Reconstruction of violent tornado environments in Europe: High-resolution dynamical downscaling of ERA5

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This research has already been published in Geophysical Research Letters!

Introduction

Based on information available in the scientific literature and historical sources, it can be estimated that several violent tornadoes have occurred across Europe over the last 100 years. Analyzing historical tornadoes that occurred prior to radar or satellite measurements, and where limited information is available, is challenging. However, in such cases it is possible to use numerical weather models to study atmospheric conditions in which tornadoes developed, and use those patterns to assess risks. In this study, using ERA5 reanalysis and WRF model we provided an analysis of violent tornado environments for 12 cases which occurred between 1957 and 2021.

Data and methodology

We used the European Severe Weather Database to choose violent tornado events (F4 and F5 in Fujita scale) in the period 1957–2021 and domain presented in Fig. 1. We run WRF (v4.2) high-resolution simulations (Tab. 1), to derive vertical profiles and maximum 2–5 km updraft helicity. Simulation results and ERA5 initial conditions were compared in terms of represented pre-convective environment. To calculate parcel thermodynamic parameters we use a mixed-layer of 0–500 m.

Tab. 1. Model configuration details used in simulations.

Model parameters		Parameterizations	
Lateral/boundary conditions	ERA5 0.25 deg	PBL	YSU (Hong et al., 2006)
Horizontal grid resolution	9, 3 km	Microphysics	New Thompson (Thompson et al., 2008)
Time step	30, 10 s		
Verical Levels	45 (up to 50 hPa)	Radiation	Dudhia (Dudhia, 1989) RRTM (Mlawer et al. 1997)
Simulation lenght	24 h start at 00 UTC		
		Cumulus	Kain-Fritsch (Zheng et al. 2015), only for d01

