An Evaluation of Mean Radiant Temperature Estimations in an Arid Urban Climate

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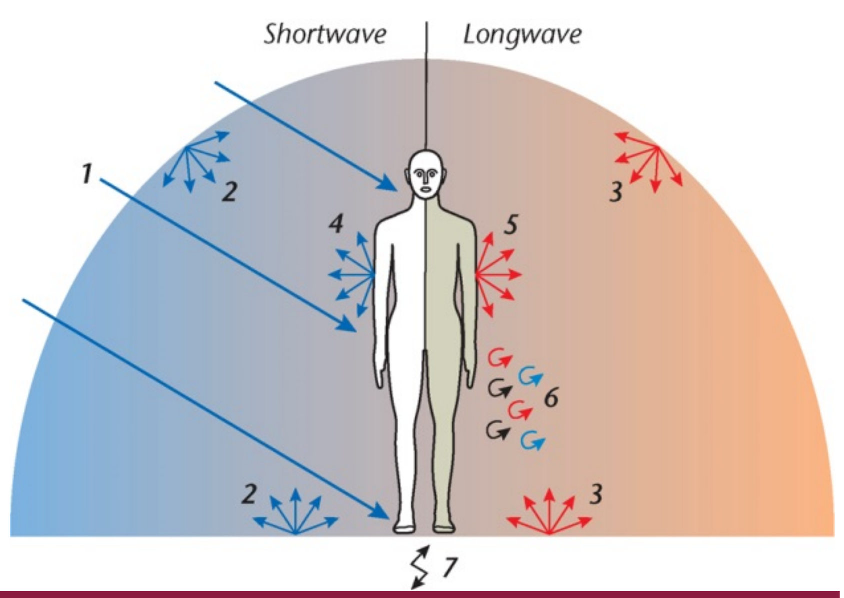
Introduction

- Urban thermal conditions are a growing health concern[1-2]
- Mean radiant temperature (T_{MRT}) improves thermal environment estimation (Fig. 1)[3]
- Radiation loads are dependent on urban form[4]
- We seek to understand the efficacy of and limitations to Rayman[5] and ENVI-met[6,7] models for T_{MRT} and compare them to physical measurements in downtown Tempe, AZ, USA[8]

Figure 1. Energy exchanges at the surface of the human body. (1) Direct SW rad, (2) diffuse SW rad, (3) diffuse LW rad, (4) reflected LW rad, (5) emitted LW rad, (6) convective heat loss, and (7) conductive heat exchange. Adapted from Oke et al., 2017, *Urban Climates* © Cambridge University Press 2017



Methods

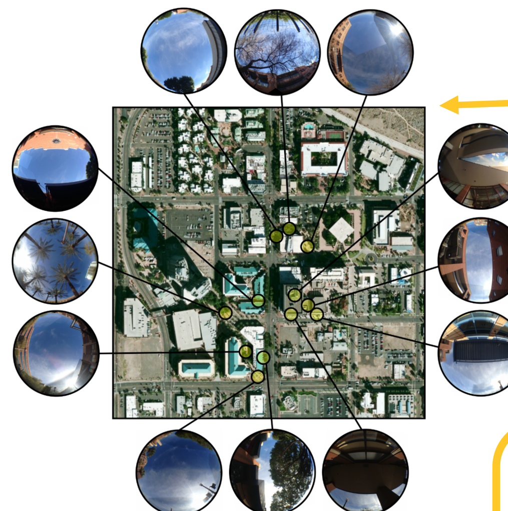


Figure 2. Downtown Tempe, Arizona, USA with fisheye lens imagery for each point along traverse. The lens imagery is input for Rayman software calculations.

Figure 3. Kestrel Heat Stress Tracker, 4600 series.

Figure 4. The cart specially adapted for fine-scale measurement of mean radiant temperature, MaRTy[9].

Figure 5. FLIR visible and thermal imagery from traverse route.

