Ms. Ref. No.: UCLIM-D-17-00016R1

Title: Development of the VTUF-3D v1.0 urban micro-climate model to support assessment of urban vegetation influences on human thermal comfort

URBAN CLIMATE

Dear Dr. Kerry A Nice,

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However, if you feel that you can suitably address the reviewers' comments (included below), I invite you to revise and resubmit your manuscript.

I would appreciate if you could submit your revised paper by Nov 10, 2017.

Please carefully address the issues raised in the comments.

If you are submitting a revised manuscript, please also:

a) outline each change made (point by point) as raised in the reviewer comments

AND/OR

b) provide a suitable rebuttal to each reviewer comment not addressed

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I look forward to receiving your revised manuscript.

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Yours sincerely,

Alexander Baklanov, Dr. Sci.

Editor in Chief

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Reviewers' comments:

Reviewer #2: Development of the VTUF-3D v1.0 urban micro-climate model to support assessment of urban vegetation influences on human thermal comfort

K. Nice, A.M. Coutts, N.J. Tapper

The authors have clearly attempted to respond comprehensively to the reviewer comments. The model is unique and a novel contribution, filling an important gap. The neighbourhood-average results are good; however the novelty of the model is not at this scale, but at the microscale. The authors have added a microscale model-observation comparison which assesses common thermal comfort quantities/indices Tmrt and UTCI. However, the model performance at this scale leaves something to be desired. My sense is that the model resolution, the model physics, and/or the mismatch between the model representation and observed reality (e.g. Tmrt for a patch on the ground vs. a measurement at 3m height) are contributing. Somewhat worrisome is the clear degradation of model performance for streets with more tree cover. To help give readers confidence, I think the reasons for the poorer model performance at the microscale and in more highly treed situations should be resolved (ideally), or at very least explained in terms of limitations of the model (including clear guidance regarding what the model CAN and CANNOT do reliably).

**Response to Reviewer #2 overall comments:**

**We appreciate the positive comments. Issues around the performance of the model at a micro-scale resolution have been addressed in the P19L54 comment below.**

Comments…

Abstract:

The fact that TUF-3D and MAESPA are not fully coupled should be stated, i.e. that they are partially coupled, or similar.

**Response to Reviewer #2 abstract comments:**

**This is a good point. The body of the paper mentions the offline use of MAESPA a number of times, but not the abstract. We have modified the abstract as follows:**

**“To achieve this, a new micro-scale model, VTUF-3D (Vegetated Temperatures of Urban Facets) has been developed. In it, offline modelling of individual items of vegetation is performed using the MAESPA process-based tree model \citep{Duursma2012} (a model that can model individual trees, vegetation, and soil components), and integrated into the TUF-3D \citep{Krayenhoff2007} urban micro-climate surface energy balance model.”**

**This (lack of coupling) is also highlighted in the limitations comments added for P19L54.**

Also, the fact that impacts of trees on longwave exchanges is not captured should also be stated here and/or in the conclusions - this is an important effect of trees, especially at night.

**Response to Reviewer #2 abstract comments:**

**Again, this is addressed in the response to the P19L54 comment below.**

At present, it is not clear to me that the following statement at the end of the abstract is supported: "Using this model, it is now possible to conduct further analysis to quantify the impact each individual tree can have on conditions in urban canyons. Further, the model can help inform the optimal arrangement and quantity of trees to deliver improvements in HTC and be used to generate best practice guidelines for urban greening in support of HTC."

**Response to Reviewer #2 abstract comments:**

**Yes, fair enough. This is again the research being further along than what is actually presented in this paper. We have removed these sentences from the abstract and will save them for the 2nd paper where the evaluations around modelling individual trees will be presented.**

Highlights: I don't think the following is accurate: "VTUF-3D is the first micro-scaled urban surface energy balance model that allows inclusion of any type of urban vegetation." ENVI-met, for example, includes several types of vegetation. I think you want to be a bit more specific, e.g., which processes you are representing that ENVI-met or similar do not, or that you are including processes more rigorously or with better model evaluation.

**Response to Reviewer #2 highlights comments:**

**The claim in the highlights is probably a bit complicated to state accurately in a highlight dot point. It is meant to compare a heavy-weight CFD model (ENVI-met) vs. a much lighter weight SEB model where the vegetation templates allow any type of vegetation to be included (instead of pre-packaged types included with ENVI-met). But yes, that is way too messy for a dot point highlight. The highlight has been changed to:**

**“VTUF-3D is a computationally efficient micro-scaled urban surface energy balance (SEB) model that allows the inclusion of any type of urban greenery through user-configurable vegetation parameter templates.”**

Sect. 2: So the energy balance associated with a tree happens at the ground? For a large tree, does the MAESPA energy balance replace multiple surfaces/grid cells, or does it only replace the one associate with the tree trunk? If so, then it seems that latent heat will be underestimated - i.e. the appropriate TUF-3D surfaces will be shaded, but this shading will only affect sensible and storage heat. Please be clear in the text.

**Response to Reviewer #2 sect. 2 comments:**

**We have added the following to Section 2.3.1:**

**“For large trees (extending beyond the edges of the grid square), the $Q\_{E}$ for the entire tree will be applied to grid square where the trunk is located.”**

**No Qe is lost or underestimated overall, but will lead to a slight distortion of Qe vs Qh and Qs in that grid square and adjoining squares. However, we have found that the shading effect far outweights the Qe cooling, so the impact of this distortion is quite small.**

Fig. 3: It seems that use of "forward" and "reverse" when referring to ray tracing is "reversed" in terms of the actual flow of radiation. Do you mean "reversed" relative to TUF-3D?

