

# VTUF-3D: An urban micro-climate model to assess temperature moderation from increased vegetation and water in urban canyons

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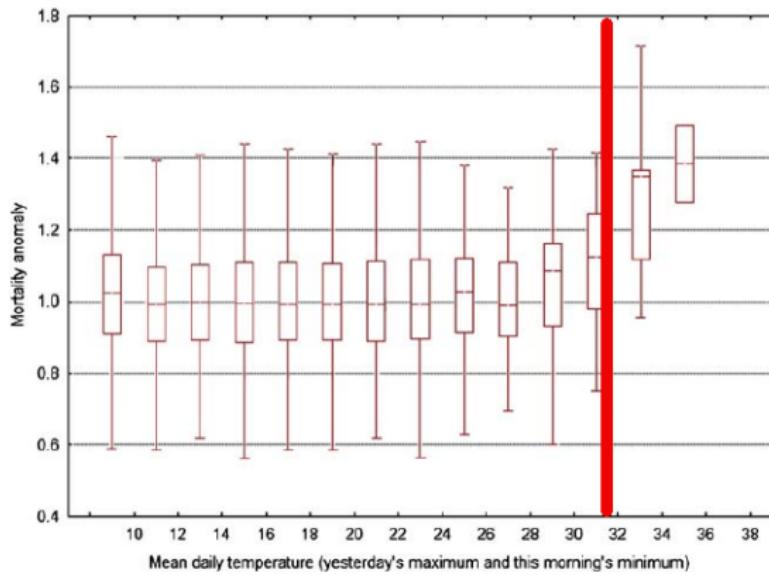
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MONASH University

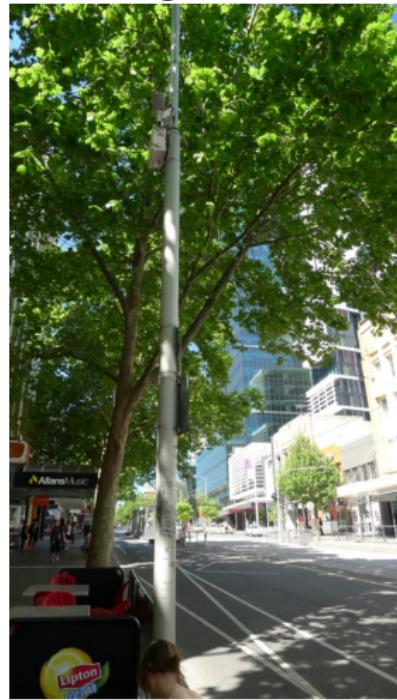
# Introduction

## Heat health thresholds

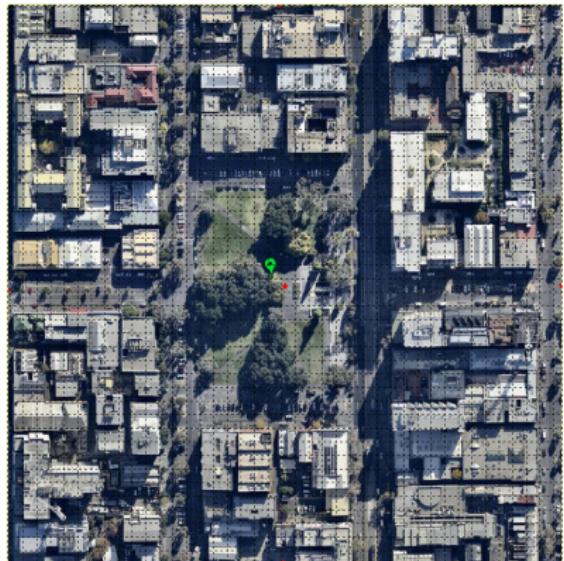


(Nicholls et al., 2008)

