Study of Urban Heat Islands Using Different Urban Canopy Models and Identification Methods

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Article

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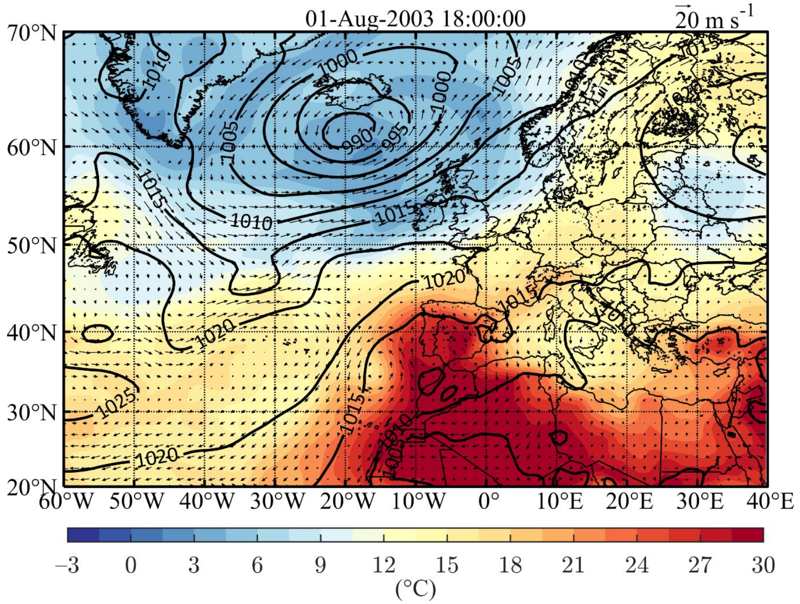
Objectives

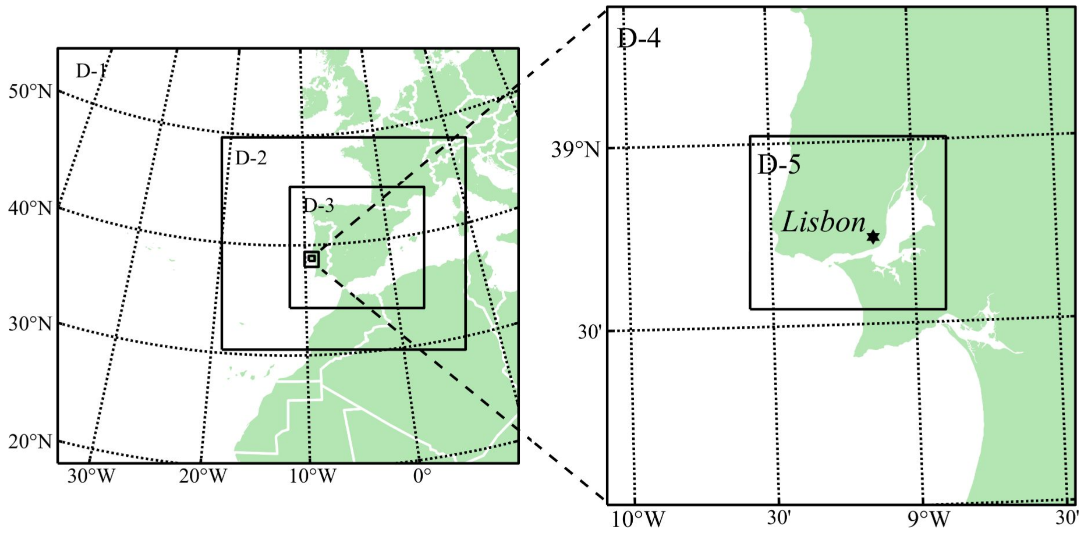
1. Assess the performance of two urban canopy models available in the Weather Research and Forecasting (WRF) modelling system (single and multi-layer urban canopy models);

2. Compare the application of two different urban heat island identification methods, namely the "Classic Method" and "Local Method" over the Lisbon Metropolitan Area, during the August 2003 European heatwave event.



Methods – model setup and description

- **Model:** Weather Research and Forecasting (WRF) v3.9;
- **Forcing data:** ERA-Interim reanalysis (ECMWF) on 37 p-levels, 0.75° x 0.75° resolution, six-hourly frequency;
- **Simulation period:** from July 28 to August 2, 2003 (including 24h spin-up);
- **Domains:** 81 km (D-1) > 27 km (D-2) > 9 km (D-3) > 1 km (D-4) > 333 m (D-5);



Physics	**Scheme**
Microphysics	WSM6
Cumulus	Grell-Freitas (off in D-4 and D-5)
Surface	Revised MM5
PBL	BouLac
LSM	Noah LSM
SW radiation	Dudhia
LW radiation	RRTM

