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Climate sensitive designs for policy makers: how well can LES models represent urban microclimates?

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Cities can offer an extraordinarily high or low urban level of climatic stressors depending on their location and topographical setting, infrastructural geometry and anthropogenic activities. To protect human well-being today and in the future, it is crucial to better understand how to mitigate temperature extremes in cities. Since cities are constantly growing and transforming in response to their residents' needs, planning a foresighted sustainable climate-friendly infrastructure is critical. This need creates a niche for research to assess local climate effects that effect the lower atmosphere ground layer where human activity takes place. Large Eddy Simulation (LES) models can simulate heat transport and mixing processes by directly resolving large-scale turbulence and are often used to simulate urban development activities potentially mitigating the adverse effects of heatwaves in cities. Despite their growing use in forming recommendations, these models are inherently difficult to validate which leads to 'simply believing them'.

We evaluate the performance of an urban LES model against a reference multi-station observational network focusing how well the space-time dynamics of distinct urban microclimate including densely-built hot spots, peri urban and park-cool islands agree. We selected a 72-hour extreme heatwave period in July 2019 in a mid-sized city in Germany which suffers from a similarly large urban heat island effect as larger cities. We investigated air temperature, air humidity, wind speed and direction as key elements impacting the perceived heat stress or relief by humans. Observations were compared to the PALM-4U LES model with a nested domain dynamically driven by the mesoscale COSMO-D2 output by the German Meteorological Service at spatial resolutions of 20 m and 5 m domain. We employed the stochastic multiresolution decomposition (MRD) technique applied to two-point correlation statistics for characterizing the space-time behavior.

Absolute air temperatures differences amounted to +5 K overestimation of modeled nocturnal air temperatures. A key finding from the MRD analysis is that correlation between stations does not follow separation distance (as expected for homogeneous domains) but rather the distinct urban microclimatic for air temperature and specific humidity in both observations and model at both resolutions. Separating the results into day and night shows distinct differences for air temperature and specific humidities for both model resolutions compared to the observations, but only small differences for near-surface winds. The model performance varies with its resolution and climate element: while winds are better represented in the finer 5 m resolution,

specific humidity cannot be simulated properly by the model at night. Air temperature during day is better represented by the 20 m resolution, while the match between observations and the 5 m-prediction is better at night.

We show that the LES model can simulate the statistical space-time behavior of urban microclimates but performs poorly when absolute targets are modeled. Simulated air temperature and specific humidity follow mostly the implemented synoptic advective forcing large scale model which does not recognize local microclimatic effects. For near-surface winds, this model performs better with finer resolution as the larger eddies resolved depend on the geometry of the city.