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The ability of the mesoscale climate model COSMO-CLM with the Double Canyon urban canopy scheme to simulate the urban heat island in Berlin

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1. Introduction

The world's population will increase in the next decades especially in urban areas. Additionally, the living conditions are affected largely by the local urban climate. Due to the projected higher frequency of heat waves and the related heat stress, high resolution spatio-temporal distribution of air temperature is an important key for urban planning and development. In order to simulate simulate the urban climate, mesoscale atmospheric models and urban canopy models (UCPs) are coupled. The mesoscale model provides meteorological forcing data for the UCP, which in turn provides urban energy fluxes. The non-hydrostatic regional model of the Consortium for Small-Scale Modelling in Climate Mode (COSMO-CLM) is recently employed for studying the effects of urbanization on the climate parameters. Different urban parameterizations for COSMO-CLM have been developed and applied which can lead to a better simulation of spatial distribution and variance of temperature in urban areas.

Trusilova et al., 2013 extended the surface-layer parameterization with the Town Energy Budget (TEB) parameterization using the “tile approach” for a single urban classification. This implementation (COSMO-CLM+TEB) is used for a 1-yr reanalysis-driven simulation over the area of Berlin with the spatial resolution of 0.025°. The validation results showed that the COSMO-CLM+TEB model is able to represent the magnitude of the urban heat island in Berlin more realistically than the standard model COSMO-CLM. This finding emphasizes the importance of the urban parameterization in the model simulations on fine spatial scales. It is also suggested that on spatial scales below 3 km, models can benefit from resolving multiple urban land use classes to simulate the spatial variability of urban temperatures for large metropolitan areas.

To improve the representation of the water balance in urban land-surface models, Wouters et al., 2015 presented a new impervious water-storage parametrization which assumes a distribution of water reservoirs. This parameterization has been implemented in TERRA-URB, a new urban parametrization for COSMO-CLM’s standard land-surface module TERRA-ML. The water-storage capacity and the maximal wet surface fraction of the urban impervious land cover consisting of streets and buildings are estimated for Toulouse centre by matching the modelled and observed evapotranspiration (ET) rates. The model successfully reproduces the time span and magnitude of increased ET for both urban observations campaigns CAPITOUL and BUBBLE. Their sensitivity study reveals that water-storage parametrization largely affects the performance of modelled ET rates. The simulation employing the new water-storage parametrization is improved compared to existing water-storage parametrizations. Schubert et al., 2012, developed a double-canyon radiation scheme (DCEP) for urban canopy models embedded in COSMO-CLM which is based on the Building Effect Parametrization (BEP). The scheme calculates the incoming and outgoing longwave and shortwave radiation for roof, wall and ground surfaces of an urban street canyon characterized by its street and building width, canyon length, and the building height distribution. This scheme introduces the radiative interaction of two neighboring urban canyons which allow the full inclusion of roofs into the radiation exchange both inside the canyon and with the sky. They treated also direct and diffuse shortwave radiation from the sky independently, which allow calculation of the effective parameters representing the urban diffusion and direct shortwave radiation budget inside the mesoscale model. Sensitivity tests showed that these modifications are important for urban regions with a large variety of building heights. The urban canopy scheme DCEP coupled with COSMO-CLM is evaluated using data from the Basel Urban Boundary Layer Experiment (BUBBLE) for a summer period (Schubert et al., 2014). The simulated radiative and energy fluxes, near-surface air temperatures and wind velocities are compared with the measurements. The results indicate a good online performance of the model system. DCEP is able to simulate typical characteristics of the urban boundary layer, in contrast to the default bulk-transfer scheme of COSMO-CLM. This parameterization coupled with COSMO-CLM has been also evaluated using the data from some weather stations during several Extreme Heat Events (EHEs) in Berlin (Schubert et al., 2013). Five EHEs with duration of ca. 5 days in the period 2000 to 2009 have been considered. A reference simulation is carried out for each EHE with current vegetation cover, roof albedo and urban canopy parameters (UCPs), and is evaluated with temperature observations from some weather stations in Berlin and its surroundings. The results show, that the bulk scheme featured only a small urban heat island of up to 1 K, while COSMO-DCEP could capture UHI in Berlin during mentioned EHEs. The authors analysed the UHI considering a linear dependence on the urban fraction and the height-to-width ratio. At nighttime, this linear model describes the UHI well. As expected, the UHI increases with rising urban fraction and height to-width ratio. At daytime, in contrast, the UHI effect is very weak and the linear model is insufficient in describing the temperature distribution.

