Implementation, modification and testing of the Building Energy Parameterization Scheme (BEP)

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We implemented the **Building Effect Parameterization scheme** (BEP, Martilli et al. 2002) in the **regional climate and weather model CCLM** to improve model performance for urban areas. Furthermore, we developed a **multi-canyon radiation scheme** based on BEP's radiation scheme that (i) takes into account the **radiative interactions of roofs with other urban canyon surface elements** such as walls and other roofs, and (ii) **closes the radiative energy balance**.
We developed an algorithm to **derive urban input parameters from 3d building data** in the CityGML format. Using this data for the city of Berlin, we compared coupled CCLM BEP model output with data from surface stations.

1. Multilayer Street Canyon Model BEP

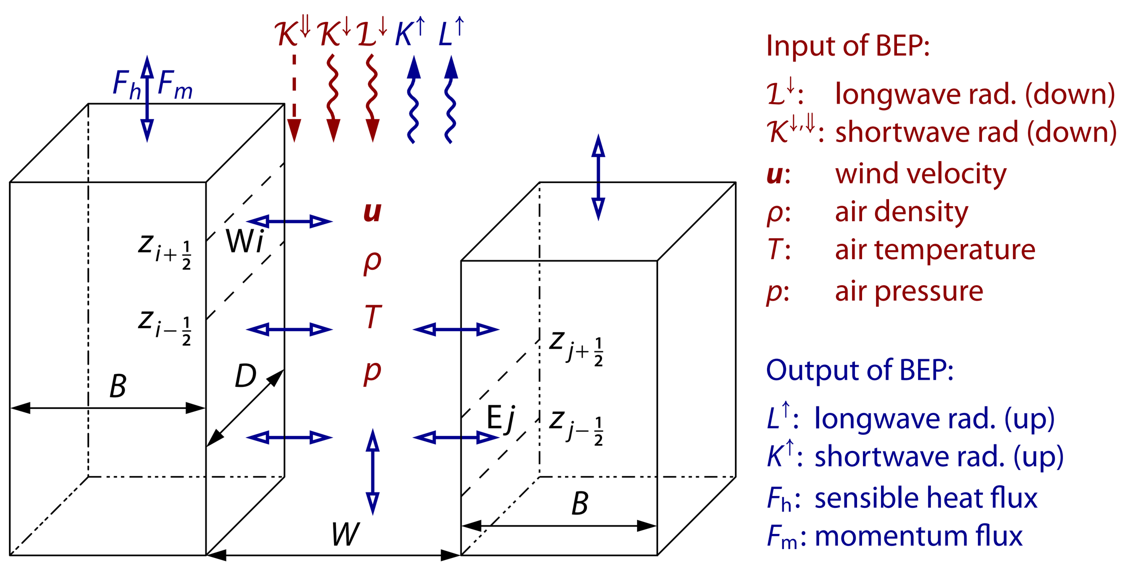


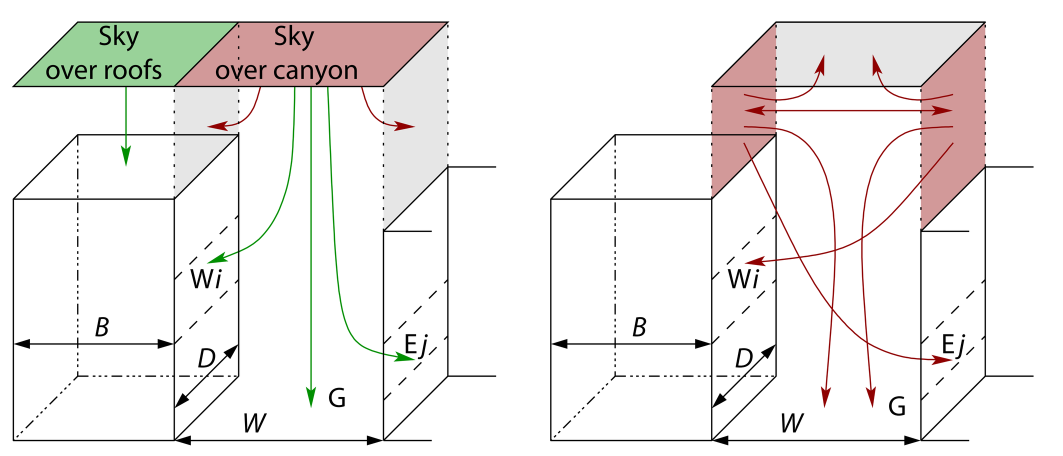
Figure 1: *Summary of the in and output variables of BEP. A basic urban canyon is described by the street width W, the building width B and the canyon length D. The distribution of roofs on the height levels i is given by γ_i.*

