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

Title: Development of the VTUF-3D v1.0 urban micro-climate model to support assessments of urban vegetation influences on HTC

URBAN CLIMATE

Dear Dr. Kerry A Nice,

The reviewers have commented on your above paper. They indicated that it is not acceptable for publication in its present form.

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 Apr 03, 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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Yours sincerely,

Alexander Baklanov, Dr. Sci.

Editor in Chief

URBAN CLIMATE

Reviewers' comments:

Reviewer #1: Review of "Development of the VTUF-3D v1.0 urban micro-climate model to support assessments of urban vegetation influences on HTC"

The authors enabled an existing urban micro-climate model (TUF-3D) to account for vegetation effects by adding an existing tree process model (MAESPA). The work fills a gap in current micro-climate models and the authors have developed an important and useful tool (VTUF-3D). However, the article needs a great deal of work in terms of writing and organization. For example, in the model design section, the authors go into detail about the equations solved by the model but there is no way for the reader to distinguish between what was already done by the existing models and what the authors changed in the models. Also, the article is full of vague pronouns and redundant sentences. I think that the work done by the authors is important and should be published but I am not sure that the article, as it is written, is worthy of publication. I recommend that the article be accepted upon completion of major revisions. The article could be hugely improved by having someone with a background in writing/communication edit the article.

Major comments:

1. As mentioned above, the model design section is confusing to the reader because it is impossible to determine between summaries of the already existing TUF-3D and MAESPA models and what the authors actually changed. Since the two models (TUF-3D and MAESPA) are already published, there is no need for the authors to go into such extreme details about the equations used in each. There are too many equations and variables introduced that are not necessary in this paper. If a reader is curious they can refer to the TUF-3D and MAESPA references. I suggest that this section be reduced in terms of degree of unnecessary detail and reorganized so that the reader knows what the authors have changed.

2. The results section is awkwardly organized. On pg. 17 line 56 and through the rest of 18, the authors begin discussing results that are not even presented until the next section. I suggest that subsection 4.2 be incorporated into 4.1 so that the performances of each scenario can be compared without having to reference results presented later in the paper. Also, section 4.2.1 seems out of place since. It may be better to incorporate that into section 4.1 as well, in which case there would be no subsections in the results at all.

3. The authors use vague pronouns throughout the paper that are confusing to the reader. I began listing each and suggesting alternative wording but there are too many and the task became far too cumbersome. As mentioned above, I suggest having someone with a background in writing/communication edit the article.

4. The authors use one modeled episode to validate the model. Is it possible to have a more robust validation by incorporating a few episodes? There needs to be a stronger argument that the model is validated.

Minor Comments:

~~1. Pg.2 line 51 - change "…deal with" to "mitigate"~~

~~2. Pg.2 line 54 - change "Incorporating more vegetation and water into urban areas can be an~~

~~effective way to mitigate extreme urban temperatures. From an examination of a range of different studies exploring cooling effects of urban greenery (Tsiros,2010; Shashua-Bar et al., 2010; Spangenberg and Shinzato, 2008), it is clear that increased vegetation and water can have positive benefits, from the city-wide scale down to a micro-climate street level scale (Coutts et al., 2012). Shading and evapotranspiration are cited as the main drivers of these cooling effects (Bowler et al., 2010)." to "Incorporating more vegetation and water into urban areas can effectively mitigate extreme urban temperatures on local to micro scales (Tsiros,2010; Shashua-Bar et al., 2010; Spangenberg and Shinzato, 2008; Coutts et al., 2012)"~~

~~3. Pg 3 line 35 - The authors mention how quickly VTIF-3D runs but to not give any other model run times to compare.~~

**Good point, I had assumed a familiarity with CFD modelling. Added that CFD modelling would take at least an order of magnitude more.**

~~4. Pg 3 line 37 - Remove the sentence beginning "This approach needs…" because it is a bit redunda~~nt.

~~5. Pg 3 line 45 - Define MEASPA~~

**Tried to clarify, MAE is not an acronym (came from MAESTRO model which was just a name), while SPA (Soil-plant-atmosphere) is.**

~~6. Pg 3 line 49 - the part of the sentence "…around identifying how…" is awkwardly worded.~~

~~7. Pg 4 line 6 - Remove first three sentences of the section as they are redunda~~nt.