The quality of the CCLM performance is different for the simulation periods and of the root-mean-square error of the 2m temperature varies between 1.1 and 2.4K. The authors concluded if CCLM simulates the regional weather reasonably well, the coupled model shows good results for Berlin and vice versa. For some stations the bulk scheme performed better than COSMO-DCEP due to large green areas dominating the station's surroundings. Therefore, these station measurements are not comparable with the simulated grid cell average temperature of urban and natural surfaces, while most of the weather stations in Berlin are located over natural surfaces and represent the previous surfaces and open areas in their immediate vicinity. Due to this reason, we are aiming to evaluate the COSMO-DCEP Model using our measuring campaign that was conducted in year 2012 in Berlin. The points of measurement were over impervious surfaces and therefore represent the urban climate better. Instead of the average diurnal temperature cycle we compare the diurnal cycle of measured temperatures on different days during the campaign to simulated temperatures. The shape and the intensity of the urban heat island will be also evaluated regarding land surface temperature from satellite data.

2. Data and Methods

The measuring campaign of the Freie Universität Berlin has been held in year 2012. 30 mobile devices (TROTEC BC20 Multi Measure, Thermo Hygrometer) have been used to measure the temperature and relative humidity at 2m height with high spatio-temporal resolution and a focus over the center of Berlin. Many students supported the measuring campaign and they measured every 15 minutes along a certain route (15 routes). Figure 1 shows the permanent weather stations of Berlin and the triangles represent the points of measuring campaign during summer 2012. It must be noted that the measuring campaign has been held only on three clear sky single days during the summer 2012 regarding the weather forecast. Clear sky days have been selected, as during several days the weather forecast didn't agree with observation. Three days during summer 2012 have been selected (02.06.12, 18.08.2012 and 01.09.2012) for evaluation of the COSMO-DCEP temperature.

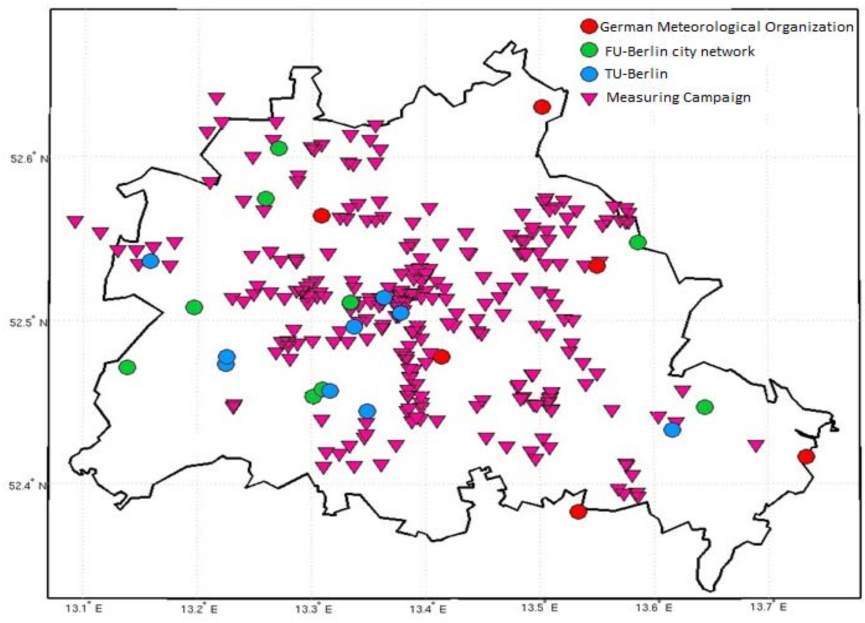

Fig. 1 the permanent weather stations of Berlin (circles) and the points of Freie Universität Berlin measuring campaign (triangles) during summer 2012