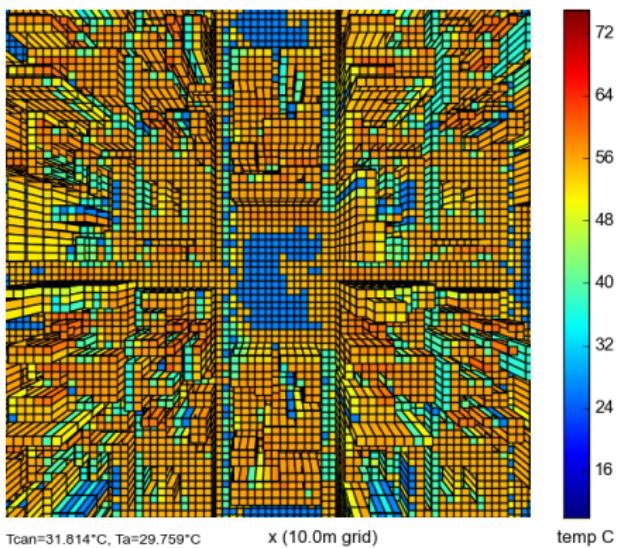
## Trees cooling streets



# Micro-climate modelling



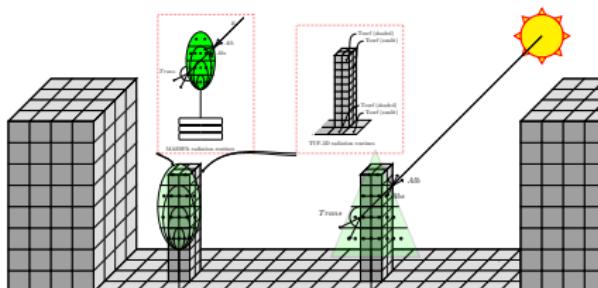
LincolnSqRun3-400m-30Days - Tsfc 2014-01-13-1600



Modelling cooling effects of trees at a microscale

# VTUF-3D energy balance modelling with MAESPA tiles

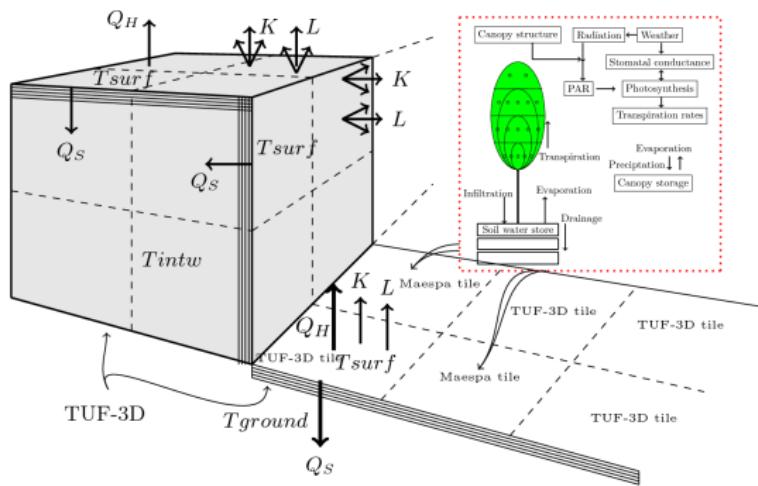
- Modifications to TUF-3D (Krayenhoff and Voogt, 2007) to resolve urban canyon radiation flux movement using placeholder vegetation structures which call MAESPA (Duursma and Medlyn, 2012) vegetation absorption, transmission, and reflection routines.
- VTUF-3D uses cube shaped structures (as TUF-3D uses to represent buildings) to represent vegetation. These cubes store the surface properties and states and interact with the rest of the VTUF-3D domain.
- The vegetation's true shape is represented in MAESPA and calls underlying MAESPA routines to calculate the vegetation's interactions with the urban canyon and radiation movement.



