MODELIZACIÓN A MESOESCALA DE LA METEOROLOGÍA, CLIMA Y ESTRÉS TÉRMICO URBANO

SIMULATION OF URBAN METEOROLOGY, CLIMATE AND HEAT STRESS AT THE MESOSCALE

Beatriz Sanchez[1], Alberto Martilli[1], Isabel Sáez Teruel[2], Fernando Martín[1], José Luis Santiago[1], Esther Rivas[1], Carlos Yagüe[2]

[1] Departamento de Medioambiente, CIEMAT, Avenida Complutense 40, Madrid, Spain, Beatriz.Sanchez@ciemat.es

[2] Departamento de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, Madrid, Spain

SUMMARY

Urban areas influence the local meteorology and climate, and these atmospheric changes affect population heat exposure. The objective of this work is to present the capabilities of a meteorological mesoscale model to simulate heat exposure across the city of Madrid accounting for urban structure effects. The results indicate that air temperatures can give only a partial representation of the heat stress to which people are exposed, and more comprehensive thermo-physiological heat stress indices, like the Universal Thermal Climate Index (UTCI), are needed.

Urban areas influence the local meteorology and climate in many ways:

- *(i)* The presence of a large amount of impervious surfaces reduces the space available for vegetation, diminishing the cooling evaporative processes and latent heat fluxes.
- *(ii)* The geometry of urban structures blocks outgoing radiation, reducing the nocturnal cooling.
- *(iii)* Urban materials have typically lower albedo and greater heat capacity than rural areas, storing more energy during daytime and slowly releasing it during nighttime.
- *(iv)* Human activities, such as transportation and building climate control, release heat to the atmosphere.
- *(v)* Buildings modify the airflow and momentum exchange within cities, and in turn affect the exchanges of heat between the surfaces and the air.

The most notorious effect of these features is the Urban Heat Island (UHI) (Oke 1982), that occurs due to differences in the rural and urban energy budgets, whereby urban regions experience warmer air temperatures than their rural surroundings, especially at night (Oke et al. 2017). The magnitude of these effects is continuously increasing due to urbanization, and, combined with climate change, has increased, and will increase in the future, growing the heat exposure for citizens. This urban overheating is one of the main challenges that cities are facing as it entails significant negative impacts on human health. Thermal exposure is determined by physiological responses that lead to human heat stress. Apart from air temperatures, humidity, wind and radiation are other relevant factors that modulate the amount of heat human beings exchange with the air. The close relationship of human physiological response to the thermal component of these atmospheric changes requires estimating a comprehensive thermo-physiological heat stress index (e.g., Universal Thermal Climate Index (UTCI)) to assess population heat exposure.

The objective of this work is to present the capabilities of a meteorological mesoscale model to simulate heat exposure across the city of Madrid accounting for urban structure effects. The model used is the Weather Research and Forecasting (WRF) model adapted to simulate urban structure effects through a multilayer Building Effect Parametrization (BEP) and Building Energy Model (BEM) (Martilli 2002, Salamanca et al. 2010). The urban canopy model BEP+BEM scheme is a sophisticated approach that separately solves energy budgets from roofs, walls, and roads, accounting for radiation trapping and shadowing in the street canyons. Additionally, the simple BEM scheme allows estimating building energy consumption for air conditioning and heating, and anthropogenic heat fluxes, making possible the study of the feedbacks between climate and energy use. The latest developments incorporated in the BEP+BEM parameterization provide the opportunity to estimate impacts for two of the most popular adaptation/mitigation strategies, namely green roofs and rooftop solar panels (Zonato et al. 2021), and heat stress indexes (e.g. UTCI) along with their sub-grid variability at the city scale (WRF-comfort, Martilli et al. 2024). Modelling urban atmosphere using WRF BEP+BEM requires accurate information of the city's extension and urban morphological parameters (e.g. building heights and building packing density) of Madrid (Figure 1).

