Title: Simulating the effect of the urban land use on a severe convective windstorm in the Po Valley

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Abstract: It is well known that cities can modify rainfall distributions, particularly by more frequently triggering deep moist convection over and downwind of urban areas. However, the effect of cities on the most extreme convective events, such as hailstorms, downbursts, or tornadoes, is poorly studied. This topic needs further investigation since exposure and vulnerability to severe storm risks are greater in cities than in the surrounding rural areas. What happens if a severe convective windstorm impacts a large city? Is the storm modified by urban land use?

Our analysis focuses on a case study that occurred on July 25, 2023, when a nocturnal convective windstorm affected the city of Milan in northern Italy, with measured wind gusts of up to 30 m/s. The intense wind gusts downed many trees in public parks and streets, blocking urban mobility. The event is investigated in depth using high-resolution numerical simulations performed with the WRF model.

Three nested WRF simulations are carried out with grid resolutions ranging from 9 km to 1 m, and 64 vertical levels starting from 5 m AGL. Two different boundary layer parameterizations are tested, namely MYJ and BouLac schemes, as well as two different microphysics schemes: Thompson and WRF Single-moment 6-class. Additionally, simulations with bulk urban parameterizations are compared with those coupled with the Building Effect Parameterization and the Building Energy Model (BEP-BEM), using data from the World Urban Database and Access Portal Tools (WUDAPT). Simulations replacing the urban land use with croplands (no-urban) are conducted to test the effect of the Milan urban area on the convective storm. Results from all these simulations are assessed using surface observations and radar data. All WRF simulations accurately reproduce the violent windstorm, both in terms of 2 m temperature and relative humidity, wind gusts, rainfall, and radar reflectivity. As a result, two physics ensembles are generated, averaging the urban and no-urban simulations, respectively. Differences between these two ensembles in the pre-storm environment and the simulated storm are thoroughly analyzed.

Regarding the pre-storm environment, Milan generates an Urban Low-Theta-e Island, i.e., a decrease in equivalent potential temperature (Theta-e) of about 4 K just above the surface, extending up to 300 m AGL, due to reduced moisture over the city compared to the surrounding rural areas. Despite the decrease in surface Theta-e, which would suggest a reduction in potential instability, Most Unstable Convective Available Potential Energy (MUCAPE) is not perturbed due to a layer at about 1.5 km amsl with high-Theta-e values that is unaffected by urban land use. Regarding wind shear, Storm Relative Helicity in the layer between 0 and 3 km Above Ground Level (AGL) decreases by about 10% over the city. This decrease occurs in the 30-200 m AGL layer and is a consequence of the wind profile in this specific case study.

Regarding storm alterations induced by urban land use, a northward shift of the storm is observed in the upwind region. Over the city, wind gusts are reduced by about 13%: the gust front is reasonably slowed down by the increased roughness of the city, but the WRF model is unable to reproduce turbulent wind gusts generated by buildings. The ensemble mean also indicates an intensification of the updrafts over the city, likely due to the increased Turbulent Kinetic Energy produced by the gust front interacting with the buildings, which favors vertical motions. Finally, downwind of the city, the storm is broken into three convective cells, with a delay of about 5 km compared to a no-urban scenario. The southernmost convective cell produces more abundant rainfall than in the no-urban scenario.

In conclusion, the storm is significantly impacted by urban land use: its trajectory, morphology, and intensity are modified by Milan. The pre-storm environment is also altered by the city in the first few hundred meters above the surface. However, analyzing a case study has the limitation that it is challenging to disentangle the city's impact from other atmospheric and topographic factors. While it can provide

insights into the physical processes occurring, it is not straightforward to clearly identify the processes causing the observed storm modifications. To address these limitations, idealized simulations are planned.