
Wicki Andreas

# Analysis and modelling of meso- and microscale urban climate in Bucharest, Romania

[1]Wicki Andreas, [2]Vogt Roland, [3]Parlow Eberhard
[1]*University Basel, MCR Klingelbergstrasse 27, 4056 Basel, Switzerland, a.wicki@unibas.ch*
[2]*University Basel, MCR Klingelbergstrasse 27, 4056 Basel, Switzerland, roland.vogt@unibas.ch*
[3]*University Basel, MCR Klingelbergstrasse 27, 4056 Basel, Switzerland, eberhard.parlow@unibas.ch*

01 June 2015

## 1. Introduction

The study of global climate is one of the most discussed and illustrated topic in science in the recent decades. Due to the *fifth assessment report of the intergovernmental panel on climate change* (Stocker et al. 2013) and numerous climate conferences the effects and the existence of global climate change are well known and realized by the general public. Beside the consequences for the natural environment, i.e. flora and fauna, dramatic impacts of the global climate change are expected for human beings as well. At the moment, more than half of the population worldwide is living in an urban environment. This number is even higher in developed countries and will increase to almost 70 percent until 2050 (WHO). The connection between the increasing global temperatures and the increasing number of people living in an urban environment are associated in a phenomenon called the urban heat island (UHI) effect. The UHI describes the usually higher mean temperature in an urban environment, compared to the corresponding rural surroundings. This effect is most obvious in nighttime, when the urban fabric acts like a battery due to solar warming, which counteracts the nocturnal cooling. Most dramatic during heat waves, this additional warming inhibits the nocturnal recovery of the human circulation and causes health problems, especially for elderly people. The 2003 European heat wave, known as the most dramatic heat waves in the recent years and as a possible landmark for future common summer extreme conditions, caused up to 70'000 additional deaths in Central Europe (Robine et al. 2008). This indicates the importance of urban climate studies for future generations. Urban climate studies can emphasize the problematic spots in an urban environment and provide possible solutions to improve the local urban climate and therefore the thermal heat stress for every individual person.

In this study, the urban climate of the city of Bucharest was analyzed in different scales using different approaches. First, a land surface analysis (LSA) was developed using Landsat 8 data and a maximum likelihood classifier (MLC) with regions of interest (ROI) as supervised input was applied. The accuracy was improved using rasterized OpenStreetMaps (OSM) data to estimate small rivers, streets and railways. This classification was used to quantify the land cover of Bucharest and its surroundings and was compared with the land surface temperature (LST) derived from the Landsat 8 Thermal Infrared Sensor 1 (TIRS1, band 10, 10.6 - 11.19 µm, 100m).

In a second step, the local microclimate was modelled and analyzed using the 3D microclimate model ENVI-met V3.1, developing three different scenarios according to the structural changes, which occurred during the socialist regime of Nicolae Cauçescu after a big earthquake in May 1977. Thereby, a past, a present and a possible future state were developed to model urban climate change due to urban modification.

## 2. Data and Methods

### 2.1 Data

The Landsat 8 data was provided by the USGS (http://glovis.usgs.gov/) and two scenes (spring and summer 2014) were selected as an input for the classification. The vegetation information from the spring scene was thereby used to improve the accuracy of the LSA, due to the different growth phase of cereals and other cultivated plants. For the LST estimation, only the summer scene was used. Additional to the Landsat data, OSM data was used to estimate small and thin structures that were however important for the analysis. Thereby streets, railways and small rivers could be estimated using this rasterized vector data. This approach underlined the structure of the city and helped to minimize the classification error.

To compute the ENVI-met model runs, background layer were used to create the 3D model environment in the ENVI-met editor. The past state, representing the old town of Bucharest before the earthquake and the large structural changes, was reconstructed using a Corona image from 1966. A possible future state was developed using the current state model environment, but with lower vegetation fraction and stronger soil compaction.

## 2.2 Methods

The classification was done using ROI and a MLC to estimate ten different classes. The agricultural and bare soil classes were combined to one single land surface class. For the built-up areas, four different classes were developed due to the given morphology of the city: Beside the obvious and standard classes of dense urban, suburban and industrial, a class for the large neighborhoods of blocks of flats, a relic of the socialist regime, was used as a separate class. The OSM vector data was filtered to estimate the useful attributes, rasterized to the same geometry as the Landsat image and included in the classification using a decision tree. The filtered vector data was additionally used in the map display to underline the city structure together with vector data representing the administrative boundary (*Figure 1*).