Integration of MAESPA tree model into VTUF-3D radiation fluxes routines

# VTUF-3D energy balance modelling with MAESPA tiles

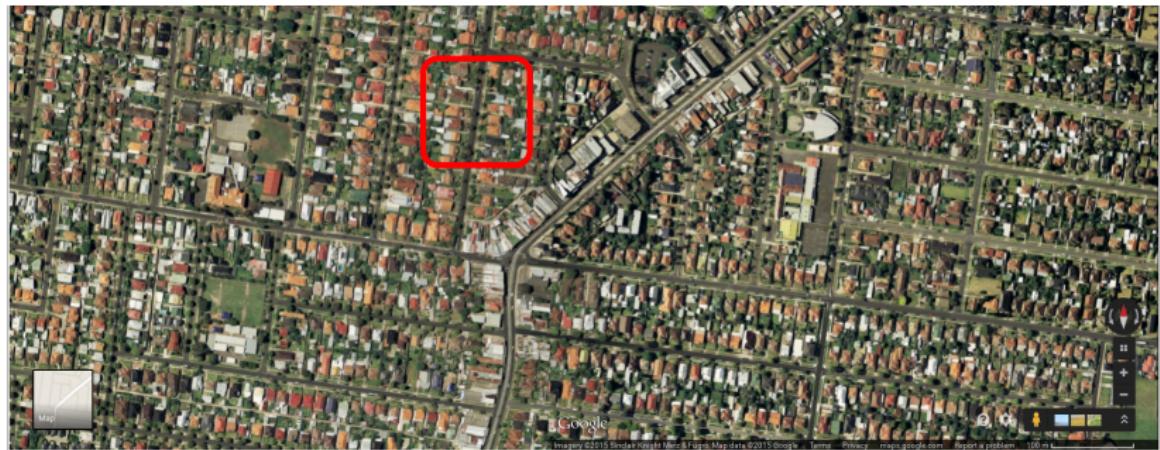
- Using a novel approach, MAESPA tiles replaces VTUF-3D ground surfaces with vegetated MAESPA surfaces and use MAESPA's photosynthesis and water cycle routines to modify VTUF-3D's energy balance calculations.
- Each embedded MAESPA surface calculates a full 3 dimensional tree (along with associated soil and movement of water within the stand) and feeds results back to VTUF-3D ground surface energy balances.



VTUF-3D energy balance modelling with vegetation MAESPA tiles

# Model testing and validation using Preston dataset

- Preston - homogeneous, medium density.
- Data set contains complete energy flux observations recorded 2003-2004, allowing validation of surface energy balances
- Modelled area (500x500m) chosen is representative of overall area observed by flux tower



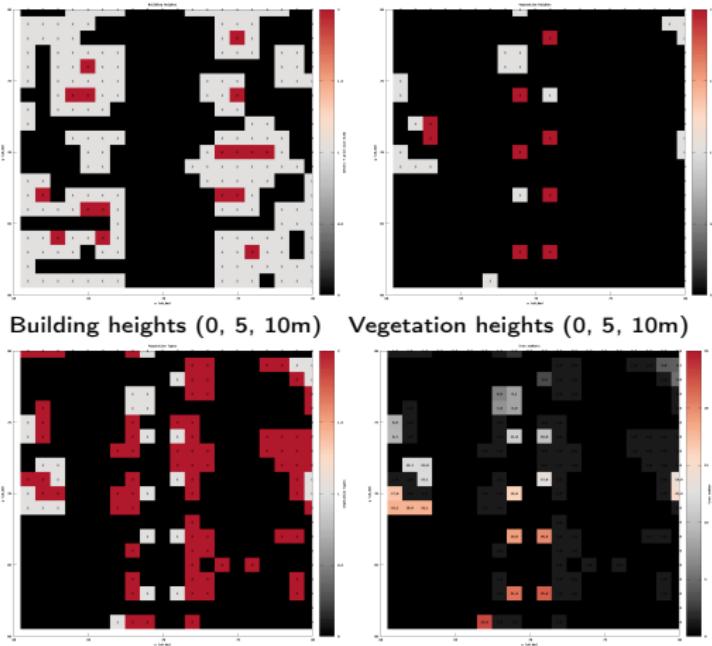
(Google 2015)

# Model testing and validation using Preston dataset

Mix of vegetation types: grass (18.5%), olive and brushbox trees (7.25%).  
Medium density area (46.75% buildings). 27.5% impervious surfaces.



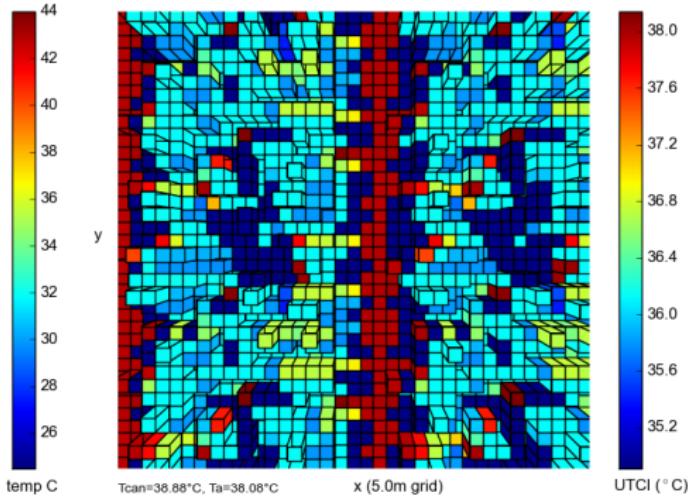
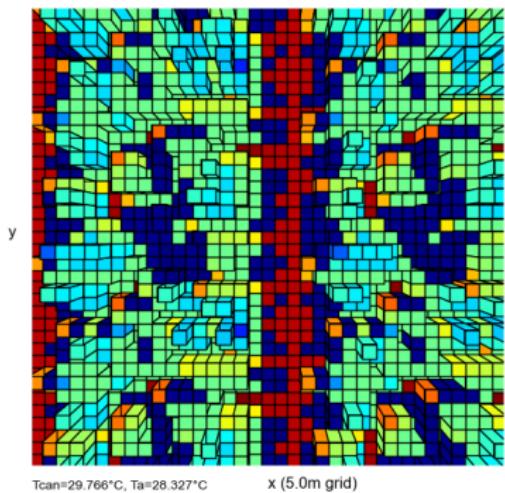
Digitization of Preston suburban street.  
(1=building heights, 1=vegetation heights)