Methods – model setup and description

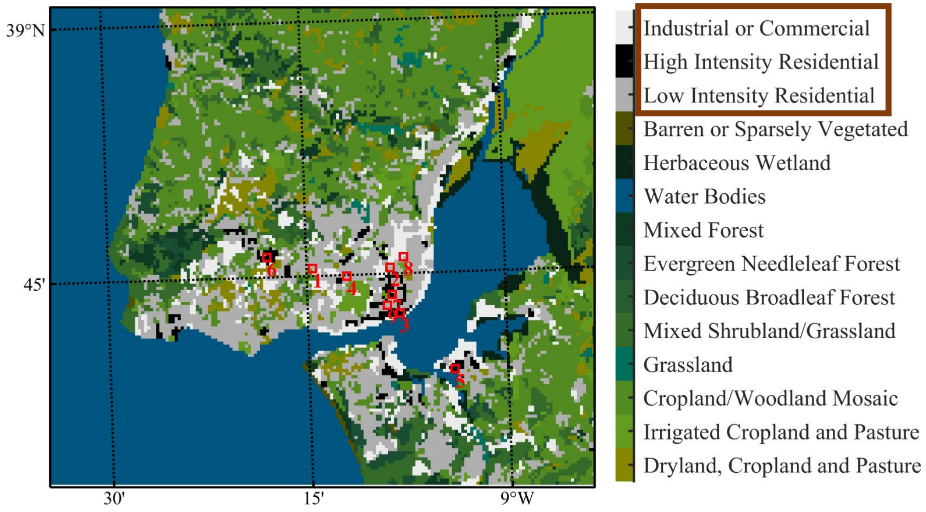
Model Land Use:

- Coordination of Information on the Environment (CORINE), for the year of 2012 with ~100 m;
- CORINE land use was reclassified to the United States Geological System with 33 categories that includes three urban classes:

  LIR - low intensity residential (50 % urban fraction)

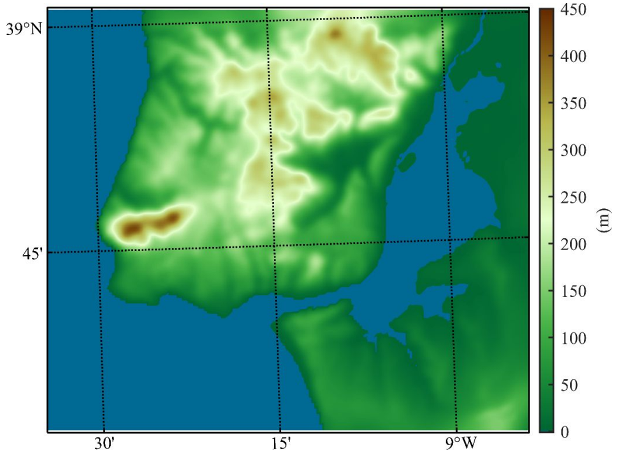
  HIR - high intensity residential (90 % urban fraction)

  CI - commercial or industrial (95 % urban fraction)

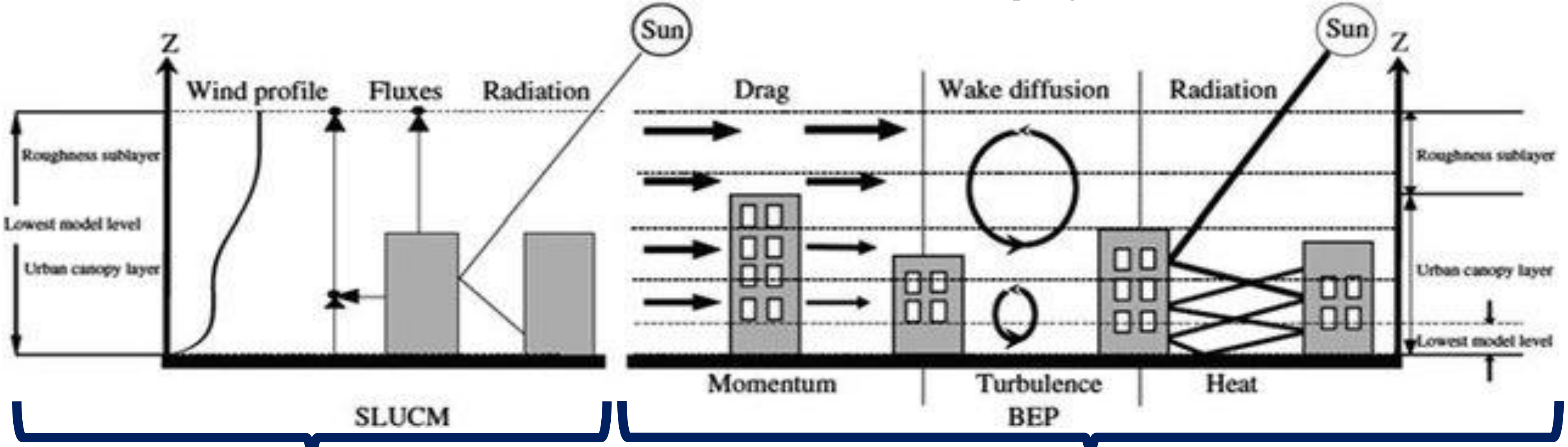


Topography:

- Shuttle Radar Topography Mission (SRTM) from NASA, with ~90 m resolution;



Methods – urban canopy models



Single-layer Urban Canopy Model (SLUCM)

- 2-D urban geometry with infinitely long street canyons (of different orientation);
- 3-D radiation treatment (accounting for radiation trapping, reflection and shadowing);
- Diurnal variation of solar azimuth angle;
- Estimation of surface temperature and fluxes from walls, roads and roofs;
- Prescribed exponential wind profile in urban canopy.

Building Effect Parameterization (BEP)

- 3-D urban geometry;
- 3-D radiation treatment at different levels of the urban canopy;
- Diurnal variation of solar azimuth angle;
- Estimation of heat and momentum sources and sinks, and sub grid TKE, all computed at multiple levels;
- Coupled with the BouLac PBL scheme (modification of the turbulent length scales due to buildings).

