This project is implemented through the CENTRAL EUROPE Programme co-financed by the ERDF

# UHI

## *"Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Islands phenomenon"*

## (3CE292P3)

## WP3 – Framework Analysis

# Action 3.2 FORECASTING MODEL

Karlsruhe Institute of Technology

KIT-Campus Alpin

IMK-IFU: Atmospheric Environmental Research

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# Activity 3.2.1 Forecasting Model

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*In collaboration with*

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## Content

# 1.Introduction

Since 2007 more than 50 % of the human population lives in urban areas. More than 70 % of this urban population lives in less developed countries (Molina et al. 2008). It is expected that more than 16 % of all cities will be megacities by 2015 (Fernando et al. 2001). In 2005 9.3 % of all people lived in megacities (UN 2006). The transformation of rural areas into urban areas is one of the most severe facette of anthropogenic land use change. Presently, 1.2 % of land surfaces are regarded as urban areas (Shephard 2005). The population density in urban areas is growing and more high-rise buildings are constructed. According to Yang et al. (2010), nearly 44% of the ground area used for residential purposes in the inner city of Shanghai in 2003 was due to high rise buildings.

Average temperatures in urban areas and especially in megacities are higher than in surrounding rural areas. These islands of higher temperatures are called “urban heat islands” (UHI). These higher temperatures lead to enhanced direct heat stress for the inhabitants. Additionally, indirect effects may occur such as worse air quality, limited water resources and energy supply problems. It is advisable to limit the temperature increase in order to avoid too high risks for the quality of life and health of the inhabitants. Mitigation and adaptation measures have to be designed to minimise the risks for the population of urban areas.

The project partners being involved in this action try to show possibilities to simulate the effect of the Urban Heat Island and analyze its characteristic features for their city of interest. They try to set up models with different backgrounds also to account for simulation of mitigation scenarios counteracting this urban climate phenomenon, to work out plans about sustainable strategies for future urban planning together with the local stakeholders. The operators of these models contributing to this report are manifold. On the one hand side there are meteorological services like the HMS (Hungarian Meteorological Service) and research institutes like the KIT (Karlsruhe Institute of Technology. On the other side there are Universities like Prague and Freiburg or territorial alliances like ARPA Emilia Romagna. In the following, the models used by the project partners trying to forecast the UHI are listed.

## 2. Collection of the models

Collection of models for investigating the extend of Urban Heat Islands and the impact of climate change for Central European urban regions in the cope of EU Project (3CE292P3): *UHI - Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Island phenomenon.*

EnviMet( http://www.envi-met.com/)

- Commonly agreed to serve as primary model for simulating urban climatology and mitigation scenarios
- three-dimensional microclimate model designed to simulate the surface-plant-air interactions in urban environment
- typical resolution of 0.5 to 10 m in space and 10 sec in time.
- ENVI-met is a **Freeware program** based on different scientific research projects
- ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermo- dynamics. The model includes the simulation of:
    - Flow around and between buildings
    - Exchange processes of heat and vapour at the ground surface and at walls
    - Turbulence
    - Exchange at vegetation and vegetation parameters
    - Bioclimatology
    - Particle dispersion and pollutant chemistry
- Applied by TU Vienna, University of Friburg and others

WRF (Weather Research and Forecasting Model)

- Developed by the National Center of Atmospheric Research (NCAR)
- Mesoscale, numerical weather prediction model, which also can be used for climate modeling
- Nested to global circulation model ECHAM5/MPI-OM http://www.mpimet.mpg.de/en/science/models/echam.html
- Open source, code downloadable from the web
- http://www.mmm.ucar.edu/wrf/users/
- http://www.wrf-model.org/index.php
- Applied by KIT, Germany

Statistical downscaling approach

- Using STREAM 1 simulations from ESEMBLES-Project (http://www.ensembles-eu.org/)
- Methodology and forcing that were definded by CMIP3 simulations contributing to IPCC AR4; CMIP3 (Coupled model Intercomparison Project) http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php
- Applied by ARPA-Emilia Romagna, Italy

Micro-Climatic Model RayMan to assess climate change on city scale

- Boundary conditions from ENSEMBLE model RT2B (http://ensembles-eu.metoffice.com) and REMO regional climate model (http://www.remo-rcm.de)
- Calculation of the Physiological Equvalent Temperature (PET)
- RayMan: calculation of short- and long-wave radiation fluxes affecting the human bodyand takes complex urban structures into account
- calculated mean radiant temperature, required for the human energy balance
- meteorolgical and thermo-physiological data as input
- open source: http://www.mif.uni-freiburg.de/rayman/intro.htm
- Applied by University of Freiburg

SURFEX combined with TEB (Town Energy Model)