~~8. Pg 4 line 12 - The sentence beginning with "The vegetation functionality…" is vague and confusing. Suggest rewording with a bit more precision.~~

9. The entire Model Design section has many variables defined in the text that are not used in the equations. These are not needed and should be removed from the text.

~~10. Section 2.5 title should be words not variables that the reader needs to go look up~~

~~11. Equation 14 is vague. All it says is that UTCI is a function of those variables but gives no detail as to how it is calculated. Also, UTCI is not discussed at all in the results so this may not be needed anyway. I suggest either making equation 14 show the actual calculation or removing it entirely.~~

**Ok, I agree that the UTCI function is not useful. The actual equation is about a page long and documented elsewhere. I’m happy to remove the actual equation (UTCI function) and point to the equation source, but I suggest that the model calculating UTCI and Tmrt are essential pieces of the model and should be highlighted. These are the outputs that make assessing human thermal comfort possible, otherwise the model is not going to be terribly useful. The evaluations of modelling of Tmrt and UTCI will be documented in the next article. Otherwise, they would add another 10-20 pages to an already long article. If you believe having all the evaluations in a single article and are not concerned about the length, I’m happy to add those to this article, but I suspect the length will be a problem.**

~~12. Pg 10 line 57 - "…ray-traced from the centre of each quarter…" to where?~~

**Clarified that ray traces are performed 4 times towards the sun for each surface.**

~~13. Pg 11 line 33 - What specific forcing data is supplied and is that easy to come by?~~

**Added (such as described in the Pr04Val evaluation in Section \ref{sec:modelsetup})**

~~14. Section 3.1 should be titled "Validation Data"~~

~~15. Pg 12 line 9 - First word should be "The" not "A".~~

~~16. Pg 12 lines 52 to 53 - Reword the sentence "An analysis by Nury…". An analysis of what?~~

~~17. Figure 5 is not needed~~

~~18. Pg 14 line 46 - The sentence is confusing. Reword using more precise language.~~

~~19. Section 3.3 is strange because it is titled "validation approach" but begins by discussing other scenarios other than the validation run. Suggest rewording the first sentence so that the reader is not immediately introduced to model scenarios when they are expecting to read about validation approach.~~

~~20. Pg 15 line 33 - Remove sentence "This will allow an …" because it is redundant~~

2~~1. Pg 15 line 34 - The sentence "As discussed earlier in this section…" should be moved to the results or the conclusion section. Also, remove "As discussed earlier in this section" so that the sentence reads "The Intercomparison project…"~~

~~22. Pg 16 line 56 - The sentence "In terms of…" is strangely worded and should be rewritten. The next sentence is also strange and there is no way to tell which numbers are modeled and which are observed.~~

~~23. Pg 17 line 3 - No need to define index of agreement as "d" unless there is a formula showing how "d" is calculated. Also, there is no discussion of what these metrics actually mean and there ought to be, otherwise they are just numbers.~~

**Moved brief index of agreement overview to evaluation approach section and added brief introduction to 0-1 scale to first usage of index.**

~~24. Pg 19 line 52 - The sentence "These modifications allow…" should be removed because it is redundant.~~

~~25. Pg 21 line 4 - The sentence "Significantly, in this…" is strangely worded and should be rewritten.~~

Reviewer #2: Development of the VTUF-3D v1.0 urban micro-climate model to support assessments of urban vegetation influences on HTC

Nice et al.

The authors further develop an established microscale urban climate model to include trees, vegetation and fair weather hydrology, for the purposes of detailed examination of effects of vegetation and water implementations in street canyons on microclimate and thermal comfort. Overall, this is a very detailed and careful work. Nevertheless, a few key details appear to be missing in the model description, particularly with respect to the vegetation treatment. As well, the model evaluation is performed at a different scale from the intended use of the model. Provided the main comments are sufficiently addressed, this work deserved to be published.

General questions/comments

Do trees shade surrounding surfaces via these stacks of blocks depicted in Fig. 1 (e.g., ignoring tree shape, which is represented in MAESPA?). Can trees shade building roofs? What happens to radiation scattered/reflected by trees? Do trees intercept longwave/reflected shortwave radiation between building surfaces? Please clarify in the text.

