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Modelling and visualisation of heat stress in urban areas using high-resolution geospatial data

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Abstract:

With rising global temperatures and more frequent heatwaves due to climate change, heat stress is becoming a significant public health concern, particularly for vulnerable populations such as children, the elderly, and outdoor workers. Adapting urban environments with green spaces, cooling centres, and heat-resilient infrastructure is essential for mitigating these risks. To understand the phenomenon and associated risks, new modelling approaches based on high-resolution geospatial data and 3D modelling tools are inevitable. The goal of this study is to apply the ENVI-met microscale simulation model to the city of Košice using high-resolution geospatial data to better simulate dynamics of the heat stress within the city.

In this study we present a microscale approach for numerical atmospheric simulations of heat stress on a city-wide scale. The proposed approach is based on the ENVI-met microscale model and the implementation of detailed urban morphology inputs prepared using various geospatial data and tools. By employing these environmental models, a wide range of environmental dynamics can be simulated, enabling detailed analyses of real-case weather scenarios (Fiorillo et al. 2023). Such analyses encompass the complete diurnal dynamics of radiation processes, thermodynamics, humidity, and atmospheric flow, which influence the advection of variables (Fedor and Hofierka, 2022). Diverse urban morphology is a key component of these simulations (Hofierka et al., 2020), and its preparation remains challenging for large city-wide areas at a grid scale of several meters.

The main procedural steps of the methodology are presented in Figure 1. The methodology was applied to the wider area of the city of Košice, Slovakia, covering the urban core and surrounding densely populated areas. The input urban morphology data consisted of a 3D city model comprising landcover, buildings, and tall vegetation (trees). The landcover was derived from airborne LiDAR and multispectral satellite data. It included six categories implemented in the ENVI-met software: asphalt, buildings, bare land, grass, trees, and water. Asphalt roads and waterways were delineated using available vector data derived from airborne photogrammetric data for improved spatial accuracy. Buildings, which are critical urban features influencing the spatial distribution of heat stress indices, were derived at Level of Detail 1 (LoD1) from airborne photogrammetric data. They were represented as polygons, with their median heights calculated from aerial LiDAR data within these polygons. Tall vegetation was also derived from LiDAR point cloud data using a classification script in R, which generated a point vector layer categorizing tree height as small (5 m), medium (15 m), or large (25 m).

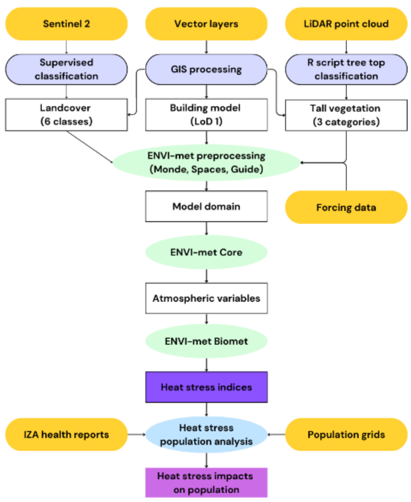

Figure 1. The flowchart describing main procedural steps to derive heat stress indices.

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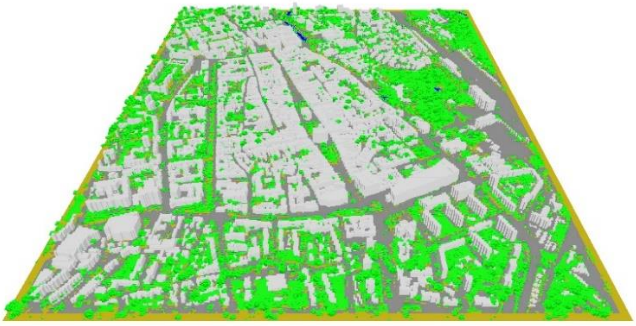

Figure 2. 3D view of model domain with buildings (light grey), asphalt (grey), water (blue) and vegetation (green).

The simulation was conducted during a clear-sky heatwave event on June 30, 2022 over a 24-hour period starting at 5:00 Central European Time (CET), covering the entire diurnal cycle and allowing for model spin-up. Hourly surface synoptic observations from the local airport were used as input forcing for the simulation. The model domain was configured with a horizontal resolution of 5 m, a vertical resolution of 1.5 m, and 60 vertical levels. The simulation was validated using available surface meteorological measurements within the model domain. Heat stress indices were calculated from the model output, which contained raw atmospheric parameters, using the BioMet postprocessor. The Physiological Equivalent Temperature (PET), Standard Effective Temperature (SET), and Universal Thermal Climate Index (UTCI) were selected to quantify heat stress (Figure 3). The diurnal maximum of heat stress was observed at 15:00 CET, coinciding with high temperatures, strong solar irradiation, and weak wind. These conditions resulted in reduced turbulent momentum exchange due to diminished convection.

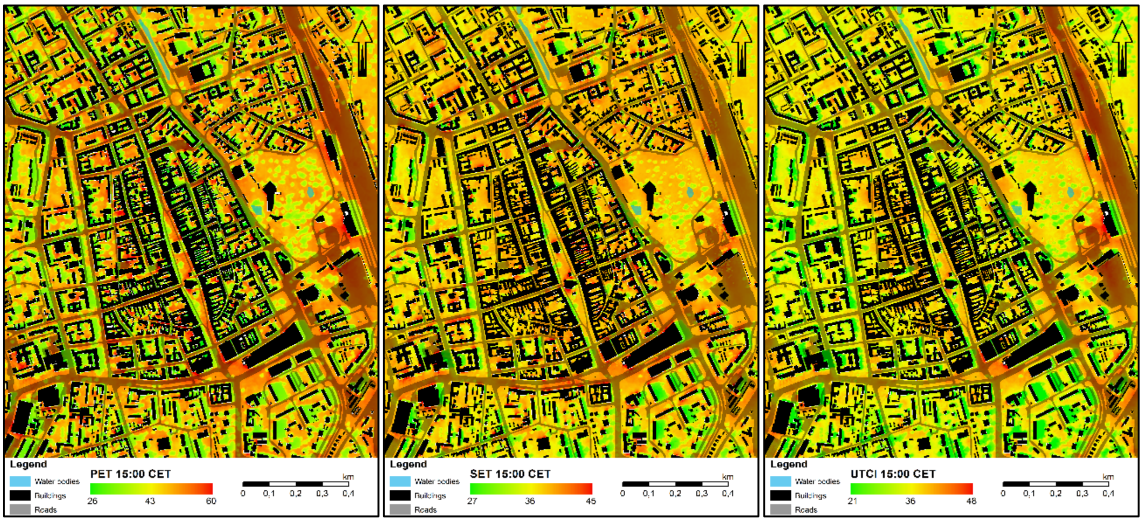

Figure 3. Calculated PET, SET and UTCI at 15:00 CET, June 30, 2022

The urban areas have very complex and diverse morphology and proposed methodology can provide a quick solution for preparation and implementation of the input model data allowing detailed simulations. The high-resolution large-scale urban simulations can better define the urban heat island dynamics and atmospheric interactions and allows better understanding of its diurnal cycles, circulation and advection. Such analysis can be beneficial for detailed urban heat island mapping, urban planning, or the preparation of mitigation strategies for the urban heat island.

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