Implementation in the regional model:

- **urban momentum and sensible heat fluxes** included in wind and temperature tendencies
- additional **TKE production** due to urban fluxes
- averaging of **turbulent length scales** and **effective height over the ground surface**
- calculation of **effective urban radiative parameters** and averaging with CCLM's radiation parameters at the ground: effective surface radiation temperature, longwave emissivity, albedo for direct and diffuse radiation
- averaging of **2 m temperature**
- modification of **vegetation parameters** and **roughness length** at urban sites (parameters are to represent vegetated surfaces there)

2. Energy closure and multi-canyon radiation scheme

In the original formulation of BEP's radiation scheme, roof surfaces receive the full sky radiation whereas the diffuse radiation from the sky received by ground and wall surfaces is calculated using the sky view formalism (fig. 2(a)). Energy that is received by side surfaces where no walls are present (grey surfaces in fig. 2(a)) is not accounted for. Instead, this area acts as a diffuse radiation source with the same flux density as from the top sky (fig. 2(b)). Each surface element inside the canyon receives radiation from both sources, the top sky and the areas where wall elements are not present. In general, the total calculated amount of radiative energy received by the canyon is larger than the incoming radiation from CCLM. Therefore, the energy ratio τ which is given by the energy distributed inside the street canyon divided by the radiation energy at the top of the urban canopy is usually larger than 1. We introduced a factor c in BEP that scales the radiative flux from the missing wall areas to **ensure energy conservation.**



(a) from the top (b) from the side

Figure 2: *Distribution of diffuse radiation inside the street canyon*

We analysed the energy ratio τ for different fixed urban roof height distributions γ where the urban height levels have been distributed with different probabilities between 0 m and 50 m. For example, γ^{max} is characterized by 50 % of the roofs at the lowest level and 50 % at the highest. The boxes are based on real data for the city of Berlin (see section 4). Depending on the street canyon geometry, more than 5 times the incoming energy from diffuse radiation can be distributed inside the street canyon.

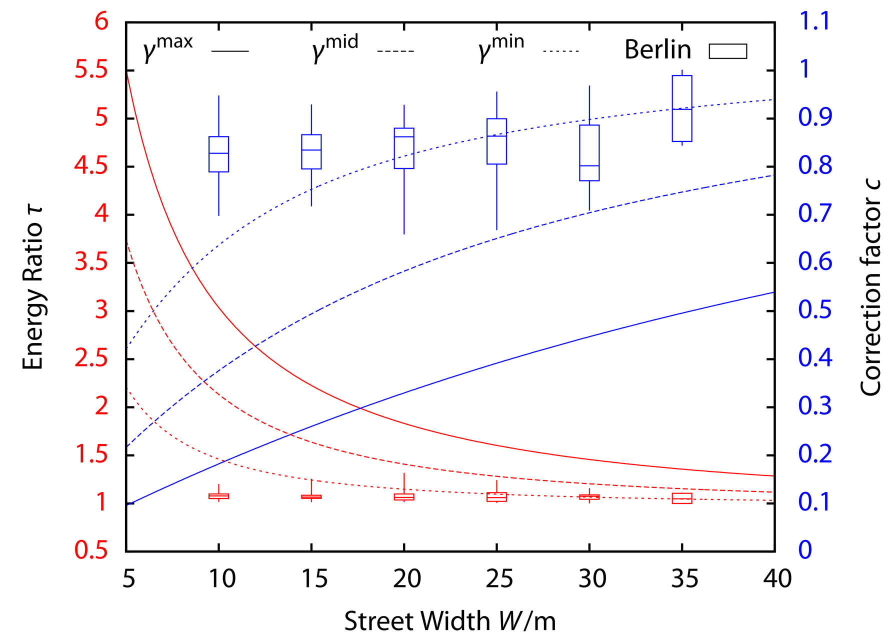


Figure 3: *Energy ratio τ and correction factor c dependence on the street width W. The curves are calculated for different height distributions γ and the boxes are based on data of the city of Berlin.*

Furthermore, to **incorporate roof surfaces in the radiation exchange** between urban surface elements and to allow **shadows on roofs**, we developed a **multi-canyon radiation scheme** based on the radiation scheme of BEP (fig. 4). In opposite to the original formulation in BEP, the radiation received by roof surfaces depends on the urban morphology parameters in fig. 4 and the height distribution γ.

