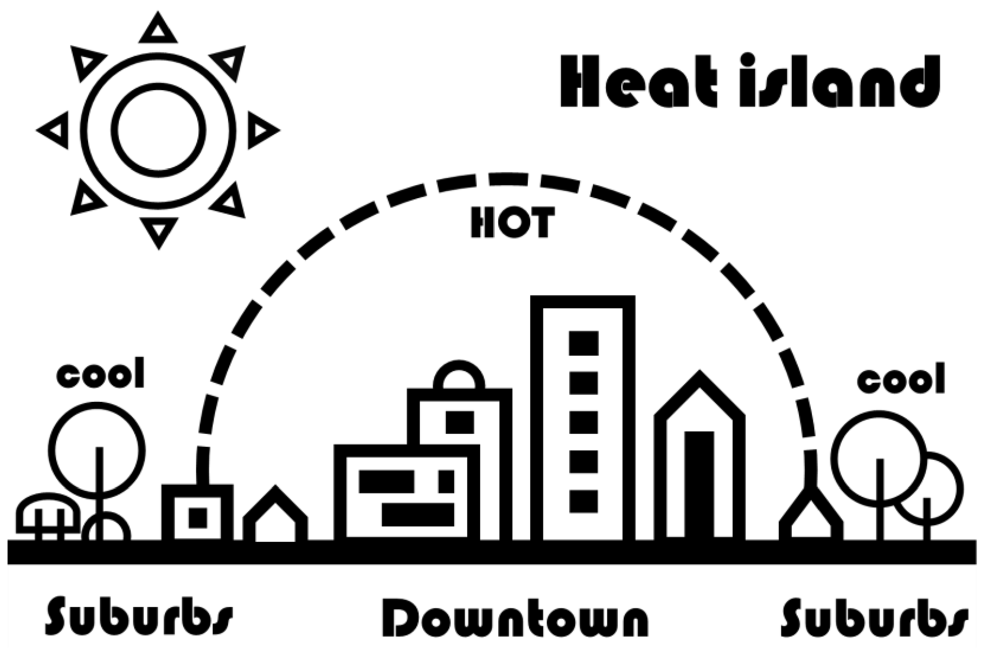
Impact of urban form on heat index spatial and temporal distribution based on WRF-BEP/BEM



Background: Urban heat islands exacerbate heat waves, leading to a high incidence of heat stroke. WBGT index has been published by Japan's Minister of the Environment to warn the risk in advance, but there are still shortcomings:

- Sparse monitors can hardly reflect the detailed distribution of WBGT across the city;
- Most stations are located in open areas, without taking into account the impact of dense buildings on wind, radiation, etc.

What should we do: Widespread deployment and maintenance of monitors is unrealistic, but a weather-urban canopy coupling model WRF-BEP/BEM can be used instead to reproduce the spatio-temporal distribution of WBGT within cities and explore it's relationship with urban form.

