Review of egusphere-2025-219_R2

“MLUCM BEP+BEM: An offline one-dimensional Multi-Layer Urban Canopy Model based on the BEP+BEM Scheme”

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Replies to the Reviewers’ remarks

We sincerely thank the Reviewer for the thorough evaluation and constructive feedback. The comments have been greatly appreciated and have informed a careful revision of the manuscript. Below, we provide detailed responses to each point raised.

Referee: 1

The authors have done quite a lot of work in responding to the reviewers comments from the first round. The manuscript now does a better job of highlighting assumptions that are within this model formulation. I also appreciate the extra care they have done in responding to my comments about clarifying the performance of the energy fluxes.
After carefully reading through this new paper, I still have a few reservations about the presentation of this model. Specifically, this model is being presented to “bridge the mesoscale and microscale phenomena occurring in the planetary boundary layer and within the urban canopy, accounting for exchanges and feedback between different scales and processes” (line 63). Yet, there are critical processes that are missing that make this a tool that would not be useful outside of a very small subset of heavily urbanized regions that lack much vegetation. While those are important (the most heavily urbanized and likely to have the most intense impacts of heat), this model formulation is likely going to be severely biased due to the lack of hydrology and reliance on empirical formulations.

I agree that this model will be useful as either a quick analysis of longterm simulations of modulation of thermal parameters or after substantial model development be able to fill a gap in actionable science for climate adaptation that could be used by decision makers. Unfortunately, at the current state, the latter is not possible despite some language used in the manuscript. My comments are directed to help clarify this point and give a better representation of what this model could provide and where it would be helpful to use.

We understand the concerns regarding the model’s current limitations, particularly the absence of an explicit hydrological component and the use of empirical formulations. In the revised manuscript, we have clarified the intended scope and applicability of the model, emphasizing its focus on densely urbanized areas with limited vegetation cover. We also acknowledge that further development will be needed to extend its applicability to a broader range of urban contexts. The suggested clarifications have been implemented to better reflect the model's current capabilities and potential future developments. If on one hand the MLUCM BEP+BEM model does not currently include a fully developed hydrological component, it offers a highly detailed representation of turbulence and building-atmosphere energy exchanges, features that are often simplified or absent in other comparable models. Our results indicate that the performance of MLUCM BEP+BEM is comparable to, and in several key variables even exceeds, that of other state-of-the-art models.

Comments

1) As the authors have mentioned in their reviewer comments, a user manual should be created to be ready for publication when this paper is live to ensure that the code is as accessible as possible.

R: We thank the reviewer for emphasizing the importance of accessibility and usability of the proposed model. We have prepared a user manual to accompany the first release of the model (please find the file in Zenodo https://doi.org/10.5281/zenodo.14773142). This manual is intended to support users in setting up and running simulations with the current version of MLUCM BEP+BEM model. Furthermore, the authors are committed to ensuring that the model becomes as accessible and widely usable as possible. Future efforts will focus on enhancing documentation, facilitating user support, and promoting broader adoption within the research community.

2) Do the authors believe that 8 cm is enough hydrologically active soil to be able to model rain gardens? While appropriate for a green roof, specifically an extensive green roof with short shrubbery as is modeled by Zonato et al. 2021, rain gardens usually do not have such a shallow growing media and to not have an impermeable bottom. This could be a difference that is occurring due to terminology, where a rain garden could mean a planter boxes that have an impermeable bottom, but should thus be defined more clearly.

R: We fully agree that the hydrological characteristics of rain gardens typically involve deeper soil layers and often permeable bottoms, which differ significantly from the active soil assumed in our current setup. These limitations are acknowledged and will be addressed in future developments of the model.
We have clarified this point in the revised manuscript in lines 217-220.

"*The modeled gardens are implemented with a simplified soil layer structure and a bottom boundary condition that does not account for infiltration into deeper permeable soil. While this setup may resemble planter boxes with impermeable bottoms, it does not aim to capture the full range of hydrological responses of gardens to precipitation and complex evapotranspiration processes."*

Furthermore, a note is included in the user manual to warn about the limitations of the model to represent the effect of large gardens.

3) I believe that the presentation of the results, specifically for sensible and latent heat, are obfuscating the real impact that these model simplifications (e.g. lack of hydrology and reliance on empirical coefficients) are causing. I would ask that the authors re-create Figure 3, but only during daylight hours. This would give a better idea of Sensible and Latent heat flux biases. Both fluxes are more variable during the daytime (latent heat is ~0 during the night most of the time, and sensible heat is slightly negative). This does not need to be in the main body of the text but should be pointed to for a clear representation that model structural development choices are creating.