# Model results using Preston dataset

Hourly results for Tsfc and UTCI for 14 Februry 2004

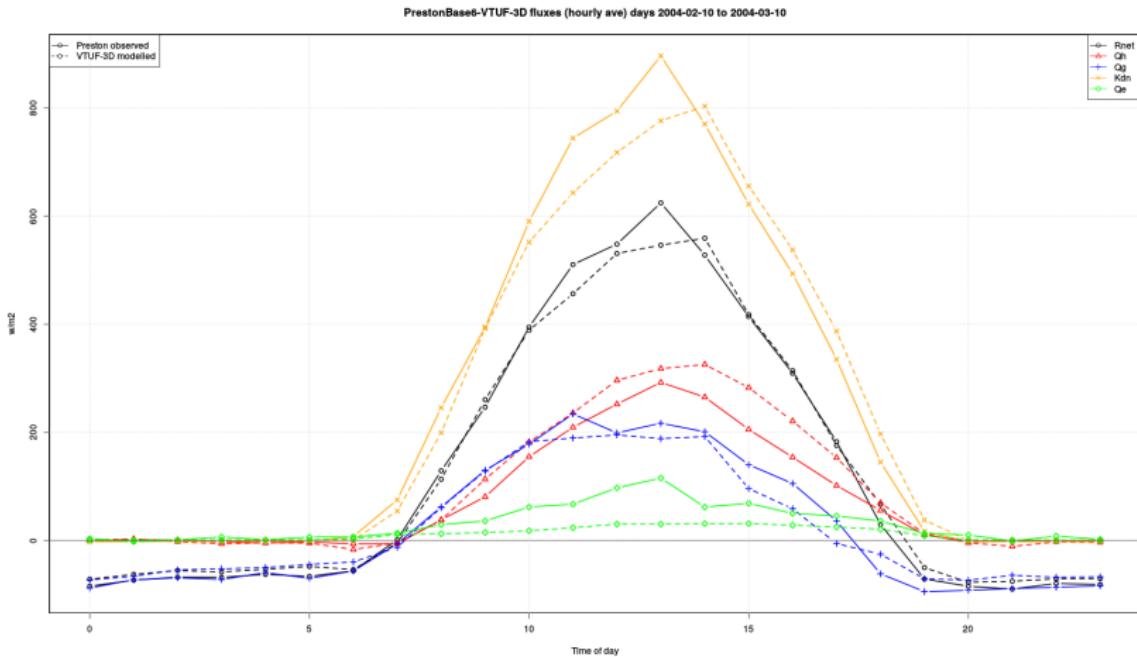
PrestonTest9NewDomain30Days - Tsfc 2004-02-14-1100 PrestonTest9NewDomain30Days - UTCI at 2004-02-14-150



(UTCI is a human thermal comfort index combining air temperature, surface temperature, wind, humidity, radiation load, etc. into a 'feels like' equivalent temperature.)