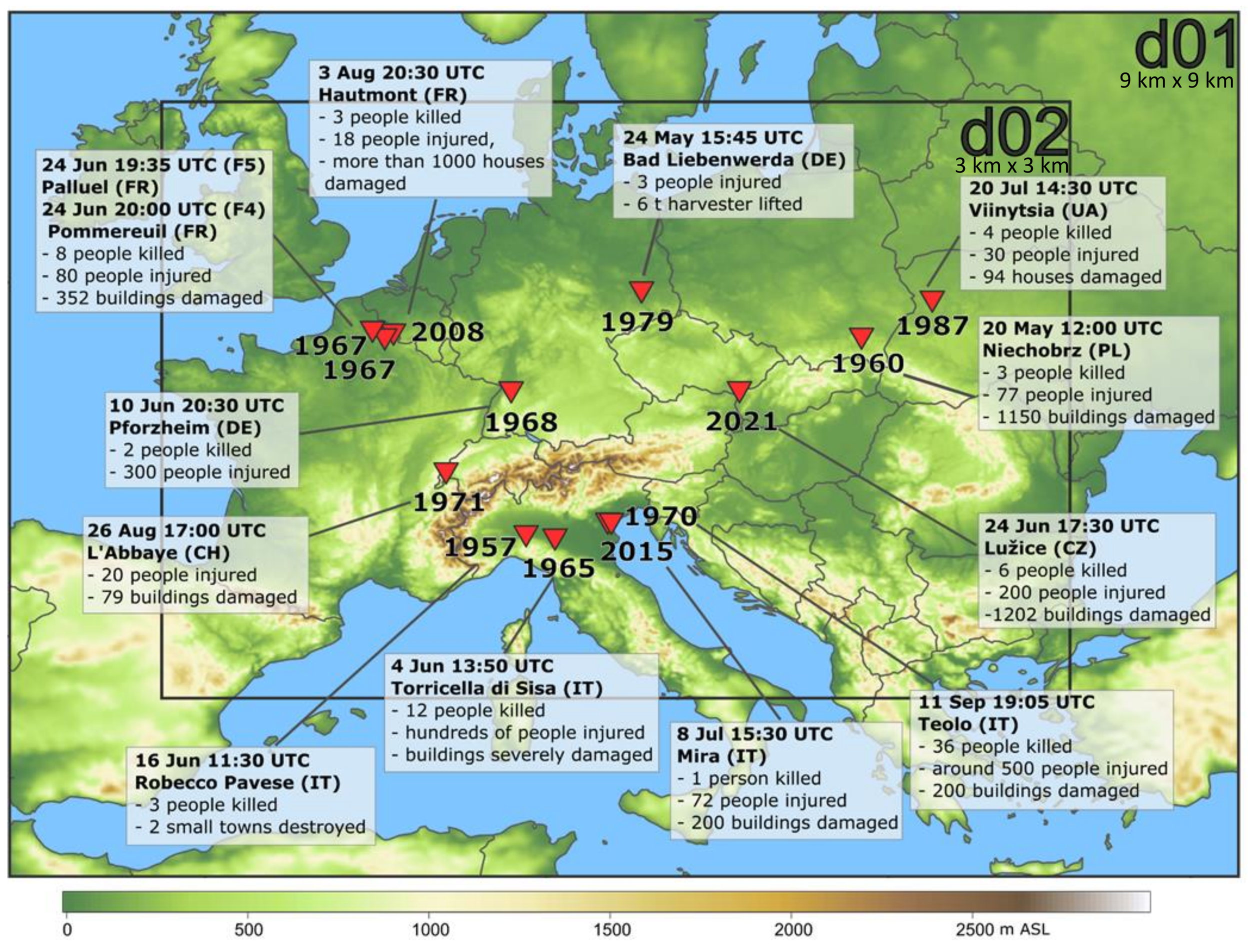

Fig. 1. WRF model domains (d01, d02) and violent tornado events evaluated in this study.