The simulations have been conducted using a 4 step one way nesting approach: a) resolutions of approx. 25 km (without DCEP starting 2011-01-01), b) 7 km (without DCEP starting 2011-10-01), c) 2.8 km (without DCEP starting 12 days before the considered day) and d) 1 km (with and without DCEP starting 5 days before the considered day). The initial and 6 hourly boundary conditions are provided by ERAInterim reanalysis data. COSMO-CLM, driven by ERA-interim re-analysis data, is either used with its default bulk formulation (no DCEP) of the urban surfaces or online coupled with the Double Canyon Effect Parameterization (DCEP) urban canopy scheme.

3. Results

Figure 2 shows the mean error (ME) of the COSMO-CLM model simulation for the rural station Lindenberg on the three analysed days of measuring campaign. Figure 3 shows ME for the simulation with and without DCEP (DCEP/no DCEP) averaged over Berlin (Model-OBS). On 02.06 the COSMO-CLM underestimated the temperature values (except for 5 hours); in this case the simulations with DCEP parameterization show better results comparing to no DCEP (Figure 3, left). The model has an improvement up to 1 K especially for the nocturnal temperatures. On 18.08, the COSMO-CLM model did not capture the temperature at rural station Lindenberg and ME shows also high values especially before sunrise. COSMO-DCEP represents also no improvement on this day. It must be noted, that on 18.08 the high pressure "Achim" dominated wetter situations over middle Europe and led to high cloud and calm wind in Berlin during the day and clear sky during the night time. On 01.09 the performance of COSMO-CLM to simulate the 2m temperature over Lindenberg shows a small improvement. We conclude that whenever the COSMO-CLM underestimates the temperatures, the DCEP parameterization improves the model performance for Berlin. In the case of the overestimation of COSMO-CLM (nights of 18.08 and 01.09), DCEP parameterization leads to higher errors. The results show that the temperature overestimation of COSMO-CLM may be due to the uncertainty in the cloud parameterization which has been confirmed through a comparison of model with radar data (not shown).