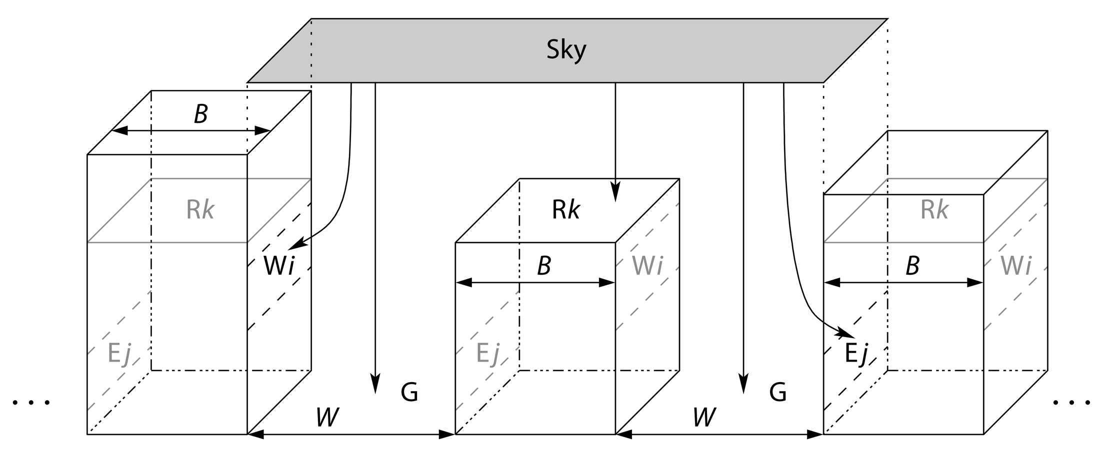


Figure 4: *Extended urban morphology to allow interaction of roofs with other urban surfaces and to represent sky radiation on roofs more realistically.*

3. Sensitivity analysis of the BEP changes

We conducted simulations with fixed street width W = 20 m, building width B = 10 m and roof height distribution of γ^{max} but realistic urban fractions for the city of Berlin starting 2003-08-01 00UTC at an resolution of 2.8 km. We either used the original formulation of BEP's radiation scheme ("orig"), the version with correction factor ("corr") or the multi-canyon approach ("roofs").
The introduction of the correction factor reduces the air temperature T_1 of the level nearest to the ground (fig. 5). The first level is deep inside the urban canopy, where wall surfaces receive less radiation in the corrected version than in the original formulation and the extended version. In the latter, the radiation trapping effect is increased leading to higher air temperature near the ground. Consequently, the radiation temperature and the albedo for direct radiation are *lower* (fig. 5 and fig. 6) because less radiation is emitted back into the sky.
The overestimation of the incoming diffuse shortwave radiation in the original BEP leads to a *negative* albedo for diffuse radiation. As a result, also the average total albedo becomes negative (fig. 6). The modified schemes do not exhibit these unphysical values.