How interactive are the two models in time? Do they interact each timestep? Please clarify further in the text.

~~Ultimately, is energy conserved in both models (VTUF-3D and MAESPA)? This is a common basic test of any model with energy flows/storage, and should be one of the first tests performed in a model evaluation; it should be mentioned if you have performed one, and performed if you have not. There is some casue for concern here I think because some energy balance terms are computed differently in the two models.~~

**Yes, this test was performed, but not presented. Added “tests were performed (not presented here) and found the model conserved energy despite different sources of modelled fluxes.”**

Evaluation of VTUF-3D is performed against local-scale fluxes (overall surface-atmosphere exchange), whereas the model is clearly designed to represent detailed microclimates in street canyons (and associated thermal comfort). How does this overall evaluation yield confidence in the model at the microscale/street canyon scale? The calculation of thermal comfort indices is never evaluated, for example, or surface temperatures in the canopy. Please comment in the text why this dataset is chosen, and is possible test against a dataset at the desired scale of application. [I now notice that this is addressed in the conclusions. Please include this context at the start of the evaluation section. I also suggest that the UTCI treatment in Sect. 2.5 is removed and instead introduced in the subsequent article where UTCI is evaluated.]

~~In general, the Mean Absolute Error (MAE) is recommended over the RMSE. See Willmott et al. (2009). I suggest calculation of MAE instead of RMSE.~~

**Added calculations of MBE (instead of MAE) in order to compare to Best & Grimmond (2012) who uses RMSE and MBE.**

The writing is a bit wordy and could be simplified in many locations.

~~Title: HTC -> human thermal comfort~~

Line by line comments

~~P5L36-37: This sentence is unclear - 'matched'? The analytical equations are for what? View factors?~~

**Simplified description in the text, as this functionality exists in the original TUF-3D model.**

~~P5L45-46: What happens to the radiation scattered by the tree? Does it impinge on other surfaces surrounding the tree?~~

**Added clarification, scattered radiation is currently not distributed in VTUF-3D.**

~~P6L41: "thought" seems wrong~~

~~P7L43: Change to "suitably"~~

~~P8L32: "iterative converging Tcan…"? Please clarify.~~

**Simplified. Replace Tconv with Tcan. Iterative converging method to calculate Tsfc then Tcan is fully contained in original TUF-3D model, so is not necessary to detail in this article.**

Eq. 8: Does this yield the same heat flux from vegetation as is calculated by MAESPA? If not, please justify your approach.

Eq. 10: The "2/Tm" portion of the equation does not fit. The storage at street surface should not depend on the temperature of the deepest layer, but should instead be a thickness such that you have a gradient dT/dz. The "2" is unclear. Please check/correct/explain further.

Eq. 11: Third term on RHS seems incorrect. Why A/4 and not A/2? Surely half of the sphere is illuminated. Please check. Secondly, presumably the exposure of a pedestrian in the canyon will differ from the surfaces themselves, and this deserves a contextual comment in the text. Furthermore, Tmrt usually involves a weighting by the direction of the incoming radiation (see VDI guidelines/Rayman articles by Matzarakis). If this is not included, it should be acknowledged in the text.

~~P10L52-P11L8: This section seems unnecessarily wordy and is not exceptionally clear. I recommend rewriting it and focusing on the essentials.~~

**Rewrote the paragraph to clarify the important points.**

~~Fig. 3: Does vegetation/trees affect exchange between building surfaces? Please clarify. Also, text in Fig. 3d is too small~~.

