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Modelling the impact of green solutions upon the urban heat island phenomenon by means of satellite data

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DEPARTMENT OF ARCHITECTURE
AND URBAN STUDIES

Introduction

Currently, the increase of temperature and frequency of heat waves in urban areas threaten the health and wellbeing of citizens.

Mitigating the effect of the Urban Heat Island (UHI) in the cities is mandatory and requires undertaking both urban design actions and policy design strategies.

Actually, incrementing green infrastructure allows an effective solution for reducing the impact of the UHI effect at local level.

However, suitable tools for quantifying, assessing and monitoring the effectiveness of urban greening measures over time are lacking.

Introduction

Satellite-based optical and thermal imagery provides key resources for investigating those features that can effectively reduce the UHI effect.

Besides, statistical modelling has been widely investigated for estimating spatial correlation among vegetation and temperature.

In particular, negative correlation among temperature and Normalized Difference Vegetation Index (NDVI) is demonstrated at different spatial resolutions.

In order to compensate for inaccurate results when modelling non-stationary phenomena, Geographically Weighted Regression (GWR) has been experimented. GWR enables site-specific statistics.

Introduction

The objective is to explore the effectiveness of remotely sensed data and statistical modelling for assessing urban greenery measures for reducing the UHI in order to better inform decision-makers on urban resilience strategies.

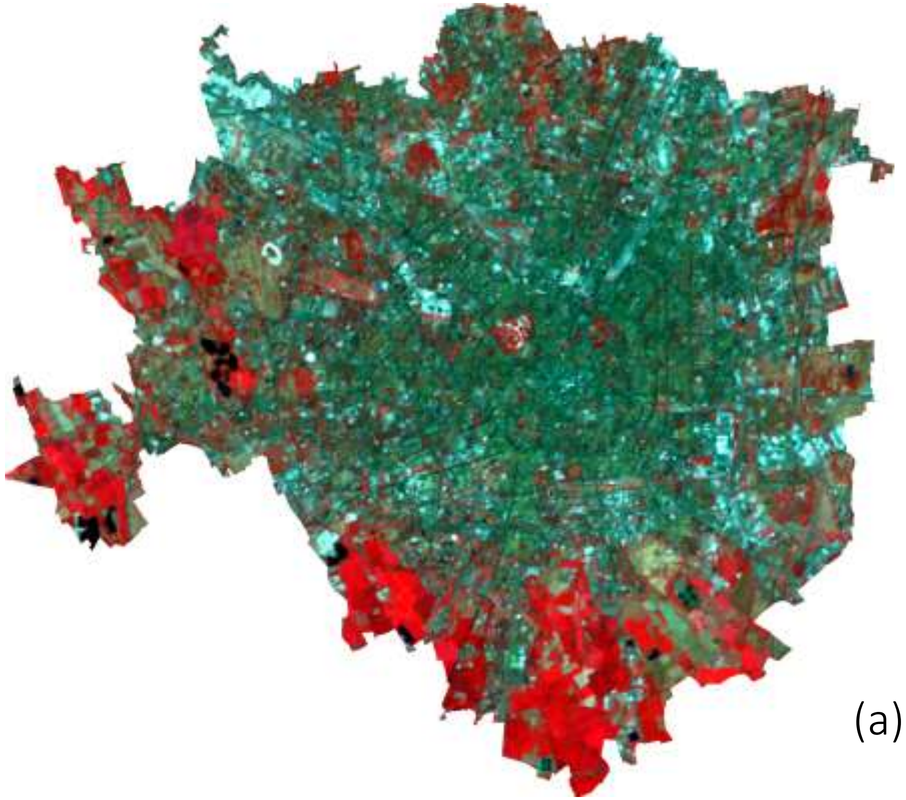
We experiment a GWR model based on NDVI as the independent variable (predictor), and near surface air temperature as the dependent variable. Both global linear regression and GWR model have been tested.

The study area is the Municipality of Milan (Città di Milano - CdM), which covers an area of approximately 181,7 km^2, with a population of around 1,370 million.

