Synoptic Analysis and Simulation of the High-Shear, Low-CAPE (HSLC) F4-Tornado in Hautmont, France from August 03, 2008, using ERA5 data and Cloud Model 1

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Motivation

- Strong High-Shear, Low-CAPE (HSLC) type 1 tornado cases are rare in Europe
- The Hautmont F4 tornado case is poorly analysed and modelled
- Numerical modelling is a useful tool for understanding tornado formation

Research Objectives

1) Which synoptic- and mesoscale processes contributed to the development of this F4 tornado in a HSLC environment?

2) How does Cloud Model 1 (CM1) react to a reconstructed HSLC Sounding using different lifting mechanisms?

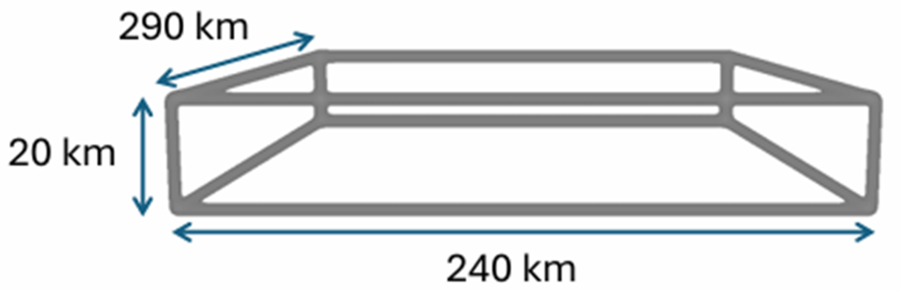
Methodology

- **Data:** ERA5 Reanalysis on Model Levels[2]
- **Model:** Cloud Model 1 (v. cm1r21.1)[1,3]

Model Configuration

Parameter	Configuration
Horizontal Resolution	500 meter
Vertical Resolution	250 meter
Time Resolution	5 minutes (9h total)
Bottom Boundary Condition (bbc)	Partial interaction (semi-slip)
umove / vmove	24.0 / 14.5 [m/s]

Domain:



Lifting Mechanism	Pertubation
Warm Bubble (WB)	+2 Kelvin
3 WB in line (3WB)	+2 Kelvin each
Convergence (CO)	permanent (surface)
Updraft Nudging (UN)	45 min (center)

Executed Simulations

A Simulations with all lifting mechanisms using the vertical profile with the **unprocessed** dewpoint (Fig.4, straight line)

→ Simulations A unsuccessful/unrealistic, because of extreme moisture content in the boundary layer
→ Solution: Manually reducing the dewpoint

B Simulations with all lifting mechanisms using the vertical profile with the manually **reduced** dewpoint (Fig.4, dashed line)

ERA5: Synoptic Analysis of the Hautmont Region

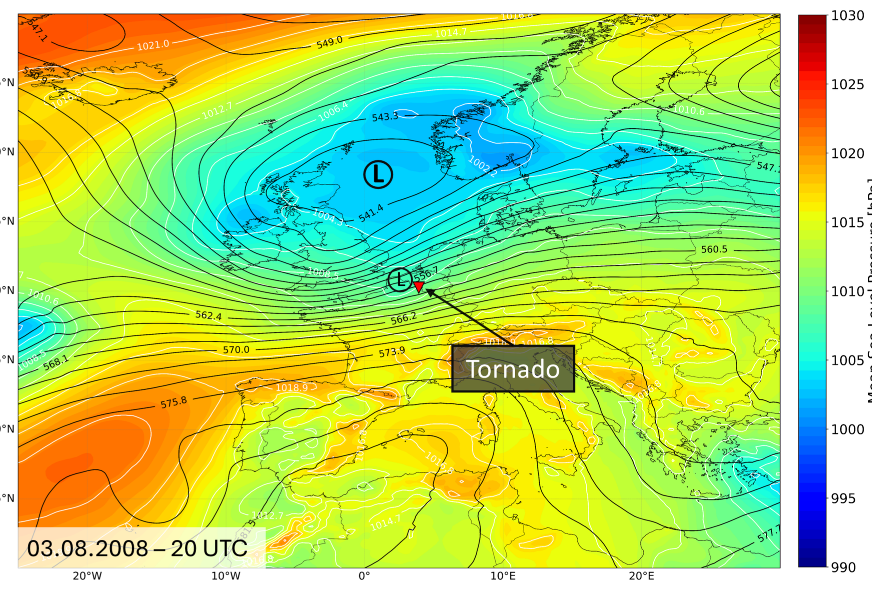


Fig.1 – Surface Pressure & 500 hPa Geopotential
Shown is the large-scale weather pattern. White isobars depict the surface pressure, black isohypes the 500 hPa Geopotential.