Results

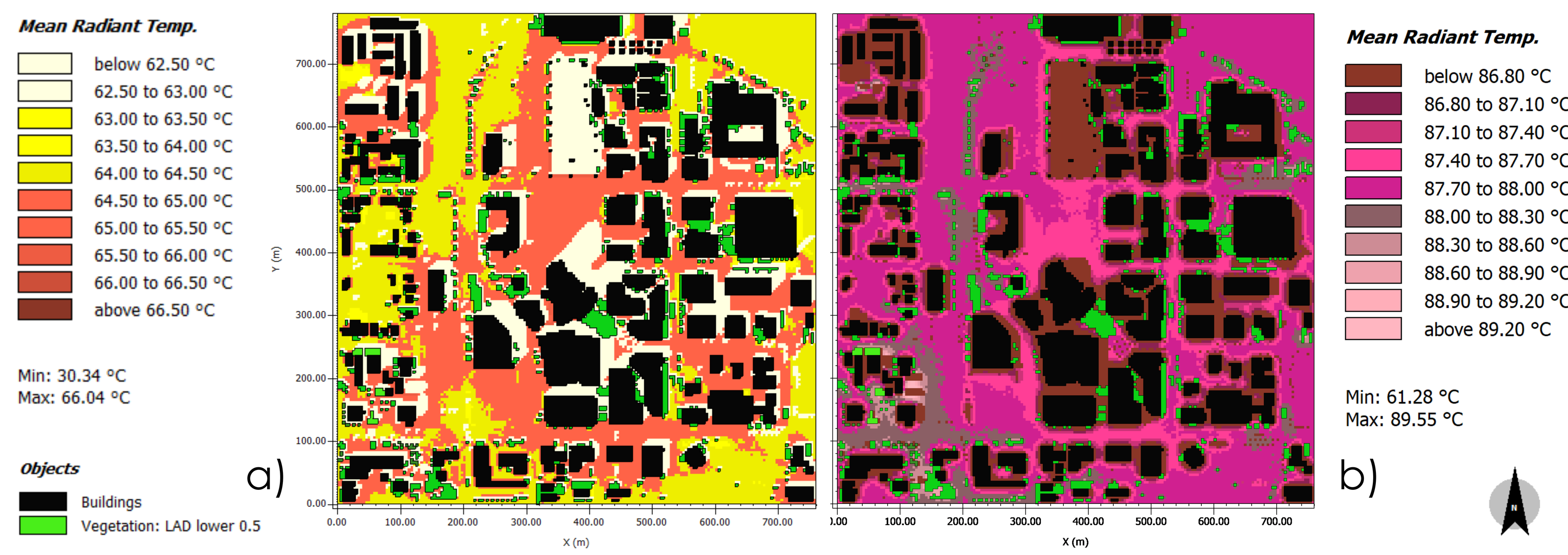


Figure 6. *ENVI-met simulated T_{MRT} for 3 pm in (a) February 2015 and (b) June 2017.*