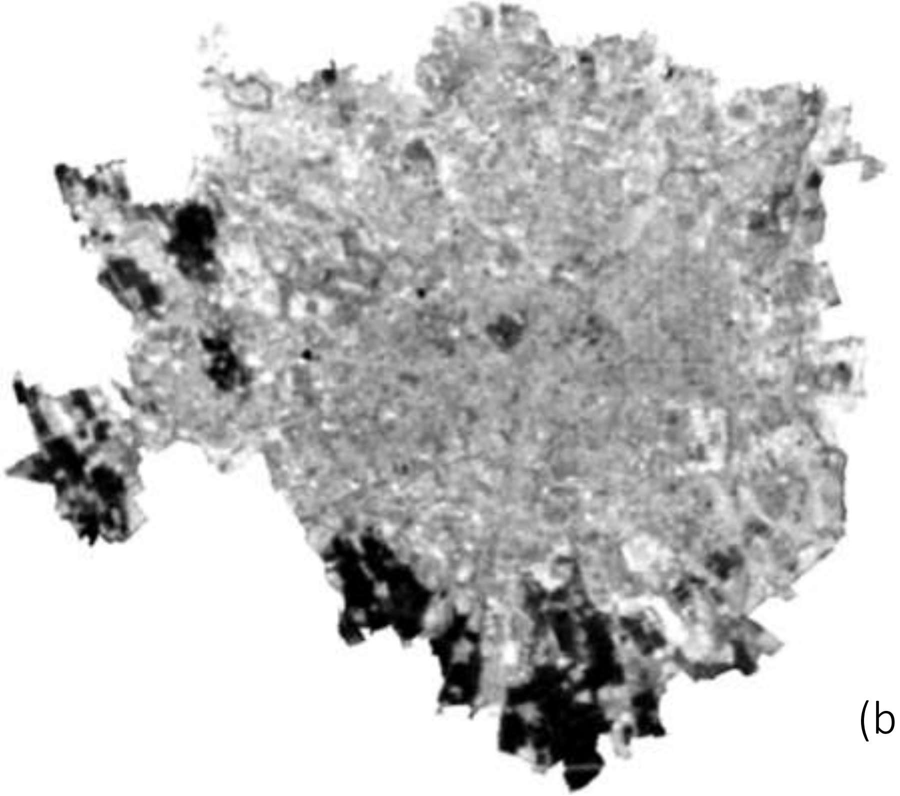
We have simulated the impact of implementing green roofs over the city of Milan, at both day- and night-time.

Employed Data

Optical and thermal data from Landsat 7 ETM+, acquired August the 4th, 2017



(a)



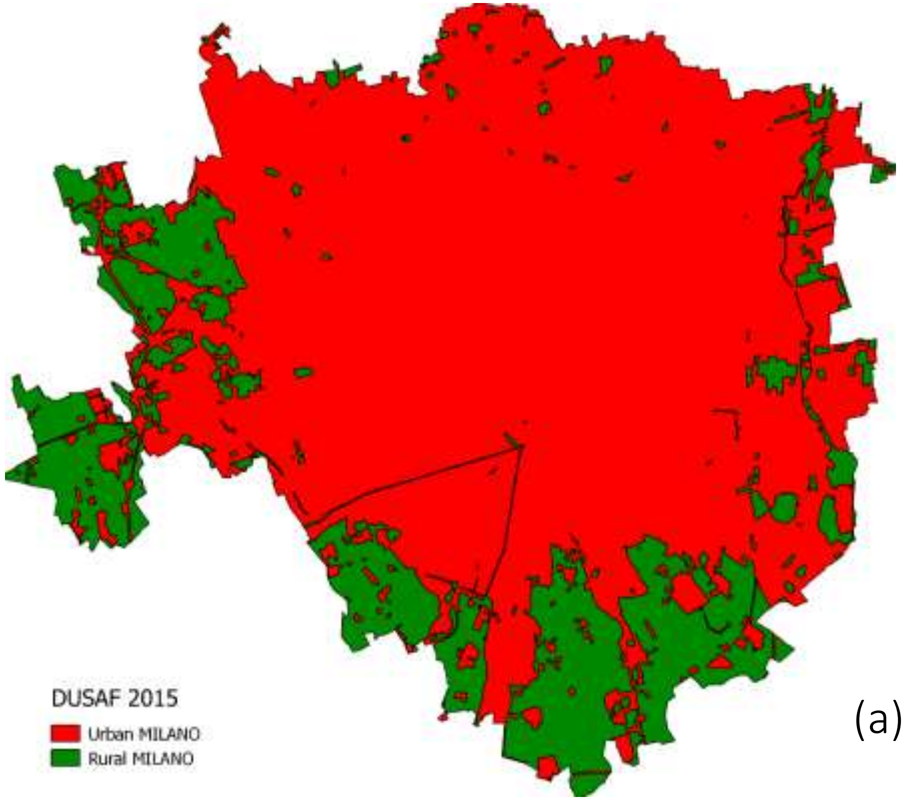
(b)

(a) Multispectral imagery at spatial resolution of 30 meters, and six bands spectral resolution ranging from visible to near-infrared and short wave infrared (SWIR).

