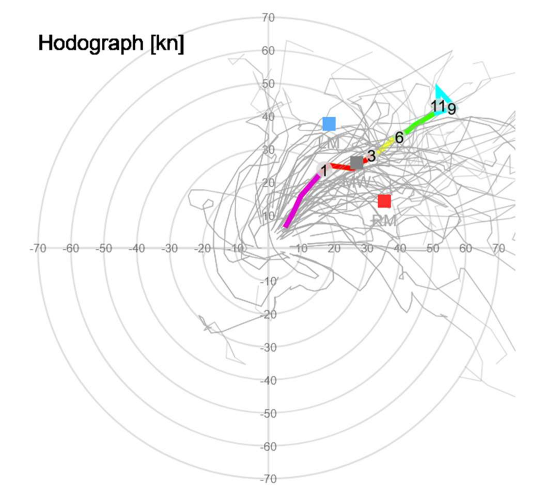

Fig. 11: Given is the mean hodograph from all 51 fall/spring cases.

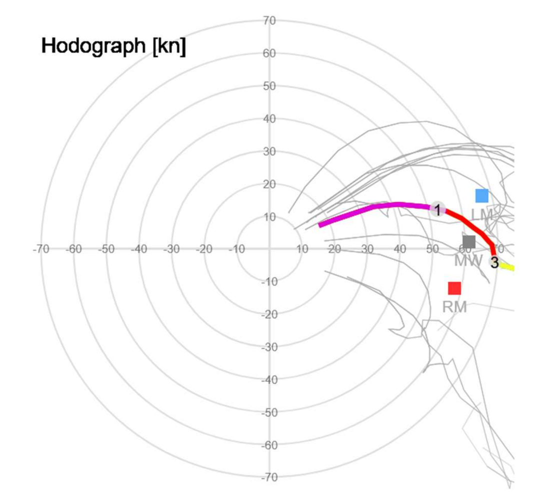

Fig. 12: Given is the mean hodograph from all 13 winter cases.

Helicity / Shear:	Mean	Min	Max
SRH 0-1 km	74 m²/s²	-36 m²/s²	205 m²/s²
SRH 0-3 km	141 m²/s²	14 m²/s²	400 m²/s²
Shear 0-1 km	15 kn	1 kn	33 kn
Shear 0-3 km	28 kn	10 kn	51 kn
Shear 0-6 km	27 kn	3 kn	66 kn
Effective Shear	25 kn	0 kn	58 kn
MW-Inflow 0-2 km	13 kn	4 kn	27 kn
MW-Outflow 6-12 km	24 kn	4 kn	55 kn

Helicity / Shear:	Mean	Min	Max
SRH 0-1 km	145 m²/s²	-20 m²/s²	342 m²/s²
SRH 0-3 km	222 m²/s²	41 m²/s²	795 m²/s²
Shear 0-1 km	23 kn	3 kn	39 kn
Shear 0-3 km	37 kn	11 kn	80 kn
Shear 0-6 km	28 kn	1 kn	54 kn
Effective Shear	26 kn	0 kn	80 kn
MW-Inflow 0-2 km	15 kn	6 kn	36 kn
MW-Outflow 6-12 km	30 kn	8 kn	63 kn

Helicity / Shear:	Mean	Min	Max
SRH 0-1 km	304 m²/s²	105 m²/s²	531 m²/s²
SRH 0-3 km	501 m²/s²	116 m²/s²	919 m²/s²
Shear 0-1 km	36 kn	19 kn	50 kn
Shear 0-3 km	55 kn	28 kn	80 kn
Shear 0-6 km	42 kn	17 kn	64 kn
Effective Shear	25 kn	0 kn	66 kn
MW-Inflow 0-2 km	22 kn	10 kn	32 kn
MW-Outflow 6-12 km	43 kn	23 kn	91 kn

Thermodynamics:

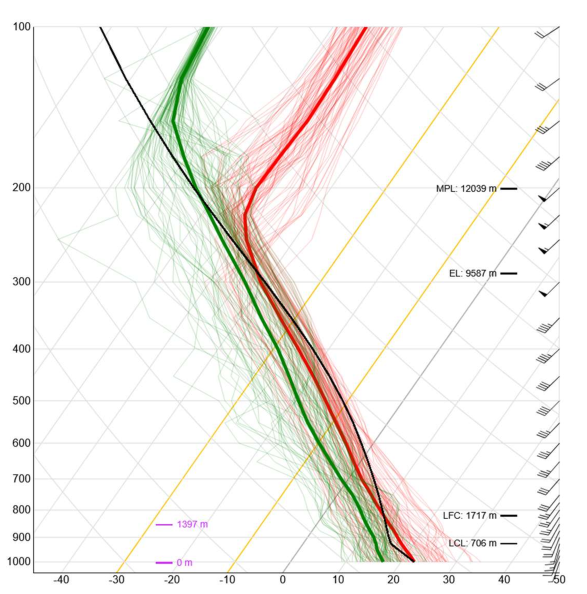

Fig. 13: Given is the mean skew-T from all 86 summer cases. (MU Parcel)

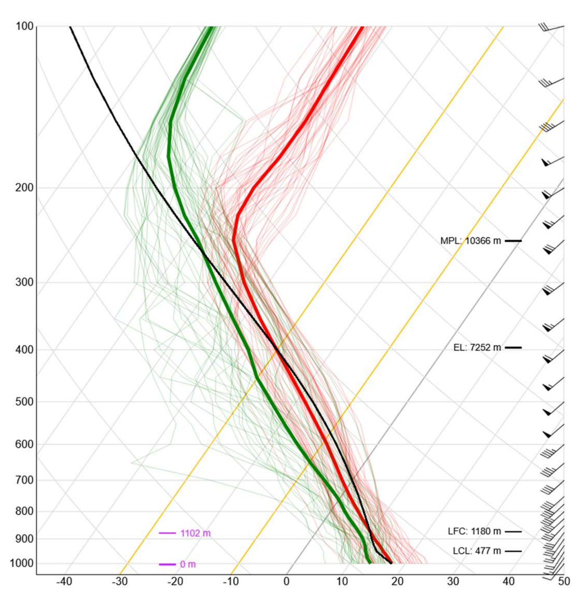

Fig. 14: Given is the mean skew-T from all 51 fall/spring cases. (MU Parcel)

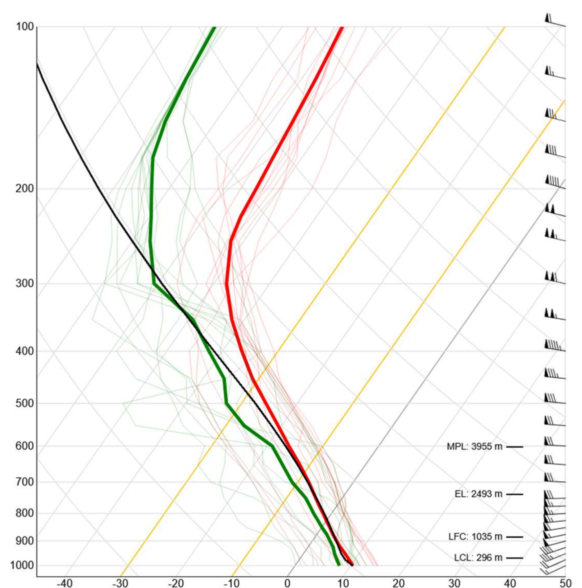

Fig. 15: Given is the mean skew-T from all 13 winter cases. (MU Parcel)

Bouyancy:	Mean	Min	Max
MU CAPE	997 J/kg	0 J/kg	4434 J/kg
MU ECAPE	945 J/kg	0 J/kg	4434 J/kg
MU 3CAPE	83 J/kg	0 J/kg	217 J/kg
DCAPE	536 J/kg	5 J/kg	1498 J/kg
ML CIN	-48 J/kg	0 J/kg	-467 J/kg

