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Geoscientific Model Development Discussions

Interactive comment on “The Air-temperature Response to Green/blue-infrastructure Evaluation Tool (TARGET v1.0): an efficient and user-friendly model of city cooling” *by* Ashley M. Broadbent et al.

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Referee #3

This study presents a simple urban climate numerical model aimed at being used as decision support tool by urban planners. The paper first presents the principles and equations of the model, then an evaluation of simulated surface temperatures and air temperatures against remote-sensed observations and in situ measurements, and finally an example of application for urban planning scenarios evaluation. The model is intended to by applied for evaluating urban design choices at very fine scale but is however based on very simple approaches:

Thank you for your comments. We welcome the opportunity to clarify TARGET’s scientific value.

Based on the comments from this referee it is clear that we need to improve communication of TARGET’s purpose and limitations in the manuscript. We have also decided that based on all the referees comments we will recommend a minimum spatial resolution of 100 m. for air temperature simulations This way, the model is not attempting to resolve microscale features. We have redone our analysis at 100 m and have clarified this in manuscript (specific modifications are listed below). We hope that this adjustment will assuage the referees main concerns.

Figures 6,7,8,9,10 and Table 2 have been amended to reflect 100 m resolution simulations rather than the previously used 30 m resolution. Modifying the resolution did not substantially impact the results of the model evaluation of air temperature or the heat mitigation scenario simulations

We also updated the calculation of cooling sensitivity (equation 19) for clarity.

Before getting to some specific issues mentioned by the referee we will make some broader comments here: TARGET is not a microscale model like ENVI-met or TUF3D or CFD approaches - it cannot (and is not designed to) capture micro-scale climate variations that influence human thermal comfort at the scale experienced by an individual. It is designed to be used at the “canyon” to “block” scale - these features fall in the overlap between “micro-” and “local-scales” according to the commonly used nomenclature in urban climatology (see Figure below).

Figure: Time and horizontal space scales of selected urban climate dynamics and wind phenomena (Oke et al., 2017).

The issues discussed above were raised by the other reviewers, and we have added a clarification to the introduction as follows (at P3L23):

“TARGET calculates the average air temperature at street level in urban areas, but does not represent micro-scale variations of radiation exchange or wind flow at the human scale. The model is designed to be used at the urban canyon-to-block scales (100 - 500 m). We recommend a minimum spatial resolution of 100 m for air temperature simulations and 30 m for surface temperature. It can be used to assess the canyon averaged impacts of street scale interventions or larger-scale suburban greening projects. TARGET is climate-service-oriented tool that provides a first order approximation of the impacts of GBI on surface temperature and street level air temperature to provide scientific guidance to practitioners during the planning process.”

We will remove the following sentence (P3 L25): “TARGET is formulated to be applied at the micro-to-local-scales (street-to-precinct scales); meaning it can be used to assess the cooling benefits of small scale interventions (e.g. a single street or small urban park) to suburb scale greening projects”.

Apart from the communication in the original manuscript, we sense that the referee disagrees philosophically with the approach taken. The authors of this paper (and indeed the other 2 reviewers) believe that there is scientific value in a simple and accessible model that can generate first order estimates of local cooling impacts. Such a model will limit complexity wherever it is unnecessary and use simplified physical representations where possible. A fit-for-purpose model balances the level of physical representation, computational efficiency and ease of use appropriately. We believe we have done so here. Relative to more complex urban climate models with more complete physical representations, we use simplified physics in favour of a computationally- and parameter-light and user-friendly model. All models are abstractions of reality. The role of a model developer is to choose the appropriate type and degree of abstraction for the purpose at hand.

There are already many complex urban climate models that can be used by trained

scientists with access to powerful computers. However, these complex models are, by and large, not used by practitioners or environmental consultants who work with policymakers. Therefore, TARGET’s simplicity is by design; motivated by the need for such tools in the planning and policy community. We believe TARGET should be judged with the goals of computational efficiency and accessibility in mind.

We posit that, in many ways, building a simple but reliable model is more difficult than a complex model that includes relatively complete, computationally-intensive physical representation of processes. We believe strongly that a carefully designed and robustly evaluated simple model like TARGET does represent a valuable scientific contribution.

We respond to each comment below.

(1) The concept of urban canyon used in TARGET (without considering various building heights, street directions, street intersections, public spaces like squares etc.) is no more realistic for such spatial resolution.

The canyon approach utilized by TARGET is widely used at the neighbourhood scale: Krayenhoff & Voogt (2010); Yang & Wang (2015); Song & Wang (2015); Broadbent et al., (2018).

