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Using ENVI-met to simulate the impact of global warming on the microclimate in central European cities

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Abstract

Within the BMBF joint research project KLIMES, the micro scale climate model ENVI-met is used by the subproject KLIMES JGU to simulate the effects of global warming on heat stress in central European cities and to evaluate possible countermeasures proposed by urban planners. In this study two simulations run with a model that contains structures which can be found in most central European cities. The first simulation runs with boundary conditions that are typical for central European summer days, the second simulation with boundary conditions that can be expected at the end of an extreme, longer lasting summer heat wave like 2003. The simulations are compared and the results are discussed.

1. Introduction

In the last years much effort has been put into meso scale simulations of climate change (e.g. Jacob, 2008). With resolutions of several kilometres, these simulations only display the climate within the main human habitat – the city which creates its own distinct urban climate - very coarsely. Due to their specific albedo, roughness length and soil sealing, cities create their own micro climate, mostly referred to as the urban heat island effect (Grimmond, 2006). Summerly heat-waves are aggravated within cities and the thermal discomfort and the health of the population is deteriorated. As regional climate models for central Europe predict heat waves to occur more often, be more intensive and longer lasting (e.g. Meehl and Tebaldi, 2004), it is necessary to study the effect of cities on heat waves in order to identify possible countermeasures. The joint research project “Development of strategies to mitigate enhanced heat stress in urban quarters due to regional climate change in Central Europe”, abbreviated by KLIMES, has the goal to study and quantify this urban heat island effect on human health and to propose possible countermeasures for urban planners. Within the KLIMES project the micro climate simulation ENVI-met is used to simulate and study the interaction of cities on the human thermal comfort and to predict how it will be affected by climate change. In this study the effects of the more extreme summerly weather conditions on an exemplary quarter of a central European city are investigated by comparing two simulations with different boundary conditions, one presenting an average European summer day, the other representing the conditions of an extreme summer heat wave.

2. ENVI-met

ENVI-met is a three-dimensional non-hydrostatic microclimate model including a simple one dimensional soil model, a radiative transfer model and a vegetation model (Bruse and Fleer, 1998). The software is developed by Prof. M. Bruse, University of Mainz and his team. An advanced air quality model is being provided by the Flemish

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Institute for Technological Research (de Maerschalck et al., 2008). The software runs on standard x86 personal computer running Windows XP or Vista and does – at the moment - not take advantage of more than one processor or distributed computing. Therefore the maximum number of grid cells is quite limited and it is not possible to simulate the micro-climate of whole cities but only single quarters within. ENVI-met uses an uniform mesh with a maximum of about 300x300x35 cells with the horizontal extension ranging between 0.5-10m and a typical vertical height of 1-5m. The version of ENVI-met used in this study is a developer version and contains some ameliorations and features that are not available in the version 3.1 which is currently available to the public. One of these new features, the possibility to explicitly force the meteorological parameters at the inflow boundaries, is used in this study. This allows an exact control of the diurnal development of all atmospheric parameters.

3. Model area

As there does not exist a typical central European city, a model area was selected that contains elements which can be found in many central European cities. A modified part of a model area which is being analysed within the KLIMES project was chosen as model area for this study. The model area (see Figure 1) has a size of 460x432.5m, resulting in 184x173x30 cells with a resolution of 2.5x2.5x2.0 meters. The average building height is about 12m, ranging from garages with slightly more than 2m height to a church tower with more than 20m. Within the area one can find detached houses with gardens and row houses with inner courtyards of different sizes and with different degrees of vegetation. All streets have a nearly South-north and East-West orientation. A river is located at the north part of the model area and a small park at the south. The geographic coordinates of the model area were set to 48° northern latitude and 7.8° western longitude.

