Ingredient-Based Analysis and Simulation of Violent European F4/F5 Tornadoes between 1965 and 1971

Jerome Schyns[1], Lisa Schielicke[1,2,3], Christoph Gatzen[2,3]

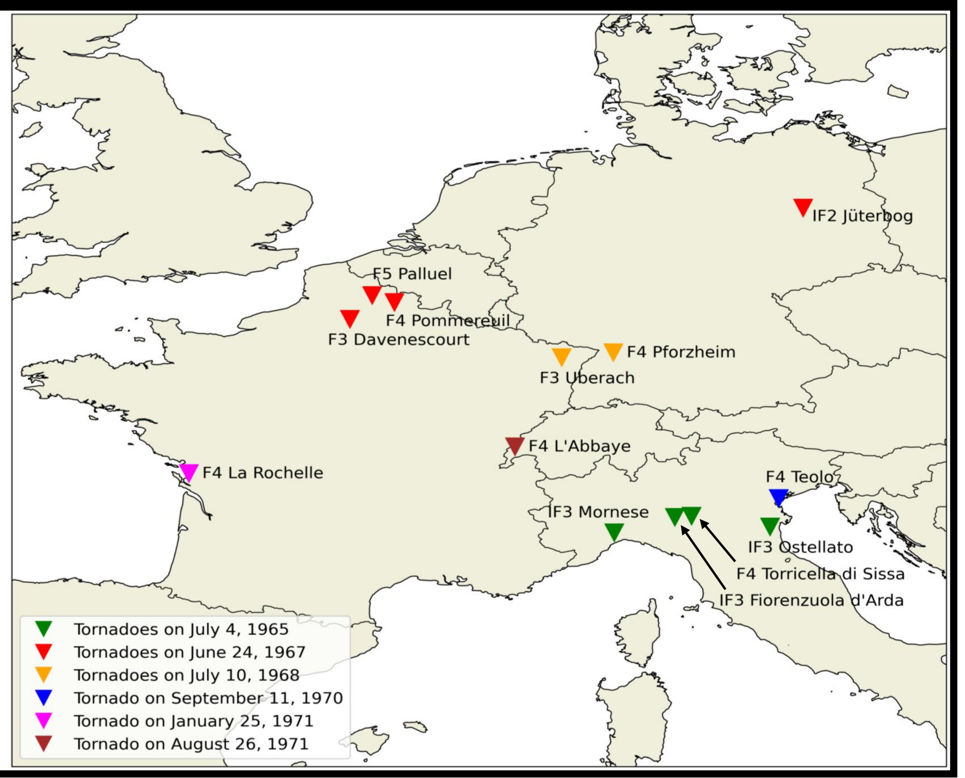
[1]Institute of Geosciences, University of Bonn, Germany (**Contact: s6jeschy@uni-bonn.de**)
[2]Department of Physics and Astronomy, Western University, London, Ontario, Canada
[3]Canadian Severe Storms Laboratory, Department of Civil & Environmental Engineering, Western University, London, Ontario, Canada

Motivation

- Unusual cluster of F4 (6) and F5 (1) tornadoes in a short period (1965 –1971), where some of them haven't been well researched
- Historical events and high-resolution simulations can help to improve our knowledge about the necessary ingredients for future tornado events in Europe

Objectives

(1) Better understanding of synoptic/mesoscale processes and ingredients that can lead to devastating tornadoes in Europe
(2) Are there connections between the individual cases? Can they be divided into different categories?
(3) Can Cloud Model 1 (CM1) be used to reproduce a tornadic cell based on ERA5 reanalysis data that were present during these weather events?[1,2,3]



Ingredients for Tornadic Weather Situations

General ingredients for deep moisture convection

- High amount of low-level moisture } Generation of CAPE
- Instability (steep lapse rates) } Generation of CAPE
- Sufficient lifting processes (quasi geostrophic, frontal, etc.)