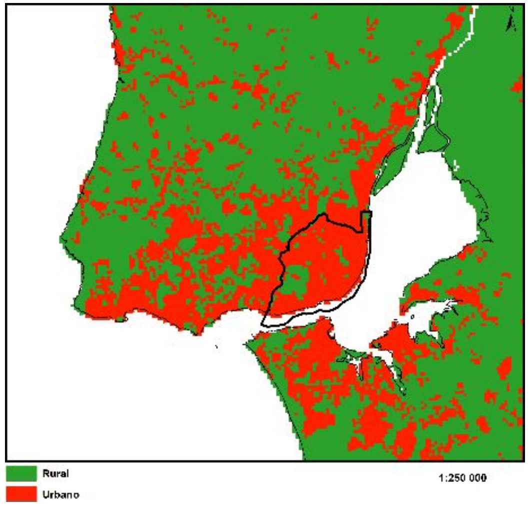
Methods – UHI identification

Classic method (Method 1) – accounts for geographical and urban canopy effects:

- Comparison of spatial averaged T2m at urban and rural grid points;

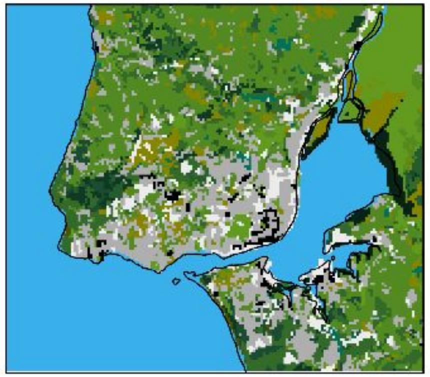
  or

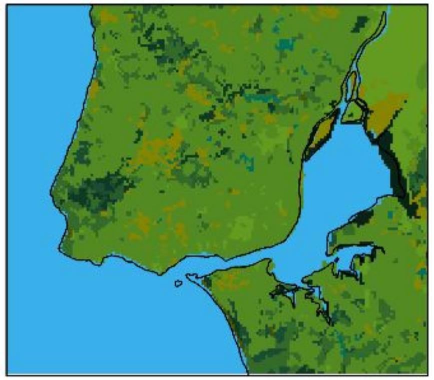
- Comparison of T2m at each urban grid point with the spatial averaged T2m of all rural grid points.



Local method (Method 2) – accounts only for urban canopy effects:

- Comparison of T2m at each urban grid point location, when the urban classes are present, with the case where urban classes were replaced by the dominant LU category of D-5 (i.e. cropland and woodland).





Methods – Simulation experiments

Simulation name	Nº of vertical levels	Urban parameterization	Urban land use categories
SLUCM		Yes	Yes
NURB_SLUCM	46 (first level at ~54 m)	Yes	No
NO_SLUCM		Noah bulk	Yes
BEP		Yes	Yes
NURB_BEP	49 (3 additional levels at ~40, ~24,~12 m)	Yes	No
NO_BEP		Noah bulk	Yes

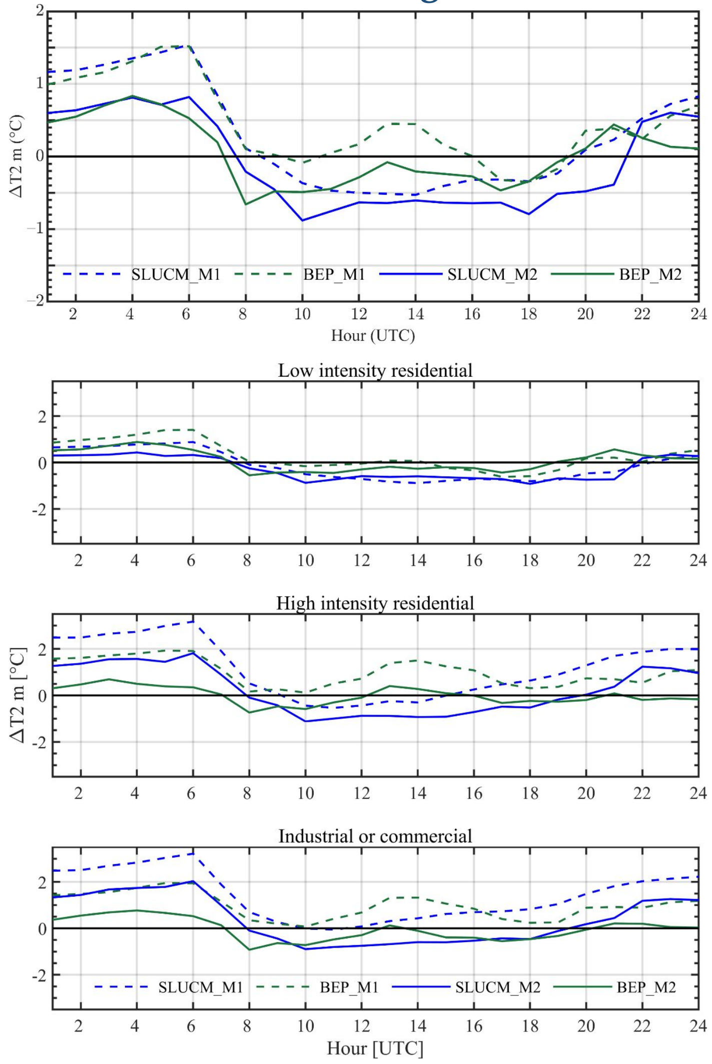
Only for UCM validation

The modelled 2m temperature was validated against data from 9 meteorological stations and SLUCM showed the best performance, followed by BEP.

