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# A study of urban thermal environment in Tokyo in summer of the 2030s under influence of global warming

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ABSTRACT

Enhancement of very hot weather conditions in summer due to climate changes at global and local scales can increase mortality through thermal stresses. To estimate the impact of climate changes on the risks of heat disorder (HD) in Japan around the year 2030, we conducted numerical climate simulations using a global circulation model (GCM) and a regional climate model (RCM). The GCM results for the global climate change analysis were provided as initial and boundary conditions, and climate information was dynamically downscaled by the RCM. We carried out simulations of the situation in August over 10-year periods for the present (2001–2010) and near-future (2026–2035) cases. The wet-bulb globe temperature (WBGT) was used as a thermal stress index. The modeled 10-year average WBGT values for the present time agreed very well with observation data. An increase of 1.11 °C (from 24.96 °C to 26.07 °C) in average WBGT from the present to the future cases was predicted based on the data. Changes in HD incidence rates were then evaluated using the obtained results and past statistical data. The average number of people transported by ambulance per day in August was predicted to increase by 63%.



## 1. Introduction

Climatic changes such as global warming and urban heat island effects can have serious consequences such as increase of energy demand and deterioration of thermal comfort [1–3]. One issue of concern is an increase in the number of heat disorders (HDs) as a result of the enhancement of very hot weather conditions during summer periods. An increase in mortalities was reported during previous heat waves that occurred in Western Europe (2003) [4–6] and Russia (2010) [7,8]. Thus, once high temperatures persist for a while, inhabitants of the region are at a greater health risk due to unfavorable thermal environments [9].

The number of people suffering from HDs in Japan has been increasing in recent years [10]. In 2010, Japan experienced an extremely hot season during which 53,843 people were transported by ambulance [11] and 1731 people died because of serious HDs [12]. Factors leading to rises in HD mortality include population aging and the deterioration of the thermal environment [13,14]. The Intergovernmental Panel on Climate Change (IPCC) has concluded that there was an increase in global mean surface temperature of 0.85 °C over the period 1880–2012 and that the possibility exists for continued warming of 0.3–4.8 °C by the end of the 21st century [15]. The combination of steady increases in the population age and global warming is expected to result in high HD risks for people living in cities. Mitigation and adaptation measures are therefore becoming urgent priorities for urban planning and public health [16].

Notwithstanding a general global warming trend, the degree of temperature increase varies according to geographic location [15]. In addition, the risk of HDs can vary for locations within the same urban area [17]. Global circulation models (GCMs) are used for the analysis of global climate and climate change predictions. Although GCMs can predict long-term global warming and heterogeneity on a global scale, they cannot provide detailed analyses of the distribution of the thermal environment in urban settings because of their coarse grid resolution (~100 km). To overcome this problem, we employed a dynamic downscaling method [18]. Specifically, we conducted simulations with a regional climate model (RCM) using GCM data for initial and boundary conditions, and we dynamically downscaled GCM data based on numerical models of physical processes for local climate phenomena. The RCM uses nested regional climate modeling and can analyze climate at a high resolution (~1 km).

The impact of global warming is frequently discussed in terms of air temperature. However, humidity is also a key factor that determines the risks of HDs in extremely hot environments. The

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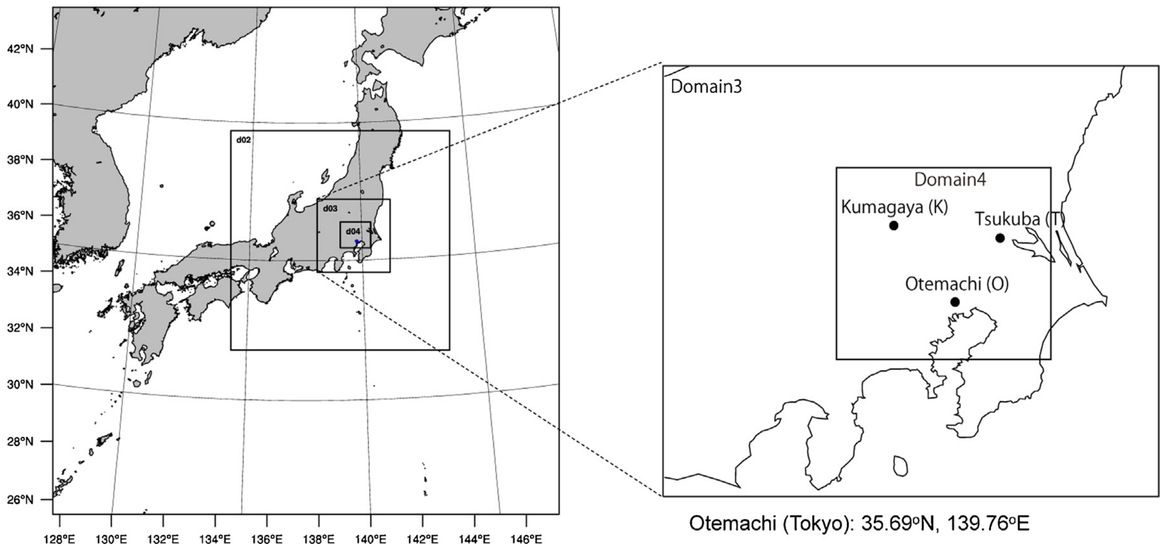