Conditions for updraft rotation (mesocyclogenesis)

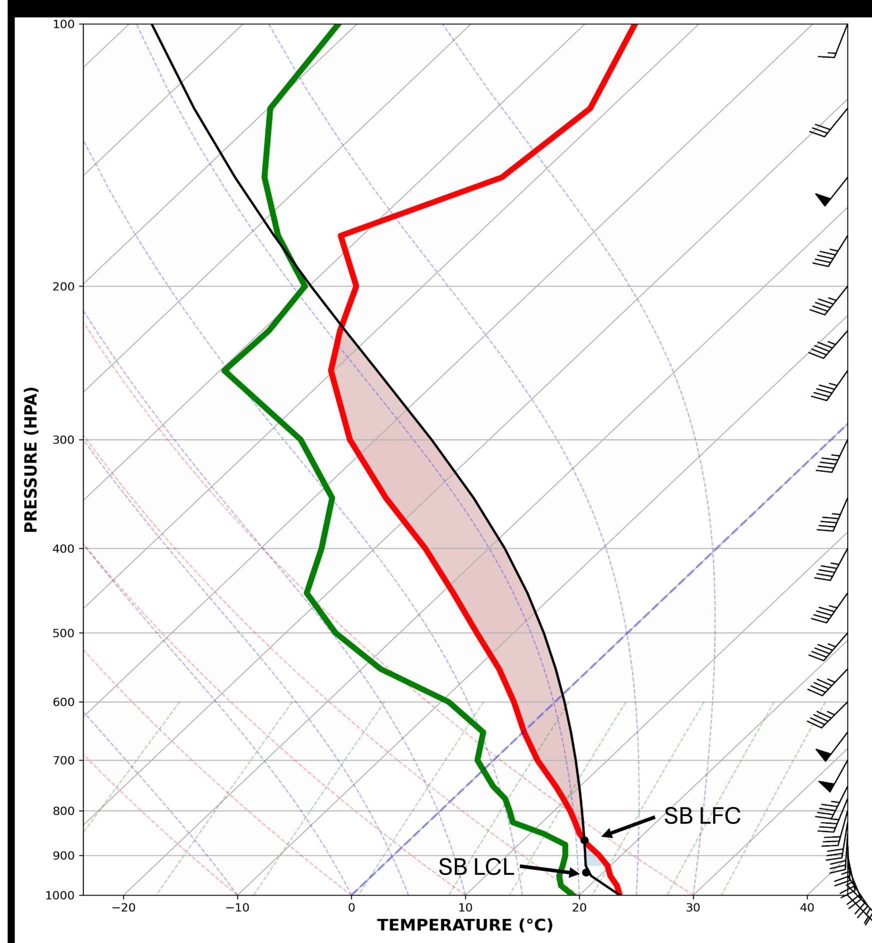
- Strong vertical wind shear (0-6 km bulk shear ≥ 35-40 kn)*
- 0-3 km storm relative helicity (SRH) ≥ 250 m^2/s^2*

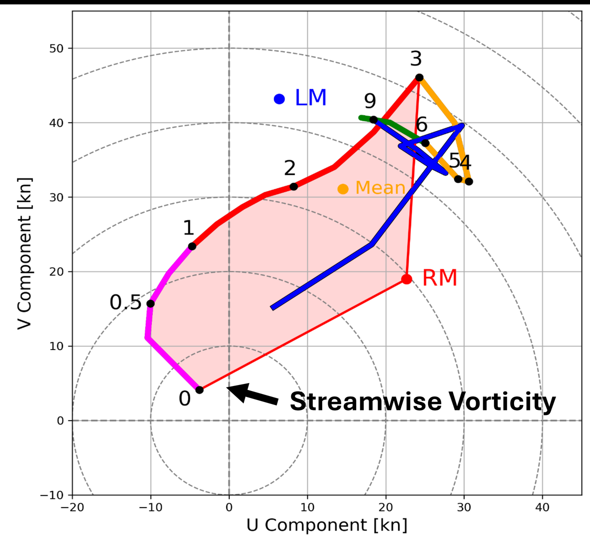
Helpful parameters for tornado genesis

- Low LCLs (low cloud bases, limited evaporation cooling)
- 0-1 km SRH ≥ 100 m^2/s^2 (prop. to streamwise vorticity)*
- Moderate 3 km CAPE (strong low-level stretching)*

