IMPLEMENTATION AND TESTING OF THE BUILDING ENERGY PARAMETERIZATION MODEL (BEP) IN THE CLIMATE LOCAL MODEL (CLM)

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1 INTRODUCTION

In this study the Building Energy Parameterization Scheme (BEP) (Martilli et al. 2002) was implemented in the regional Climate Local Model (CLM) which is the climate version of the German Weather Service numerical weather forecast model COSMO (COnsortium for Small-scale MOdeling) formerly known as "Local Model" (Steppeler et al. 2003).

Currently in the standard CLM cities are parameterized by means of a bulk-transfer scheme as natural land surfaces but with an increased surface roughness length (1 m), reduced vegetation cover (20%) and leaf area index (1 $m^2 m^{-2}$) in order to account for the increased vertical momentum flux and reduced evapotranspiration, respectively. The advantage of this approach is the relatively low demand on input parameters and the simplicity of its coupling with the atmospheric model (Masson 2006). However, this simple parameterization is not able to fully represent the characteristics of urban areas that influence the atmosphere (Best 2005), such as a significant increase in heat storage and small values of the nocturnal sensible heat flux. Therefore characteristics of the urban planetary boundary layer (PBL) such as the urban heat island (UHI) as well as a near-neutral nocturnal vertical temperature profile and its downwind advection cannot be simulated sufficiently well (Best 2005). Also, bulk-transfer schemes do not resolve the vertical effects of buildings on the urban canopy air and do not differentiate between several urban land use / land cover (LULC) classes (Liu et al. 2006). This leads to limitations for some model application usually related to air quality, air temperature variability within urban areas and human comfort (Masson 2006).

In contrast, the multi-layer scheme BEP recognizes aspects of the three-dimensional nature of urban surfaces and the fact that buildings vertically distribute sources and sinks of heat, moisture, and momentum through the urban canopy layer. BEP uses the geometry of a generic street canyon that is characterized by road width, building width and building height distribution. Exchanges with the atmosphere occur at multiple vertical levels within the urban canopy by directly modifying the prognostic differential equations of the regional atmospheric model to include additional terms for the urban drag force, heating, turbulent kinetic energy production and dissipation. At each level within the urban canopy the urban surface energy balance is solved for roofs and walls and, at the bottom of the model, for roads. The coupling of BEP with a regional atmospheric model requires the preprocessing of appropriate input data such as building height distribution, roof and road width, fraction of natural and man-made surfaces in a model grid cell; the averaging of surface energy and momentum fluxes from natural and urban fractions of a model grid cell; and the integration of urban tendency terms in the prognostic equations of the atmospheric model.

In this study the BEP scheme as implemented in CLM was enhanced by roof related radiation processes (section 2). BEP input parameters (building height distribution, road width, building width) were derived from building data in the City Geography Markup Language (CityGML format). The procedure is presented in section 3. The coupled CLM BEP model was tested against data from surface stations (section 4) for typical summer conditions for the city of Berlin (Germany). Two model versions are applied: (1) using a LULC class approach, i. e. model parameters are assigned to each urban LULC and (2) model grid cell dependent values for building and vegetation characteristics.

2 BEP Modifications

BEP's radiation scheme calculates the short and longwave radiation budget for each urban surface element (walls, roofs, road). Inside the street canyon, the radiation from the sky is distributed using view factors. If a wall element is present at a particular height level, the radiation from the sky is received by that element. However, if it is not present, this energy is not accounted for (see fig. 1a: red arrows indicate unaccounted energy). In addition, the area with no walls acts as a diffuse radiation source with the same flux density as from the top sky (see fig. 1b). Each surface element receives radiation from both sources leading, in general, to an overestimation of the total received energy. Therefore, the total calculated amount of radiative energy received by the canyon is larger than the incoming radiation from the mesoscale model. To fix that problem, a factor c is introduced which scales the radiative flux from the side of the canyon to ensure energy conservation. The factor c only depends on morphology parameters, thus it is a runtime constant.

