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# Anatomy of a windstorm in the light of Doppler lidar measurements and large-eddy simulations

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As one of the main natural hazards in Europe, cyclonic windstorms need to be accurately modelled for weather and climate applications. However, even today's high-resolution numerical weather prediction (NWP) models with O(1 km) rely on crude subgrid-scale parameterizations to represent damaging wind gusts that occur in storms.

A fast-scanning Doppler lidar was operated during the Wind And STorms EXperiment (WASTEX) that took place in the Upper Rhine Valley near Karlsruhe in winter 2016-17. The lidar performed range-height-indicator scans at low elevation angle in the mean wind direction, providing observations of radial velocity with an along-beam resolution of approximately 70 m every about 10 s. The instrument range under such conditions reaches a few km and thus matches the typical size of a grid point in a high-resolution NWP model. Observations are complemented with large-eddy simulations using the ICOsahedral Nonhydrostatic (ICON) model with grid spacing down to 78 m.

Although low aerosol concentrations make Doppler lidar observations challenging during the passage of cyclonic windstorms, the case of Thomas (Doris) on 23 February 2017 was well sampled. Thomas was an intense windstorm with unusually high temperatures in its warm sector as well as a low-level jet and a dry layer aloft. Downward mixing during the storm onset results in a peak in wind gusts and a drop in dew point. The 2.8-km deterministic COSMO forecast for Germany poorly predicts the storm onset due to the difficult representation of a temperature inversion. However, the corresponding ensemble forecast contains a few successful members which highlight the contribution of upstream orography to the downward mixing in a process similar to the breakthrough of foehn.

Doppler lidar observations further reveal the presence of long-lasting (several minutes at least) wind structures during the storm onset, which later become short-lived after the downward mixing. The structures appear to result from a combination of convection- and shear-driven instability in the boundary layer. Despite higher horizontal and vertical resolutions, large-eddy simulations do not better predict the downward mixing than operational NWP models from which they inherit initial and lateral boundary conditions. However, they also contain long-lasting, elongated structures in the wind direction that are qualitatively similar to those observed by the Doppler lidar. The presence of such anisotropic structures is found to coarsen the effective resolution of large-eddy simulations by a factor of about five.

These results emphasize that modelling surface gusts during a windstorm crucially relies on the accurate representation of convection- and shear-driven instability in the boundary layer. They further suggest that gust parameterizations in weather and climate models should account for coherent wind structures found in Doppler lidar measurements and large-eddy simulations.