How to calculate WBGT? -- Measurement-based and simulation-based

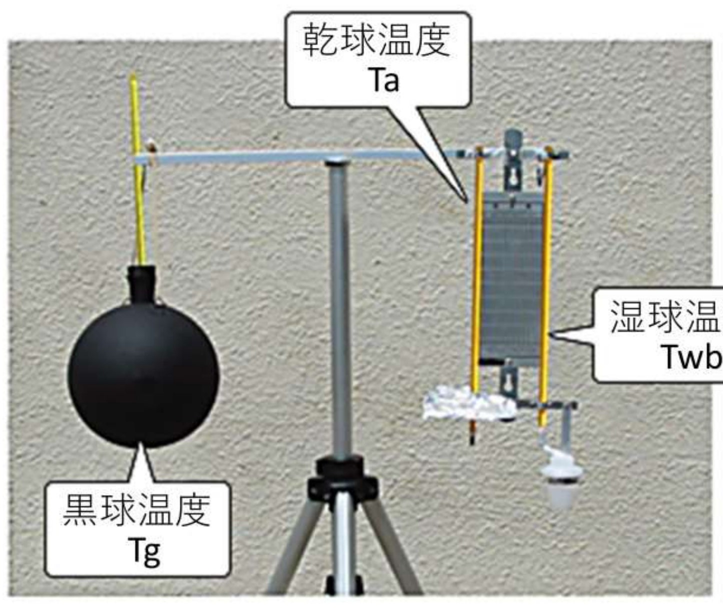


Fig. 1. WBGT measuring equipment

Standard calculation formula from ISO ➡ $WBGT = 0.7 \times T_{wb} + 0.2 \times T_g + 0.1 \times T_a$

Measurement-based method

- The measurement system includes 3 types of thermometers, placed in an open area.
- T_a, T_{wb}, T_g are measured by dry bulb thermometer, wet bulb thermometer and black bulb thermometer, respectively.
- Thermometers are located 1.5m above the ground

Mesoscale simulation-based method

- T_{wb} can be calculated iteratively by air temperature, pressure and humidity.
- T_g can be approximated by air temperature, global solar radiation and wind speed:

$$T_g = T_a + \frac{(SR - 38.5)}{(0.217SR + 4.5U + 23.5)}$$

Methodology: WRF-BEP/BEM with Gridded Urban Canopy Parameters (UCPs) imported

- High temperature days from 2018-2022 were selected for simulation, 85 days in total.
- The gridded Urban Canopy Parameters (UCPs) were calculated based on the Tokyo GIS building information to provide an accurate input for the WRF-BEP/BEM. Fig. 2 c.
- Case 1CAT was created as a controlled experiment, taking the geometric parameters of all urban grids as an average of 23 wards. Fig. 2 b.
- The gridded UCPs gave each computational grid independent geometric parameters, which are key factors in reproducing the impact of urban form on microclimate. Fig. 3.

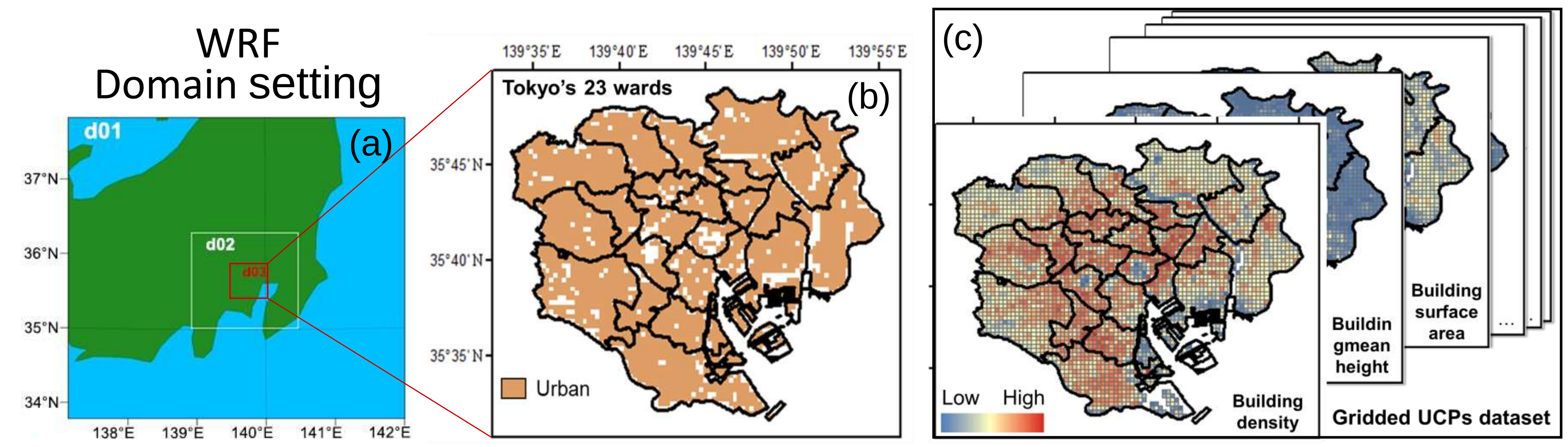


Fig. 2. Simulation area (a) and urban canopy parameters input settings. (b) 1CAT, (c) UCPs