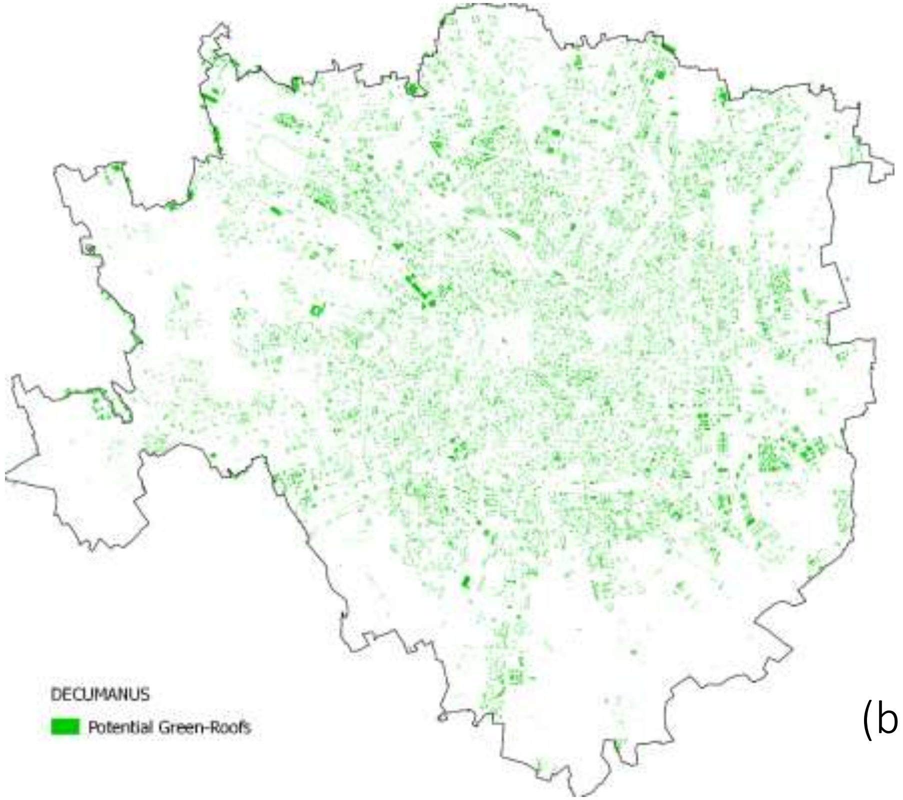
(b) Thermal infrared at spatial resolution of 100 meters, resampled to 30 meters.

Employed Data

Land Use/Land Cover classification, and potential green roofs



(a)



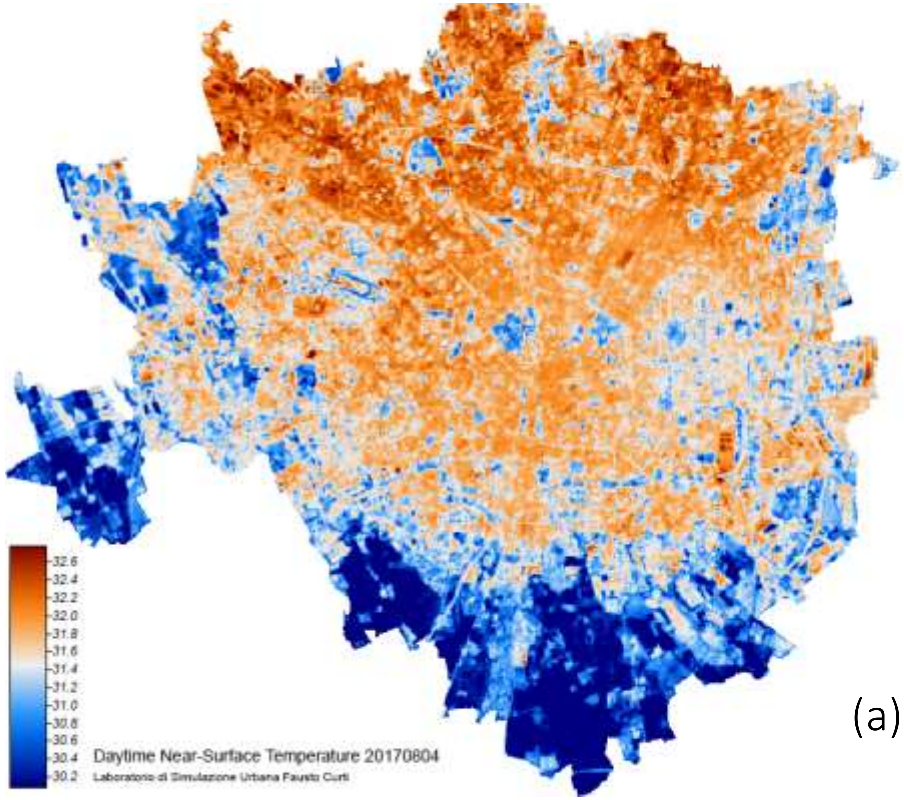
(b)