R: In the present results we follow the Urban-PLUMBER protocol, to allow the comparison with other models involved in the experiment, as well as to provide publicly available output. This protocol does not consider the division between day and night. However, we thank the

Reviewer for the valuable suggestion, and we carried out the requested analysis. We added in the supplementary material a new version of the Figure 3 considering only daylight hours (i.e. shortwave downward radiation > 10 W m^{-2}) and added to the article (lines 356-363) that: "*Further analysis indicates that the model reproduces observations more accurately during the daytime than at night (Fig. S1). The overall unsatisfactory performance of the model appears to be primarily due to the unrealistic simulation of nighttime fluxes, whereas daytime fluxes are reasonably well captured. As a result, the sensible heat flux is well reproduced when it represents a significant component of the surface energy budget, and less accurately reproduced at night, when its contribution is minimal.*

This discrepancy is not expected to significantly affect the estimation of quantities such as building energy consumption, which is in the focus of the model scope. Similar considerations apply to the latent heat flux, albeit to a lesser extent. These findings are consistent with the widely recognized limited role of latent heat fluxes in densely urbanized environments."

The version of Figure 3 considering only daytime is provided here (Fig 1R2) and it is added to the supplementary material of the manuscript (i.e. Fig. S1), while Table 1R2 reports the performance metrics.

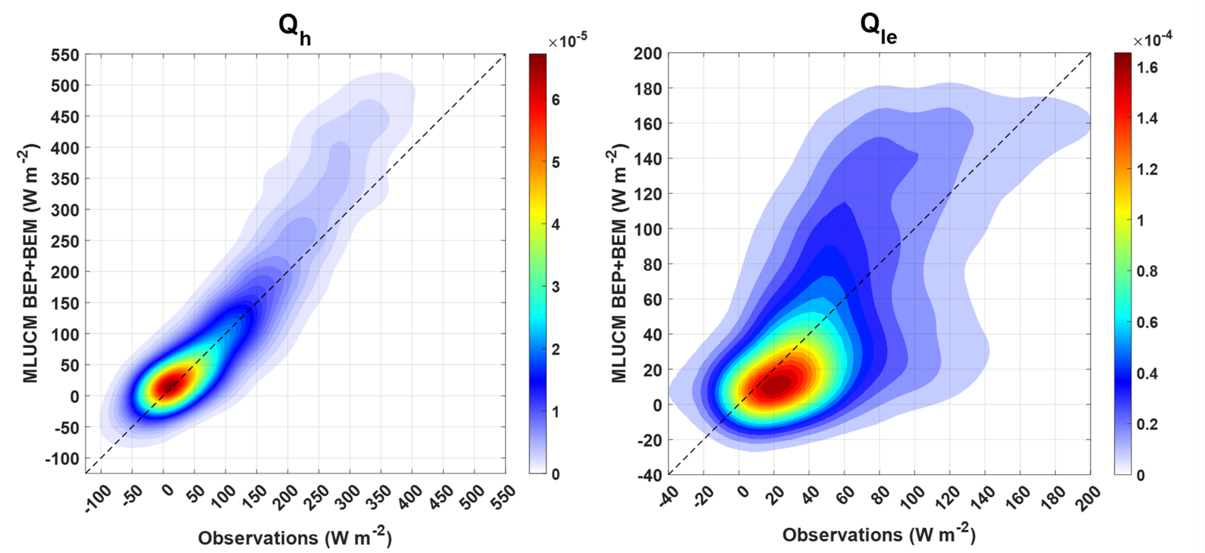

Figure 1R2: As in Figure 3, but during daytime (i.e. shortwave downward radiation > 10 W m^{-2}).

	Qh	Qle
BIAS	15.98	-1.19
NME	0.33	0.62
SLOPE	1.13	0.55
COR	0.92	0.58

Table 1R2 Statistics of the MLUCM BEP+BEM model for "complex" experiment during daytime.

4) The new results, even after the new parameters that the authors have identified, do not introduce much model sensitivity. The improvement of the Baseline simulation compared to the Complex simulation are not as large as the "Results show that the integration of detailed, site-specific information on urban elements such as building geometry and vegetation generally improves the simulation of energy fluxes" on line 461 mentions. Please revise, especially as the changes between comparisons in Table 3 and Taylor diagrams in section 4.3 are not that large.

R: We agree with the Reviewer. We have revised the sentence at lines 482-483 to better reflect the results .