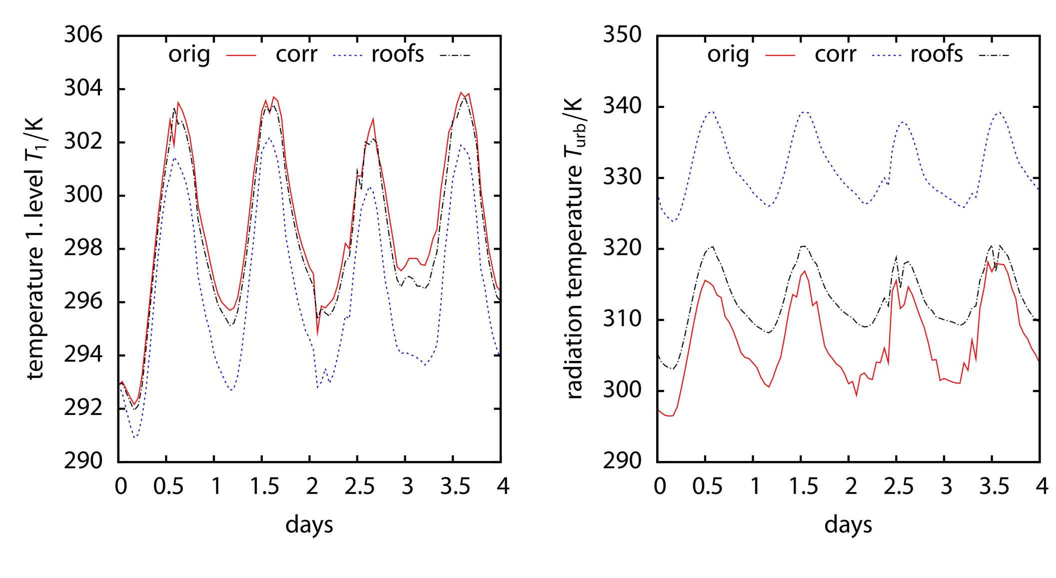


Figure 5: *Urban temperatures using an idealized urban morphology and different radiation schemes*

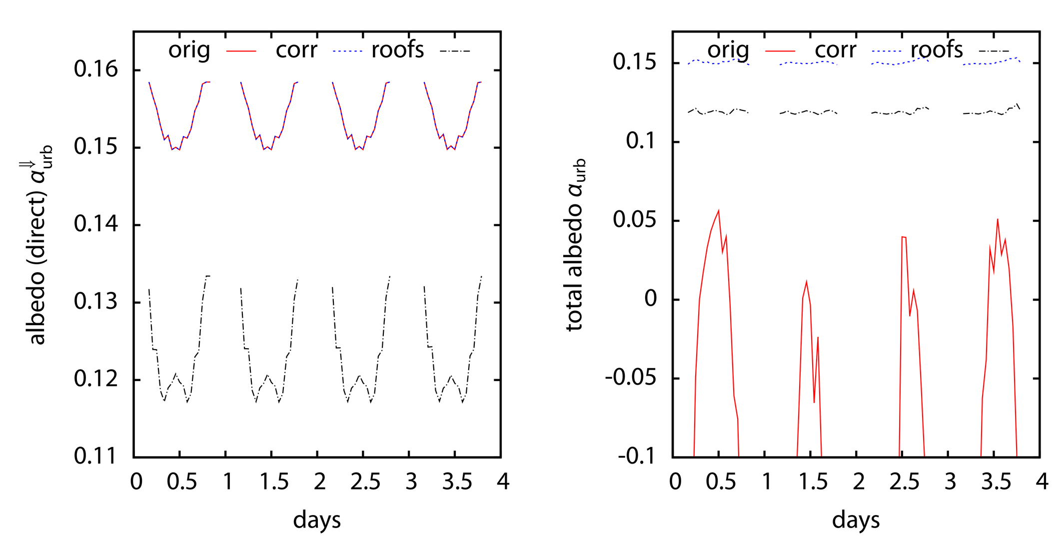


Figure 6: *Urban albedo $a^{\Downarrow}_{urb}$ for direct shortwave radiation and urban albedo a_{urb} for direct and diffuse shortwave radiation using an idealized urban morphology and different radiation schemes*

4. First Results for Berlin

Highly detailed 3d data in CityGML format (>460 000 buildings) is available for Berlin (fig. 7). We developed an algorithm to **derive urban input parameters** from this data **for every grid cell** of the regional climate model (e.g. fig. 8).

