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Downscaling climate projections to map future outdoor thermal comfort in cities based on a deep learning approach

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Outdoor thermal comfort is influenced not only by meteorological variables air temperature, radiation and humidity at regional and local scales but also by local parameters such as mean radiant temperature and wind patterns, which vary at meter-scale within cities. All these factors can be affected by ongoing climate change. Hence, modelling future thermal comfort requires a multi-scale approach. Thermal comfort in outdoor settings can be quantified and described by thermal indices such as the Universal Thermal Climate Index (UTCI), which reflects the human response to environmental and physiological forcing. To date, several microscale modelling approaches have been proposed to model the meteorological and geometric variables that contribute to the UTCI, but they are all highly detailed, complex and computationally intensive. As a result, only individual heat waves, short case studies or single points have been modelled to estimate future heat stress conditions in cities.

This study introduces a novel and efficient deep-learning model that instantly and accurately predicts thermal comfort maps across entire cities and for long periods. This model is unique in its adoption of a solitary deep learning architecture, avoiding the use of sub-models that separately model, for example, air temperature or wind speed. We will refer to this model as the Unified Human Thermal Comfort Neural Network (UHTC-NN). Training and evaluation of the UHTC-NN is based on a machine learning model from a previous study, which combines four sub-models modelling air temperature, mean radiant temperature, wind speed, and relative humidity into UTCI. The UHTC-NN has a mean absolute error of 0.5 K compared to its preceding model. The UHTC-NN enables new applications of thermal comfort modelling, including meter-scale urban climate projection to support climate adaptation management in cities.

In a case study, we apply UHTC-NN to downscale 15 EURO-CORDEX climate projections with a 3-hour resolution over 30 years to generate high-resolution (1x1 m) street-level outdoor thermal comfort maps for the city of Freiburg, Germany. We compare the changes in UTCI frequency distribution and uncertainties of three different Representative Concentration Pathways (RCP2.6, 4.5 and 8.5) for the years 2070-2099 with the historical climate (1990-2019). Our study models the

entire city center of Freiburg, with a domain size of 2.5x2.5 km, covering various aspects of the city's urban form. We show that the average number of hours per year with strong to extreme heat stress (UTCI >= 32°C) will increase up to three and six times for RCP2.6 and RCP8.5, respectively. The number of night-time hours with UTCI >= 20°C will increase by a factor of two and five, respectively for RCP2.6 and RCP8.5, compared to the 1990-2019 period. In addition, the 80th UTCI percentile shifts by 2°C and 4°C for RCP2.6 and RCP8.5, respectively. The presented high-resolution urban climate simulations allow us to identify intra-urban variability and daytime / nocturnal hot-spots where climate change will have the greatest impacts on outdoor thermal comfort. Such urban climate simulations therefore allow for an effective selection of areas where climate adaptation needs to be prioritized.