(a) Land Use/Land Cover from the regional database DUSAF (*Destinazione d'Uso dei Suoli Agricoli e Forestali*) 2015.

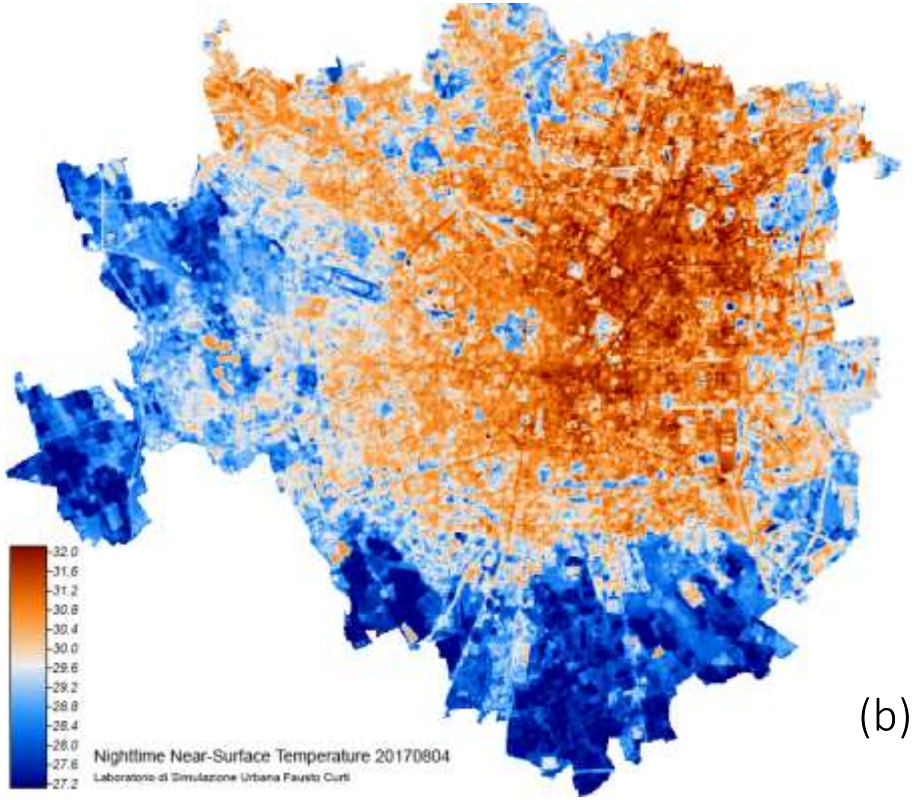
(b) Potential green roofs as estimated by Decumanus project, based on very-high resolution Digital Surface Model (DSM), Colour-Infrared (CIR) imagery, and imperviousness map (Available: http://www.decumanus-fp7.eu/home/).

Methodology and Application

Estimating the UHI for the City of Milan



(a)



(b)

Near-surface air temperature (°C) estimated for August the 4th, 2017 (warmest day). Obtained by combining optical and thermal data from MODIS and Landsat satellites, with air temperature measured by weather stations.

(**a**) Daytime temperature, at 10:30 am; (**b**) Nighttime temperature, at 09:30 pm.