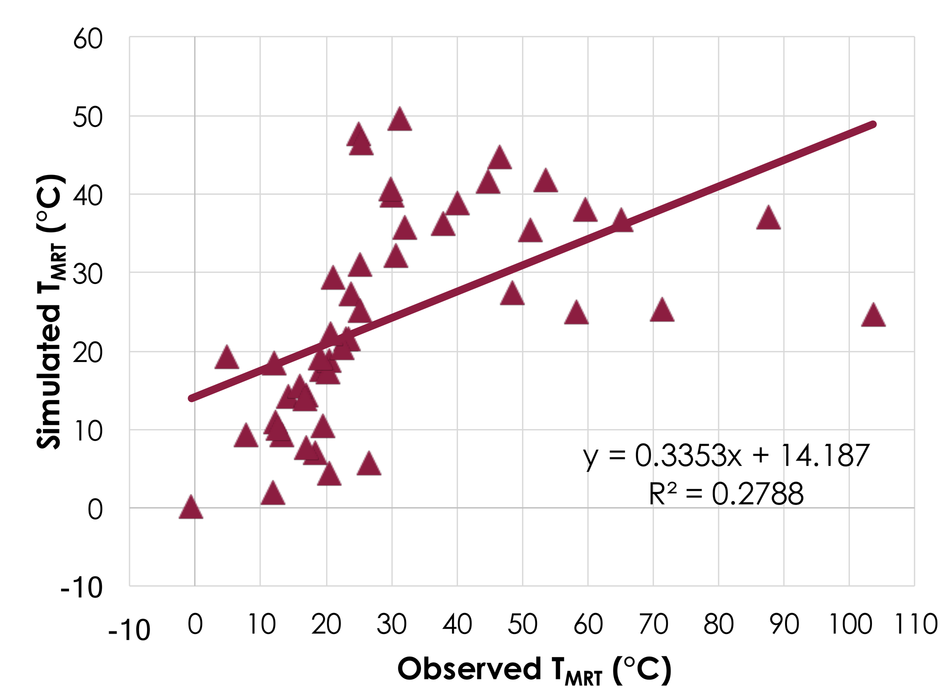


Figure 7. Linear regression of February 2015 mean radiant temperature (from Kestrel) for Rayman.

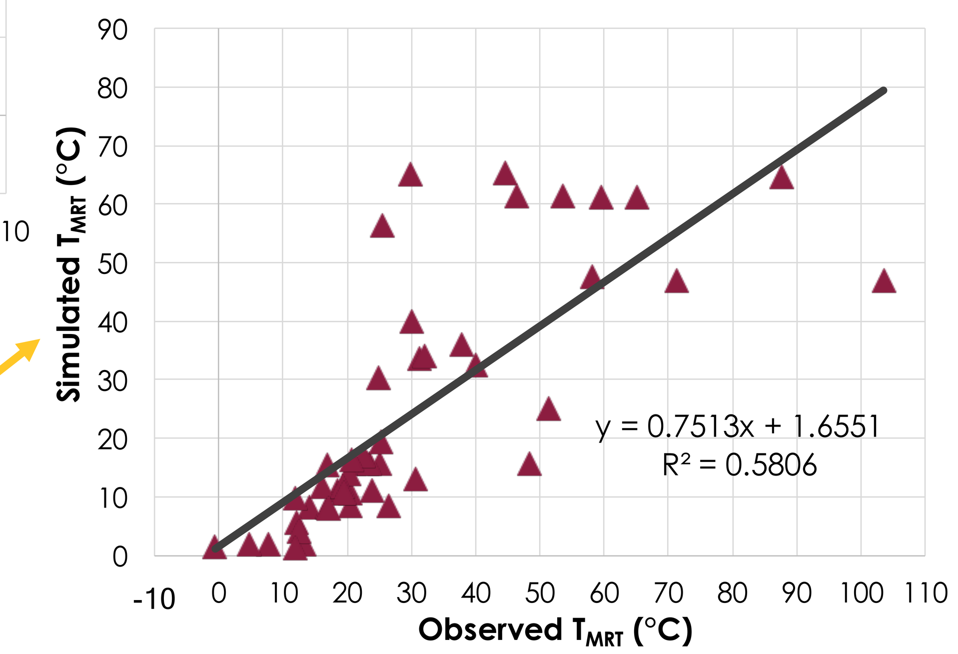


Figure 8. Linear regression of February 2015 mean radiant temperature (from Kestrel) for ENVI-met.