*Threshold values taken from the National Weather Service (NWS), USA

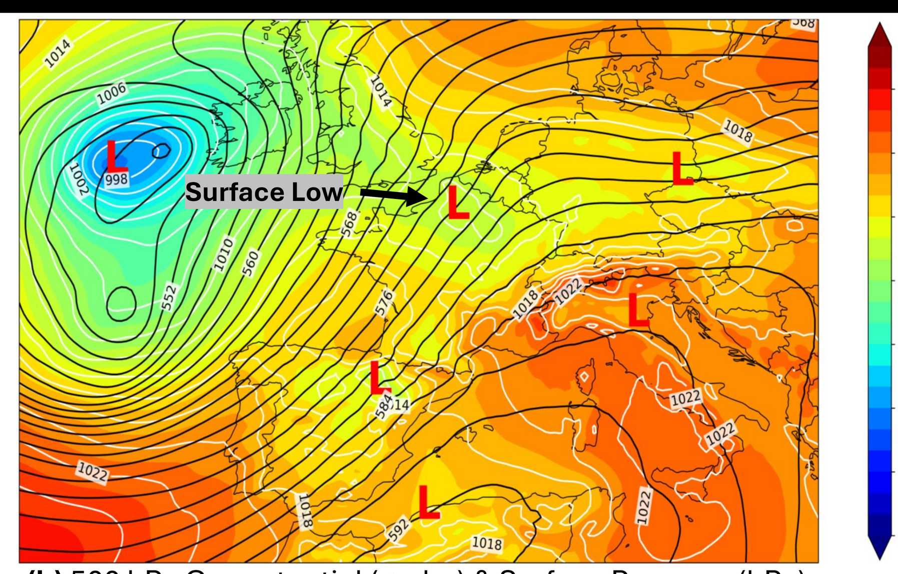
(1) Synoptic Overview using ERA5: Tornado Outbreak on June 24, 1967 (18 UTC) in Northern France