**Increased font sizes.**

~~P11L12: "...in the initial ray tracing…"~~

~~P11L11-16: What about vegetation effects on radiation exchange between building/road surfaces?~~

**Added additional clarifications. Radiation exchanges proceed normally using TUF-3D methods if no vegetation is encountered. Otherwise, additional processing determines radiation exchanges between surfaces and intervening vegetation.**

~~P11L27-29: This sentence needs clarification, particularly "zero to many surface interceptions".~~

**Yes, that was probably written as by a software engineer. The sentence wasn’t really necessary, took it out.**

~~P11L32-33: Diffuse exposure will be affected by changes to the sky view (e.g. a tree beside a large building will receive much less diffuse). Is this accounted for? Please explain/justify in the text.~~

**No, with only two variations, there will be some variations that are not exactly captured. Added “However, these variations will not be able to exactly capture every variation, such as a reduction in diffuse shortwave due to a nearby building.”**

~~P11L33-39: Please communicate this more clearly - I cannot understand what is happening.~~

**Rewrote the paragraph to clarify and removed some unnecessary confusing details.**

~~Sect. 3.1: Consider using "evaluate" instead of "validate" throughout the section/article. Can a model ever be shown to be 'valid' for all situations it might be applied?~~

P12L12-13: Presumably the radiation measurements are much more local.

~~Table 3: Why is internal floor temperature needed if internal air temperature is constant?~~

**This is just a piece of the original TUF-3D model. It is assumed the building interiors are kept to a constant temperature and can impact the amounts of anthropogenic heat generated.**

~~P14L47: I don't think "pluggable" is the appropriate word.~~

~~P15L11: Do these global shortwave values match those measured at Preston and used to force the rest of the model? If not, energy will not be conserved in the model. Yes, this issue is seen later at P16L22-24.~~

**Conservation of energy was also raised by the general comments of reviewer #2. I added a comment to the article that conservation of energy was tested but not presented in the article. The concern is that TUF-3D and MAESPA are different sources of fluxes but this was not found to be a problem. In normal operation of the model, the special circumstances requiring dual sources of forcing data in the Preston evaluation to compare the performance against the observation shouldn’t be necessary and this potential energy conservation problem will not be applicable.**

P15L47: Does VTUF not account for interaction radiatively between the two models at each timestep?

~~P16L58: Units: 294 W m-2.~~

~~P17L4: "The index of agreement, d, …" This is not an error analysis, formally.~~

P21L21-27: The local-scale evaluation does not support this, in my opinion, but the planned evaluation focused on Tair and UTCI will. Remove this paragraph and include it in the subsequent publication?

References

Willmott CJ, Matsuura K, Robeson SM, 2009: Ambiguities inherent in sums-of-squares-based error statistics. Atmos Environ 43, 749-752.

Reviewer #3: This paper presents a detailed explanation and validation of the VTUF-3D model. This model builds upon the functionality of the MAESPA tree process model, but introduces new functions to incorporate enhanced tree shading and evapotranspiration components to adequately model the impact of urban greening on human thermal comfort. The model is well constructed and validated using field observations, and is shown to perform well with only minor limitations.

I believe this model is impressive, and goes a long way toward filling some significant shortcomings of urban canopy modeling. I approach this article from the perspective of urban planning and scenario modeling, and I must admit I have been often underwhelmed by many modeled greening scenarios. In particular, my experience with WRF scenario modeling literature and research has often tended to find albedo far more effective than greening in reducing urban temperatures. This paper helps to confirm my understanding that this type of modeling has not handled the benefits of shading well, which may be why greening scenarios often underperform. This approach gives me far more confidence in the ability to model temperatures in the urban canyon, and I am excited to see its future application.

That being said, I do believe there are some opportunities to strengthen the argument for this method as a tool for planners. The literature review is well structured, and contains many of the papers that came to my mind as I began reading this paper. However, I wanted to call your attention to some other relevant literature beyond Bowler et al. (2010) for your literature review. Regarding tree orientation for cooling and energy savings, I think Donovan & Butry (2009), Rosenfeld & Romm (1996), and Simpson & McPherson (1996) could help structure your argument about optimizing tree orientation. Additionally, Oliviera et al. (2011) and Sanusi et al. (2015) regard specifically street tree orientation and cooling ability. In regards to the QE limitations around page 18, just a few studies came to mind that could inform improvements to the watered impervious surface component: Nakayama et al (2010) and Kim et al (2012).