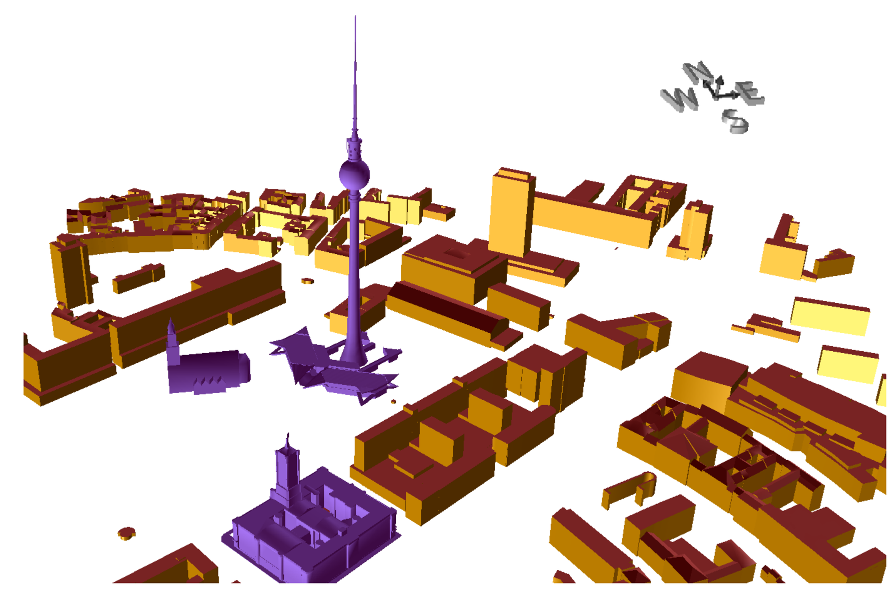


Figure 7: *Rendered example of the 3d data of Berlin in CityGML format*

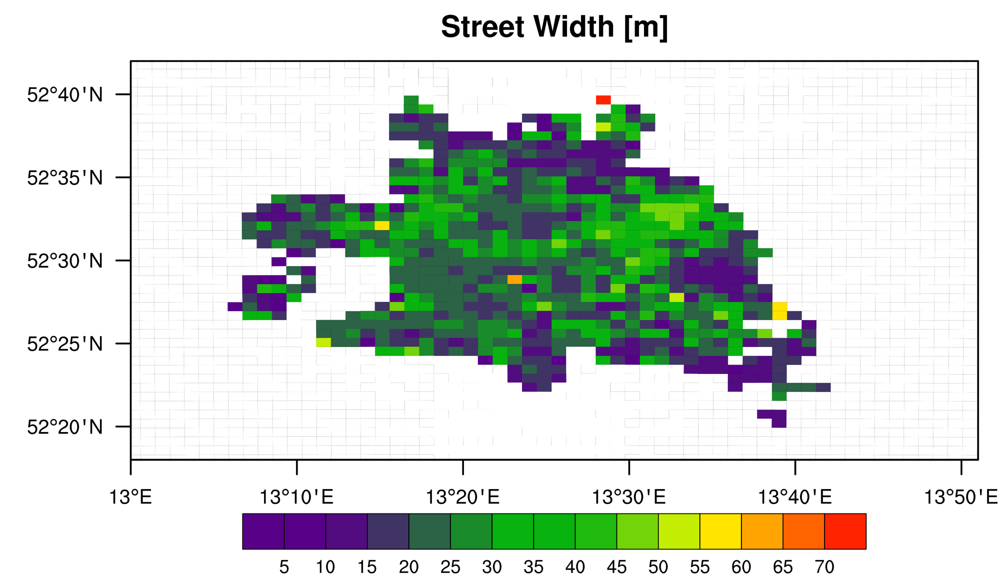


Figure 8: *Street width in Berlin derived from 3d CityGML data*

Our simulation for August 2003 using the coupled BEP-CCLM employed a three step downscaling approach: global reanalysis ERA-Interim data by ECMWF and CCLM grids with a spacing of approx. 7 km, 2.8 km and 1 km, respectively.
The model output (fig. 9) shows good results for the rural station with a tendency to overestimate nighttime temperatures for some nights. Consequently, temperatures at the urban station using the standard CCLM roughness approach agree well with the station data whereas simulations with BEP overestimate temperatures. However, the roughness approach exhibits a too small urban heat island (UHI), e.g. during the night of August, 5th of about 1 K. Using BEP, the UHI is approx. 4 K (fig. 10), which is in good agreement with the station data.