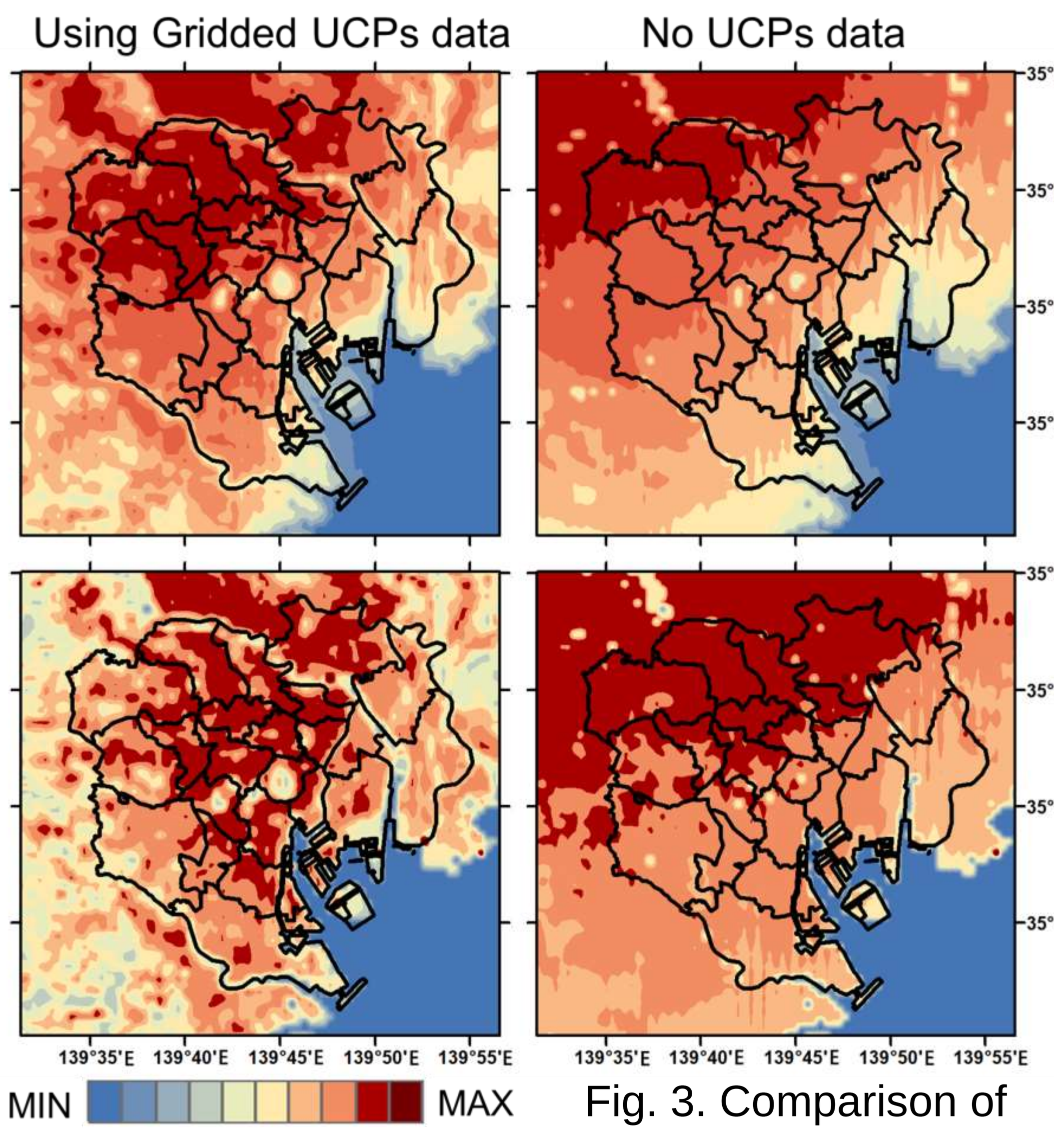


Fig. 3. Comparison of simulation results with and without gridded UCPs.