**Response to Reviewer #2 Fig. 3 comments:**

**The phrasing is an artifact of the development process. It makes sense in terms of the internal model design but is likely unclear to everybody else. The wording has been changed to include ‘upward’ and ‘downward’ for greater clarity.**

Fig. 10: The color coding of the boxes appears backwards. Legend should say what the numbers in the figures represent.

**Response to Reviewer #2 Fig. 10 comments:**

**Fixed color coding. Added number explanation.**

P19L54: In general, air temperatures and wind speeds in the canyon, when used as above-canyon forcing for an urban climate model, do not lead to good performance. Please justify this approach.

**Response to Reviewer #2 P19L54 comments:**

**To address a number of the comments, the following paragraph has been added to the conclusion to better explain some of the limitations of VTUF-3D and of the evaluations, as well as how these limitations were considered in the weighing the trade-offs between accessibility and accuracy.**

**“A key design goal of VTUF-3D was to simplify the approach, maximising the efficiency and accessibility of the model for a wide audience, yet be accurate enough for these users to start investigating the impacts of urban greening. This trade-off leads to some potential limitations. The offline aspects of the model means that some interactions and exchanges are not accounted for in the model. Future development plans include an option to couple VTUF-3D with a mesoscale atmospheric model (an online approach), but until then, evolving interactions and feedback between the boundary layer and the urban canyon are not captured. In the George St. evaluation, the forcing data used, observations from within the canyon, can lead to reduced accuracy. However, this highlights the relative levels of accuracy that can still be obtained using this source of easily obtained forcing data. Finally, not accounting for longwave exchanges between urban vegetation and the urban canyon due to the offline vegetation modelling is a further limitations of the current model. Future model development to bring the vegetation online into the model will eliminate this problem.”**

Fig. 13: It does not appear that the model can capture the microscale variation of Tmrt (in particular the trend between sites, irrespective of the absolute value, even with the 30-day averaging). This raises concern that the model is missing a key process that varies spatially at the microscale. I think I would disagree with the statement on p. 23, line 18-19: "However, even at this relatively coarse resolution, VTUF-3D is still able to produce good results within a complex canopy." Also (line 23), the stronger agreement in the open canyon points to a potential problem with the implementation of trees - i.e., the more trees, the worse the model results?

p.24: What d-value is considered to be poor agreement? I think I have rarely seen a low d-value for diurnal energy balance/climate model-observations comparisons during fair weather. The fact that the main trend is driven by solar radiation and forcing air temperature means that correlation should be high, and therefore so should d. It strikes me that good agreement is probably d > 0.95, which many of the treed sites do not meet.

**Response to Reviewer #2 Fig. 13 and p.24 comments:**

**These sections have been modified to better reflect some of the limitations of both the evaluation and of the model.**

**“A statistical analysis of predicted vs. observed results is presented in Table \ref{tab:georgetmrt}. Results of d index of agreement for $T\_{mrt}$ and UTCI for the more complex treed canyon (George St.) show values of 0.91 to 0.93 while the open Gipps St. canyon shows superior performance in the range of 0.95 to 0.96 for $T\_{mrt}$ and 0.95 to 0.97 for UTCI. Other statistics (RMSE, MBE, and MAE) also show this pattern of good performance within the open canyon compared to reduced performance in the treed canyon.”**

**“These wider divergences of modelled results from observed values within the treed canyon suggests a number of possible limitations of this study and of the VTUF-3D model. The first is of the evaluation process. High quality, high resolution observations of $T\_{mrt}$ and UTCI in urban areas, particularly underneath a dense canopy, are difficult to make, and very few datasets are widely available for model evaluations. The small number of observed locations available within this evaluation led to difficulty in matching the precise position of the observation sensors (and the precise amounts of rapidly fluctuating illumination on the black globe sensors) to the more detailed resolution of the modelled results. The divergences also suggest some limitations of VTUF-3D when modelling dense vegetation. This can result from the challenges of designing an exact detailed representation of the observed area within the modelled domain using a 5m resolution, as small differences in timing can lead to large differences in the comparisons. It also suggests further work is needed to improve the physical representation of the vegetated canopy in the next version of VTUF-3D.”**

Table 8: Please make it clear in the table which statistics refer to Tmrt vs. UTCI.

**Response to Reviewer #2 Table 8 comments:**

**Yes, the headers are a little confusing. They have been corrected (also in Table 5).**

Reviewer #3: The authors have adequately addressed all of my comments and more, and have substantially strengthened this paper. My greatest concern about the prior submission was in regards to the framing of the research gaps filled by this study and the statement of utility. As a member of the planning community, I think the addition of the last paragraph about the need to orient the results of this model specifically toward the needs of planners and policymakers is a great way to conclude the paper. Additionally, Furthermore, I feel a much greater sense of the model's utility in the second to last paragraph about proper mitigation strategies tailored each section of the urban canyon. This is a very useful framing of the results, particularly for planners and urban designers. The paper is an appropriate and welcome addition to the greater scope of this journal. I look forward to being able to use this model in the future, and encourage the authors to continue working with planners and policymakers to enhance the utility of this model's output.

**Response to Reviewer #3 overall comments:**

**Yes, thanks for the comments on the first version. They did help us think through how to present a fairly dry model description and evaluation process as something that can describe how the model can be used by a wide variety of users.**

Detailed comments:

Page 25, line 45: "addition" to "additional"

**Response to Reviewer #3 P25L45 comments:**

**Fixed**