To ilustrate the capabilities of the model, a heatwave event in July 2022 is simulated in Madrid. With the model results, maps of heat stress (UTCI index in Figure 2b-c) can be produced for the city of Madrid, in addition to classical temperature maps (Figure 2a). The results indicate that air temperature can give only a partial representation of the heat stress to which people are exposed, and more complete indices like UTCI are needed.

The main applications of this type of modelling are 1) extreme heat forecasts that can be used to release warning to the population, and 2) evaluation of the effectiveness of heat mitigation strategies, for example, green roofs and cool roofs. Both applications are expected to be increasingly useful in the near future for Spanish cities.

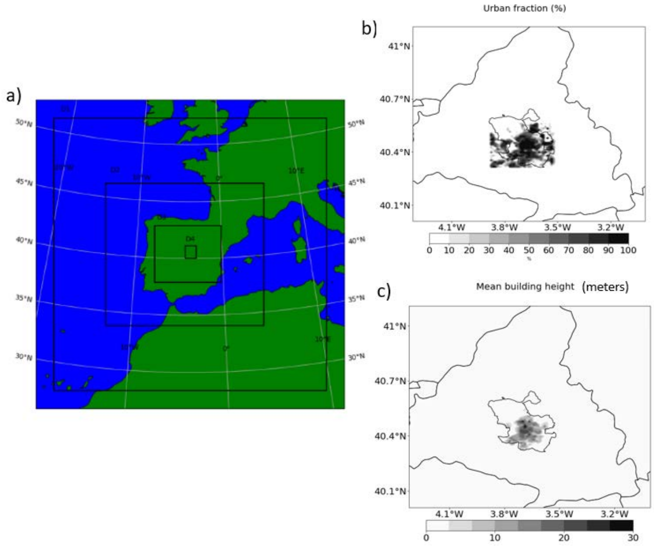

Figure 1 - a) The four domains used in the WRF simulations with 27, 9, 3, and 1 km horizontal resolution, b) the urban fraction, and c) the horizontal fraction occupied by building and mean building heught for Madrid.

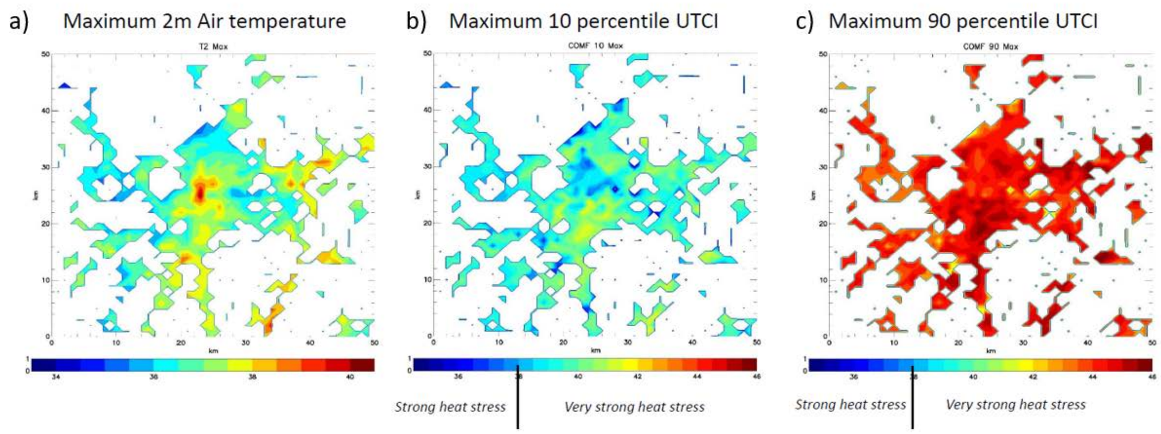

Figure 2 - a) Maximum 2-m air temperature in Madrid during a heat wave, b) maximum UTCI for the cool spot (10th percentile) in each grid cell and c) maximum UTCI for the hot spot (90 percentile) each grid cell.

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