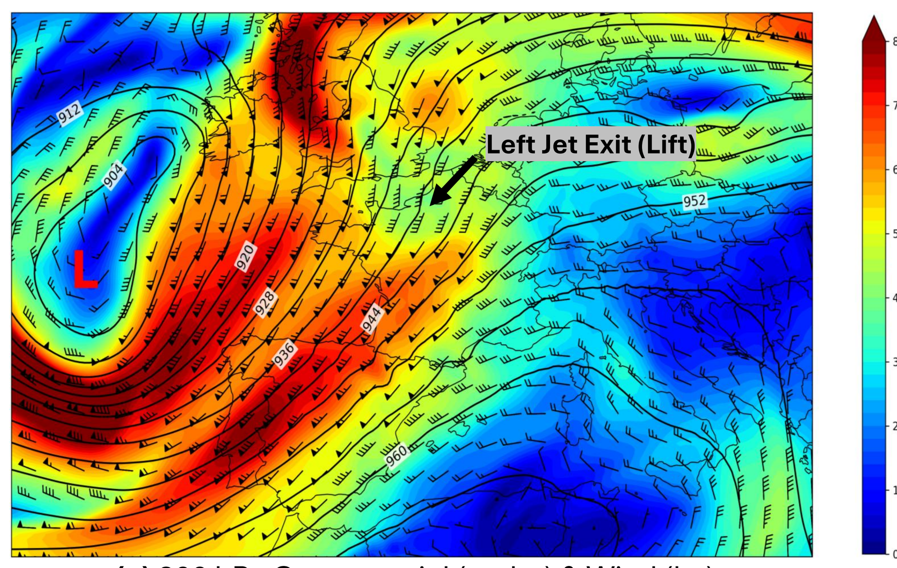


SB CAPE:	2006 J/kg	SRH 0-1km:	191 m²/s²
SB CINH:	-36 J/kg	SRH 0-3km:	359 m²/s²
ML CAPE:	1585 J/kg	Shear 0-1km:	19 kt
ML CINH:	-44 J/kg	Shear 0-3km:	50 kt
MU CAPE:	2006 J/kg	Shear 0-6km:	44 kt
MU CINH:	-36 J/kg	RM Direction:	230 deg
SB 3CAPE:	126 J/kg	RM Speed:	30 kt
ML 3CAPE:	84 J/kg		
MU 3CAPE:	126 J/kg		
LI:	[-6] Δ°C	LCL Pressure:	941 hPa
TT:	52 Δ°C	LCL Height:	616 m
K Index:	33 °C	LFC Pressure:	864 hPa
VT:	28 Δ°C	LFC Height:	1319 m

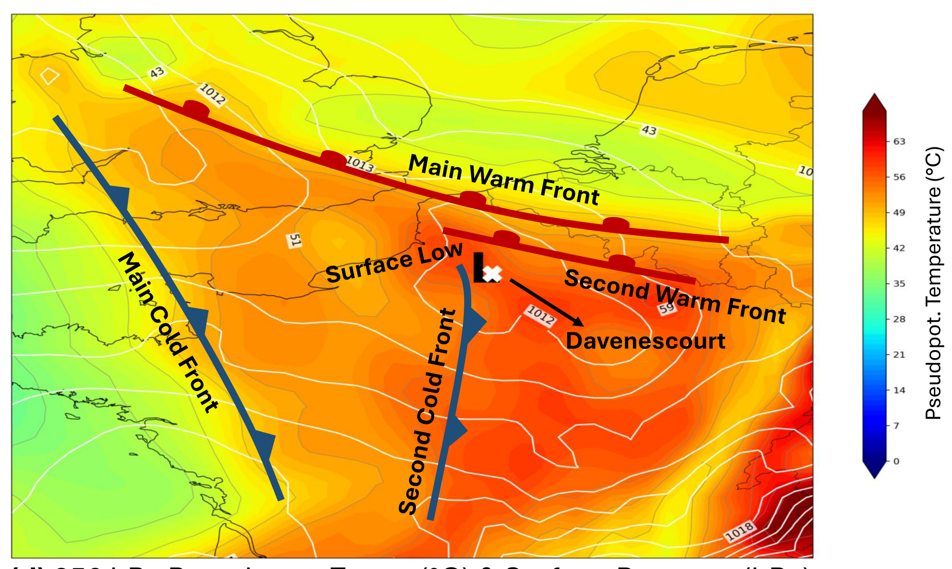
(a) Davenescourt (France) – Vertical Profile



(b) 500 hPa Geopotential (gpdm) & Surface Pressure (hPa)



(c) 300 hPa Geopotential (gpdm) & Wind (kn)



(d) 850 hPa Pseudopot. Temp. (°C) & Surface Pressure (hPa)

Large Scale Synoptic Situation

- Long-wave trough over N Atlantic **(b)**
- Spanish Plume: Hot air masses from Africa and Iberian Peninsula
  ➡ Elevated mixed layer (Pyrenees) promotes steep lapse rates in the mid-levels (instability)
- Moisture advection from the Mediterranean **(d)**
  ➡ CAPE generation
- Cyclogenesis at the left jet exit **(c)**
  ➡ Surface low over N France (supports lifting) **(b), (d)**