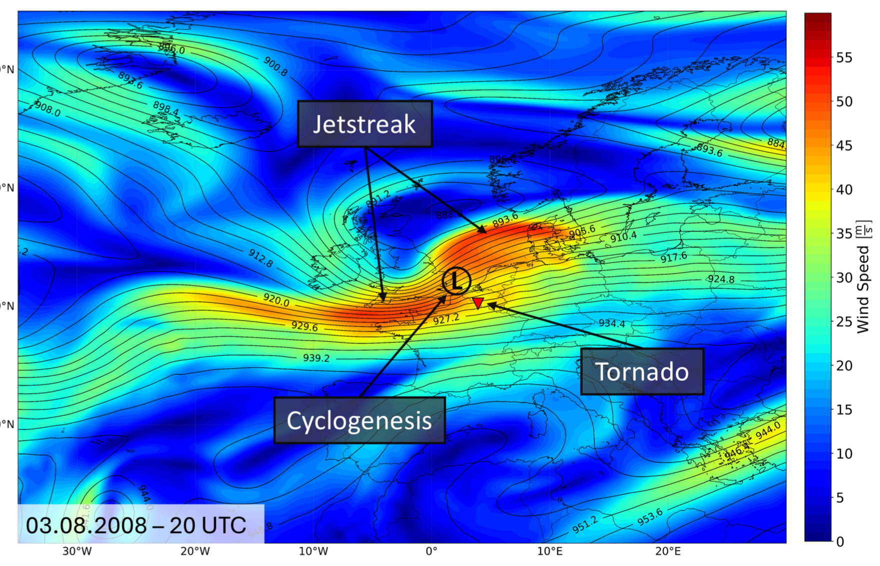


Fig.2 – 300 hPa Wind & Geopotential
Shown is the Jetstream-/streak configuration. Black isohypes depict the 300 hPa Geopotential.

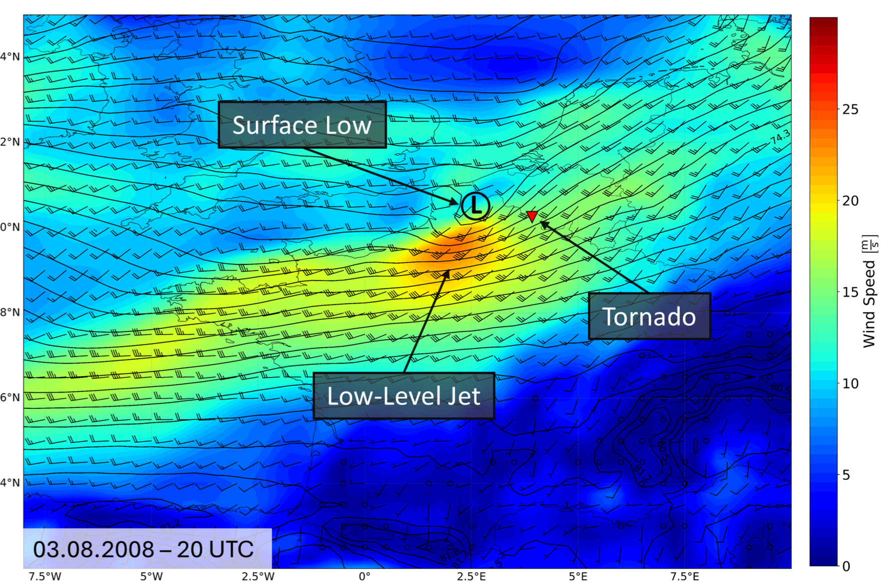


Fig.3 – 925 hPa Wind & Geopotential
Shown is the forced Low-Level Jet. Wind barbs [knots] depict the 925 hPa wind and black isohypes the 925 hPa Geopotential.