Furthermore, we modified BEP to include the radiative

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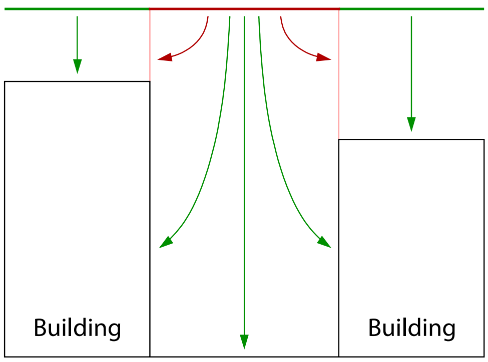
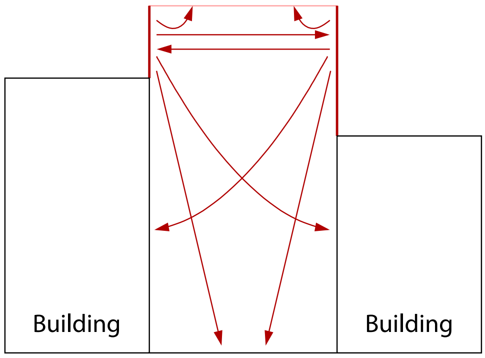


(a) Radiation from the area over the roofs is completely received by the roofs. Radiation from the area over road surfaces is distributed inside the canyon. The energy that leaves the canyon through the light red areas is not accounted for.



(b) The open canyon sides also act as a radiation source. This radiation is distributed inside canyon. The radiation that leaves through the canyon sides and the top is not accounted for.

Figure 1: Distribution of diffuse radiation from the sky on the urban surfaces in BEP (Martilli et al. 2002). The combined incoming radiating from (a) and (b) is larger than the sky radiation. The introduction of a correction factor *c* in section 2 solves that problem.

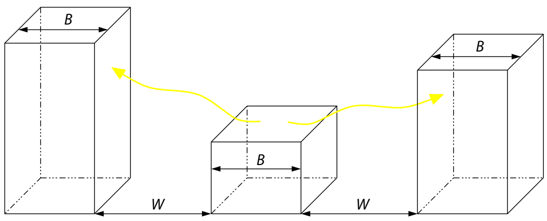


Figure 2: Canyon model extended in order to include the radiative interaction of roofs with the sky and other urban surface elements in BEP

interaction of roofs with the sky and other urban surface elements. To achieve this, we combined two canyons in the radiation scheme (fig. 2) resulting in additional terms in the exchange equations. Details will be presented in a manuscript (in preparation).

3 INPUT PARAMETERS

Highly detailed 3d data in CityGML format are available for Berlin. CityGML (Gröger et al. 2008) is an approved Open Geospatial Consortium (OGC) standard, which allows to employ several levels of detail. The Berlin data are in "level of detail 2" format. On this level, buildings are modelled with polygons allowing differentiated roof structures and a semantical distinction between ground, wall and roof polygons.

The processing tool is written in java using the library citygml4j[1]; its input parameters are the numerical grid parameters and the street directions which will be considered in the mesoscale model run.

The effective urban input parameters are derived for every grid cell. The algorithm for that is described in the following. In BEP, the urban part of a cell is characterized by a 100 % impervious surface. Therefore, we use the average coverage of impervious surfaces in a cell to estimate the urban fraction f_{urb}. The summed up ground surfaces of the buildings in a cell define the fraction of buildings f_{build}. The remaining area in the urban part is the street surface with its fraction f_{str}:

$$f_{\text{urb}} = f_{\text{build}} + f_{\text{str}}\,. \tag{1}$$

The building height probability γ_i is given by the ground area weighted distribution of building heights. Here, the heights of the several roof levels of a building are averaged (weighted by the roof surface size of the level) to define *the* height of a building. The normal to a wall surface is projected on the horizontal plane to define the street direction of that surface and the canyon width W is calculated from the average distance to other wall surfaces.

All other parameters follow directly from the requirement that the total roof and ground surfaces of the simplified model equal that of the input data (Martilli 2009). Since both, buildings and streets, are supposed to have the same length D in the canyon, the ratio of their respective widths is given by

$$\frac{B}{W} = \frac{f_{\text{build}}}{f_{\text{str}}}\,, \tag{2}$$

resulting in

$$B = \frac{f_{\text{build}}}{f_{\text{urb}} - f_{\text{build}}} W \tag{3}$$

for the building width B. Figure 3 shows some results of that algorithm at a resolution of approximately 1 km for Berlin.

Figure 4a shows the urban fraction as obtained with the procedure described above. The evaluation of CORINE LULC data for Berlin with the classes "Continuous urban fabric", "Discontinuous urban fabric" and "Industrial or commercial units" results in the urban fraction in fig. 4b. The different values in fig. 4b compared to 4a are mainly caused by the definition of the industrial class which is based on usage and not on the building morphology. The CORINE data also cover smaller cities in Berlin's vicinity and therefore cover a larger area than the city GML data.