Methodology and Application

Estimating the UHI for the City of Milan

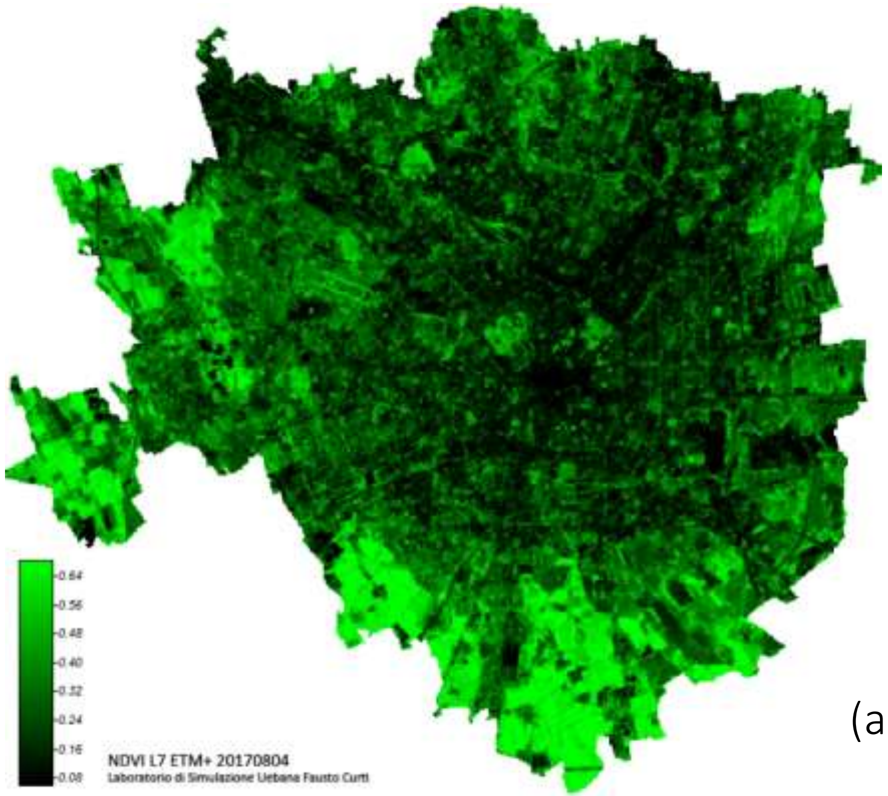
UHI intensity for August the 4th, 2017 has been quantified based on the near-surface air temperatures, and urban/rural classification obtained from DUSAF.

Both daytime and nighttime values have been calculated for urban areas (T_u) and non-urbanized (or rural) areas (T_r). UHI intensity is given by the difference among urban temperatures minus rural temperatures (ΔT_{u-r}).

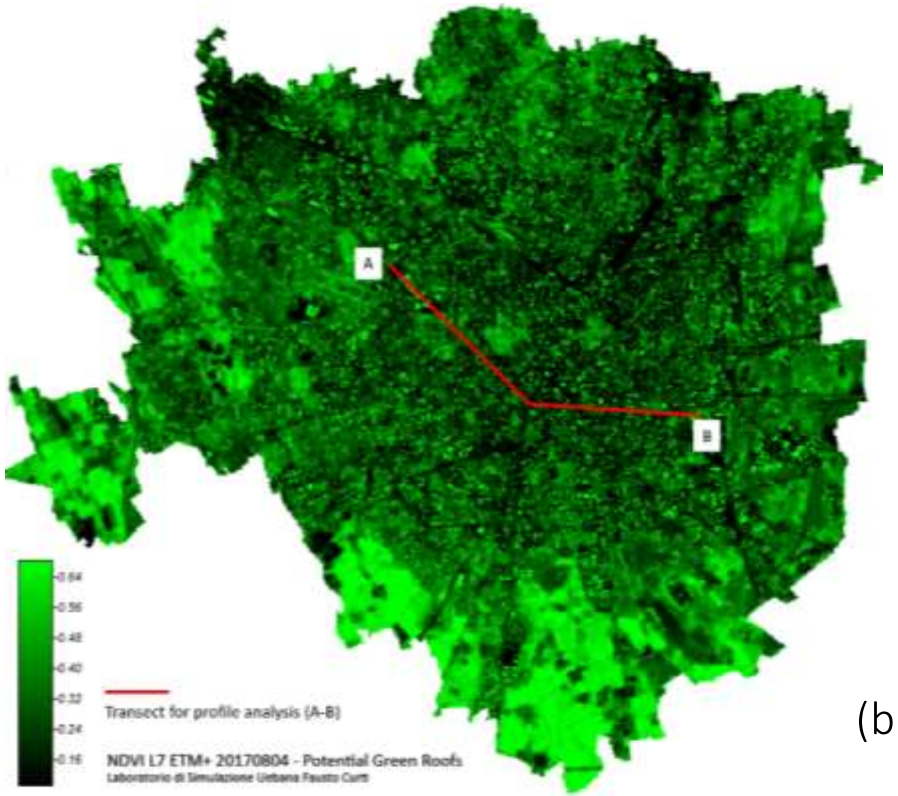
		Daytime (10:30 am)		**Nighttime** (09:30 pm)	
		T_{mean} °C	T_{max} °C	T_{mean} °C	T_{max} °C
Urban	T_u	**31.6**	34.6	**30.0**	35.0
Rural	T_r	**30.5**	32.7	**27.9**	32.0
UHI	ΔT_{u-r}	**1.1**	1.9	**2.1**	3.0