More specifically, the reviewer mentions 4 features: “building heights, street directions, street intersections, public spaces like squares”.

Street orientations: The author is correct to point out that TARGET cannot be used to assess the impacts of different street orientations. Street orientation has a substantial impact on wall temperatures and mean radiant temperature (MRT) (Johansson, 2006), but the effect on air temperature is a 2nd order impact, due to atmospheric mixing. This is especially true for relatively low density urban areas/suburban areas (open low rise LCZ5 and LCZ6), which make up the largest proportion of cities (See Figure below from Matthias Demuzere).

We do not believe that the additional data requirements and preprocessing needed to include street orientation is justified for a first order approximation of street level air temperature.

Figure: Global distribution of local climate zones (LCZs) (provided by Matthias Demuzere).

Building heights:

Building height is in fact accounted for. Heterogeneous building heights are included (model resolution average) - these heights ultimately influence the radiation received by the canyon and the heat exchange coefficients. However, it is true to say that TARGET cannot represent sub-grid scale building height heterogeneity. For example, a single tall building amongst lower buildings is not directly accounted for.

Street intersections, public spaces:

Again, these features cannot be explicitly resolved by TARGET (i.e the exact geometry). A intersection or plaza will be represented as a “canyon” without any walls. We believe that the first order impacts of these features are captured by TARGET. Only microscale models (e.g., ENVI-met, TUF3D, CFD models) captures these geometrical features, but those models are orders of magnitude more computationally intensive than TARGET.

(2) Some of the parameterizations are based on many simplifying assumptions, e.g.: ÂżRadiation calculation: it does not account for diffuse/direct partitioning of incoming radiation and applies sky-view factor approach, nor multiple radiation reflections inside the canyon.

The author is correct we do not account for direct / diffuse partitioning of incoming shortwave radiation. We could add this feature to the model but we do not believe it would add much to the air temperature calculation. However, these physics will be more important for future work in human thermal comfort realm. Adding direct/diffuse partitioning increases data input requirements and given our guiding principles of simplicity and low input data requirements it does not seem justified.

The referee is also correct that multiple reflections are not considered.

The calculation for tree canopy are not detailed so that it is not clear if the radiation transmission through foliage canopy is considered etc.

Radiation transmission through tree foliage is not considered. This does needs to be clarified in the manuscript. We propose adding this at P4 L7:

“To represent the first order shading impacts of trees, we effectively represent tree canopy as part of the urban canyon. As shown in Figure 1, the width of the canyon (and therefore the amount of radiation the enters and leaves the canyon) is modulated by the planar area of trees. The simple method, implies that none of the radiation effectively “intercepted” by trees enters the canyon. The area underneath trees (not shown in planar land cover maps) is added to the model to represent the additional thermal mass. This simple approach allows for a first order representation of two major process associated with trees: solar shading and longwave trapping.”

Storage heat flux: it is calculated following an empirical formulation with constant coefficients (Eq. 5). It is not clear how they are prescribed (despite biblio references), and how they could make possible to represent the spatial heterogeneity of urban material properties.

The OHM parameters are taken from the literature and are prescribed for each land cover category, as indicate by literature references indicated in Table 1.

Spatial heterogeneity:

The surface heterogeneity of surface types that can be simulated (e.g. dry grass, irrigated grass, asphalt, concrete, buildings etc), is consistent with other microclimate models e.g. ENVI-Met. The land cover categories chosen for TARGET are representative of typical categories found in urban land cover maps that practitioners usually have access to. Adding additionally land cover categories/heterogeneity would increase input data requirements and must be avoided.

(3) To run the surface model in offline mode, i.e. without retro action of surface processes on the low-level atmospheric conditions and without horizontal advection effect, is also a strong limitation. The spatial extend of cooling effects of green or blue infrastructures cannot be correctly captured.

The referee is correct that the model uses an offline method - and it is correct to state that low-level atmospheric mixing is not captured in the model. There are no low computational cost methods for representing atmospheric mixing to our knowledge.

Further, a benefit of excluding advection is that the cooling effects of green infrastructure are “entirely local” - i.e. no horizontal mixing. We would argue that this is a useful way to report cooling magnitudes as practitioners can more easily understand a “maximum local” benefit associated with design proposal. Secondly, advection is case specific - its direction and magnitude will vary throughout the day and between individual days, which is not useful for generalized (i.e., time-averaged) results of the type typically sought by planners and policy makers. Again, omission of advection functions to create a fit-for-purpose model.