4 NUMERICAL SIMULATIONS

The simulation for August 2003 using COSMO-CLM employed a three step downscaling approach using global reanalysis ERA-Interim data by ECMWF. The grid covering central, west and parts of south and south east Europa had a grid spacing of approx. 7 km. The next smaller simulation

[1]`http://opportunity.bv.tu-berlin.de/software/projects/show/citygml4j`

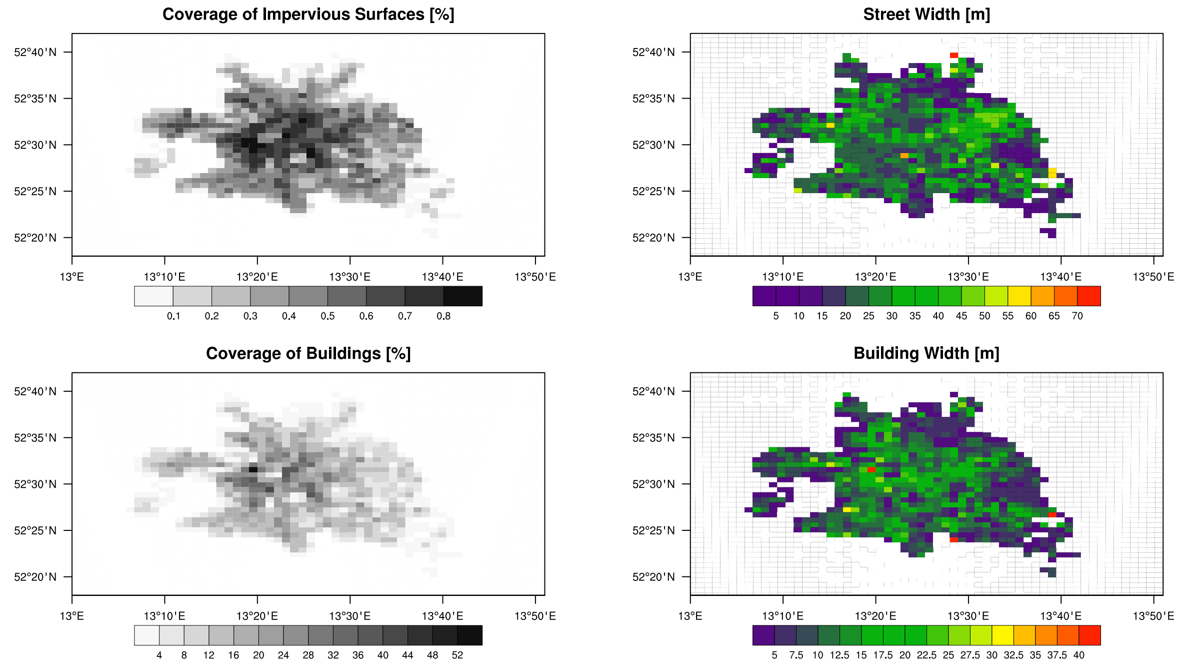
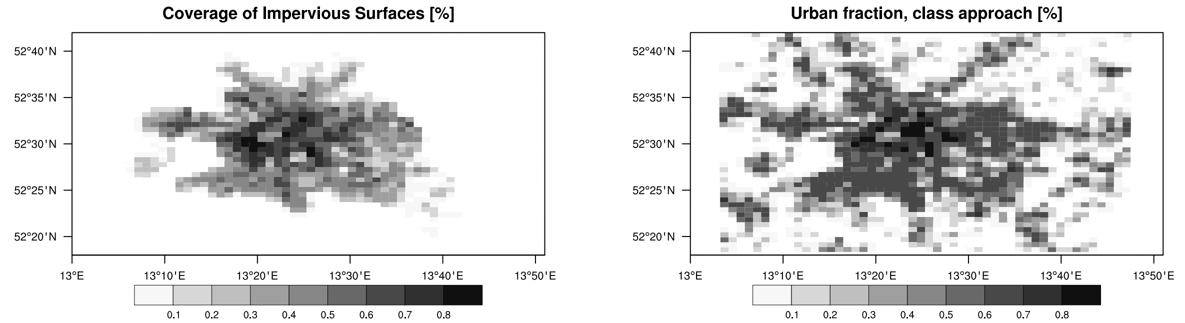


Figure 3: Urban input parameters for Berlin at a resolution of 1 km. They are based on the fraction of impervious surface in a grid cell and a 3d building data set of Berlin in the CityGML format.



(a) Estimation based on the impervious surface fraction. Data is only available for Berlin.

(b) Estimation based on the CORINE Land Use dataset. This includes data for the surrounding cities of Berlin.

Figure 4: The urban fraction in Berlin based on two different approaches

for north east Germany is based on a 2.8 km grid and simulation for a 200 km×200 km including Berlin used a 1 km grid spacing. All simulations used a Mellor-Yamada parametrization for PBL processes and the two finer ones used BEP for Berlin.