- SURFEX (Surface Externalisée) is the surface modelling platform developed by Meteo-France
- computes averaged fluxes for momentum, sensible and latent heat for each surface grid box → boundary condition for meteorological model
- input land cover information from ECOCLIMAP database
- TEB: computes energy balance considering canyon concept
- ALADIN-Climate RCM as atmospheric forcing
- http://www.cnrm-game.fr/spip.php?article145&lang=en
- Applied by Hungarian Meteorological Service

Regional Climate Model RegCM (http://users.ictp.it/RegCNET/regcm.pdf)

- Boundary conditions from GCM CNRM-CM5 (http//www.enes.org/models/earthsystem-models/cnrm-cerfacs/cnrm-cm5)
- Community Land Surface Model v3.5 (CLM3.5) as an optional land surface parameterization
- Urban surface treated by coupling with Single Layer Urban Canopy Model linked to SUBBATS surface scheme
- Applied by Charles University, Prague

## 3. Using the numerical weather prediction model WRF to simulate the Urban Heat Island of Stuttgart and forecast the effect of urban planning scenarios on UHI-formation (contribution from KIT)

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Specific urban planning strategies like green roofs or facades and highly reflective materials are able to reduce the negative effects of the UHI, for example by reducing peak summertime temperatures (Taha 1997) or decreasing energy consumption through air conditioning by a considerable amount (Solecki 2005). Comparable results can be found in a vast amount of publications all over the world and the number of papers on different subjects in urban meteorology as well as studies of the UHI in different climate regions is increasing. For more information see the 'Knowledge Report' (Emeis 2013), available at http://www.eu-uhi.eu/.

Angevine et al. (2003) stated that urban–rural contrasts and the urban heat island have been extensively studied, but the community's understanding remains qualitative and anecdotal. General, quantitative understanding awaits well-designed future studies. This statement is probably still true today, although much work has been done since then. Such a quantitative understanding is a necessary requirement for the design of adaptation and mitigation strategies for the UHI.

Conducting case studies and scenario simulations is of great importance in quantifying the effect of urban planning scenarios on the development of the Urban Heat Island as well as urban climate related issues like heat stress and worsening air quality.

In the course of the project UHI - Development and application of mitigation and adaptation strategies and measures for counteracting the global UHI phenomenon" (3CE292P3) – CENTRAL Europe. (2011-2014), these kinds of scenarios are conducted for the urban area of Stuttgart. Due to its geographical location in a valley, the weak mountain – valley circulation leads to increasing potential for natural heat trapping in the urban region. Modeling work of the environmental agency of Stuttgart shows, that the area with more than 30 days/year heat stress is anticipated to increase from 6% (1971-2000) up to 57% (2071-2100). This reflects the calculations of the Intergovernmental Panel on Climate Change (IPCC) on global climate change.

The Karlsruhe Institute of Technology (KIT) conducts simulations using the numerical mesoscale Weather Research and Forecasting Model WRF (Skamarock 2005) on regional scale, coupled to urban parameterization schemes (Kusaka 2001, Martilli 2002). The results reflect the effects of certain urban planning strategies on near surface air temperature and on UHI intensity.

'Is there an Urban Heat Island for my City?' – could be the first question and the basis for further modelling procedures. Coupling the regional model WRF to specific urban canopy models, which represent 3-dimensional structures of urban surfaces and their effect on atmospheric circulations, makes it possible to 'forecast' the UHI for a specific period of time and location.

The term 'forecast' is not really true here, because we are looking at a period in the past, compare modelling results with observation data and simulate scenarios for changing boundary conditions like different urban planning strategies. To account for the future aspects, we have chosen a period with extreme heat events all over Europe, so to say the European Heat Wave 2003. According to IPCC, these extreme events will occur more often in the future.

Using a multi-layer urban canopy model for the area of Stuttgart, the Urban Heat Island for that region can be simulated, like depicted in Figure 1. The difference between the averaged urban and the mean rural temperature can be projected for August 13th 2003 20:00. It is clearly visible that the impervious surface within the city border show a distinct warming compared to the surrounding. Because of radiative and geometrical features of the urban canopy, the absorbed heat during the day is still visible, whereas the rural surrounding already started to cool down.