Result and conclusion

Impact of urban form on the spatio-temporal distribution characteristics of WBGT

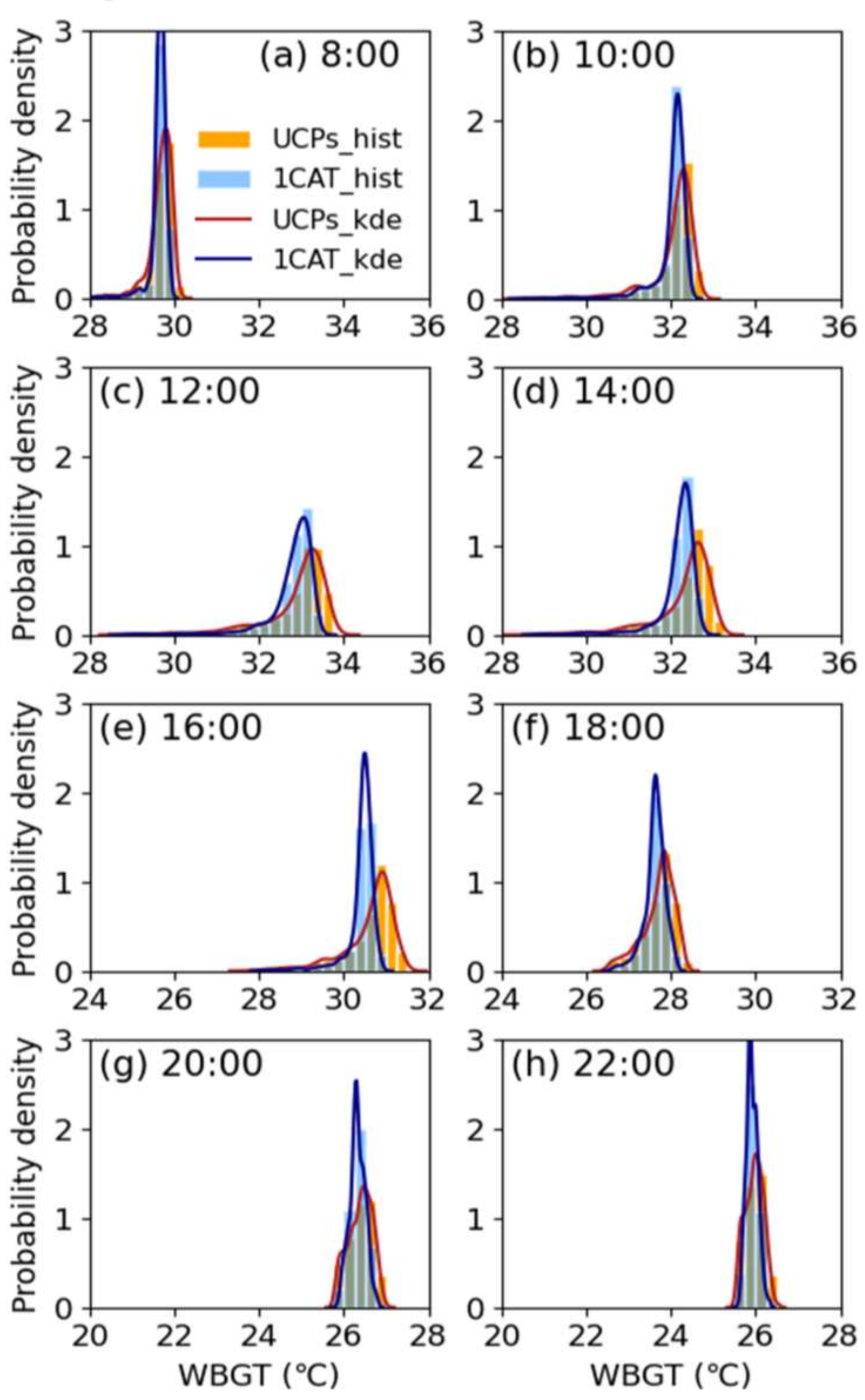


Fig 5. WBGT probability density distribution in 23 wards at different times (width of bins is 0.25°C)

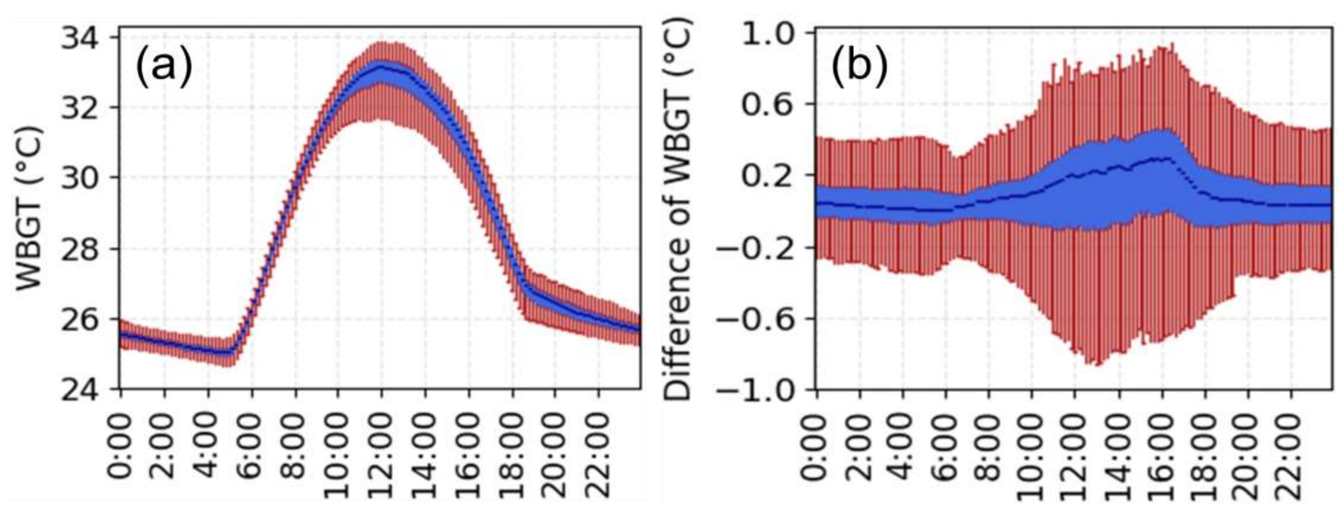


Fig. 4. WBGT in 23 wards at different time, box plot. (a) case UCPs, (b) difference between cases (UCPs-1CAT)

Temporal characteristics – Fig.4 and Fig. 5

- WBGT difference between regions peaked around 12:00 noon, then narrowed slightly and remained broadly unchanged in the afternoon.
- Differences in WBGT due to urban form were significant throughout the afternoon until rapidly decreasing around sunset.

Spatial characteristics – Fig. 6

- The pronounced temperature gradient caused by the ocean confuses the the effect caused by the urban form. However, the control experiment 1CAT can be used to eliminate the influence of landform with the following formula:

$$WBGT^* = (WBGT_{UCPs}/WBGT_{1CAT}) \times WBGT_{ave}$$

- An equivalent WBGT (WBGT*) can intuitively reflect the influence of urban form on the spatial distribution of WBGT, and the influence is greater in the afternoon than at midday.