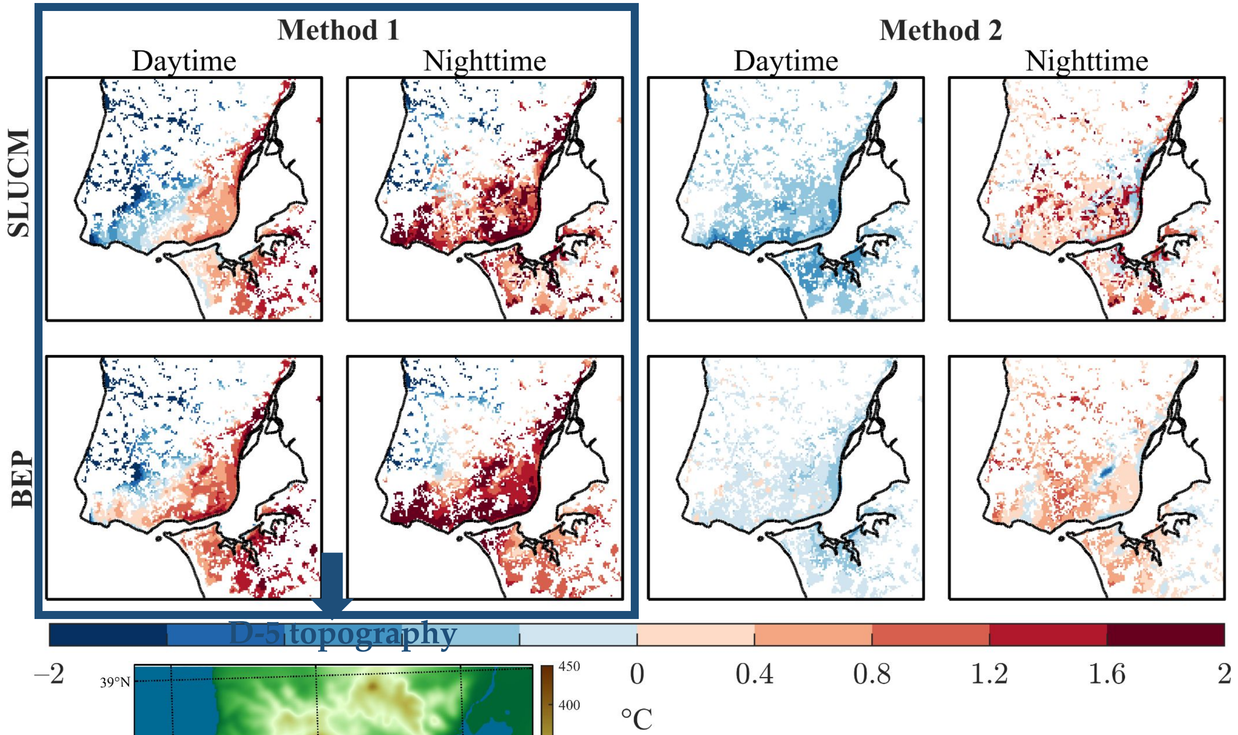
Results – UHI analysis

- Method 1 (avg.: 0.93 ˚C, max. 1.5 ˚C) shows higher UHI intensity than Method 2 (avg.: 0.46 ˚C, max. 0.8 ˚C) during nighttime;
- Urban cold island during daytime (except for BEP when using Method 1);
- The higher nighttime UHII using Method 1 means that geographical and urban canopy effects have a considerable contribution for the increase in UHI;
- UHII is much lower in BEP than in SLUCM in HIR and IC classes during nighttime.