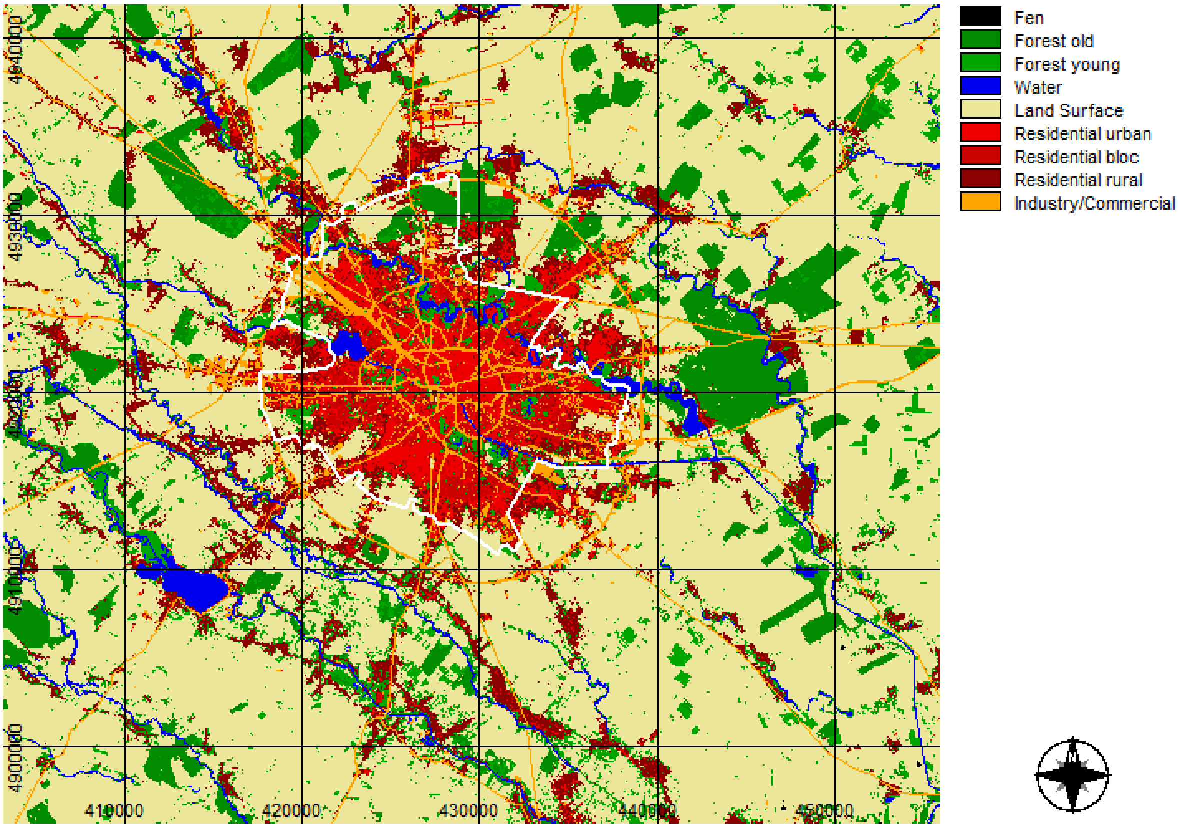



*Figure 1: Land Surface analysis of greater Bucharest with ten different classes and vector data of the main roads, railways and rivers as a vector overlay. The administrative city boundary of Bucharest is represented as a white line. The map is oriented to the north and the map grid coordinate system is UTM-35 North.*

Due to uncertainties in band 11, the LST was estimated using only band 10 of Landsat 8 TIRS. The atmospheric correction was done using the atmospheric correction parameter calculator provided by the NASA (http://atmcorr.gsfc.nasa.gov/atm corr.html). The received band average atmospheric transmittance (τ), the effective bandpass upwelling radiance ($L_{up}$) and the effective bandpass downwelling radiance ($L_{down}$) was used to correct the top of atmosphere (TOA) radiance. The corrected radiance was converted into Kelvin using the inverse Planck Function. Normalized Difference Vegetation Index (NDVI) calculations were done using simple normalized ratios between the red and the near infrared (NIR) channels. The albedo calculation was done using the Liang-Method (Liang 2001). The LSA and the LST estimation were used to generate class specific maps of the LST distribution and to analyze class dependent dynamics of the LST.