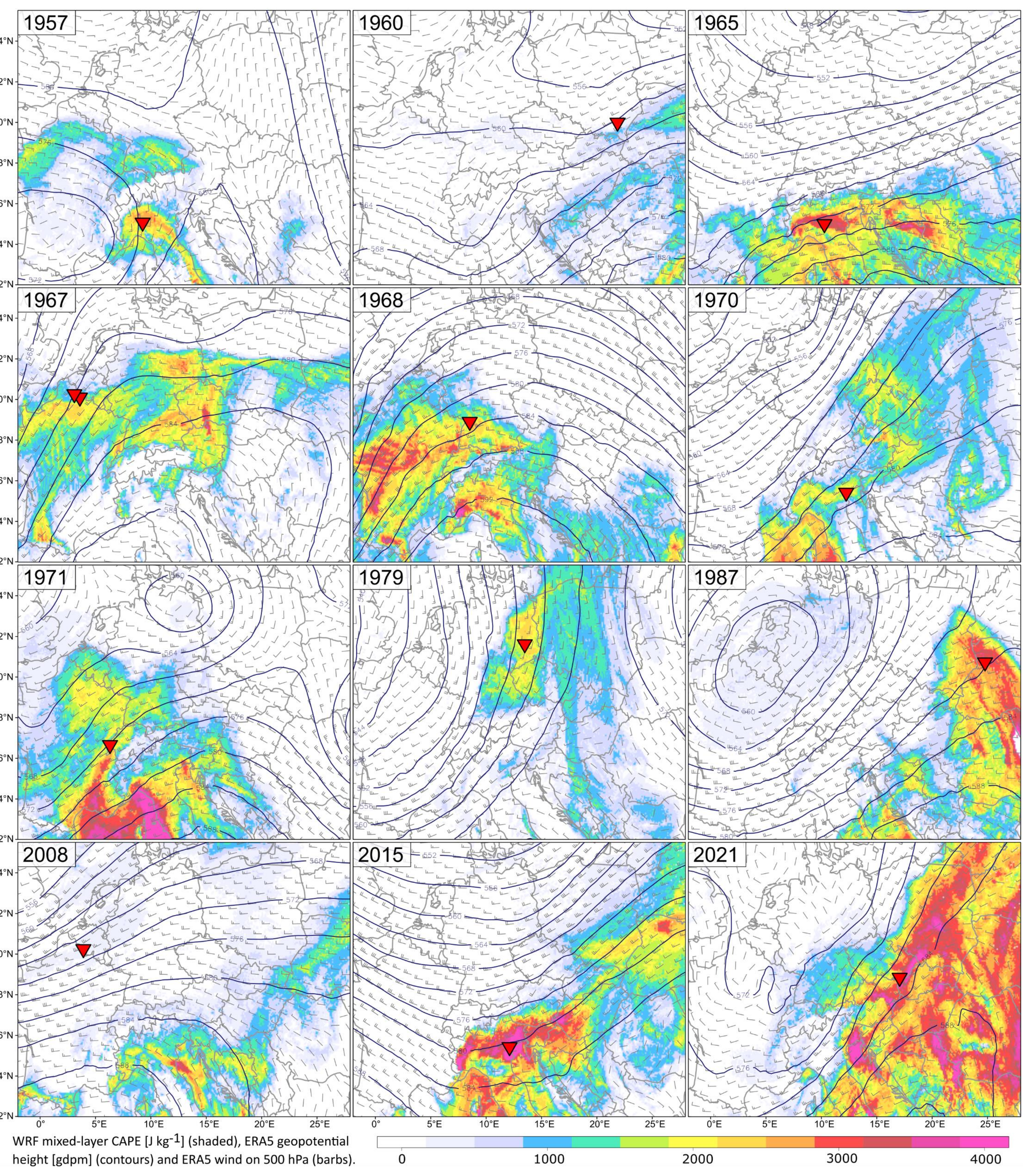

Fig. 2. Maximum 06–00 UTC ML CAPE (shaded), 500 hPa geopotential height (contour lines) and 500 hPa wind (barbs). Red triangles denote location of violent tornado events.

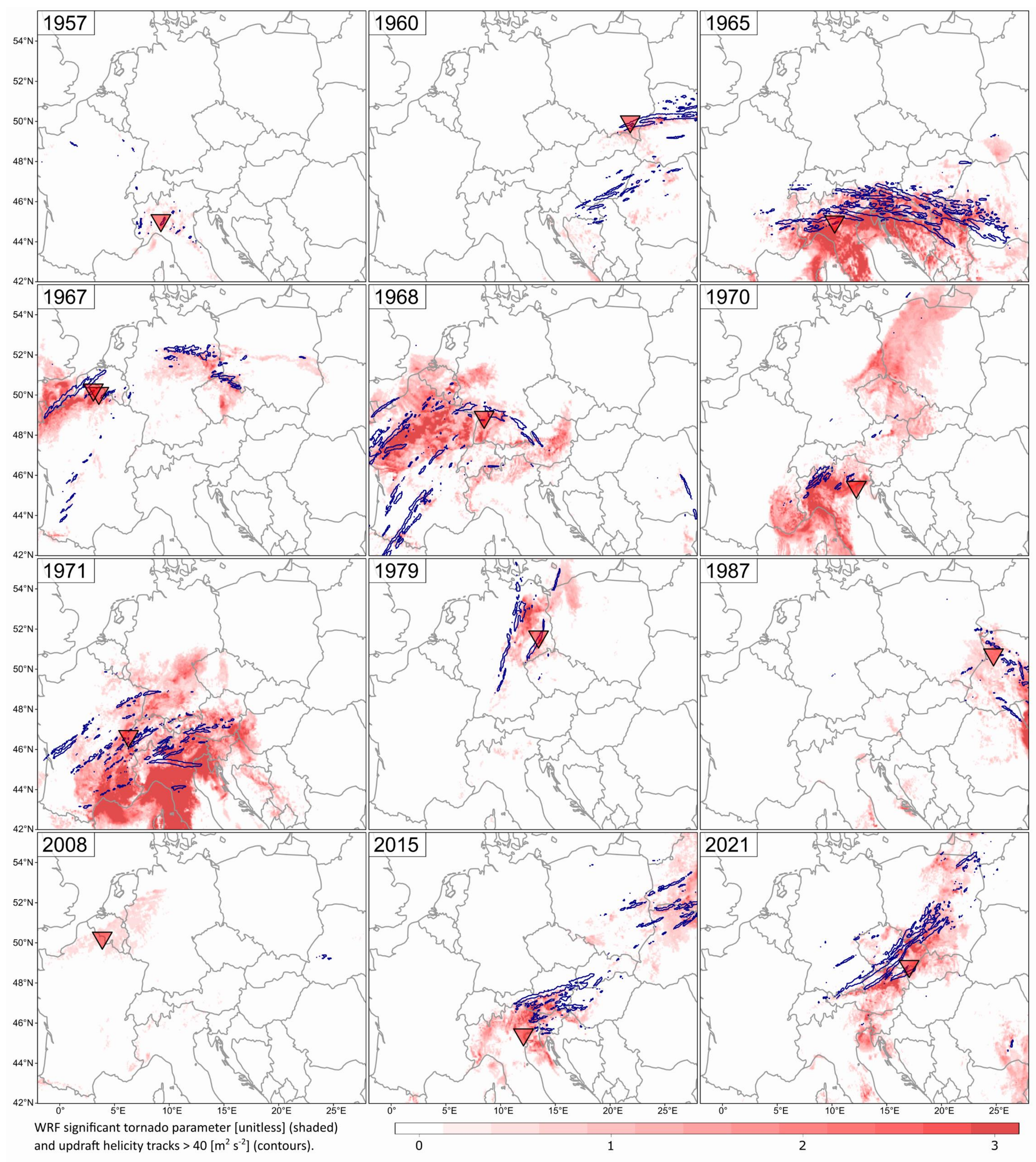

Fig. 3. Maximum 06–00 UTC STP (shaded) and UH > 40 m 2 s^{-2} tracks (contour lines). Red triangles denote location of violent tornado events