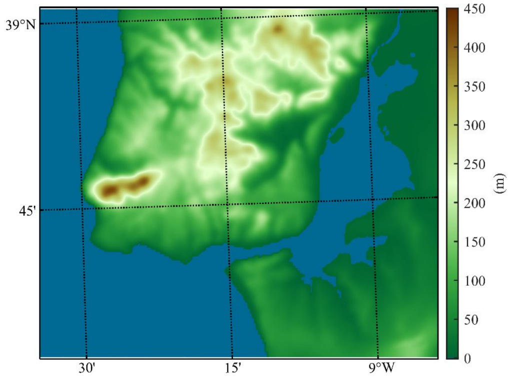
Heatwave averaged UHI



Results – UHI analysis



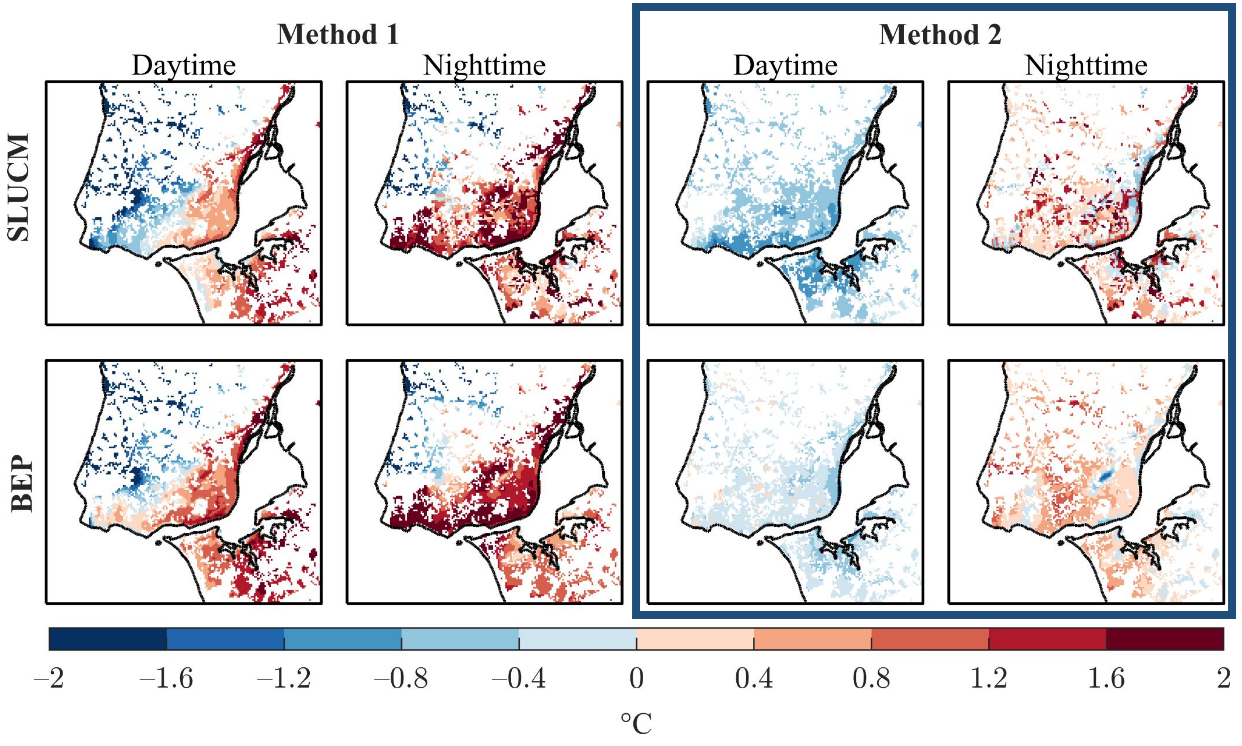
D-5 topography



- Spatial patterns are similar in for both UCMs;
- Higher UHI intensity during nighttime;
- Daytime and nighttime negative thermal anomalies in the northwestern part of the domain, and positive thermal anomalies north and south of the Tagus Estuary.

Sheltering effect due to the high topography in the northwestern part of the domain that blocks northern winds.