Finally, regarding your discussion, I believe it would help to provide some specific examples regarding how you see this tool being used by planners. Since your paper is framed as a way to enhance planning strategies to combat heat in a changing climate, it is important to make this connection at the end as well to reach out to the planning community. It is documented in the literature that planners often lack the personal expertise, personnel or time to run and interpret complex models such as the one you have created (Eliasson, 2000; Moser, 2014; Winkler, 2011). Even a short discussion about partnerships or other methods of implementation would go a long way to enrich the discussion. In terms of utility, I would like to see this model used in the species selection process. You currently use existing species in the validation procedure, which makes sense in the context of this paper. But current species may not always be appropriate in a changing climate. This tool could be

useful to determine the impact of various species that may be more appropriate in the future under a new climate regime. Similarly, I see this tool being most useful for long-term planning goals rather than short-term emergency response. I think you will need to further explain your reasoning on page 21, line 26 regarding this model's utility in emergency planning in order to convince planners that it can be used in such a case.

Aside from the above recommendations, I believe this is a strong paper and a promising model.

Detailed notes:

~~Abstract line 17: remove "future" as this sentence describes trends already occurring~~

~~Abstract line 23: Spell out MAESPA acronym for its first use~~

**SPA is Soil-plant-atmosphere but MAESTRO doesn’t stand for anything (Wang, Y.P. and Jarvis, P.G., 1990. Description and validation of an array model - MAESTRO. Agric. For. Meteorol., 51: 257-280.)**

~~Page 1 line 44: change "increases" to "growth"~~

~~Page 1 line 50: "In addition, climate trends point toward…" or "In addition, average and extreme temperatures are increasing in a changing climate"~~

~~Page 1 line 53: "shifting toward a more elderly population" (older and elderly seem similar to me)~~

~~Page 2, line 50: (passive voice) "In coming years, cities and their residents will need to adapt to…"~~

~~Page 3, line 46: spell out MAESPA acronym the first time~~

**(amalgamation of the MAESTRO and SPA (Soil-plant-atmosphere) models)**

~~Page 14, line 3: change "uncertainly" to "uncertainty"~~

~~Page 17: lines 56-57: change to "It is anticipated that this method of tiling out and incorporating vegetating into a micro-scaled surface energy balance model will bring performance…" As it is now, this sentence is very long.~~

~~Page 18, line 3: change to: "The results suggest that this is the case" (current awkward phrasing)~~

Page 18, line 39: use some language to quantify (roughly) the amount of uncertainty here. As stated, I do not know how big a concern this uncertainty would be.

~~Page 18, lines 39-40: "because of the nature of both" is unclear to me. Perhaps "because of inherent uncertainties to both approaches"~~

~~Page 21, lines 23-24: remove "can be developed" at the end of the sentence. Currently not in agreement with the beginning of the sentence. Or, replace with "… how best to best use urban greenery to reduce urban temperatures."~~

~~Page 21, line 26: Please expand on how this model can be used to plan for emergency responses. Currently, this could be overstating the utility of the model, as I see it far more likely to be used as a long-term planning tool, rather than a short-term emergency response tool.~~

**Ok, I replaced the emergency response with understanding how the urban designs respond to extremes. One of the major intended uses of the tool (and major effort in evaluating model performance) is to examine short term extreme heat scenarios.**

References:

Donovan, G. H., & Butry, D. T. (2009). The value of shade: Estimating the effect of urban trees on summertime electricity use. Energy and Buildings, 41(6), 662-668. <http://doi.org/10.1016/j.enbuild.2009.01.002>

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Kim, R., Park, J., Jung-soo, M., & Jung-hun, L. (2012). Reduction Effects of Urban Heat Island by Water-Retentive Pavement. Materials Science Forum, 724, 147-150. <http://doi.org/10.4028/www.scientific.net/MSF.724.147>

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Oliveira, S., Andrade, H., & Vaz, T. (2011). The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. Building and Environment, 46(11), 2186-2194. <http://doi.org/10.1016/j.buildenv.2011.04.034>

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Winkler, J.A., G.S. Guentchev, M. Liszewska, Perdinan, and P.-N. Tan. (2011): Climate scenario development and applications for local/regional climate change impact assessments: An overview for the non-climate scientist. Part II: Considerations when using climate change scenarios. Geography Compass, 5/6, 301- 328. DOI 10.1111/j.1749-8198.2011.00426.x.