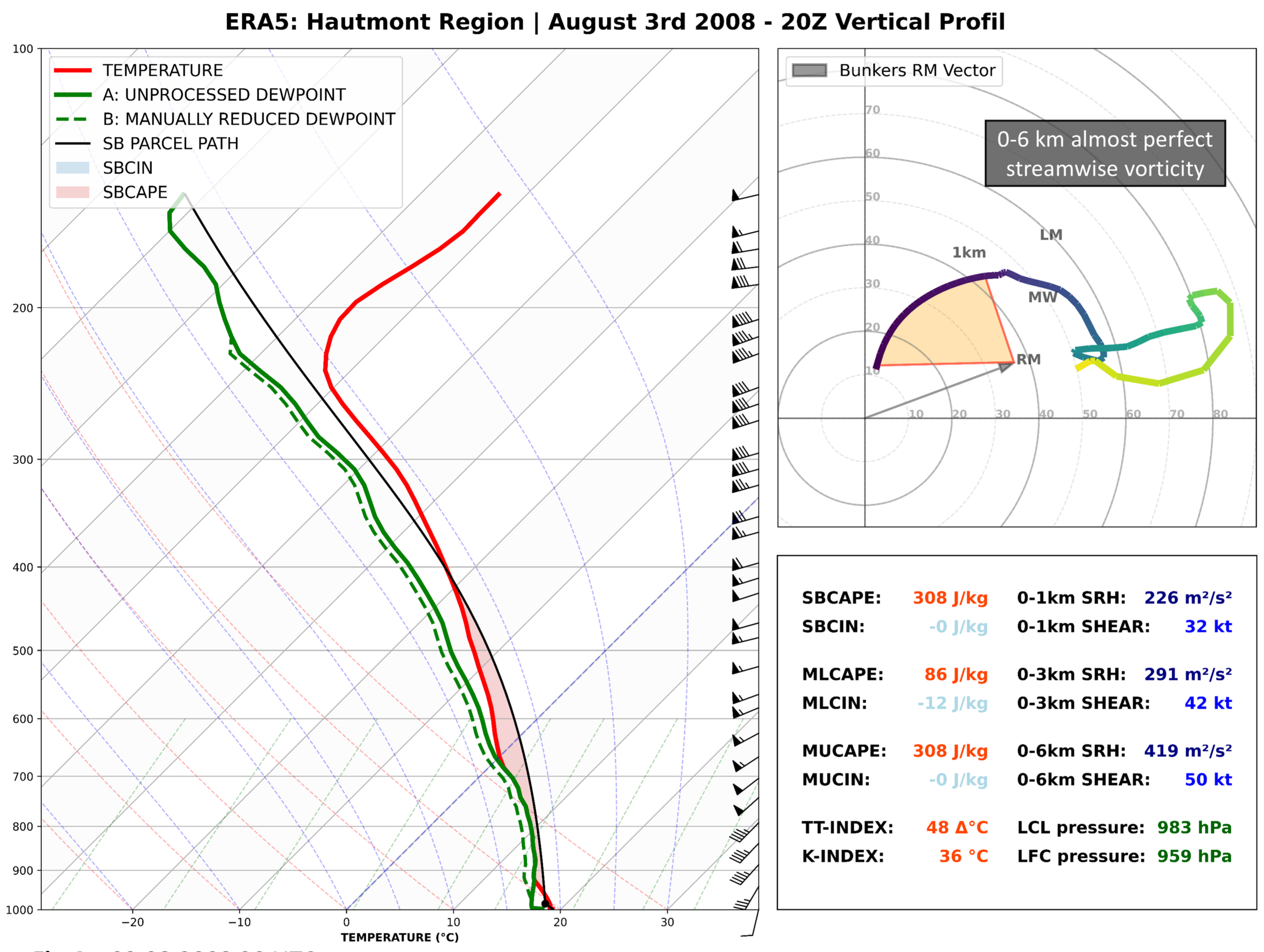


Fig.4 – 03.08.2008 20 UTC
ERA5: Reconstructed vertical Sounding and Hodograph for the Hautmont Region. The unprocessed Dewpoint is from ERA5 data. The manually reduced dewpoint is used for the modelling in CM1.

- Jetstream configuration leads to large scale quasigeostrophic lifting processes, inducing cyclogenesis near the surface (Fig.2) (Coupled-Jet effect)[4]
- Development of a (surface) short-wave trough, leading to the formation of a low-level jet (LLJ) and cyclonic vertical wind shear (Fig.2 & Fig.3)
- Right Mover experiences nearly perfect streamwise vorticity with extreme SRH values of 0-1 km 226 m²/s² (Fig.4)
- High moisture along the profile also leading to a low LCL (Fig.4)

➢ **Despite a skinny CAPE profile, the dynamical setup itself indicates a favorable tornadic HSLC environment[5,6]**

Cloud Model 1 Simulation Results

Observation Simulations (B)	Lifting Mechanism			
	WB	3WB	CO	UN
Convection	Yes	Yes	Yes	Yes
Hook echo	No	No	No	Yes
Supercell	No	No	No	Yes
Squall line	No	Yes	Yes	Yes
Bow echo	No	Yes	No	Yes
Tornado-like Vortex	No	No	No	Yes