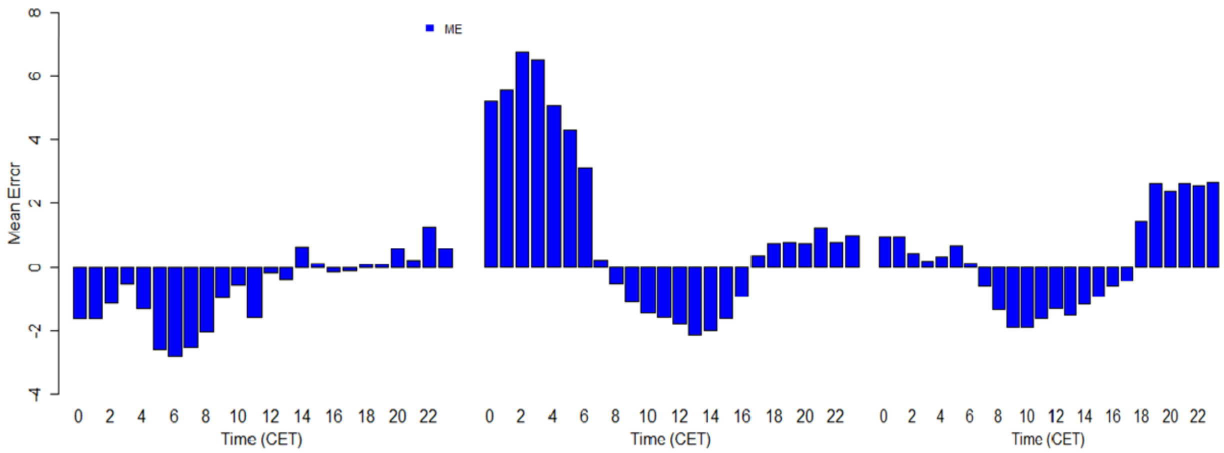

Fig. 2 Mean error of 2m temperature simulated by COSMO-CLM for the station Lindenberg (rural area, without DCEP) on three days of measuring campaigns(02.06, 18.08 and 01.09.2012)

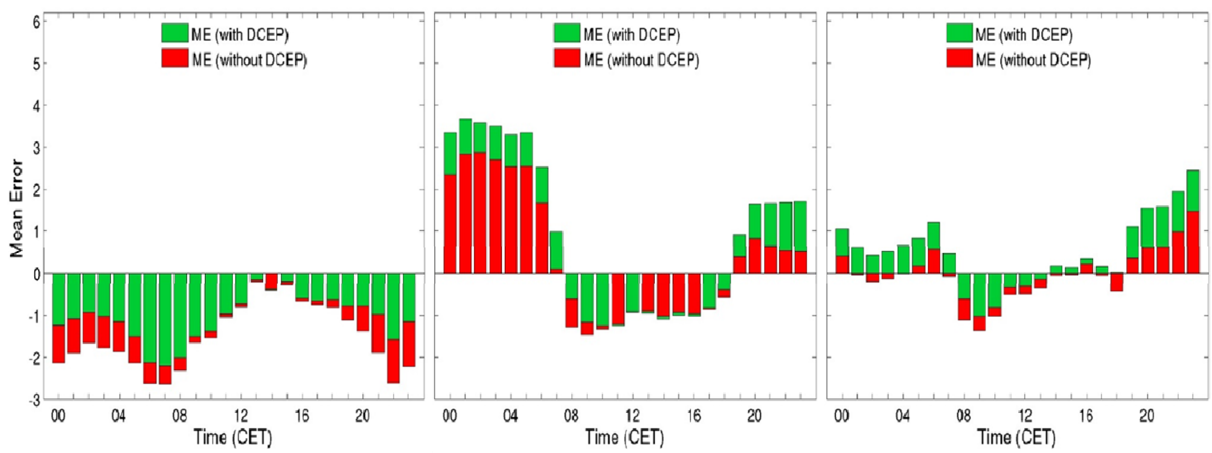

Fig. 3 Mean error of 2m temperature simulated by COSMO-CLM with and without DCEP for whole Berlin (averaged) on three days of measuring campaigns(02.06, 18.08 and 01.09.2012)

The spatial distribution of the 2m temperature in Berlin with and without DCEP is shown in Figures 4 and 5, respectively. During daytime (at 1 pm) the DCEP parameterization leads to cooler temperatures, while the spatial distribution of nocturnal temperature (Fig. 5) shows an Urban Heat Island (UHI) over the center of Berlin. This cannot be observed in the simulation without DCEP. This result can be confirmed through one of our earlier studies (Lange 2009) which studied the ability of COSMO-DE to simulate the spatial distribution of temperature during 2007 over Berlin. Lange pointed out, that in contrast to the model results, Berlin is in average cooler than its surrounding during the day and warmer during the night. In spite of the high resolution of model and consideration of vegetated and impervious land surfaces, the temperature variances especially during day time are much smaller than variance of observation comparing to the nocturnal variances (Figure 6).