Fig. 4. Damage associated with selected violent tornadoes in Europe. Source of images: 1957 - Stampa Sera newspaper (17 Jun 1957 release), 1965 - La Stampa newspaper (5 Jun 1965), 1967 - courtesy of Keraunos Observatoire and Mr. and Mrs. Varlet, 1970 – courtesy of Studio Fotogtafico Bertadelo di Venezia, 2015 - courtesy of Mr. Alois Holzer, 2021 - courtesy of Dr. Tomáš Púčik.

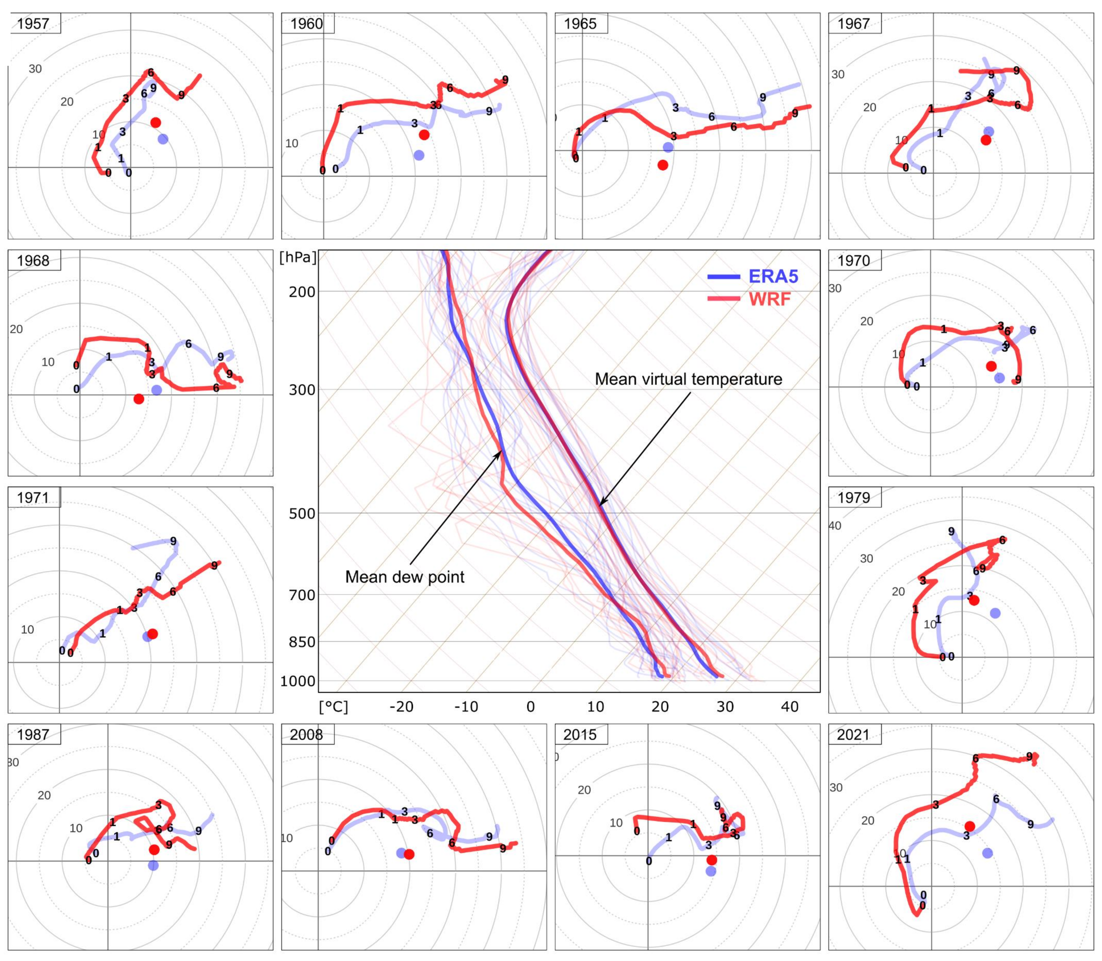

Fig. 5. Pre-convective profiles with hodographs for tornado events. The right-moving supercell storm motion is represented with a point.

