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Evaluation of the WRF Model for Simulating Deep Convection and Cold-Pool Characteristics Relevant to Wind Energy Applications in Germany

Gerard Kilroy and Jeffrey Thayer
German Aerospace Agency (DLR), Oberpfaffenhoffen, Germany (gerard.kilroy@dlr.de)

Deep convection and cold-pool characteristics over Germany during July 2023 are investigated using DWD radar observations and a WRF model simulation. The analysis includes both instantaneous snapshots of convection and a Lagrangian approach tracking the life cycles of isolated convective cells. Evaluation against radar observations reveals that WRF captures the general distribution, morphology, and evolution of deep convection and the associated cold pools, though it tends to simulate smaller, more intense rain-producing cells.

Simulated cold-pool characteristics, including median and extreme values of wind gusts and Δv differences from the ambient background, align well with observations, indicating WRF's skill in replicating the key features. Modeled Δv drops (median of -2.95 K; extreme < -10 K) and wind gusts (median of 4.28 m/s; extreme > 10 m/s) highlight the potential for cold pools to impose significant impacts on wind turbines, although more observational statistics on extreme wind ramps due to convective cold pools are required for further model assessment.

The temporal evolution of convective cell features reveals a downward-facing parabolic pattern in both WRF and observations, in terms of cell size, maximum rain rate, and mean radar reflectivity. However, WRF intensifies convective cells too quickly and overestimates rain rates throughout the life cycle, while cell shape remains in good agreement with observations.

An analysis of wind energy-relevant metrics reveals that convective cold pools drive significant changes in wind speed, atmospheric stability, and vertical shear, with estimated power output associated with cold-pool passages increasing by 35-60% for long-lived cells and 33-50% for short-lived cells, peaking mid-to-late lifespan. These findings emphasize the importance of understanding and forecasting cold-pool dynamics for optimizing wind energy production.