Bouyancy:	Mean	Min	Max
MU CAPE	543 J/kg	0 J/kg	1859 J/kg
MU ECAPE	518 J/kg	0 J/kg	1755 J/kg
MU 3CAPE	95 J/kg	0 J/kg	249 J/kg
DCAPE	324 J/kg	-23 J/kg	951 J/kg
ML CIN	-22 J/kg	0 J/kg	-67 J/kg

Bouyancy:	Mean	Min	Max
MU CAPE	94 J/kg	0 J/kg	614 J/kg
MU ECAPE	86 J/kg	0 J/kg	528 J/kg
MU 3CAPE	28 J/kg	0 J/kg	117 J/kg
DCAPE	118 J/kg	29 J/kg	380 J/kg
ML CIN	-11 J/kg	0 J/kg	-31 J/kg

Lapse Rates:	Mean	Min	Max
0-1 km Γ	-6,7 K/km	-2,3 K/km	-9,8 K/km
700-500 Γ	-6,1 K/km	-4,6 K/km	-8,7 K/km

Lapse Rates:	Mean	Min	Max
0-1 km Γ	-6,9 K/km	-0,9 K/km	-9,6 K/km
700-500 Γ	-6,2 K/km	-4,3 K/km	-7,2 K/km

Lapse Rates:	Mean	Min	Max
0-1 km Γ	-6,8 K/km	-5,4 K/km	-7,6 K/km
700-500 Γ	-6,9 K/km	-5,4 K/km	-8,1 K/km

Moisture:	Mean	Min	Max
PPW	35 mm	20 mm	51 mm
RH < LCL	76 %	42 %	97 %
Spread (T_{Sfc}-T_{DP})	7.2 K	1.8 K	17.7 K
Spread (T_{Sfc}-T_d)	5.6 K	0.9 K	22.3 K

Moisture:	Mean	Min	Max
PPW	28 mm	14 mm	44 mm
RH < LCL	81 %	62 %	98 %
Spread (T_{Sfc}-T_{DP})	4.9 K	-2.5 K	11.1 K
Spread (T_{Sfc}-T_d)	3.8 K	0.2 K	9.4 K

Moisture:	Mean	Min	Max
PPW	19 mm	8 mm	26 mm
RH < LCL	89 %	80 %	97 %
Spread (T_{Sfc}-T_{DP})	2.0 K	-2.3 K	5.1 K
Spread (T_{Sfc}-T_d)	2.4 K	1.0 K	3.3 K

**T_{Sfc}-T_{DP}: Differenz between Surface Temperature & Downdraft Parcel Temperature [7]*

Convective Mode:

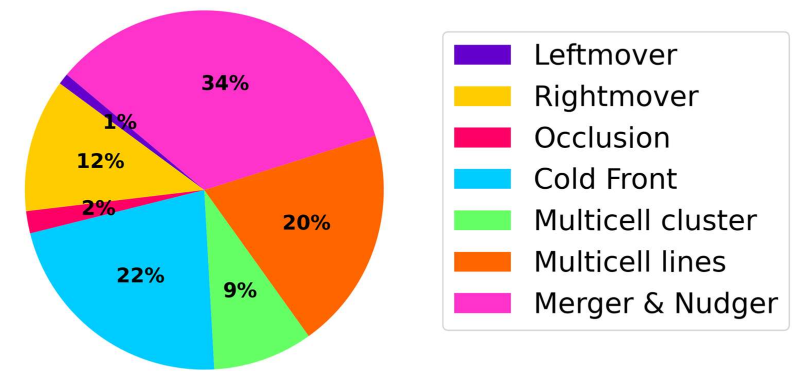

Fig. 16: Convective Mode (Total: 100 Cases)

Under which type of thunderstorms did the F2-Tornadoes occur?
We analyzed the convective mode of 100 cases using available radar data from the German Weather Service (DWD).

Note: The results could be personal biased.