Methodology and Application

Current NDVI and green roofs-based simulated NDVI



(a)



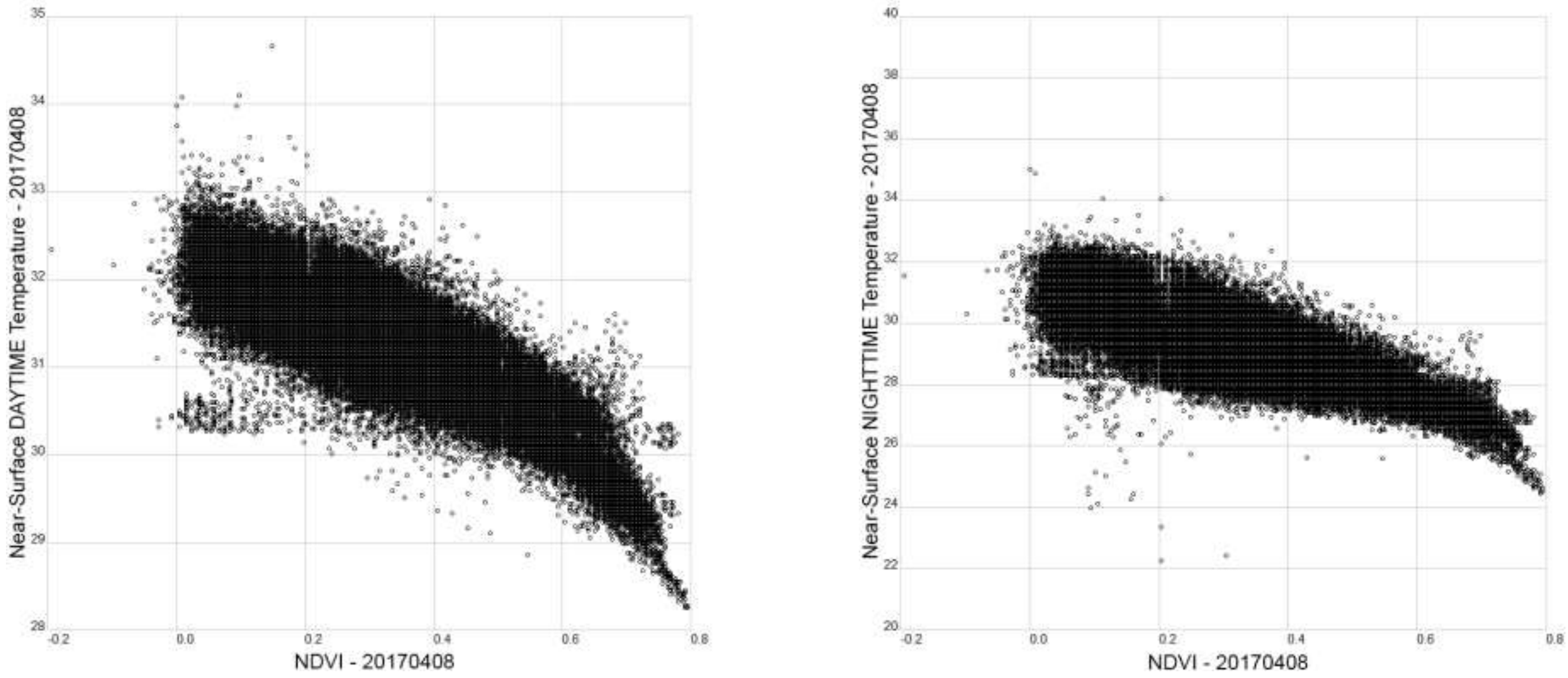
(b)

The NDVI, for August the 4th 2017, is derived combining red and near-infrared spectral bands as provided by Landsat ETM+ sensor. Images have been calibrated and atmospherically corrected. Also, a gap-fill algorithm has been applied.