**Fig. 1.** Analytical region and nested domains.

wet-bulb globe temperature (WBGT) is well known as a heat stress index [19] and can be used to evaluate the integrated effect of air temperature, humidity, and radiation on the human body. Kusaka et al. [18] applied the dynamical downscaling method to analyze future changes of the thermal environment up until the 2070s in major Japanese cities including Tokyo. They employed the WBGT as the thermal index and concluded that there is a possibility for increased risk of HDs in the future; however, they did not assess quantitative values for the increases in HD risk.

In this study, we simulated August climate conditions in Tokyo and the surrounding area over 10-year periods, both for the present (2001–2010) and near-future (2026–2035). Using these results, we then calculated the WBGT and estimated the future incidence rate for HDs using statistical relationships that were derived from WBGT data and the past number of patients suffering from HDs. Thus, based on the change in WBGT between present and future time points, we were able to quantitatively estimate the impact of climate change on thermal stress in Tokyo.

## 2. Analytical methods

### 2.1. GCM data

From the variety of GCMs available, we employed a model for interdisciplinary research on climate (MIROC4h, version 4) that was developed by the Atmosphere and Ocean Research Institute (University of Tokyo) and a number of other institutes [20]. Two types of 30-year integrations were carried out using MIROC4h; these spanned 1981–2010 and 2006–2035. For predictions from 2006 onwards, the IPCC RCP4.5 scenario was employed for greenhouse gas emissions [21].

We utilized the outputs of these calculations for the last 10 years as input data for simulations of the present (2001–2010) and near-future (2026–2035) cases. The MIROC4h data has a grid resolution of approximately 60 km in both horizontal directions. Although this is relatively high compared to other GCM simulations, it is insufficient for local climate conditions in urban areas and a RCM was needed. The GCM climate data (e.g., geopotential height, temperature, specific humidity, and wind velocity) that were measured every 6 h were used for initial and boundary conditions in the RCM simulation.

### 2.2. RCM simulation and case settings

We employed the Weather Research and Forecasting model (WRF, version 3.4) as the RCM [22]. Using MIROC4h data and nested regional climate modeling, we carried out dynamic downscaling through WRF simulations [23,24].

In this study, we focused on the thermal environment in the Tokyo region of Japan. We set four levels of nested regions, namely, domains 1–4, and these had horizontal grid resolutions of 54, 18, 6, and 2 km, respectively, as shown in Fig. 1. Detailed conditions for domain settings are summarized in Table 1. We used 24 categories of the USGS (U.S. Geological Survey) classification system to represent urban and all other land use patterns [24]. The urban canopy model (UCM) can simulate the effects of urban geometry on the radiative and turbulent sensible and latent heat fluxes [25,26]. However, the predictions of the fluxes have large variations according to UCMs, and the employment of the UCM raises another difficult problem of the necessity to set appropriate parameters [27,28]. In this study, we did not utilize the urban canopy model, because we did not intend to simulate climate within the canopy and the model requires additional parameterizations which remain to be established. Physics schemes used in WRF simulations are listed in Table 2.

We carried out WRF simulations for August for the present (2001–2010) and near-future (2026–2035) cases. A total of 20 months were therefore analyzed. For every WRF run, we started

**Table 1**
Domain settings in WRF simulations.

| Items | Content |
|---|---|
| Map projection system | Lambert conformal conic projection |
| Horizontal grid dimensions and grid spacing | Domain 1: 38 × 38 (horizontal scale, 54 km)<br>Domain 2: 49 × 49 (horizontal scale, 18 km)<br>Domain 3: 49 × 49 (horizontal scale, 6 km)<br>Domain 4: 61 × 52 (horizontal scale, 2 km) |
| Vertical levels | 35 (from the surface to the 50 hPa level) |
| Time step | Domain 1: 180 s; Domain 2: 60 s;<br>Domain 3: 20 s; Domain 4: 20/3 s |
| Nesting | One-way nesting |
| Land use | Domain 1–3: U.S. Geological Survey, 24 categories<br>Domain 4: National land numerical information |