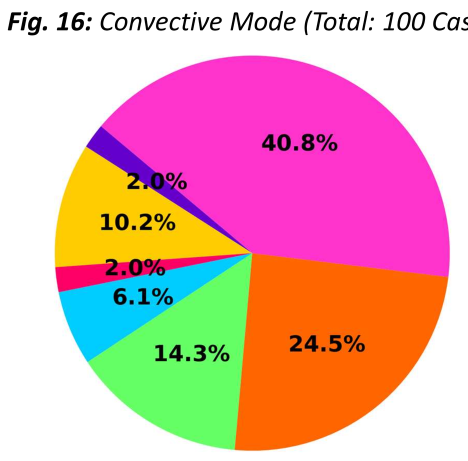

Fig. 17: Convective Mode (Summer: 49 Cases)

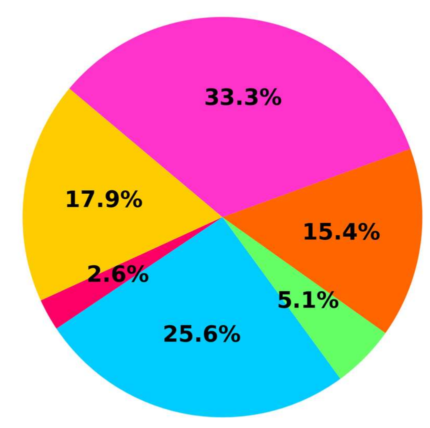

Fig. 18: Convective Mode (Fall/Spring: 39 Cases)

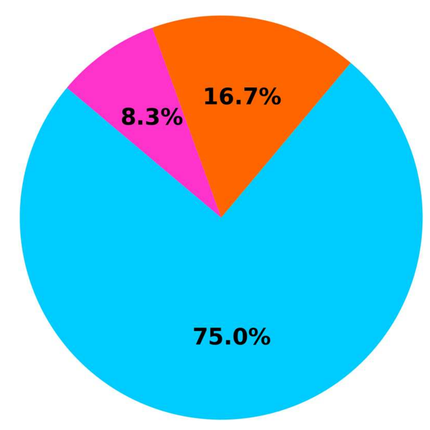

Fig. 19: Convective Mode (Winter: 12 Cases)

Key Findings:

Climatology:

- varying tornado activity over the past years with uptick since 2000 [4] (Fig. 2)
- most F2 Tornados occur during summer with peak in afternoon/evening [5] (Fig. 5)
- there is a downtime during the peak between 15-16 UTC in diurnal cycle [4] -> Why?

Thermodynamics & Kinematics:

- tornado setups in summer are more instability driven with SW-Flow (Fig. 7, Fig. 13)
- tornado setups in winter are more shear driven with W-Flow (Fig. 9, Fig. 12)
- tornado setups in fall/spring tend to be in between -> Pattern shift (Fig. 8)

Convective Mode:

- most tornados occur due to cell interactions (nudger/merger) [6] -> "Kick-off-process?"
- in summer more tornadoes caused by isolated convection or (organized) multicells.
- in winter most tornadoes were associated with convection along dynamic cold fronts [8,9]

References:

[1] Climate Data Store, ERA5 Reanalysis Data
[2] Tornadoliste Deutschland (Tornado archive operated by Thomas Sävert)
[3] Bunkers et al. 2000. Weather and Forecasting, AMS
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[5] Dotzek, N., 2001. Tornadoes in Germany. Atmos. Res., 56, 233-251. p. 238, Fig. 3
[6] Nixon, C., 2025. Storm Interactions - Cell Mergers and Nudgers, YT
[7] Richardson, Y., Markowski, P., 2010. Mesoscale Meteorology in Midlatitudes, p. 286, Fig. 10.14
[8] Sävert, T., Nov. 2015. Winterstürme und Tornados, Beitrag auf Wetterkanal der Kachelmann GmbH
[9] Pucik, T., 2022. Windstorms and tornado outbreak of February 2022, Post on ESSL Page

QR-Code: *Here you find all F2 Tornados together with ERA5-Reanalysis Data.*
Contact us: ***team.b.l.weather@gmail.com*** *or visit our website:* ***www.team-bl.de***

Special thanks goes to Thomas Sävert for documenting tornadoes in Germany.
Check out: ***www.tornadoliste.de***