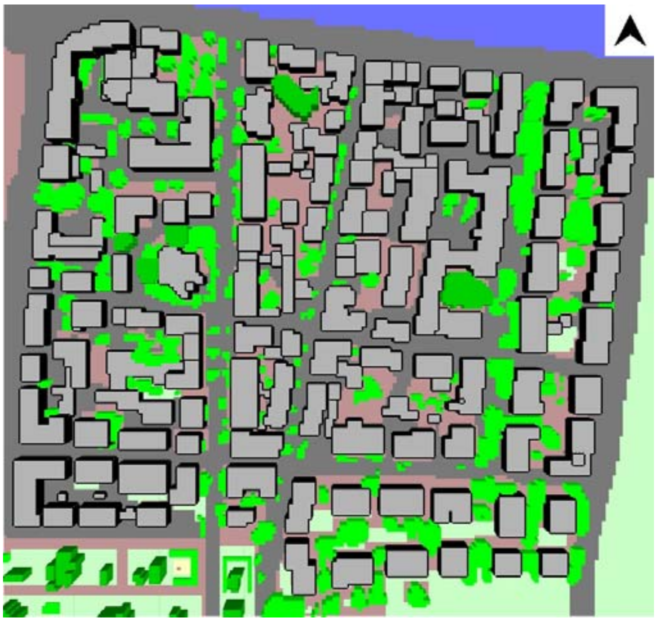

Figure 1: Model area

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4. Scenarios

Two simulations with the model area were run for this study. One with a temperature profile of a normal summer day with up to 30°C and one with temperatures of up to 35°C and very dry and warm soils, representing a day like at the end of a longer lasting heat wave. The boundary conditions for this scenario were derived from data of the extreme heat wave in central Europe in the summer of 2003. The diurnal profiles for air temperature are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. For both simulations the 21st of June was selected as simulation day, due to its maximum solar radiation on the northern hemisphere. For both cases westerly winds with 2m/s in 10m above ground level were assumed. The relative humidity of the air at the start of the simulation was set to 60% for first case and to 25% for the worst case scenario.

5. Results

As can be seen in Figure 4, the difference in air temperature between the two scenarios is, over most parts of the model area, larger than the difference in air temperature at the inflow boundaries for that time of day. The biggest increase in air temperature occurs in the parts with natural soils. While moist natural soils lead to a cooling of air temperature, very dry natural soils can reach nearly the same temperature as asphalt or concrete. Furthermore dry natural soils have a higher albedo than wet ones (Idso, 1974) so that the mean radiant temperature over these areas also increases significantly.

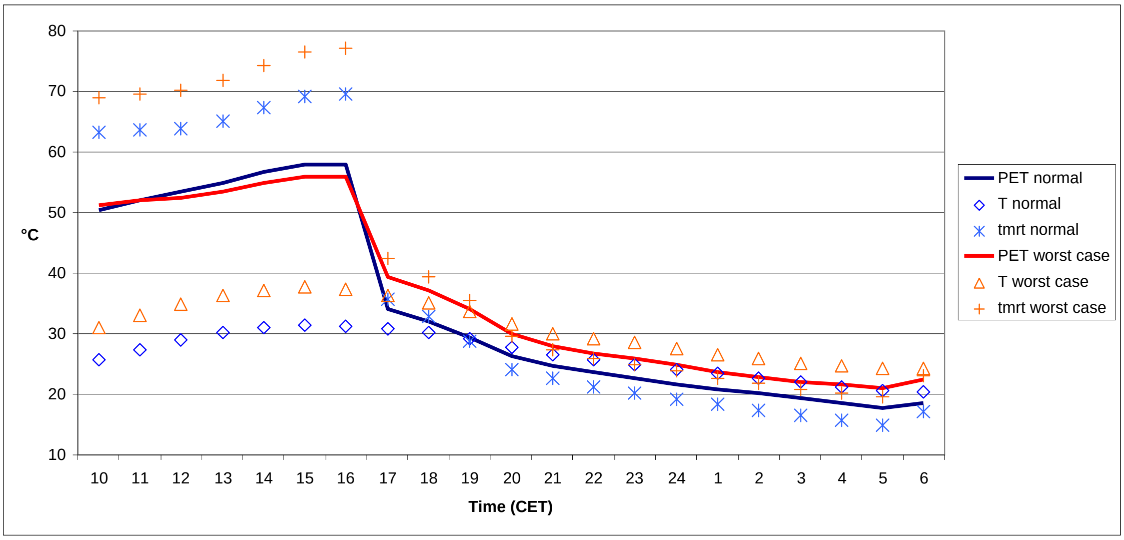

Figure 2: PET, air temperature and mean radiant temperature at point where PET of worst case scenario is smaller than for typical summer day.