(**a**) Current NDVI; (**b**) Green roofs-based simulated NDVI, and transect (A-B) for profile analysis (red line).

Methodology and Application

The effect of vegetation upon temperature: the Linear regression model



(a) (b)

Correlation between vegetation and temperature is negative, i.e. increasing the vegetation can reduce temperature. Also, both R and R^2 are significant, with a mean square error (RMSE) of 0.32 ^{o}C and 0.63 ^{o}C respectively for day and night.

Temperature (Y) and NDVI (X) for August 04, 2017. (**a**) Daytime situation; (**b**) and night-time situation.

Methodology and Application

GWR model to assess the effect of green measures

With respect to global models, GWR provides a powerful tool to address spatial heterogeneity based on local calibrated regressions at each geographical position.

The model has been processed in GRASS GIS. A Gauss weighting function is applied. GWR model has been validated and compared with the global model based on same measures.

	Daytime (10:30 am)		**Nighttime** (09:30 pm)	
	Linear Regression	**GWR** Bandwidth 7	**Linear Regression**	**GWR** Bandwidth 7
Observations (*n*)	201,991	201,991	201,991	201,991
R^2	0.77	0.97	0.74	0.95
F	693,500.37	8,496,120.00	580,738.58	3,899,040.00
AIC	- 459,602.91	- 918,828.00	- 182,505.42	- 517,044.00
BIC	- 459,582.48	- 918,807.00	- 182,484.99	- 517,024.00
RMSE	0.32	0.10	0.64	0.28
MAE	0.26	0.07	0.49	0.19

Methodology and Application

Results and observations

We assess the impact of increasing green coverage upon temperatures and UHI. A theoretical NDVI is simulated by changing pixel values for potential green roofs. Three NDVI are tested: 0.6, 0.7, and 0.8 as constant values for green roofs.

Lowering rate of the overall UHI, resulting from simulation, is reported.
Results show that the lowering rate of the overall UHI is more sensitive at night and increases during nighttime when using a higher NDVI.

		Daytime (10:30 am)				**Nighttime** (09:30 pm)			
		T_{mean} °C				T_{mean} °C			
		Actual	NDVI 0.6	NDVI 0.7	NDVI 0.8	**Actual**	NDVI 0.6	NDVI 0.7	NDVI 0.8
Urban	T_u	**31.6**	31.5	31.5	31.5	**30.0**	29.8	29.8	29.7
Rural	T_r	**30.5**	30.5	30.5	30.5	**27.9**	28.0	28.0	28.0
UHI	$\Delta T_{u\text{-}r}$	**1.1**	**1.0**	**1.0**	**1.0**	**2.1**	**1.8**	**1.8**	**1.7**
UHI lowering			0.1	0.1	0.1		0.3	0.3	0.4

Findings

Results and observations

Because the non-stationarity of the phenomenon, GWR shows widely improved results.