*Figure 2: Setup of the ENVI-met runs of scenario one and two with a GoogleEarth, respectively Corona image (left) and the corresponding ENVI-met model environment (right) from 2012 (above) and 1966 (below).*

The ENVI-met model runs were drafted using the ENVI-met editor (ENVI-met Eddi) with background information as a template (plans, images and GoogleEarth). Thereby, to reconstruct the former state of the Bucharest old town, a Corona image from 1966 was used as a visual guideline. The third scenario (future state) was designed in case of a restructuring of the street capacity: At the moment, the “Bulevardul Unirii” holds main streets lined with trees covering the pedestrian walkways in front of the large socialistrealist apartment blocks. The future scenario simulates a clearing of these trees. The visualization was done using ENVI-met Leonardo and the further analyses were performed with Matlab.

## 3. Results

### 3.1 Land Surface Analysis

The LSA revealed a land cover composition of 65% land surface, 18% built-up areas, 15% forest and 2% water as the four major land uses. The combination of the LSA and the LST estimation enabled the analysis of class specific dynamics in surface temperature. The built-up classes show thereby the highest LSTs (*Figure 3*).

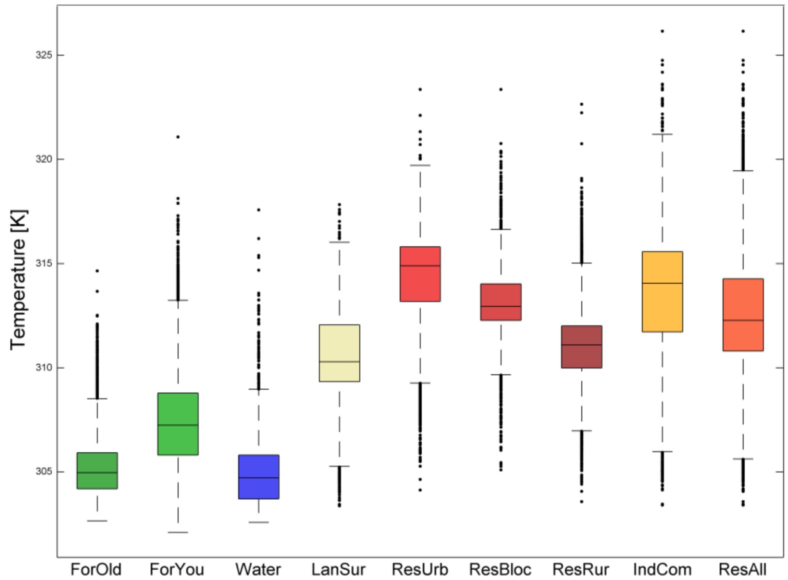



*Figure 3: Box plot with distribution of the LST of each class separately. The central mark is the median, the edges of the box are the 25th and 75th percentiles and the whiskers extend to the most extreme data points considered not to be outliers (points).*

Regarding the spatial distribution of the LST dynamics, the city center showed a clear tendency to develop a surface urban heat island (SUHI). Despite this SUHI, the numerous industrial sites located at the city borders and the international airport showed as well very high surface temperatures (Figure 4).