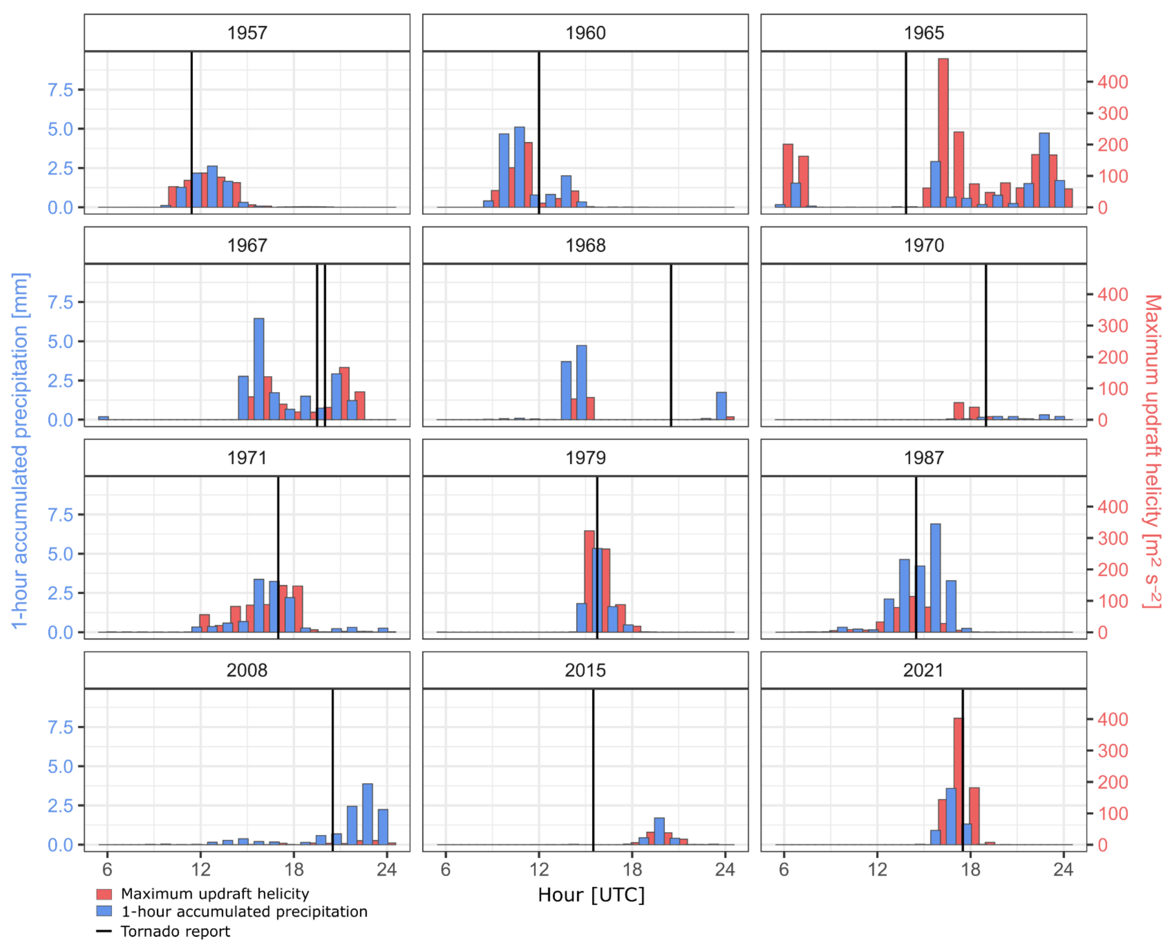

Fig. 6. Mean 1-hr accumulated precipitation and maximum 1-hr updraft helicity within 50 km proximity of the tornado report.