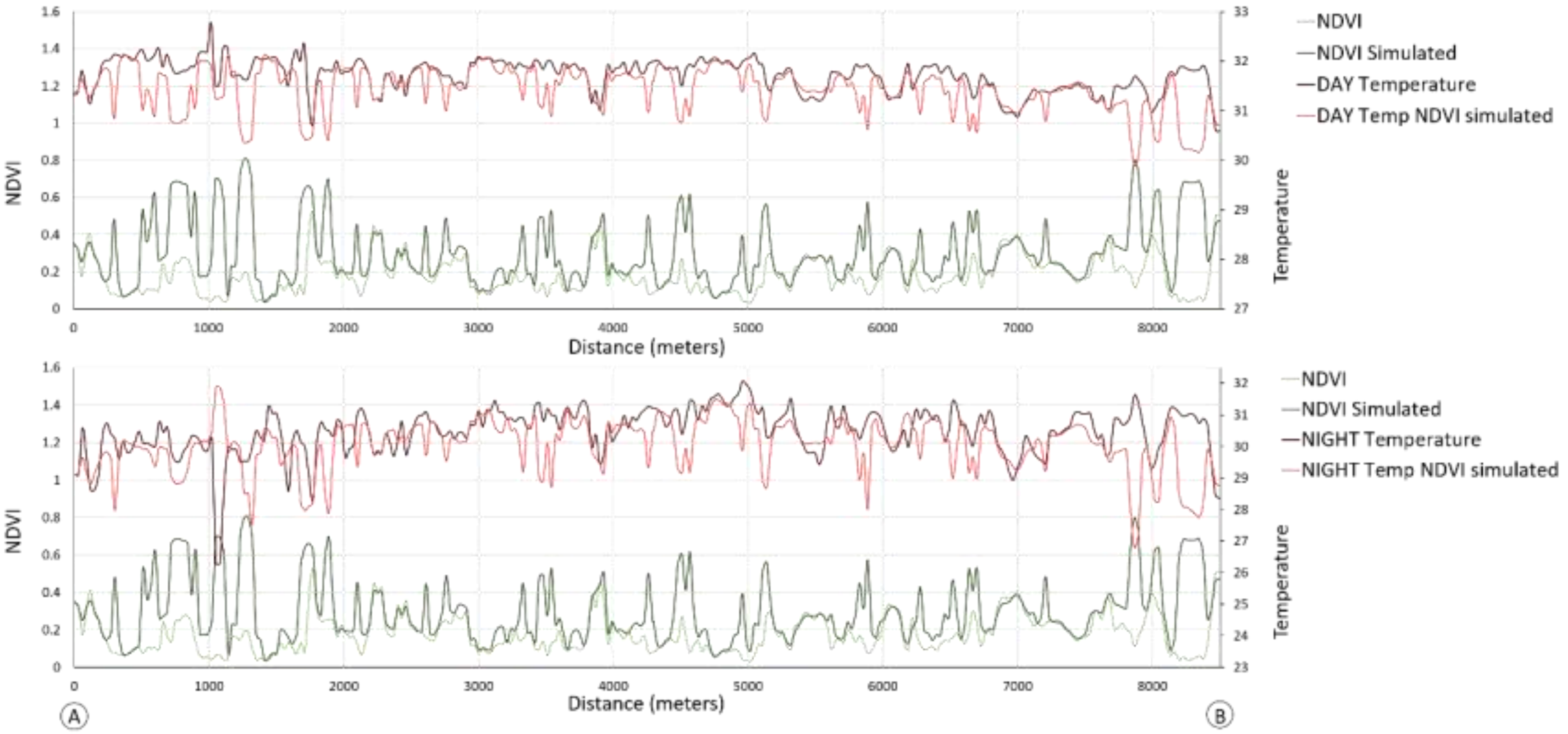
The impact of greening is actually more sensitive at night.

Moreover, we emphasize that the impact on temperature reduction through implementing green roofs is much more sensitive at the local scale.

Actually, if we outline a profile about the trends of NDVI and temperature values, either current and estimated, for a transect through the city, we observe that significant temperature differences at local level.

Findings

Results and observations



The profile (A-B), as previously identified, of current and simulated NDVI and temperatures, shows that, locally, temperature difference is reaching around one degree daytime and, in some cases, even more than one degree nighttime.

(Upward) NDVI versus daytime temperature. (Beneath) NDVI versus nighttime temperature.

Conclusions

The ultimate goal is to better inform decision-makers on urban resilience strategies and the meaning of an effective climate-proof urban planning. This is fundamental to assess the most suitable measures to mitigate climate change effects in cities.

Actually, implementing green infrastructure in cities decreases temperatures, with evident benefits on wellbeing and the reduction of energy demand.

Quantifying different spatial patterns of temperature as vegetation changes, allows the evaluation and monitoring of the impacts induced by greening projects upon urban comfort.

Future Investigation

The availability of assessment tools also provides the opportunity of weighting the benefits of different greening measures.

Here the case study was based on assessing the implementation of green roofs, but actually the work aims at demonstrating that the approach is suitable for assessing and monitoring further adaptation actions, like for instance tree planting or replacing urban materials.

GWR model could be improved by introducing further variables such as the albedo and/or morphological features (i.e. sky view factor, urban canyon, etc.).

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THANK YOU FOR YOUR ATTENTION

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