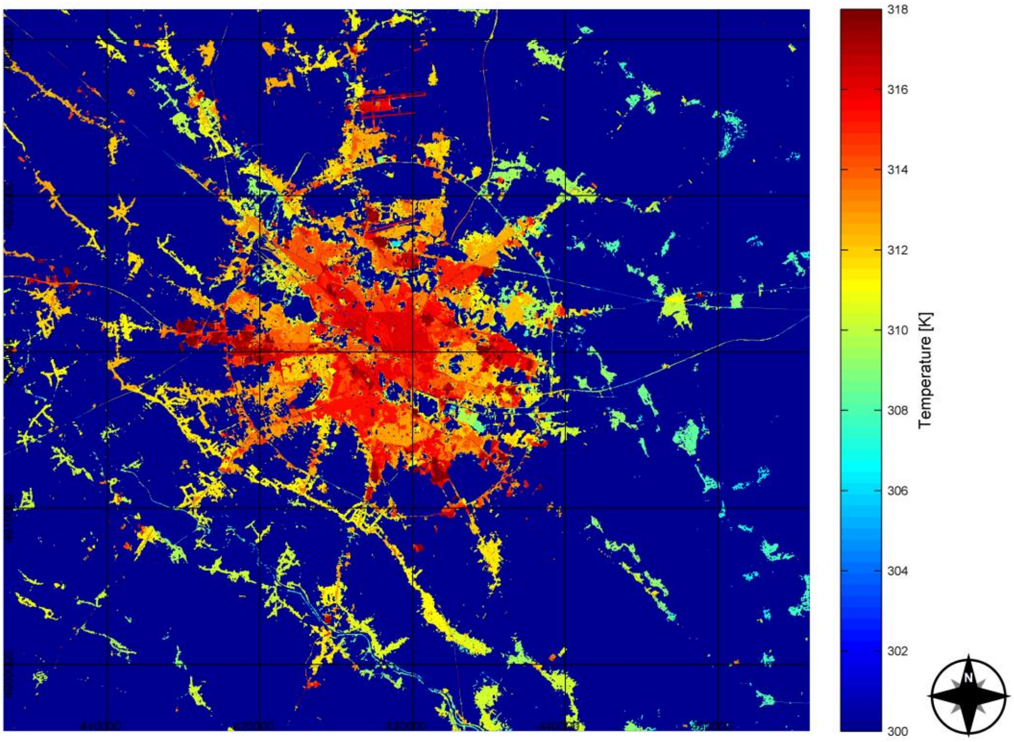
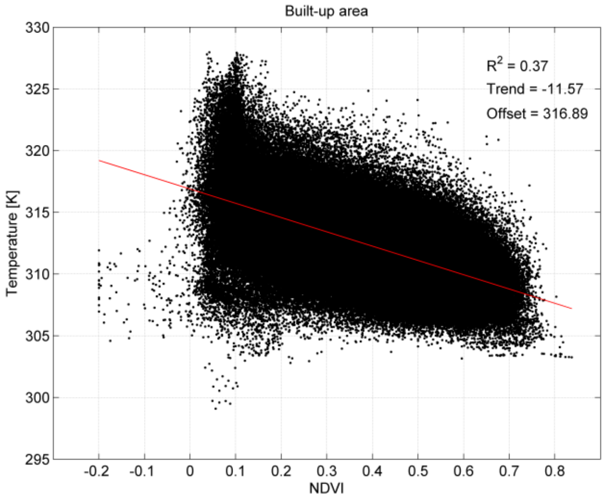



*Figure 4: Map of the mean LST of all built-up classes (ResUrb, ResBloc, ResRur, IndCom) with mean LST for each separated patch of each class and the other classes masked to zero. The map is oriented to north and the map grid coordinate system is UTM-35 North.*




To get an understanding of the causes of this distribution, NDVI analysis were done and compared with the LST in the specific classes. The LST estimation and the NDVI calculations were combined in a scatter plot. The linear regression shows a trend of decreasing temperature with increasing NDVI, although the values are spread in a wide range.

Near an NDVI of 0, the highest LST occur. This must be the very dense city center and the industrial areas, where most of the land surface is covered with concrete.

*Figure 5: Scatter plot of the NDVI (x-axis) vs. LST (y-axis) in each grid point of the map within the built-up classes with the linear regression as a red line.*

The microscale modeling shows the variable behavior of the different scenarios and the influence of the city structure on the local urban climate. To exhibit the impact of these structural changes inside the urban environment on a human being, the predicted mean vote (PMV, Fanger 1974) was calculated (*Figure 6*).

On the windward side of the boulevard (i.e. south), the PMV values are significantly increased. Inside the boulevard itself, the heat stress is moderate. In the almost unaltered parts northern and southern to the boulevard, the heat stress is slightly increased, even if the changes in this part of the investigation area are small. The wind direction and velocity was aligned on the averages for June based on meteorological measurements from the international airport of Bucharest of the last few years. This resulted in a weak wind from the direction of