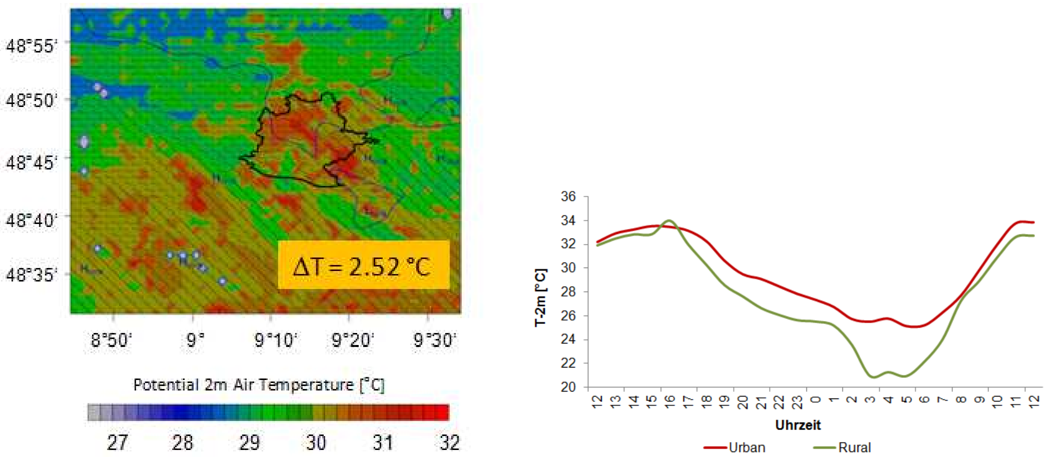


**Fig. 1** Modelled potential 2m temperature for August 13 2003 20:00 using a multi-layer urban canopy model coupled to WRF showing a temperature difference between urban and rural of 2.52 °C (left); typical temperature development in the course of a day (August 13 2003) for an urban (red) and a rural (green) location (right)

Based on this approach, 4 case studies were conducted representing different mitigation measures.

1. Increase of the reflectivity of roof and wall surfaces in the urban area up to 70% ('Albedo)'
2. Decreasing the building density by 20% by increasing the Sky View Factor ('Density')
3. Replacing urban surface by natural vegetation in the city center – 25 km² ('Central Park')
4. Replacement of single urban areas scattered around the city area ('Many Parks')

The difference in 2m Temperature between Scenario- and Base Case ('Reality') run reflects the efficiency of the mitigation procedure. To refer to an extreme case scenario, a period during the European Heat Wave 2003 (August 11-18 2003) was chosen, where summertime temperatures exceeded the annual average.

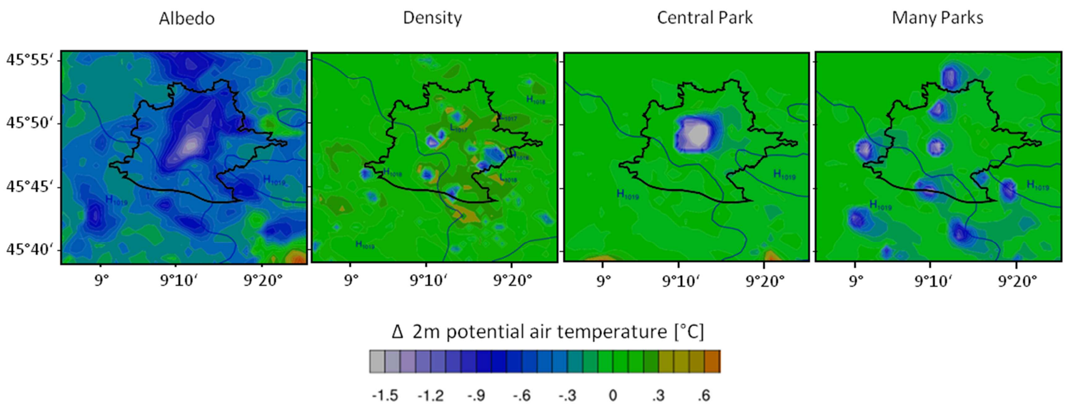

Fig.2: Difference in WRF 2m potential temperature field between scenario run and 'Real case'. According to chosen mitigation strategy up to 2 DegC decrease (bright colors). Snap-shot for Aug 13th 2003 – 18 UTC

Tab.1: Urban heat island intensity expressed as difference between areal averaged 2m air temperature of urban area and of rural surrounding (based on WRF results and GIS analysis); again for Aug 13th 2003 18 UTC

| **Scenario** | **Albedo** | **Density** | **Many Parks** | **Big Park** | **Real Case** |
|---|---|---|---|---|---|
| ϴ mean urban [°C] | 31.5 | 32.4 | 32.5 | 32.3 | 33.1 |
| ϴ max [°C] | 31.9 | 33 | 33.5 | 33.3 | 34.3 |
| Std dev. [°C] | 0.32 | 0.48 | 0.5 | 0.43 | 0.6 |
| **UHI;** delta ϴ | **0.84** | **1.32** | **1.47** | **1.19** | **2.52** |

The modeling results reveal the decrease of temperature for August 13th 2003 20:00 of about up to 2 °C depending on the particular scenario. The table indicates that changed reflectivity has the greatest potential in decreasing urban heat island intensity, expressed in urban-rural temperature difference.

The modelling work shows, how to use a meso-scale model to predict effects of urban planning measures on the formation of the Urban Heat Island in a specific city. On the basis of these results you can study the regional effects and the urban-rural interactions. As well can the results be used as input for higher resolution street scale models, which often suffer from a lack of representation of full atmospheric processes. This approach could close the gap between scales.

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