Figure 5 shows a comparison of model output at the highest resolution with data from an urban and a rural station. The model output shows good results for the rural station (fig. 5b) with a tendency to overestimate nighttime temperatures for some nights. Consequently, for those nights, temperatures at the urban station (fig. 5a) using the roughness approach agree well with the station data whereas simulations with BEP overestimate temperatures. However, the roughness approach exhibits a too small UHI e. g. during the night of August, 5th (fig. 6b) of about 1 K. Using BEP and the input data calculated with the algorithm described above, the UHI is approx. 4 K, which is in good agreement with the station data. In addition, fig. 6 also shows the results when using input parameters calculated with the land use class approach. Mainly due to the relatively higher urban fraction, this option features higher temperatures than the approach with detailed input data. This can be also seen in the map in fig. 7.

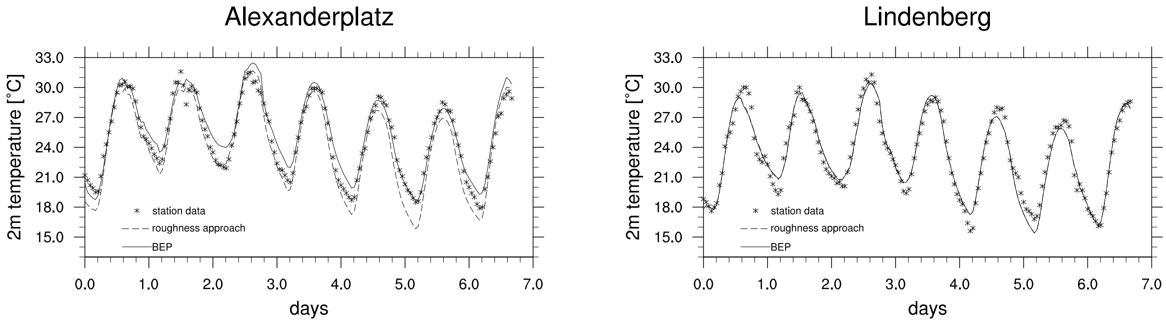
We also analysed the effect of including the roofs in the radiation exchange. Since there are shadows on roofs possible with that option, there is less radiation energy on roofs but more inside the canyon. This results in lower roof but higher road surface temperatures (fig. 8). Furthermore, the radiation trapping effect is increased, i. e. less radiation is emitted into the sky, both shortwave radiation $S_\uparrow$ and longwave radiation $L_\uparrow$. We define an effective albedo α_{eff} by

$$S_\uparrow = \alpha_{\text{eff}} S_\downarrow \qquad (4)$$

and an effective urban radiation temperature T_{eff} by

$$L_\uparrow = (1 - \epsilon_{\text{eff}}) L_\downarrow + \epsilon_{\text{eff}} \sigma T_{\text{eff}}^4 \qquad (5)$$

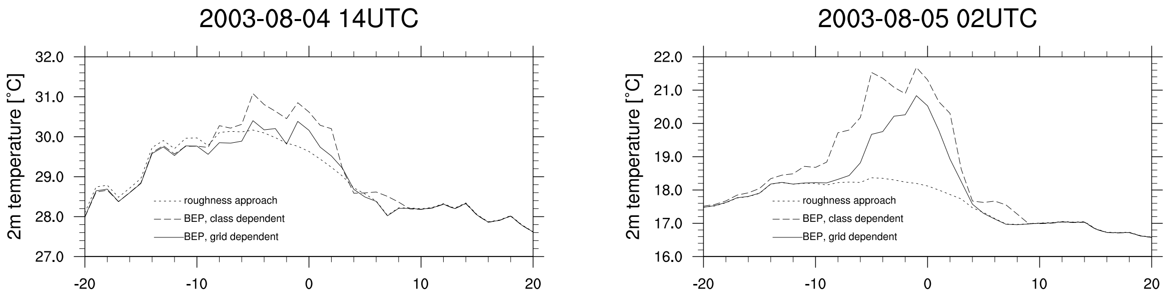
with the incoming shortwave radiation $S_\downarrow$ and longwave radiation $L_\downarrow$. The effective emissivity ϵ_{eff} is defined by the urban surface parameters and is a constant. Thus, with a constant radiative input, both α_{eff} and T_{eff} are lower. This



(a) Station at the centre of Berlin

(b) Station approx. 60 km away from Alexanderplatz, ca. 35 km away from the border of Berlin

Figure 5: Validation of the simulation with 1 km grid resolution with station data; days after 2003-08-01 00UTC



(a)

(b)

Figure 6: Simulated 2 m air temperature along the line in fig. 7. The centre is at the Alexanderplatz station.