This is explained at P22L4:

“For computational efficiency, the model assumes no horizontal advection (inside or above) the UCL. In general, advection reduces the local impacts (i.e. cooling directly adjacent the cooling intervention) of GBI due to atmospheric mixing, and therefore we expect TARGET to provide estimates of near maximum cooling benefits at the scale of model application. In reality, cooling effects will be diminished somewhat by advection, especially during the day and during high wind conditions.”

The evaluation of TARGET surface temperatures on the first experimental site is good. But there is very little details about how this evaluation is done and what experimental data are used.

Below is what we have in manuscript on model evaluation - we have added some details in quotations marks below (P12L23):.

“To test model performance at simulating Tsurf of different land cover classes and perform sensitivity analysis on a number of model parameters, we used ground-based observations of Tsurf from the Melbourne metropolitan area. Coutts et al. (2016) deployed infrared temperature sensors (SI-121 - Apogee), during February 2012 “(5 min averages)”, across a range of land cover types including: asphalt, concrete, grass, irrigated grass, steel roof, and water. “Infrared sensors were mounted above the aforementioned surface types installed at heights of approximately 1.5–2 m”. The conditions during this period represented near-typical summertime conditions in Melbourne; including a number of days (15th, 24th, and 25th February) where air temperature exceeded 30 C (see Fig. 11). These hotter days were characterised by northerly winds, which bring hot and dry air from Australia’s interior, and often result in heatwave conditions in Melbourne. Additionally, there was at least one cloudy day where incoming shortwave radiation (KâĘŞ) dropped significantly and negligible amount of rainfall occurred (17th February). “To compare the Coutts et al. (2016) observations with TARGET we ran the model for each surface type (i.e. 100 % grass or roof etc) with radiation forcing data from the Melbourne Airport weather station during the time period in question. The Tb calculation was not needed since we only calculated Tsurf for this part of the model evaluation. The 30 min output from TARGET was compared with Tsurf observations and statistics were calculated.”

The evaluation for the second site shows important biases of the model both for surface temperature and air temperature. This clearly highlights the limitations of the model to accurately simulate the urban climate at such a fine scale, and especially to reproduce the spatial variability of microclimate depending on urban landscape heterogeneity. The comparison to fixed stations data for air temperature shows important biases with an overestimation of air temperature in built-up environments and an underestimation in vegetated environments. One can then expect an important overestimation of the cooling effect of green infrastructures in case of greening scenarios evaluation. In conclusion, the simplicity of the numerical tool makes it not suitable for microscale urban climate modelling, and for an accurate evaluation of urban design strategies. In the light of this finding, I do not recommend the publication of this paper.

We appreciate the referee's concern, and we disagree with their assessment.

Firstly, the model biases mentioned by the referee are expected given the aforementioned lack of advection but should be clarified to (P17L11):

"The modelled air temperatures are biased towards warmer air temperature in urban areas and cooler air temperature in rural areas. These biases are partly driven by the lack of advection in the model. Without atmospheric mixing, the local impacts of pervious and impervious surfaces are exaggerated causing an additional cooling and warming effect in rural and urban areas, respectively."

Nevertheless, we disagree with the suggestion that model performance is poor, particularly when the wider context of urban model evaluation is considered. The most widely used model in urban microclimate modeling is ENVI-met.

Please find a summary table of ENVI-met studies below with comparable model biases to those reported in this study. There are many ENVI-met studies and a complete summary is not possible here - the table below includes a cross-section of studies from different locations with comparable model performance to TARGET.

Note that most of these studies evaluate their findings against a mere 1 or 2 stations. An evaluation of ENVI-met against 27 dispersed weather stations (i.e. not a transect) would not be possible given the computation demand. As such, we believe that the evaluation in this paper is robust and demonstrates acceptable model performance given the model simplicity. As such, we disagree with the implication that the model performance is poor.

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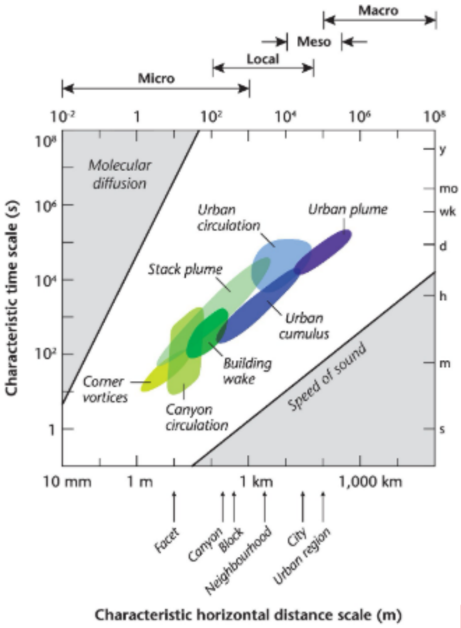


Figure: Time and horizontal space scales of selected urban climate dynamics and wind phenomena (Oke et al., 2017).