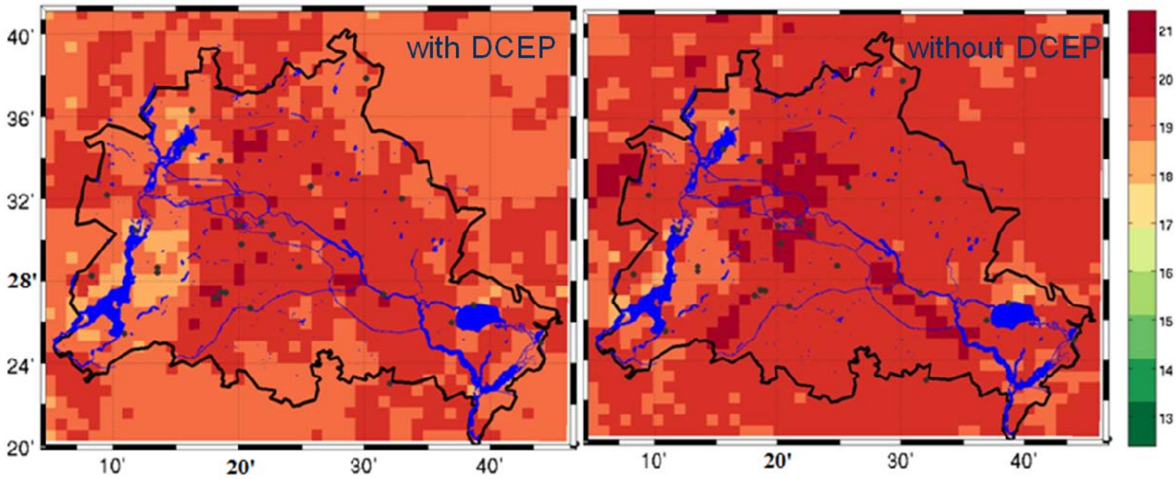

Fig. 4 Mean error of 2m temperature simulated by COSMO-CLM with and without DCEP for whole Berlin (averaged) on three days of measuring campaigns(02.06, 18.08 and 01.09.2012, at 1 pm))

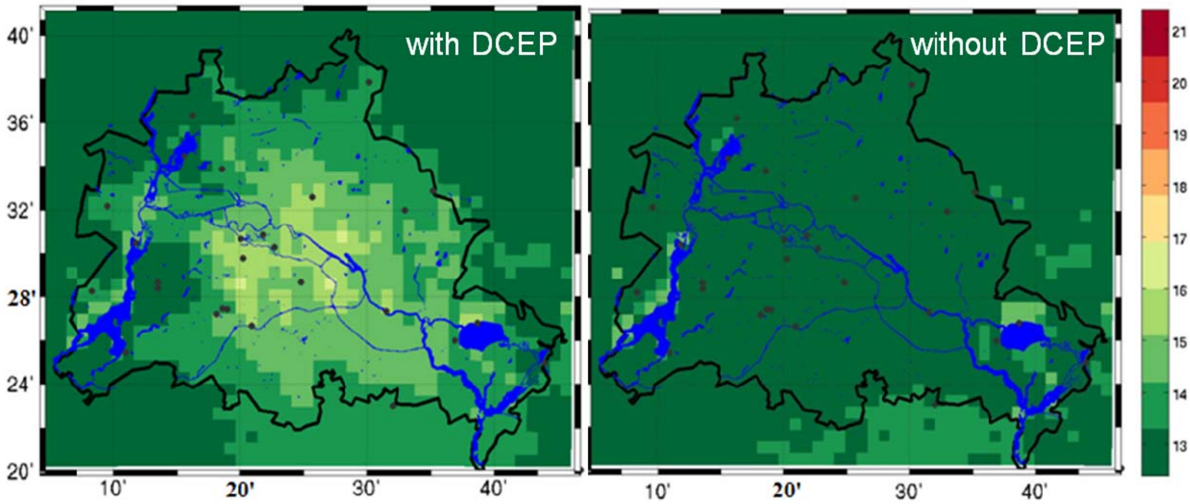

Fig. 5 Mean error of 2m temperature simulated by COSMO-CLM with and without DCEP for whole Berlin (averaged) on three days of measuring campaigns(02.06, 18.08 and 01.09.2012, at 11 pm)

Figure 6 shows the whisker plot of 2m temperature form the observation and the simulation by COSMO-DCEP for 01.09.2012. It is obvious that the model with 1 km resolution cannot capture the temperature variability inside the urban area. Although the averaged simulated temperature over Berlin is in a good agreement with the measurements (Figure 6a), the variance cannot be captured by the model (Figure 6b).