In order to judge the effects of the micro climate on the human thermal comfort, it is necessary to look at the energy balance of the human body, which is influenced by the atmospheric parameters temperature, radiation, wind speed and humidity. In this study the human thermal comfort index PET (physiological equivalent temperature) (Höppe, 1999) is used. Despite the air temperature and the mean radiant temperature being significantly higher in the worst case scenario and the wind speed being the same in both cases, the PET in the worst case scenario is in some areas lower (see Figure 5). As can be seen in **Figure 2: PET, air temperature and mean radiant temperature at point where PET of worst case scenario is smaller than for typical summer day.**Figure 2

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and Figure 3, this can be explained by the different diurnal profiles of air humidity at these points. The lower water vapour pressure in the worst case scenario compensates the higher temperatures.

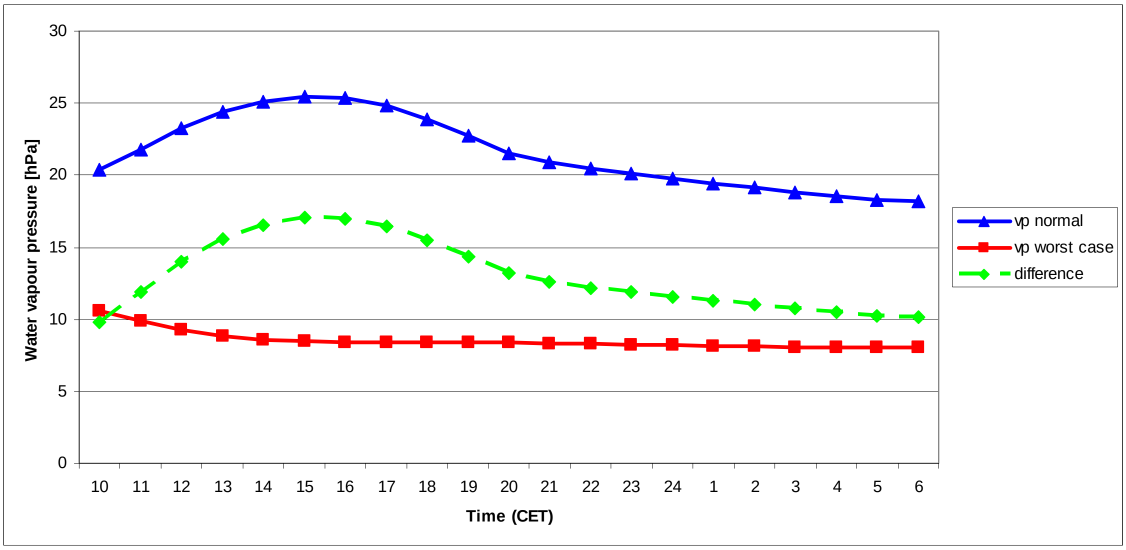

Figure 3: water vapour pressure at position where PET of worst case scenario is smaller than for typical summer day.