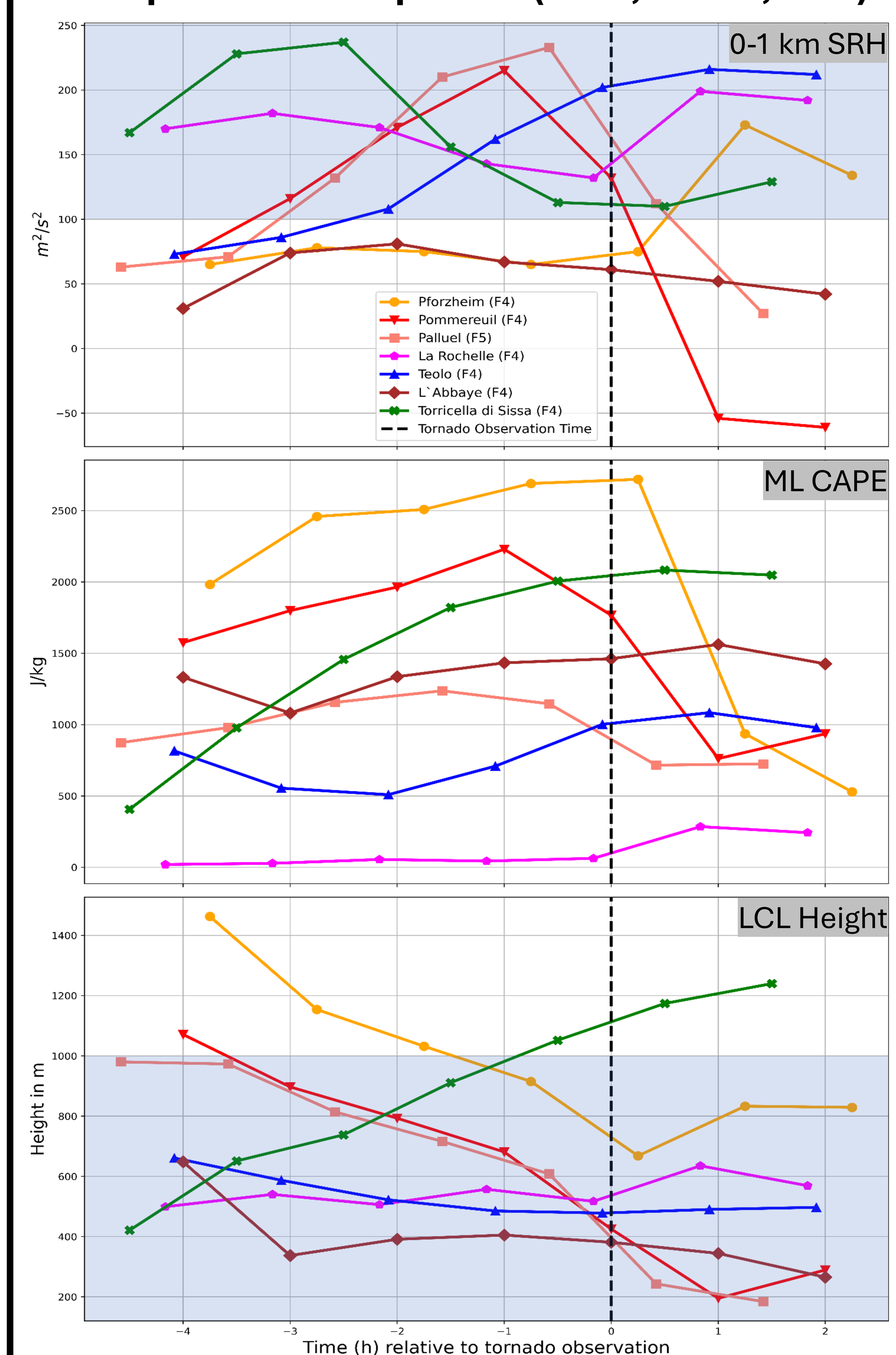
Increasing Tornado Potential

- Surface low supports low-level ageostr. east wind components **(a)**
- Increasing overlap of growing 0-1 km SRH (streamwise vorticity), CAPE and low LCLs **(a)**
- 3 km CAPE supports low-level stretching **(a)**

➡ **Best overlap for tornadoes south of the warm front at the CAPE gradient (d)**