# Model testing and validation using Preston dataset

## 30 day hourly average flux comparisons to Preston flux observations



# Model testing and validation using Preston dataset

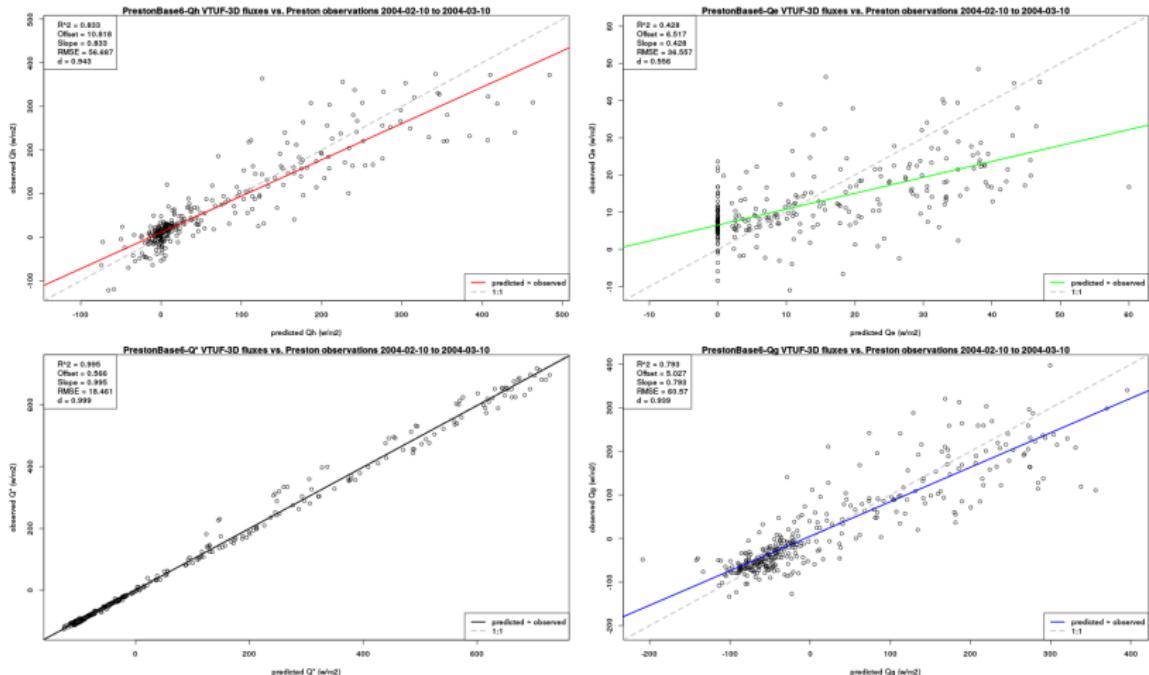


Figure : PrestonBase6 predicted vs. observations

# Model testing and validation using Preston dataset

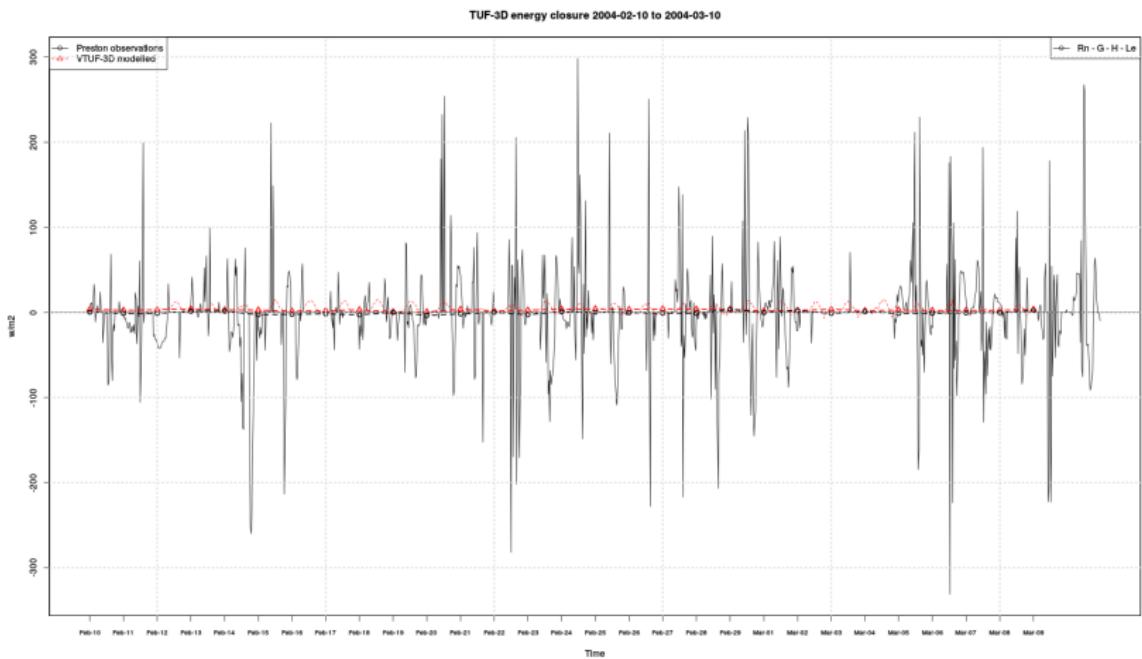
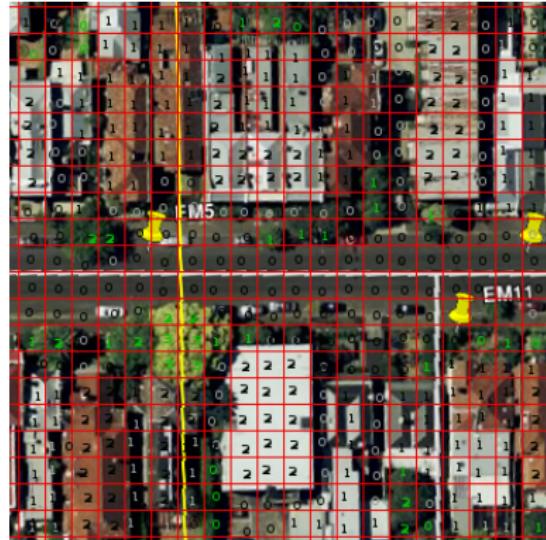