Results – UHI analysis

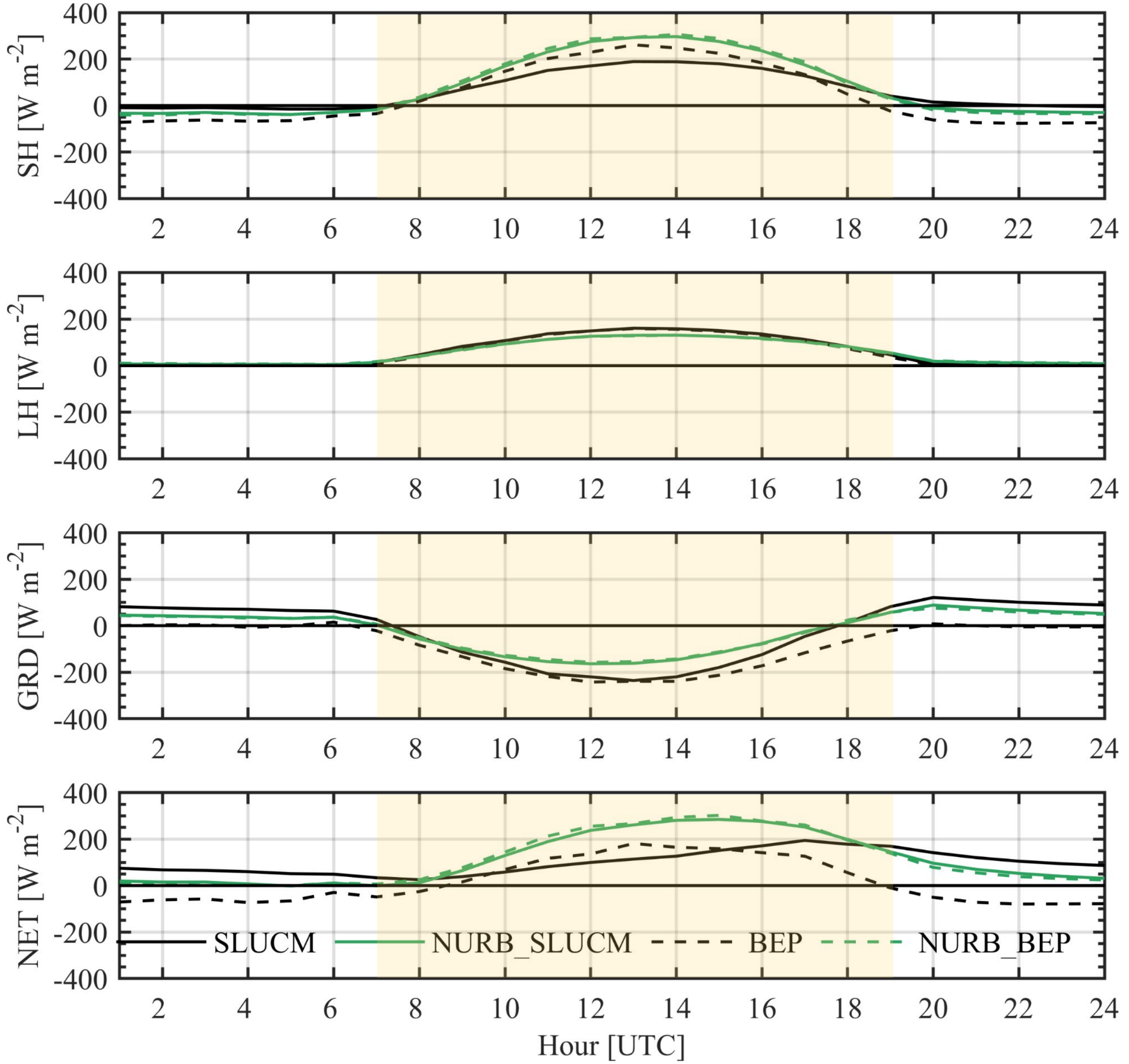


- Urban LU contributes for a reduction of the UHI during daytime and to an increase during nighttime;
- Uniform UHI signal across the domain not showing the dipole structure as in Method 1;

Results – surface heat fluxes

Daytime:

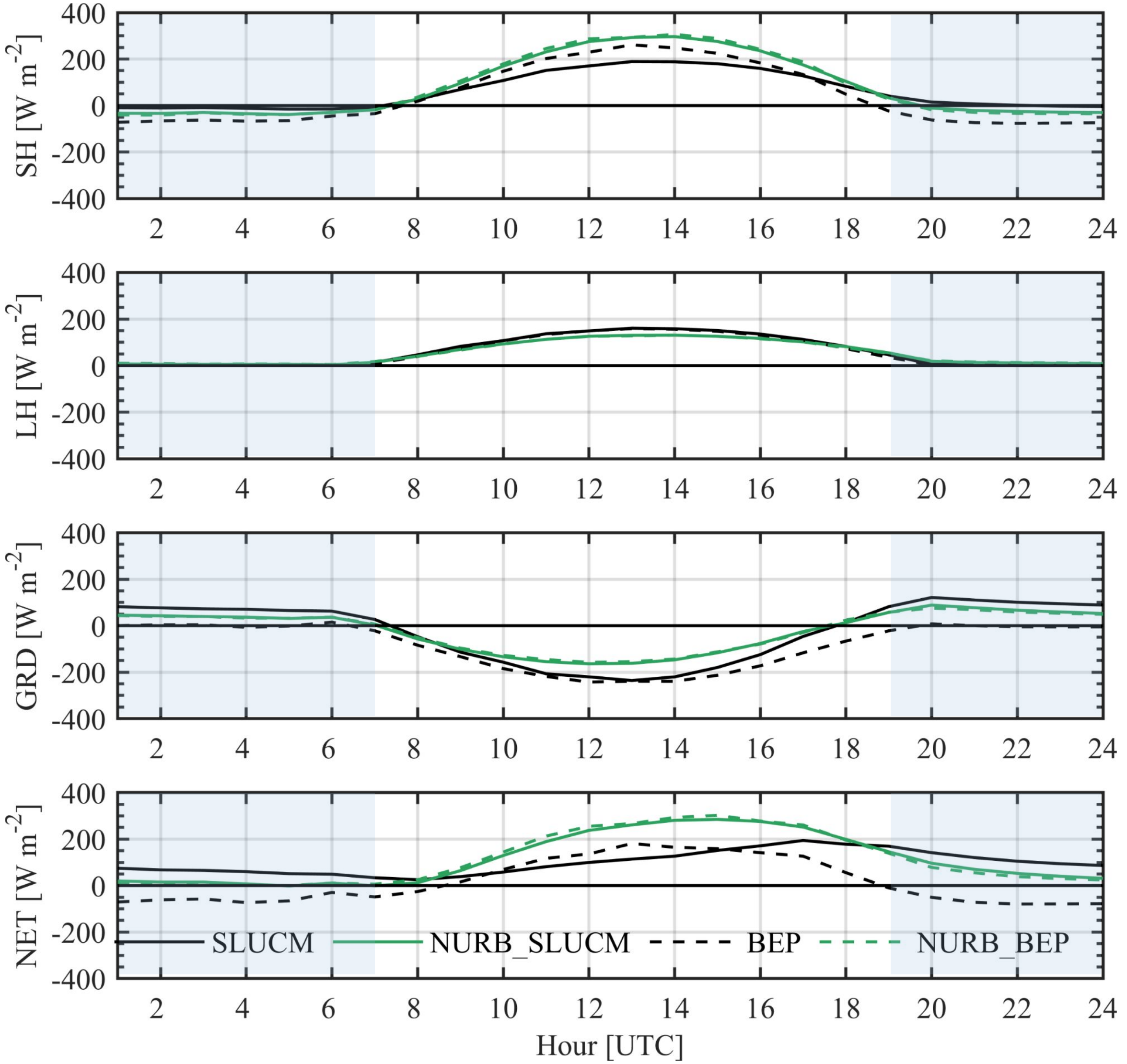
- SH fluxes are positive in all simulations but higher in BEP than in SLUCM, and higher when urban LU classes are removed;
- LH fluxes are higher when urban LU classes are included;
- Fluxes into the GRD increase by including urban land use;
- Higher NET loss (surface cooling) without urban classes.