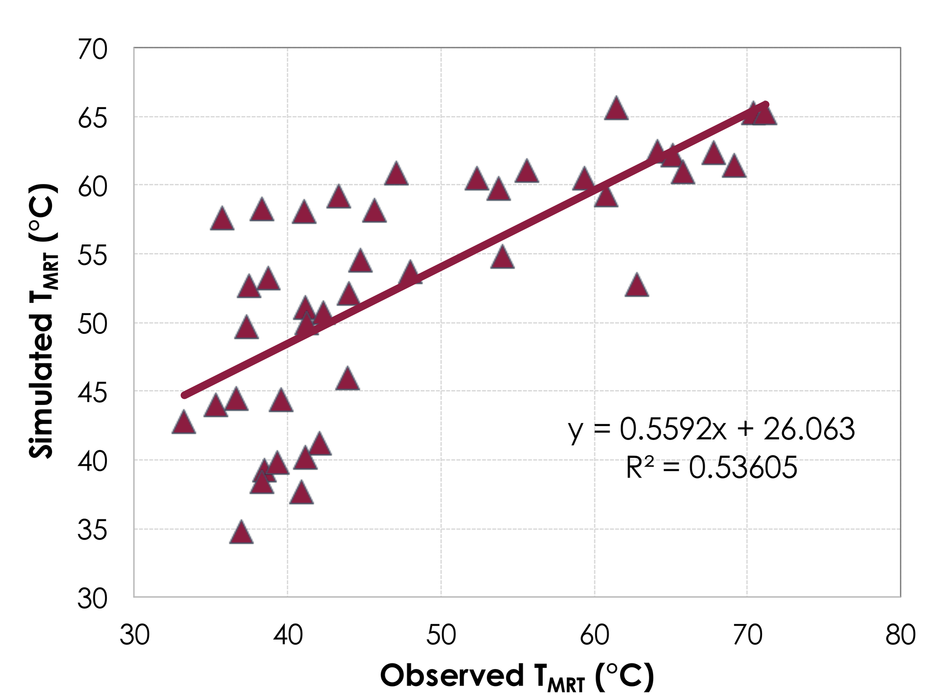


Figure 9. Linear regression of June 2017 mean radiant temperature (from MaRTy) for Rayman.

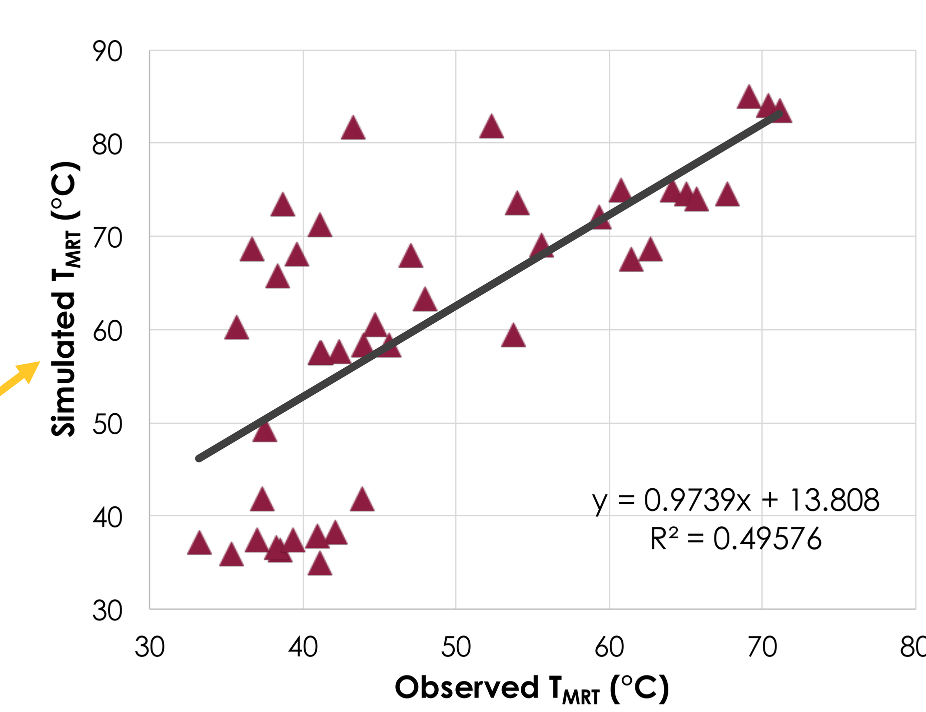


Figure 10. Linear regression of June 2017 mean radiant temperature (from MaRTy) for ENVI-met.