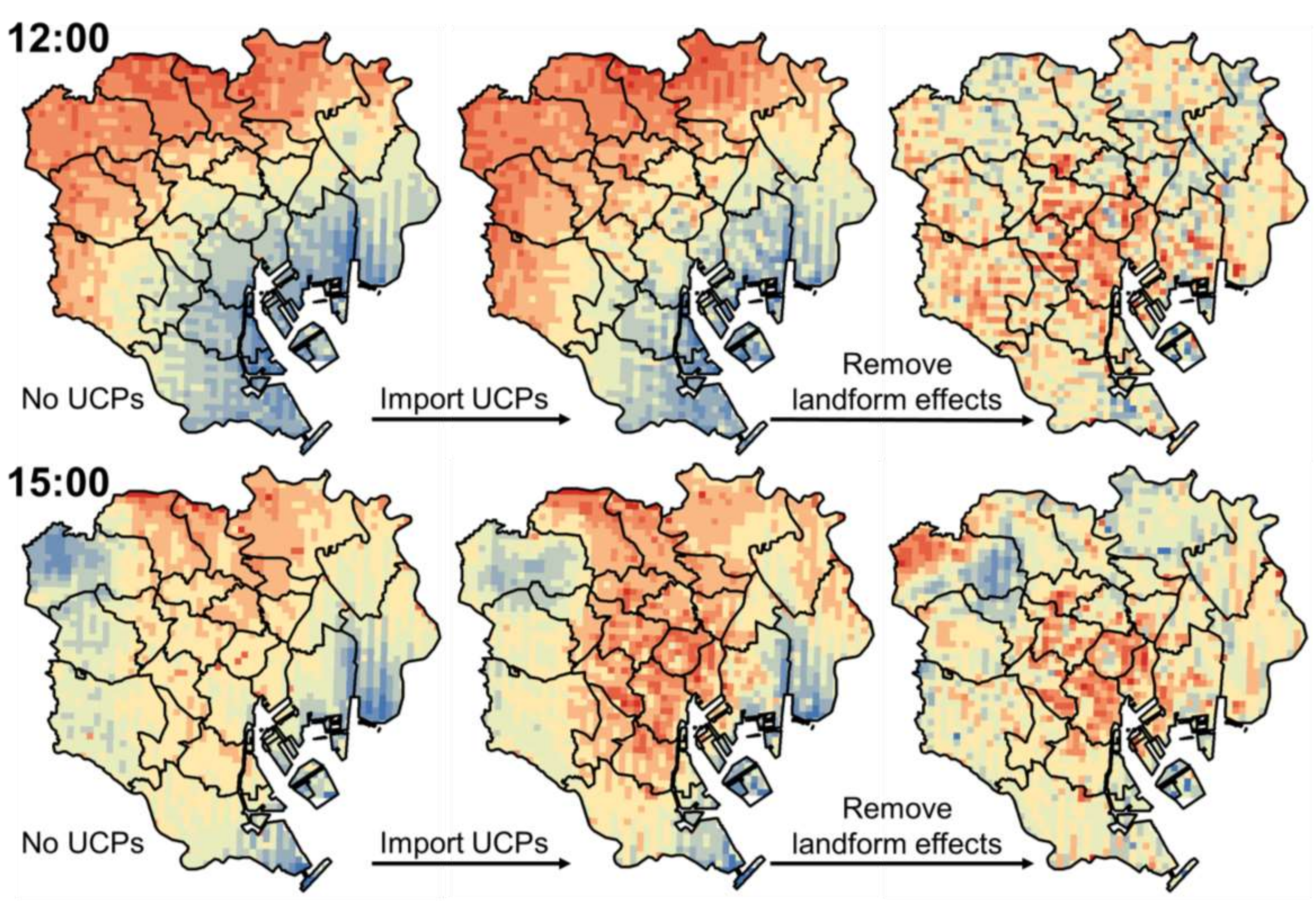


Fig. 6. Spatial distribution of normalized WBGT at 12:00 and 15:00.

Normalized WBGT 0 – 1