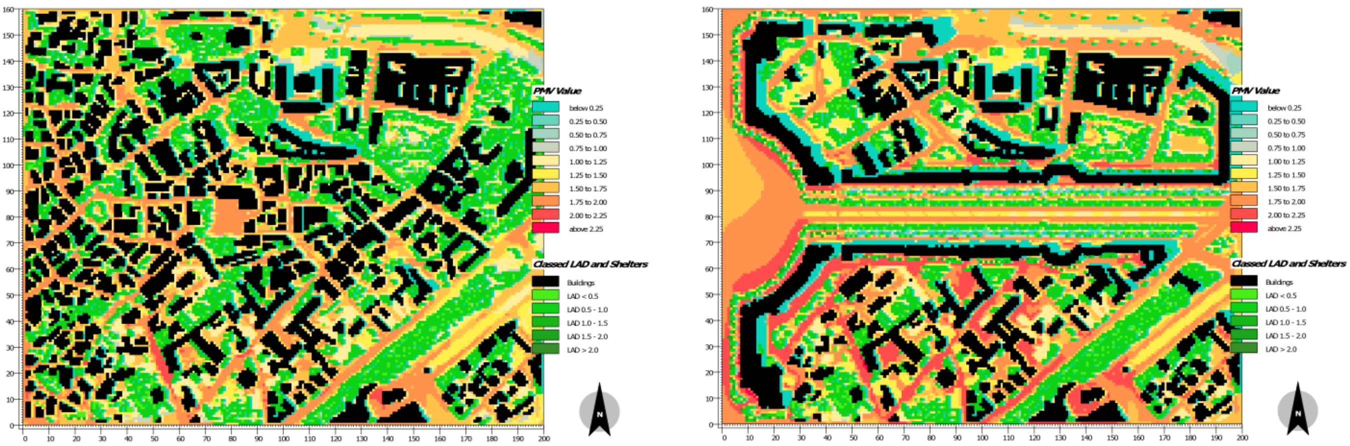



*Figure 6: ENVI-met model scenario one (old town, left) and two (Bulevardul Unirii, right) with the PMV values in 3m above the ground at the Bulevardul Unirii test site 15:00 21.06.2014.*

south. The altered wind field under these conditions is shown in *Figure 7* and *Figure 8*. Scenario three (not displayed here) shows the same tendencies as scenario two, with slightly increasing PMV values. The increased building height in scenario two causes marginally higher wind velocities above the urban canopy layer. The increased mean building height induces increasing roughness and therefore more turbulence in the urban roughness layer. Thereby, an uplift of the urban boundary layer due to the large structural changes can be assumed.

Analysis of the mean sky view factor ($\Psi_{sky}$) regarding buildings and vegetation of showed a decreasing tendency due to the building of the boulevard.

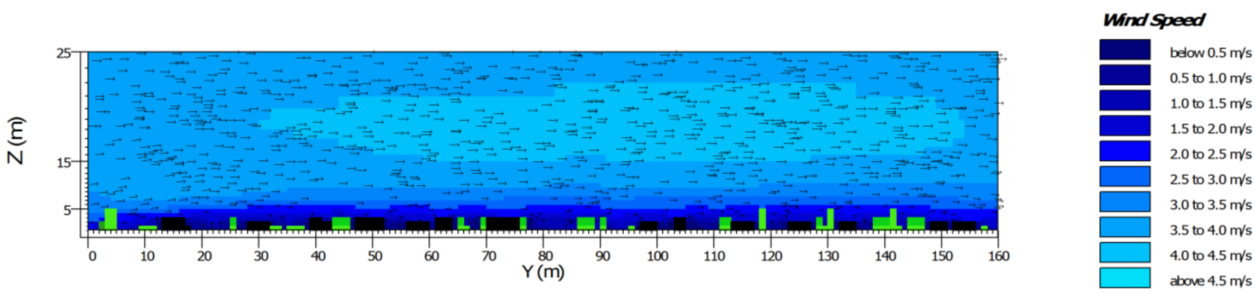



*Figure 7: Wind velocity Bucharest Bulevardul Unirii yz-cut at x = 92m scenario one (old town) 15:00 21.06.2014.*

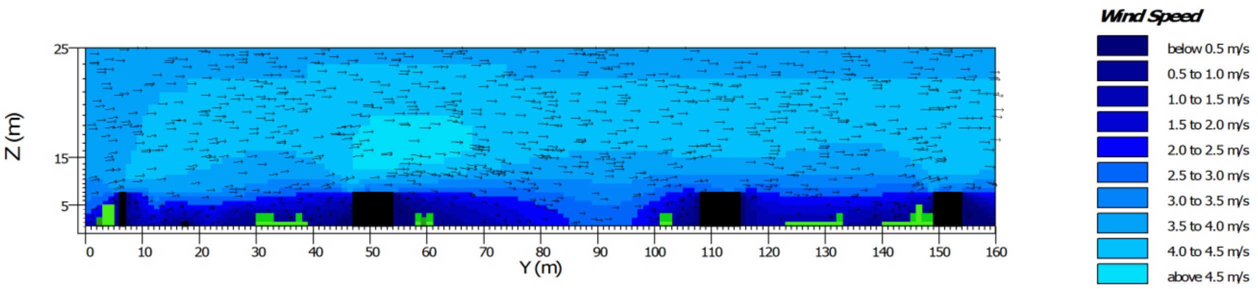



*Figure 8: Wind velocity Bucharest Bulevardul Unirii yz-cut at x = 92m scenario two (Bulevardul Unirii) 15:00 21.06.2014.*