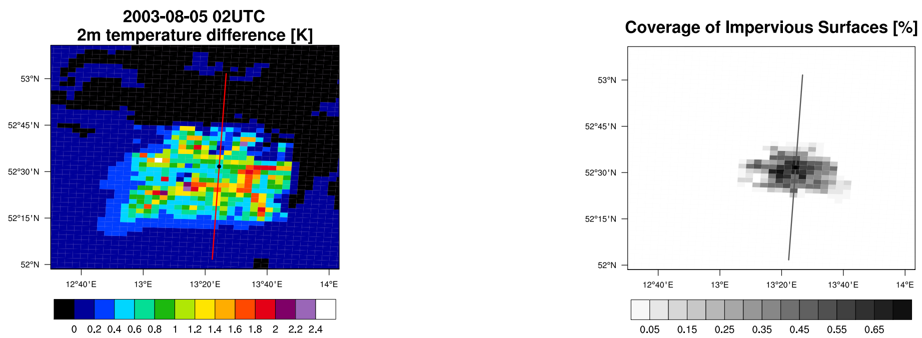


Figure 7: Temperature difference of the simulation with class based urban parameters and with spatially resolved input parameters at a resolution of 2.8 km. The lefthand figure shows the urban fraction in the latter case.

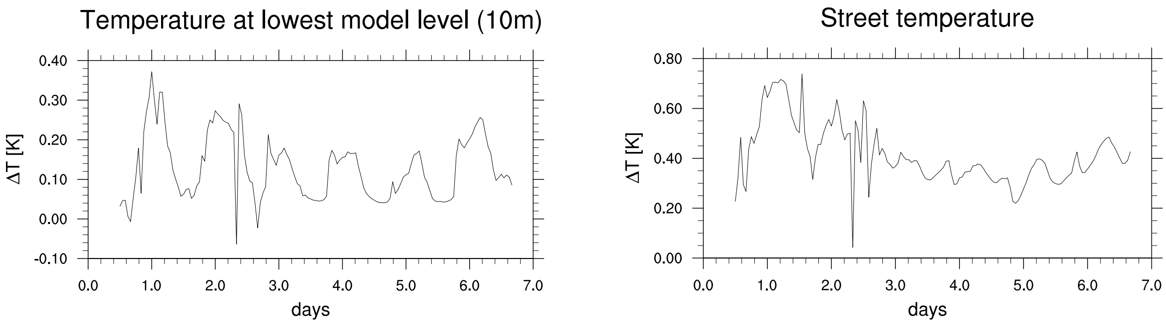


Figure 8: Differences in simulated air temperature at the lowest model layer as well as street temperature between BEP considering roofs in canyon radiation exchange and original BEP; days after 2003-08-01 00UTC.

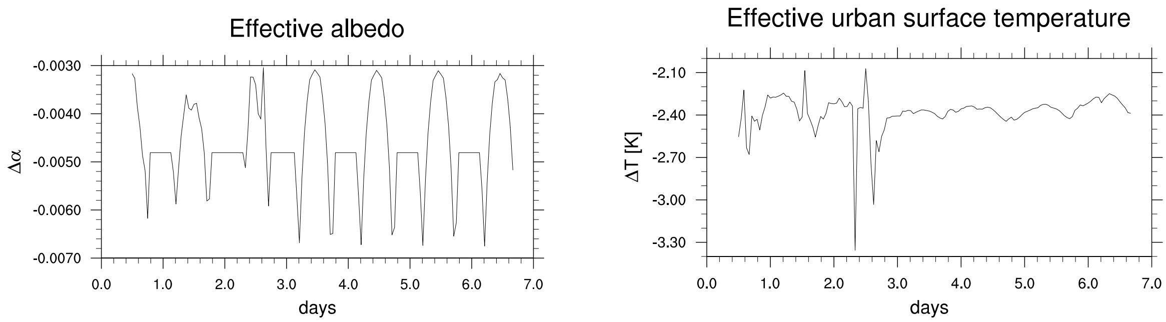


Figure 9: Same as fig. 8 but for effective urban albedo and effective urban surface temperature

is also observed in the model output (fig. 9). Therefore, although the air temperatures inside the canyon increase, the effective radiative temperature decreases. The simulated temperatures were taken from the site of Alexanderplatz station where approx. 70% of buildings have the same height. A larger impact is expected for areas with a greater variety of building heights.

5 ACKNOWLEDGMENT

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