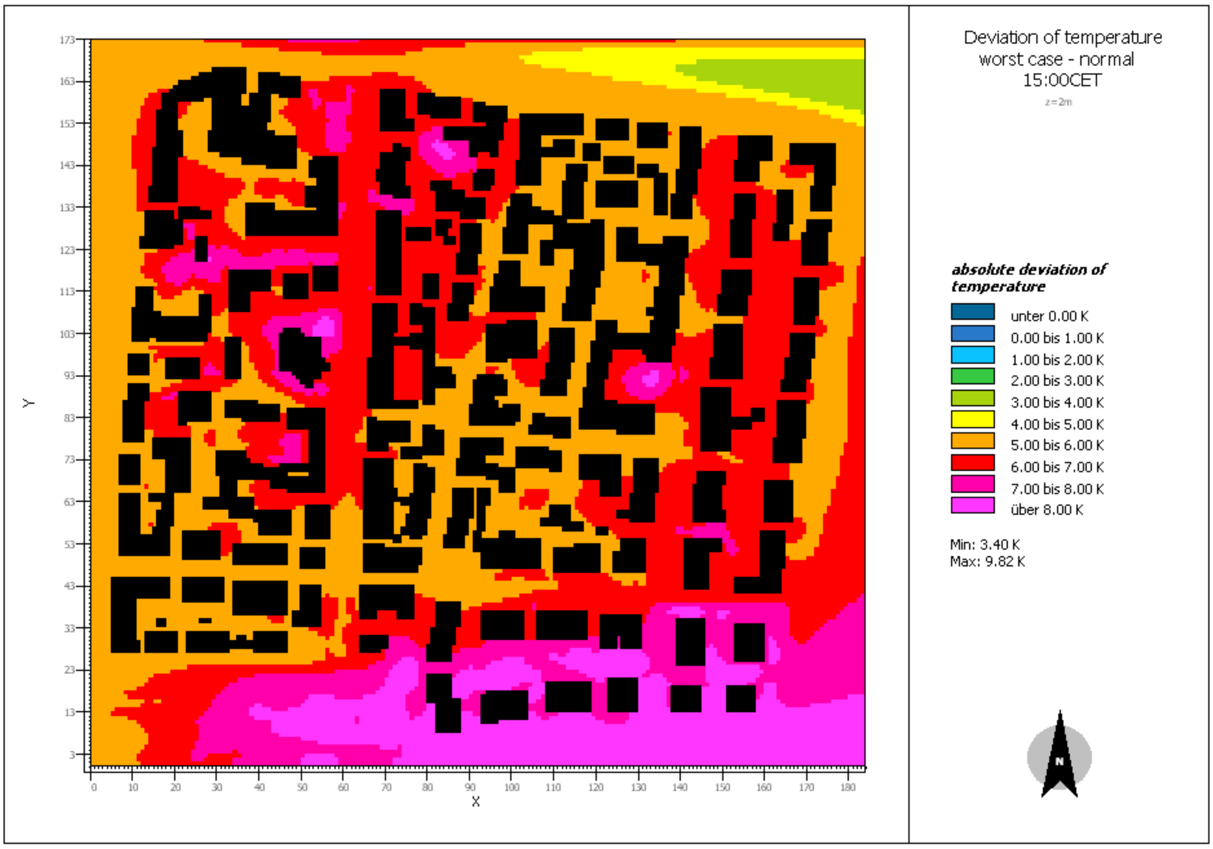

Figure 4: Comparison of air temperature (2m above ground) between the two scenarios (worst case - normal)

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Figure 5: Comparison of PET (2m above ground) between the two scenarios (worst case - normal)

6. Conclusion

The micro climate simulation ENVI-met can be used to estimate the effect of changing climate conditions on the human thermal comfort within cities. As this study shows, green spaces, which are elements of urban planning that are normally considered to help improving the human thermal comfort by reducing air temperature and reflected radiation, can develop to the contrary if they are not irrigated regularly during heat waves. The simulations also show that, according to the PET index, the human thermal comfort will not automatically be deteriorated at every point at every time of the day. Under these summerly conditions the decrease in water vapour pressure can counteract the higher air temperature and mean radiant temperature. Regarding the whole model area during the whole day, the thermal stress is going to increase significantly. Therefore it is necessary to find ways in urban planning to mitigate the negative effects of global warming in central European cities. Within the joint research project KLIMES, ENVI-met is being used for these purposes.

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References

Bruse, M., H. Fleer, 1998: Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model. Environ. Modell. Softw. 13, 373-384.

De Maerschalck, B., S. Janssen, J. Vankerkom, C. Mensink, A. van dem Burg, P. Fortuin, 2008: CFD Simulations of the impact of a line of vegetation along a motorway on local air quailty. 12th conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, http://www.harmo.org/Conferences/Proceedings/_Cavtat/publishedSections/O_S7-06.pdf

Grimmond, C.S.B., 2006: Progress in measuring and observing the urban atmosphere. Theor. Appl. Climatol. 84, 3-22.

Höppe, P., 1999: The physiological equivalent temperature – a universal index for the biometeorological assessment of the thmeral environment. Int. J. Biometeorol. 43, 71-75.

Idso, S., R. Jackson, R. Reginato, B. Kimball, F. Nakayama, 1974: The dependence of bare soil albedo on soil water content, Journal of Applied Meteorology 14, 109-113

Jacob, D., H. Göttel, S. Kotlarski, P. Lorenz, K. Sieck, 2008: Klimaauswirkungen und Anpassung in Deutschland – Phase 1: Erstellung regionaler Klimaszenarien für Deutschland, Climate Change 11/08, http://www.umweltdaten.de/publikationen/fpdf-l/3513.pdf

Meehl, G.A., C. Tebaldi, 2004: More intense, more frequent, and longer lasting heat waves in the 21st century. Science 305, 994-997.

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