## 4. Discussion and Conclusion

The mesoscale analysis using Landsat 8 TIR and VIS/NIR data revealed a clear tendency of increasing urban surface temperatures to the city center and in the industrial areas. The box plot analysis demonstrates class dependent surface temperatures with the highest median temperatures in the dense urban class and the industrial class. The comparison with the NDVI showed a slight tendency with a weak significance.

The investigation of the Bucharest downtown at the area of the parliament building and the Bulevardul Unirii showed an effect on the local urban climate due to the structural changes taking place during the socialist regime. The potential temperatures are higher at day- and nighttime and the wind field is altered due to canalization and barrier effects in scenario two, which reduces the exchange of refreshing air between the northern and the southern part of the investigation area. This affects fundamentally the thermal comfort, represented in this study by the PMV. The PMV is a measure originally developed for indoor thermal comfort, but can be applied to outdoor conditions as well (Honjo 2009). The modification in thermal comfort did not only take place in the boulevard itself, but also in the largely unaltered backyards of the investigation area. This indicates a far-reaching influence of such huge spatial changes on the urban climate in a city like Bucharest. Scenario three, representing the removal of the numerous trees lined to the main road of the boulevard, indicates the importance of the attenuating effect of vegetation on the local thermal comfort. Removing these trees would cause enhanced heat stress inside the whole boulevard and in the backyards.

Including the vegetation in the calculation of the $\Psi_{sky}$, a decrease in scenario two is measurable, indicating an enhanced heat island effect (Oke 1981). Comparing the vertical temperature analysis, a higher UHI effect due to the structural modifications can be assumed.

## Acknowledgment

The preparation of a scientific paper is often the result of great team work and constructive collaboration. For this reason, I would like to acknowledge all the people that offered support and made this thesis possible.

The former, there was the whole MCR-Team from the University of Basel that supported me in various ways, especially Prof Eberhard Parlow as the supervisor of the thesis.

Second, my thanks go to the people from the Technical University of Bucharest (UTCB) and the University of Bucharest (UB), especially Mihaela Aldea (UTCB), who made a great effort guiding me during my field trip in Bucharest and giving me useful insights in the urban development of the city. Furthermore, I would like to thank Ionut Sandric (UB), who provided important data for this work and offered great support during a meeting in Bucharest and via e-mail afterwards.

The project was co-financed by a grant from Switzerland through the Swiss Contribution to the enlarged European Union.

## References

Bruse, M., 2004: ENVI-met 3.0: updated model overview. University of Bochum. Retrieved from: www.envi-met.com.

Bruse, M. and Fleer, H., 1998: Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling & Software*, **13**(3), 373–384.

Fanger, P. O., 1973. Assessment of man's thermal comfort in practice. *British Journal of Industrial Medicine*, **30**, 313–324.

Honjo, T., 2009: Thermal comfort in outdoor environment. *Global environmental research*, **13**(2009), 43–47.

Liang, S., 2001: Narrowband to broadband conversions of land surface albedo: Algorithms. *Remote Sensing of Environment*, **76**(2), 213–238.

Oke, T. R., 1981: Canyon geometry and the nocturnal urban heat island: comparison of scale model and field observations. *Journal of Climatology*, **1**(3), 237–254.

Robine, J.-M., Cheung, S. L. K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J.-P., and Herrmann, F. R., 2008: Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes rendus biologies*, **331**(2), 171–178.

Sandric, I., Mihai, B., Savulescu, I., Suditu, B., and Chitu, Z., 2007: Change detection analysis for urban development in Bucharest-Romania, using high resolution satellite imagery. *Urban Remote Sensing Joint Event, 2007*, 1–8.

Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P. M., et al., 2013: Climate change 2013. the physical science basis. Working group 1 contribution to the fifth assessment report of the intergovernmental panel on climate change-abstract for decision-makers. *Technical report, Groupe d'experts intergouvernemental sur l'evolution du climat/ Intergovernmental Panel on Climate Change-IPCC*, C/O World Meteorological Organization, 7bis Avenue de la Paix, CP 2300 CH-1211 Geneva 2 (Switzerland)