Fig. 1.

street orientation is justified for a first order approximation of street level air temperature.

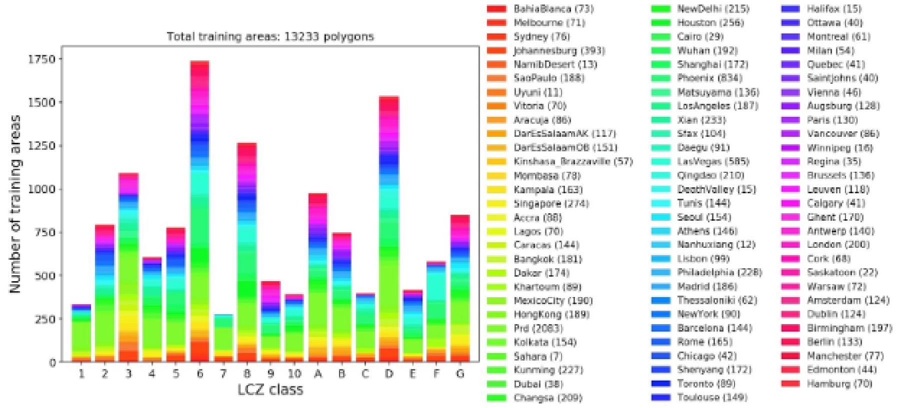
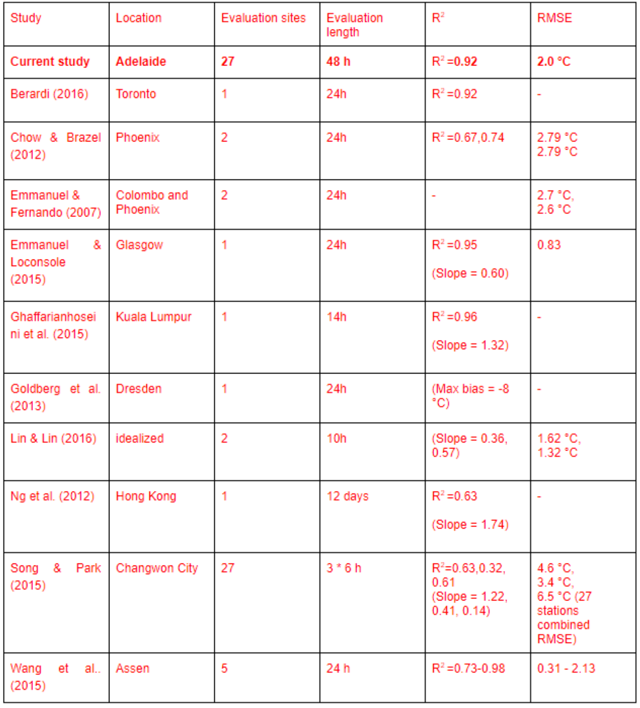


Figure: Global distribution of local climate zones (LCZs) (provided by Matthias Demuzere).

Fig. 2.

Summary of ENVI-met microscale studies



Study	Location	Evaluation sites	Evaluation length	R²	RMSE
Current study	**Adelaide**	**27**	**48 h**	**R^2 =0.92**	**2.0 °C**
Berardi (2016)	Toronto	1	24h	R^2 =0.92	-
Chow & Brazel (2012)	Phoenix	2	24h	R^2 =0.67,0.74	2.79 °C 2.79 °C
Emmanuel & Fernando (2007)	Colombo and Phoenix	2	24h	-	2.7 °C, 2.6 °C
Emmanuel & Loconsole (2015)	Glasgow	1	24h	R^2 =0.95 (Slope = 0.60)	0.83
Ghaffarianhoseini et al. (2015)	Kuala Lumpur	1	14h	R^2 =0.96 (Slope = 1.32)	-
Goldberg et al. (2013)	Dresden	1	24h	(Max bias = -8 °C)	-
Lin & Lin (2016)	idealized	2	10h	(Slope = 0.36, 0.57)	1.62 °C, 1.32 °C
Ng et al. (2012)	Hong Kong	1	12 days	R^2 =0.63 (Slope = 1.74)	-
Song & Park (2015)	Changwon City	27	3 * 6 h	R^2=0.63,0.32, 0.61 (Slope = 1.22, 0.41, 0.14)	4.6 °C, 3.4 °C, 6.5 °C (27 stations combined RMSE)
Wang et al. (2015)	Assen	5	24 h	R^2 =0.73-0.98	0.31 - 2.13

Fig. 3.