"Results show that the integration of detailed, site-specific information on urban elements such as building geometry and vegetation lead to some improvements in terms of correlation, cRMSE, and STD in the simulation of latent and sensible heat fluxes."

5) Line 473: "Its computational efficiency makes it particularly suited for exploring long-term trends and assessing large-scale mitigation strategies." Please clarify what mitigation strategies that this model would be helpful in. The model, as is currently stands, would be useful in modulating radiative parameters, but the lack of hydrologic treatment and therefor the increase/decrease of latent heat would make this difficult to use in the widespread application of green infrastructure. To work with green infrastructure, one would need to add hydrology to the land surface model in a more sophisticated way. The authors may consider citing alternatives that would be appropriate for green infrastructure strategies when they clarify this point.

R: We have revised the text to clarify the types of mitigation strategies for which the model is currently best suited in lines 494-499. In particular, we acknowledge the limitations that arise when simulating green infrastructure interventions, such as extensive greening or the planting of trees due to the model's reliance on simplified approximations. These can lead to imbalances in the representation of energy fluxes, especially in highly vegetated urban areas, given the absence of an explicit hydrological component.
This point has now been addressed in the revised manuscript, where we specify that while the model may not be ideal for fully capturing the impacts of green infrastructure, it is well structured to assess changes in the thermal and radiative properties of buildings, including interventions such as green roofs, photovoltaic panels, or their combination. These features make the model particularly suitable for evaluating long-term trends and energy-efficiency-oriented mitigation strategies at the urban scale.

"*Its computational efficiency makes it particularly suited for exploring long-term trends and assessing mitigation strategies focused on the thermal and radiative properties of the built environment, such as the implementation of green and cool roofs, photovoltaic panels, or energy retrofitting measures. Conversely, care should be taken when using the model to evaluate the role of gardens and street trees, due to the simplified treatment of soil hydrology. In such cases, more detailed models such as the Urban Tethys-Chloris (UT&C) model (Meili et al., 2020), which explicitly account for ecohydrological processes, may provide a more accurate representation of vegetation effects on urban climate.*"

Meili, N., Manoli, G., Burlando, P., Bou-Zeid, E., Chow, W. T. L., Coutts, A. M., Daly, E., Nice, K. A., Roth, M., Tapper, N. J., Velasco, E., Vivoni, E. R., and Fatichi, S.: An urban ecohydrological model to quantify the effect of vegetation on urban climate and hydrology (UT&C v1.0), Geosci. Model Dev., 13, 335–362, https://doi.org/10.5194/gmd-13-335-2020, 2020.

6) Finally, the authors mention the computational efficiency as a key selling point for this model. It would help if the authors provided somewhere (could be in a table, could be in an SI figure) differences in computational load that was needed to run this model vs. the other models in this paper. Including runtime, number of CPUs, etc. would help justify the computational efficiency point in this paper.

R: In the manuscript, we refer to the computational efficiency of the proposed column model primarily in relation to the BEP+BEM scheme when coupled online with a full mesoscale model such as Weather Research and Forecasting (WRF) model. However, it is important to note that direct comparisons of computational time can be highly dependent on the specific model configuration, the nature of the application, and the characteristics of the computing system used. For this reason, we have provided in the revised manuscript (lines 303-309) the simulation times and technical specifications of the workstation used for the case study presented in this work, to offer a clear reference framework for evaluating computational performance.

"*The model runs at one-minute time steps, with an average computational speed of approximately 4–5 ms per time step. A typical simulation covering one year of data requires approximately 30–40 minutes on a workstation using one Intel® Xeon® Gold 5218 CPU @ 2.30GHz with 2 GB RAM, operating in a virtualized environment (VMware). A fully coupled mesoscale model (e.g., WRF with BEP+BEM; Vidal et al., 2021), typically requires more than one day for a 24 hours simulation using a single core (decreasing to 1 hour in a 64-core computer). Though computational costs may vary depending on the specific application and the hardware used, it is clear that MLUCM BEP+BEM offers an enormously reduced computational cost, enabling faster simulations and making it particularly suitable for long-term studies.*"

Vidal, V., Cortés, A., Badia, A., Villalba, G. (2021). Evaluating WRF-BEP/BEM Performance: On the Way to Analyze Urban Air Quality at High Resolution Using WRF-Chem+BEP/BEM. In: Paszynski, M., Kranzlmüller, D., Krzhizhanovskaya, V.V., Dongarra, J.J., Sloot, P.M. (eds) Computational Science – ICCS 2021. ICCS 2021. Lecture Notes in Computer Science(), vol 12746. Springer, Cham. https://doi.org/10.1007/978-3-030-77977-1_41