Results – surface heat fluxes

Nighttime:

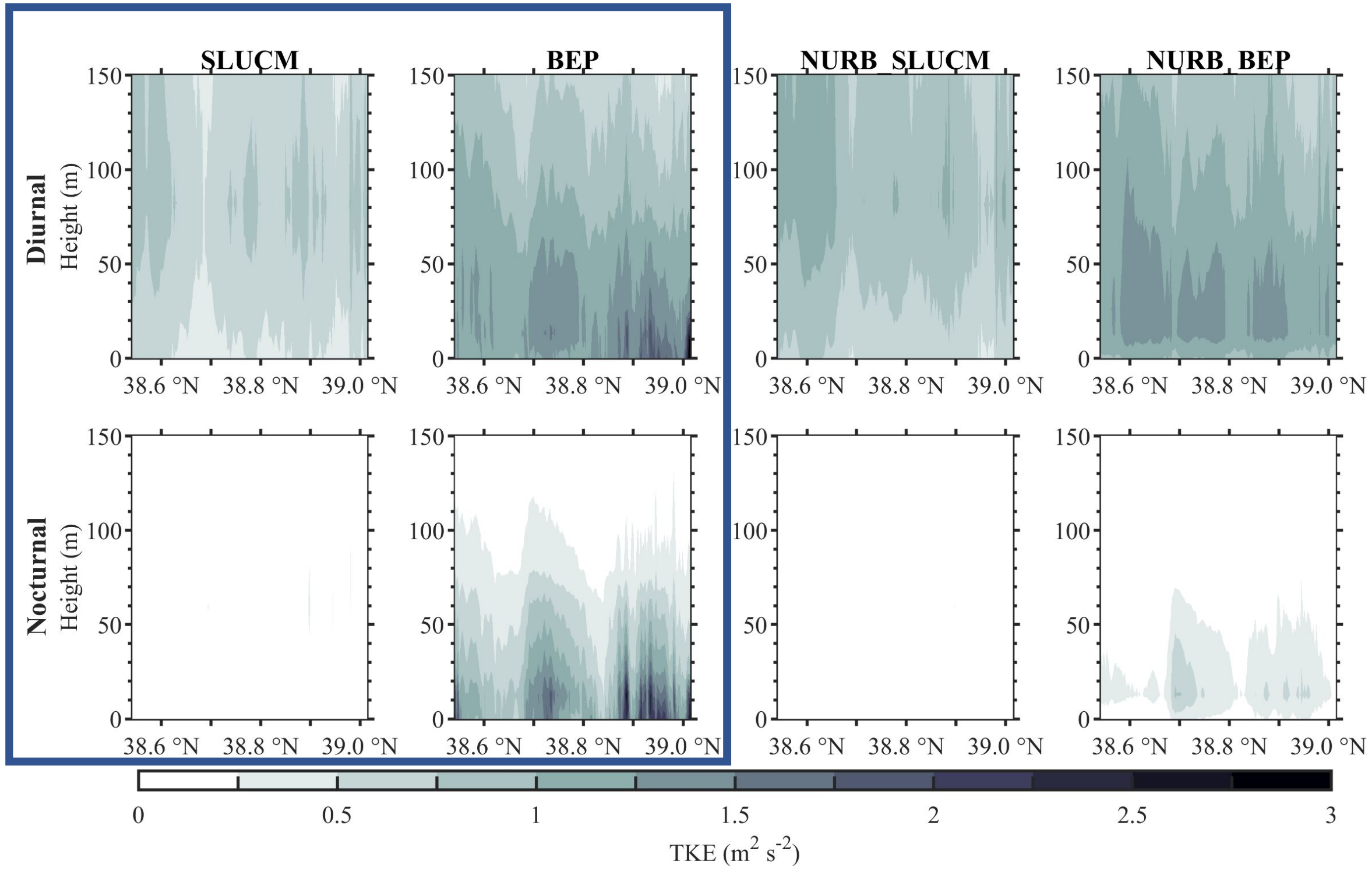
- **SH fluxes are negative in BEP** (i.e. surface is cooler than the near-surface atmosphere) **but not in SLUCM**;
- GRD fluxes are positive in most simulations and very small in BEP;
- BEP shows surface NET gain during the nighttime (i.e. surface is receiving energy from the atmosphere).