(2) Comparison of all Tornado Cases

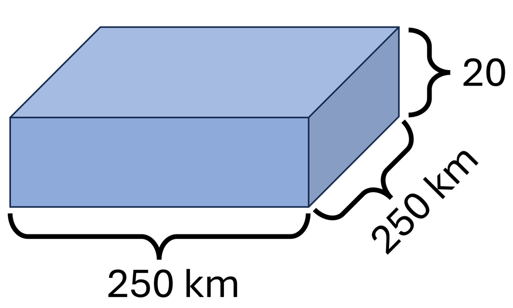
Temporal Development (SRH, CAPE, LCL)



- In many cases: Increasing 0-1 km SRH > 100 m^2/s^2 (streamwise vorticity) and ML CAPE before tornado observation
- Significant drop in LCL to below 1000 m before tornado observation (except F4 on July 4, 1965)

(3) CM1-Simulation of the Davenescourt Sounding (+ Modified Versions)

Model Domain and Settings



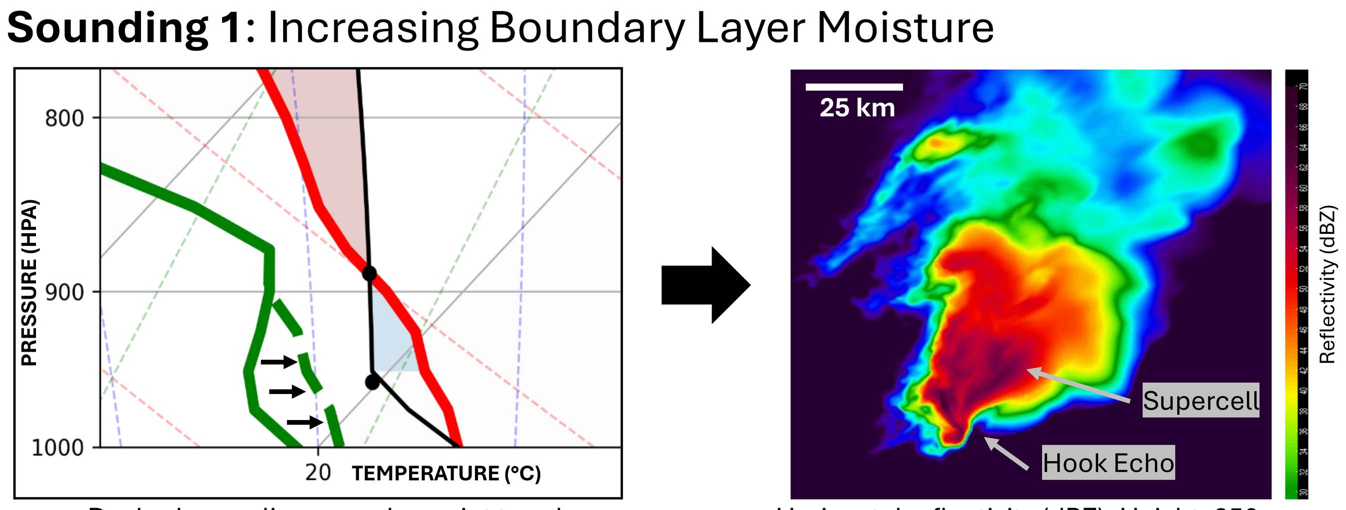
Variable	Magnitude
Hor. Resolution	500 m
Vert. Resolution	500 m
Temp. Resolution	15 min (900 s)
Simulation Time	500 min (8.33 h)
Analyzed Altitude	250 m