4. Discussion

The results show, that the simulated 2m temperature using the new scheme is consistent with the averaged 2m temperature measurements for Berlin. The urban heat island has been successfully simulated by DCEP scheme, while in the mesoscale model (without DCEP) the city center is warmer than surrounding during the day and cooler during the night. In the simulations without DCEP the urban areas are characterized as natural surfaces with higher roughness length and reduced vegetation. This may lead to warmer center during day time. In the case, that the mesoscale model overestimates the 2m temperature, DCEP scheme shows no improvement and leads to higher errors. These results will the basis for further work which evaluates the model inside the grid cells. As at each grid point, the simulated temperature is a weighted average of temperatures inside a grid cell, a detailed comparison of simulated temperatures of grid cells with different degrees of land surface mixture could better show the model performance. Furthermore, the simulated temperatures, the shape and magnitude of UHI will be evaluated using satellite data (MODIS) which is available at 1 km resolution.

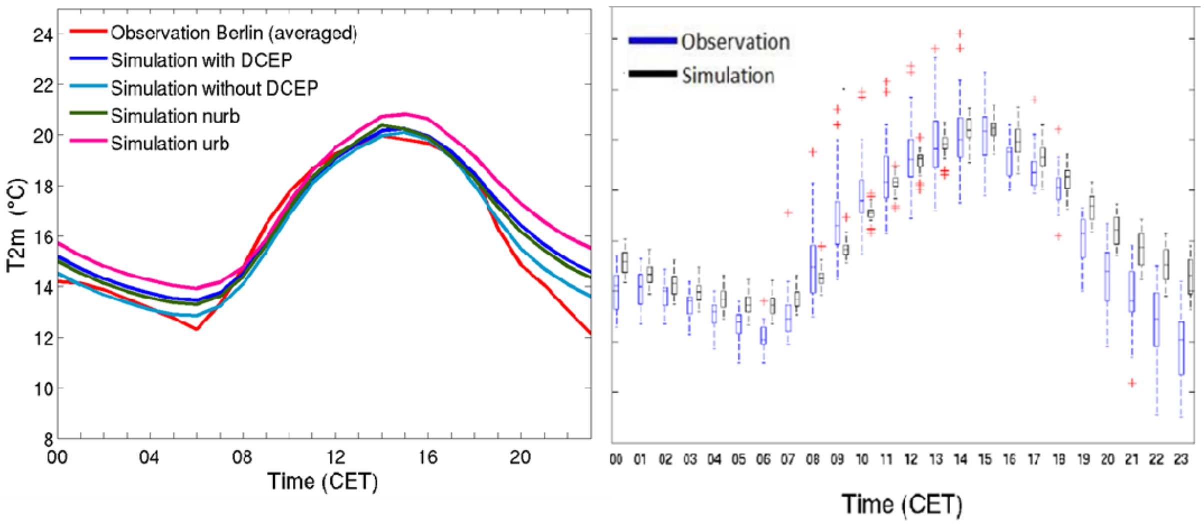

Fig. 6: a: averaged diurnal temperature on 01.09.2012 (dark blue: DCEP, blue: without DCEP, red: observation, green: temperature of vegetated part of the grid cells, pink: temperature of impervious part of grid cells), b: whisker plot of 2m temperature form all measured points in Berlin on 01.09.2012 (blue) and simulated by COSMO-DCEP (black).

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