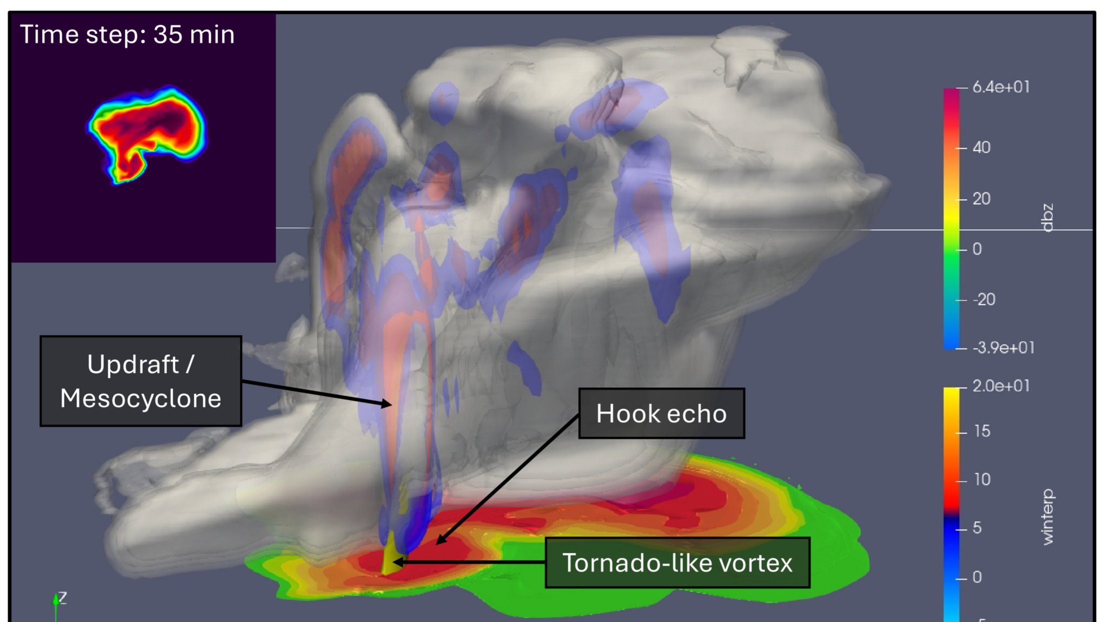


Fig.5 – Simulated Supercell and tornado-like vortex from updraft nudging. 2D simulated reflectivity in the top left.

- A single warm bubble is ineffective in HSLC environments due to insufficient updraft support
- Multiple interacting updrafts (e.g. line of warm bubble, forced convergence) can result in weak squall lines and bow echoes
- A strong lifting mechanism (e.g. updraft nudging) can sustain a weak updraft after convection initiation and allow the development of an isolated supercell and a possible tornado-like vortex

➢ **Lifting mechanisms can be split into the following two categories:**
- Updraft initiating mechanisms (e.g., WB, CO)
- Updraft supporting mechanisms (e.g., UN)

Main Results

➢ **Updraft nudging simulates a tornado-like vortex of the strength F1 (156.65 km/h)**

➢ **The supercell produced by updraft nudging only exists during the 45 min nudging window. Once stopped, the supercell decays and continues to develop into a weak squall line**

➢ **Of the four mechanisms considered, updraft nudging appears to be the most suitable lifting mechanism in HSLC environments**

References:
[1]Bryan, G. H., & Fritsch, J. M. (2002). A benchmark simulation for moist nonhydrostatic numerical models. *Monthly Weather Review*, *130*(12), 2917-2928. [2]Hersbach, H., et al. (2020). The ERA5 global reanalysis. *Quarterly journal of the royal meteorological society*, *146*(730), 1999-2049. [3]Schielicke, L. (Jan 2024). Cloud Model 1 & Visualization-A Block course. ResearchGate. https://doi.org/10.13140/RG.2.2.30017.12642. [4]Uccellini, L.W., & Johnson, D.R., 1979: The Coupling of Upper and Lower Tropospheric Jet Streaks and Implications for the Development of Severe Convective Storms. Monthly Weather Review, Volume 107, Pages 682-703. [5]Wade, A.R., & Parker, M.D., 2021: Dynamics of Simulated High-Shear, Low-CAPE Supercells. Journal of the Atmospheric Sciences, Volume 78, Issue 5, Pages 1389 1410. [6]Sherburn, K.D., & Parker, M.D., 2014: Climatology and Ingredients of Significant Severe Convection in High-Shear, Low-CAPE Environments. Weather and Fore casting, Volume 29, Pages 854-877.