Discussion

Table 1. Dimension of errors for Rayman and ENVI-met simulations relative to observed mean radiant temperature

Simulation	RMSE	RMSE Unbias	RMSE Systematic	MeanBias Error	Mean Error	Wilmott Index	n
Rayman_Kestrel	18.716	12.080	12.900	-5.837	11.163	0.653	49
Rayman_MaRTy	9.141	5.935	6.952	4.800	7.280	0.992	42
ENVI-met_Kestrel	15.388	13.267	7.796	-5.837	11.249	0.850	49
ENVI-met_MaRTy	16.827	11.205	12.553	12.550	13.549	0.977	42

Conclusions

- MaRTy results indicate better congruence with modeled T_{MRT} than Kestrel observational data
  - Wilmott Index of Agreement gives a standardized evaluation metric
- Error dimensions decrease with higher sun angles
  - Sun angle is important for estimating T_{MRT} in deep urban canyons
- Rayman & ENVI-met perform well in T_{MRT} estimation
  - Variation in agreement attributed to SVF input (Rayman) and grid resolution (ENVI-met)
- MaRTy incorporates more radiation data to calculate T_{MRT} and thus is a better fit to numerical models.
  - Highly relevant to arid climates with complex, deep urban canyons.

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References

[1]Census, U., 2010: 2010 Census Urban and Rural Classification and Urban Area Criteria. https://www.census.gov/geo/reference/ua/urban-rural-2010.html (Accessed May 30, 2018).
[2]Chen, L., and E. Ng, 2012: Outdoor thermal comfort and outdoor activities: A review of research in the past decade. Cities, 29, 118–125, doi:10.1016/j.cities.2011.08.006
[3]Mayer, H. & Höppe, P. Theor Appl Climatol (1987) 38: 43. https://doi.org/10.1007/BF00866252
[4]Krüger, E. L., F. O. Minella, and F. Rasia, 2011: Impact of urban geometry on outdoor thermal comfort and air quality from field measurements in Curitiba, Brazil. Build. Environ., 46, 621–634, doi:10.1016/j.buildenv.2010.09.006. http://dx.doi.org/10.1016/j.buildenv.2010.09.006.
[5]Matzarakis, A., Rutz, F., Mayer, H., 2007. Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. Int. J. Biometeorol. 54, 131–139. https://doi.org/10.1007/s00484-009-0261-0
[6]Bruse, M., Fleer, H., 1998. Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model. Environ. Model. Softw. 13, 373–384. https://doi.org/10.1016/S1364-8152(98)00042-5
[7]Crank, P. J., D. J. Sailor, G. Ban-Weiss, and M. Taleghani, 2018: Evaluating the ENVI-met microscale model for suitability in analysis of targeted urban heat mitigation strategies. Urban Clim., 26, 188–197, doi:10.1016/j.uclim.2018.09.002. https://linkinghub.elsevier.com/retrieve/pii/S2212095518301007
[8]Crewe, K., A. Brazel, and A. Middel, 2016: Desert New Urbanism: testing for comfort in downtown Tempe, Arizona. J. Urban Des., 21, 746–763, doi:10.1080/13574809.2016.1187558. http://dx.doi.org/10.1080/13574809.2016.1187558.
[9]Middel, A. and Krayenhoff, E.S. Micrometeorological determinants of pedestrian thermal exposure during record-breaking heat in Tempe, Arizona, USA, Science of the Total Environment, in preparation.

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