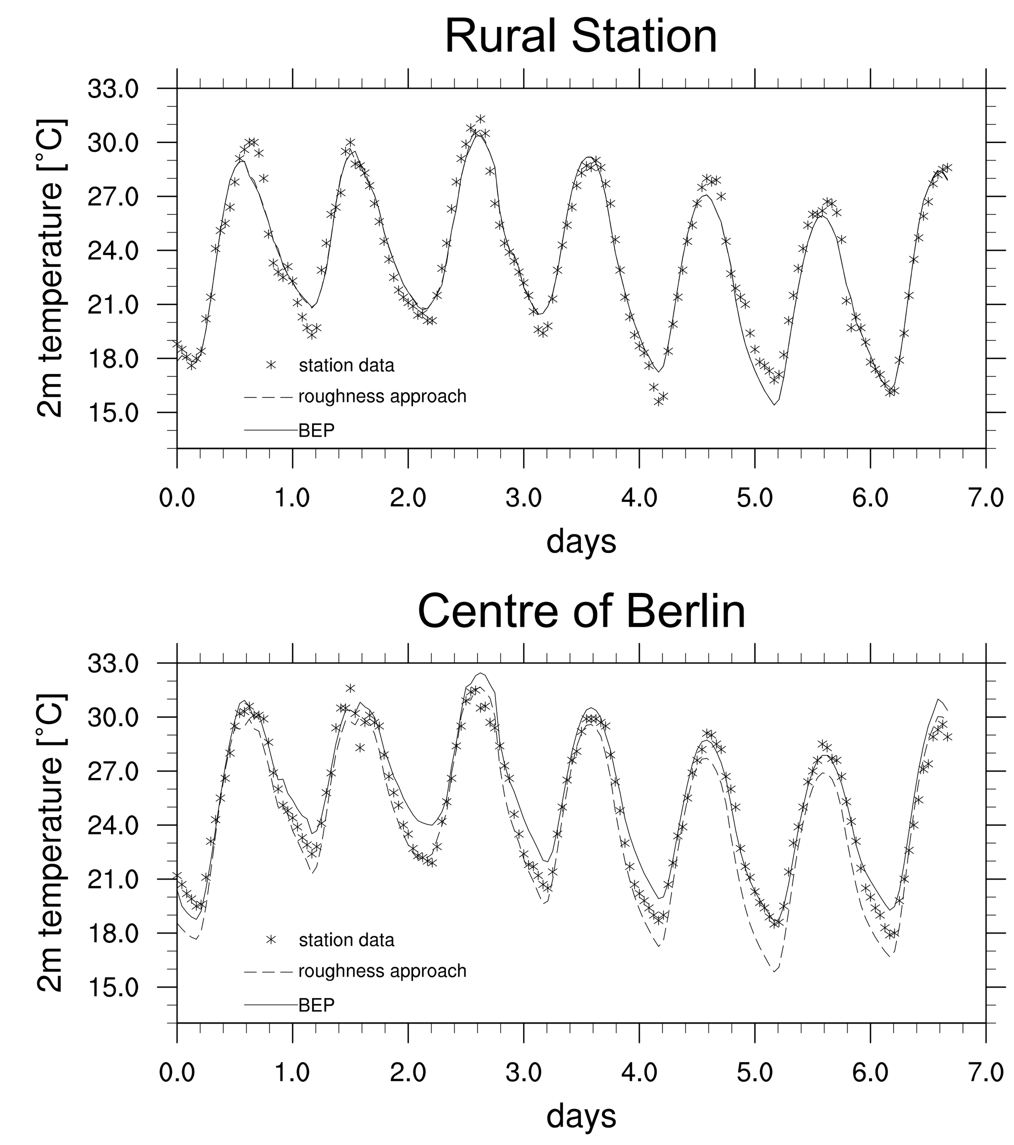


Figure 9: *Comparison of station data and model output; days since 2003-08-01 00UTC*

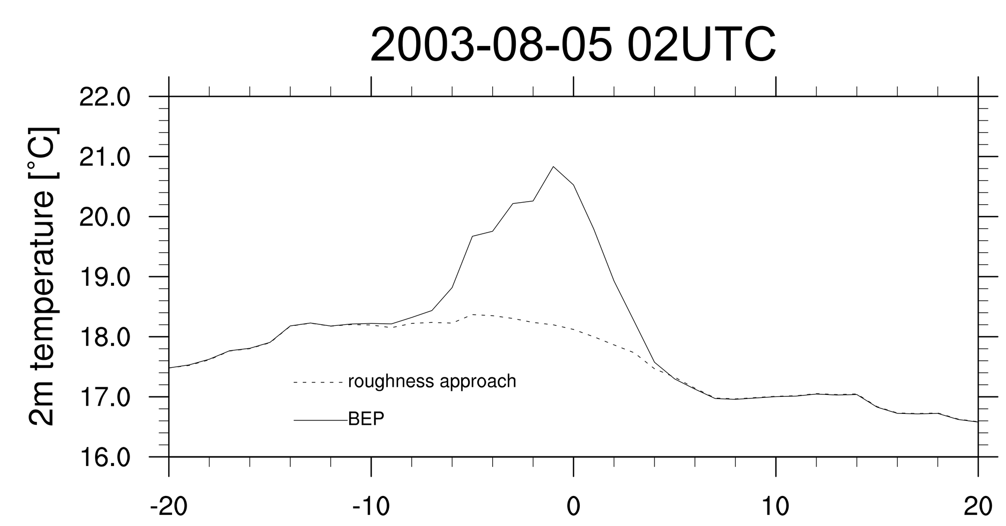


Figure 10: *Spatial distribution of 2m temperature. One unit on the x axis corresponds to 2.8 km away from the centre of Berlin.*