Year	S01 [m s^{-1}]		S06 [m s^{-1}]		SRH [m^2 s^{-2}]		LCL [m AGL]		MIXR [g kg^{-1}]		CAPE [J kg^{-1}]		CIN [J kg^{-1}]		STP	
	ERA5	WRF	ERA5	WRF	ERA5	WRF	ERA5	WRF	ERA5	WRF	ERA5	WRF	ERA5	WRF	ERA5	WRF
1957	3.6	6.0	17.6	23.8	7	43	645	365	11.9	13.6	831	2147	-8	0	0.0	1.0
1960	10.1	14.1	26.5	33.1	69	131	595	530	10.4	11.4	316	941	-2	-5	0.2	1.6
1965	10.4	5.8	31.1	35.1	24	43	1120	1210	12.6	14.8	1430	3120	-115	-2	0.2	1.4
1967	8.9	14.0	22.3	28.0	103	180	1060	840	12.3	12.0	1551	569	-63	-108	1.4	0.7
1968	10.0	16.0	26.4	30.9	77	215	1630	1450	11.5	11.9	1112	1492	-45	-65	0.4	1.7
1970	5.4	14.5	28.2	24.8	52	226	1130	580	12.2	14.5	475	1100	-182	-159	0.0	0.8
1971	9.6	14.2	26.5	26.0	44	118	680	705	10.9	13.0	403	2022	-49	-6	0.2	2.6
1979	8.6	12.1	19.4	28.6	31	124	1175	1035	10.4	11.7	1521	2246	-38	-4	0.3	3.5
1987	5.8	9.8	17.1	16.7	20	77	1130	1175	14.5	15.2	2384	2603	-14	-5	0.3	1.2
2008	14.2	14.5	22.6	26.3	137	183	490	495	11.8	11.9	136	295	-22	-9	0.0	0.5
2015	6.8	12.4	20.0	19.4	28	98	1010	1365	16.6	15.4	3009	2699	-27	-48	0.8	1.4
2021	8.7	11.4	26.3	34.1	12	124	1205	1325	14.7	14.6	3051	3475	-15	-8	0.4	3.9
Mean	**8.5**	**12.1**	**23.7**	**27.2**	**50**	**130**	**989**	**923**	**12.5**	**13.3**	**1352**	**1892**	**-48**	**-35**	**0.4**	**1.7**

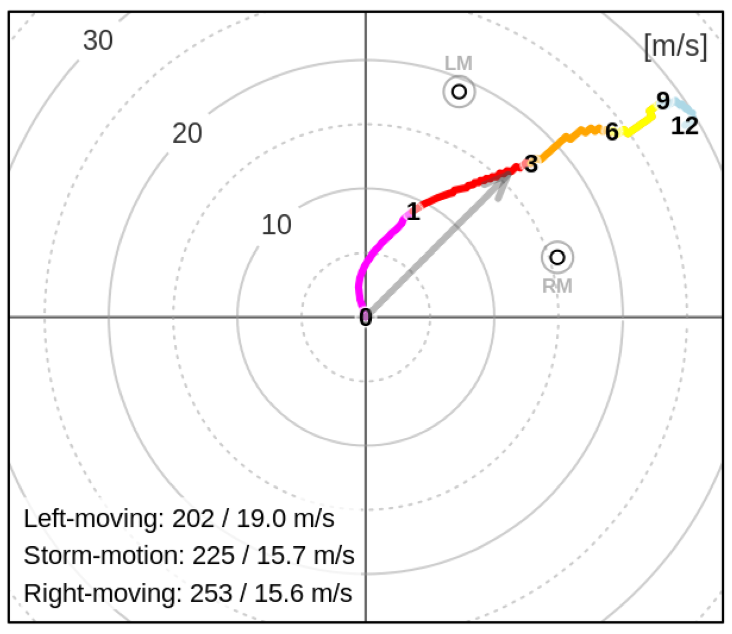

Fig. 7. Values of convective parameters for tornado events derived from WRF and ERA5 (on left). Mean hodograph for pre-convective profiles from WRF simulations (on right).

Results

- Violent tornadoes in Europe occur in a variety of synoptic and mesoscale patterns (Fig. 2), but they share environmental similarities with significant tornadoes from the United States.
- Downscaling simulations to 3 km grid-spacing showed the added value of improved resolution in representing local convective environments (Fig. 3, 5).
- In 8 out of 12 simulations, the model indicated updraft helicity (UH) tracks in a favorable convective environment in spatial (+/−50 km) and temporal (+/−3 hr) proximity to the tornado report (Fig. 3, 6).
- Tornadoes were accompanied by a mean 0–6 km wind shear of 24.3 m s^{-1} and mean convective available potential energy of 1678 J kg^{-1} (Fig. 7).
- The combination of UH tracks with convective environments offers promising results for operational forecasting in Europe, and should be explored in future studies

Acknowledgments

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