Results – vertical analysis

Much larger TKE near the surface in BEP during nighttime and daytime

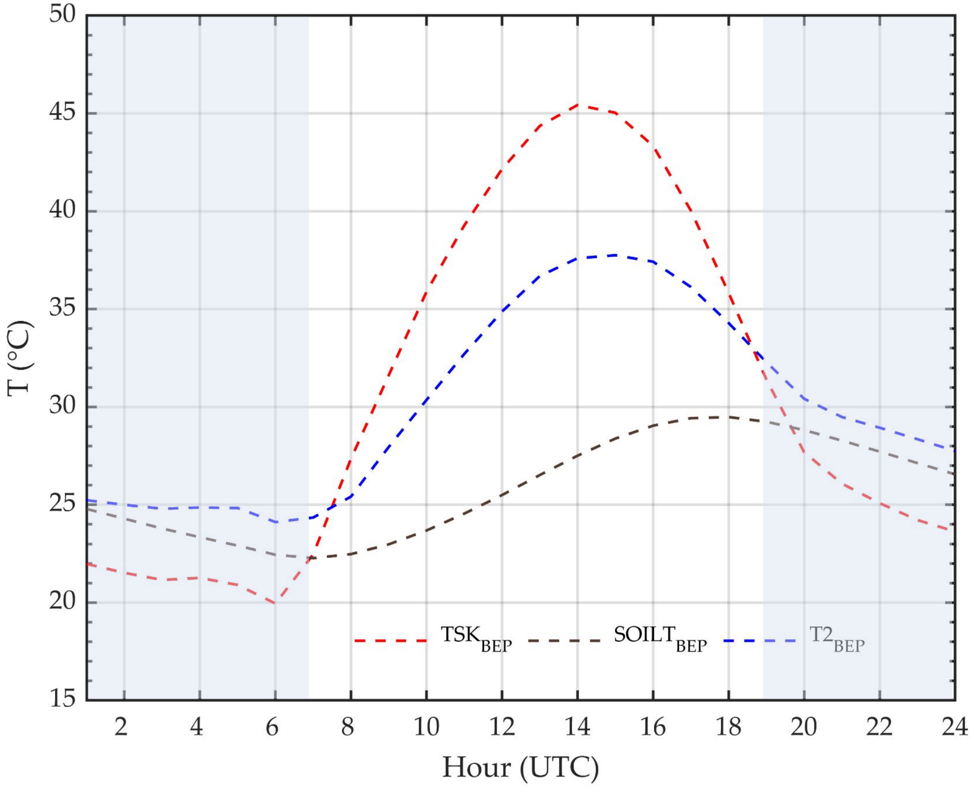
1. Higher number of levels in the lower PBL in BEP;
2. BEP parameterized subgrid length scale, accounting for the presence of buildings



Results – vertical analysis

Can the large nighttime near-surface TKE be the cause of the negative SH fluxes and lower UHI intensity found in BEP?

$T2_{BEP} > SOILT_{BEP} > TSK_{BEP}$



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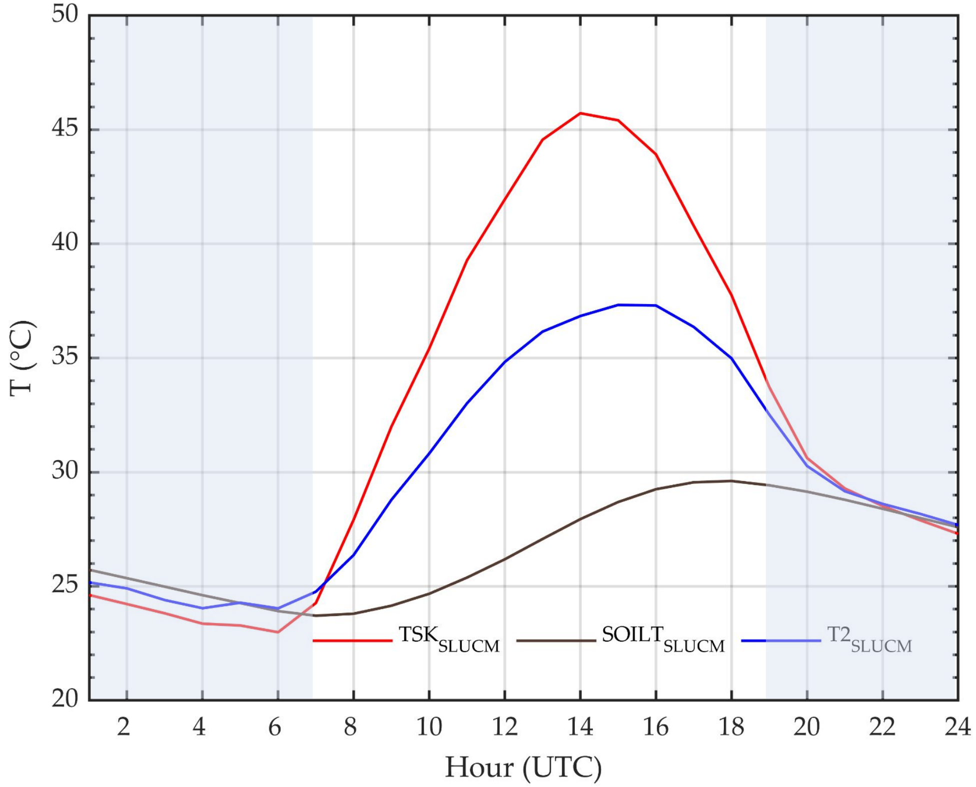
$SOILT_{SLUCM} > T2_{SLUCM} > TSK_{SLUCM}$



Conclusions

- Two main differences were found in the UHI intensity and spatial distribution between the UHI identification methods:
  - Reduction by half in nighttime UHI intensity by using Local Method (Method 1);
  - Dipole signal in the daytime and nighttime UHI spatial pattern when using the Classic Method, associated with the sheltering effect of the high topography in the northwestern part of the city, that reduces advective cooling under north wind conditions;
- Considerable improvements in the modelled T2m when using WRF coupled with UCMs, but better with SLUCM (not shown);
- The nighttime UHI intensity over HIR and IC classes is lower in BEP, which can be linked to the larger nocturnal near-surface TKE, negative SH fluxes, and lower surface temperature;
- The comparison with a previous study for the city of Lisbon, shows that BEP simulation results heavily rely on the number and distribution vertical levels within the urban canopy.

Thank you!

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