Initiation Mechanisms

- Warm Bubble
- Convergence
- Cold Blob (Outflow Boundary)
- Updraft Nudging

Sounding Modifications with Updraft Nudging: Results

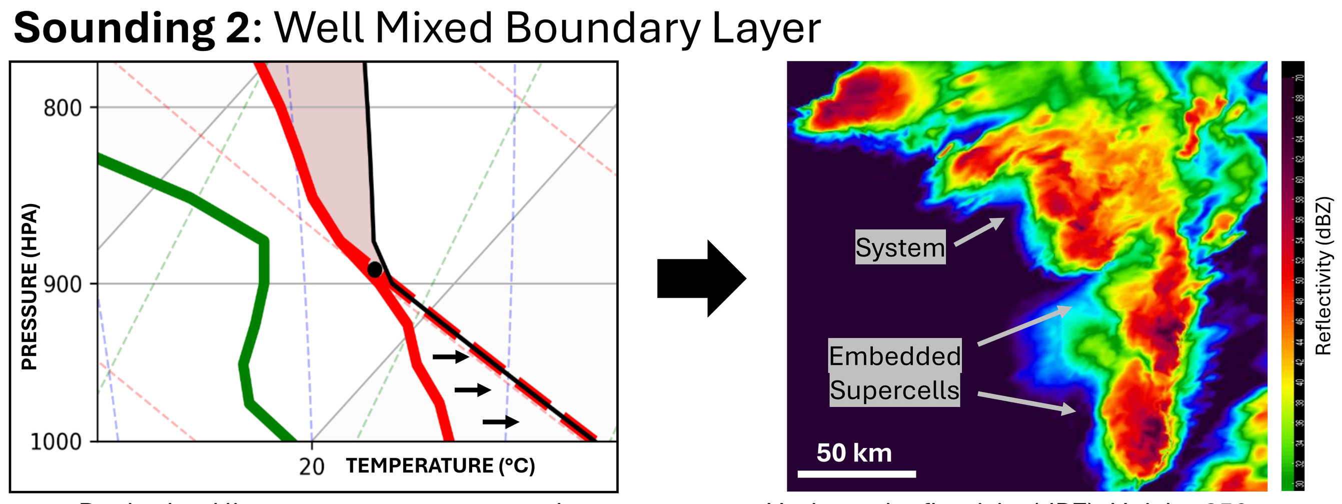
Sounding 1: Increasing Boundary Layer Moisture



Dashed green line: new dewpoint trend
Solid green line: originally dewpoint trend

Horizontal reflectivity (dBZ). Height: 250 m
Simulation time: 480 min

Sounding 2: Well Mixed Boundary Layer



Dashed red line: new temperature trend
Solid red line: originally temperature trend

Horizontal reflectivity (dBZ). Height: 250 m
Simulation time: 285 min

Results and Outlook

All CM1 Simulation Results

Trigger	Original	Sounding 1	Sounding 2
Warm Bubble	No development	Weak single cell	Weak single cells
Convergence	No development	No development	No development
Outflow Boundary	No development	No development	No development
Updraft Nudging	Weak single cell	Isolated supercell	Embedded supercells

- No or weak initiation in all soundings with warm bubble, convergence, and outflow boundary
- Updraft nudging is the most suitable choice for guaranteed initiation of (organized) convective cells

➡ **CM1 is highly sensitive to changes in boundary layer properties**

Synoptic Summary

- Certain weather patterns (e.g. Spanish Plume) and regions (e.g. N Italy) offer favorable conditions for strong tornadoes in Europe
- Curved hodographs (streamwise vorticity) primarily in the low levels support tornado genesis
- Interaction of high SRH, CAPE, lift, and low LCL height is relevant for European weather patterns with strong tornadoes

➡ **Relevant for future forecasts of European tornado situations**

REFERENCES: [1]Schielicke, L. (Jan 2024). Cloud Model 1 & Visualization – A Block course. Research Gate. https://doi.org/10.13140/RG.2.2.30017.12642. [2]Bryan, G. H., & Fritsch, J. M. (2002). A benchmark simulation for moist nonhydrostatic numerical models. Monthly Weather Review, 130 (12), 2917-2928. [3]Hersbach, H., et al. (2020). The ERA5 global reanalysis. Quarterly journal of the royal meteorological society, 146 (730), 1999-2049.