Figure : PrestonBase6 energy closure (VTUF-3D and observations),  
 $Q^* - Qg - Qh - Qe = 0$

# Model validations and scenarios using City of Melbourne, George and Gipps St datasets

Shallow urban canyons (ave building heights 7 and 8m, H:W 0.32 and 0.27) with varying canopy cover (45% and 12%)



Validation against 4 and 3 observation stations located on street

# Model validations and scenarios using City of Melbourne, George and Gipps St datasets

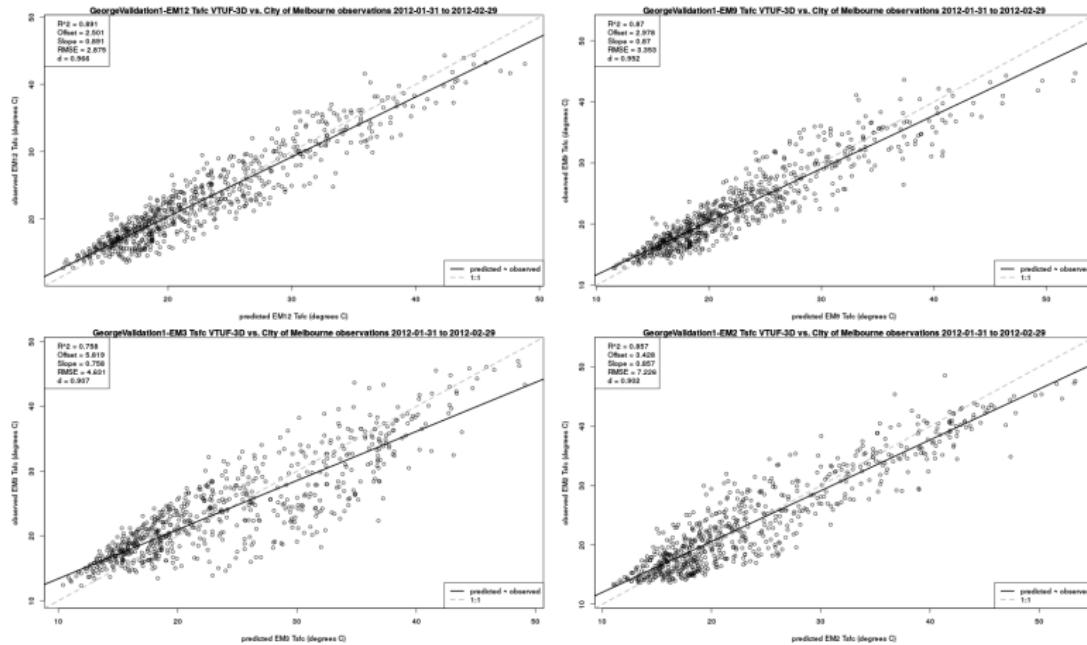


Figure : George St. point comparison of Tsfc of 4 observation stations to modelled points

# Model validations and scenarios using City of Melbourne, George and Gipps St datasets

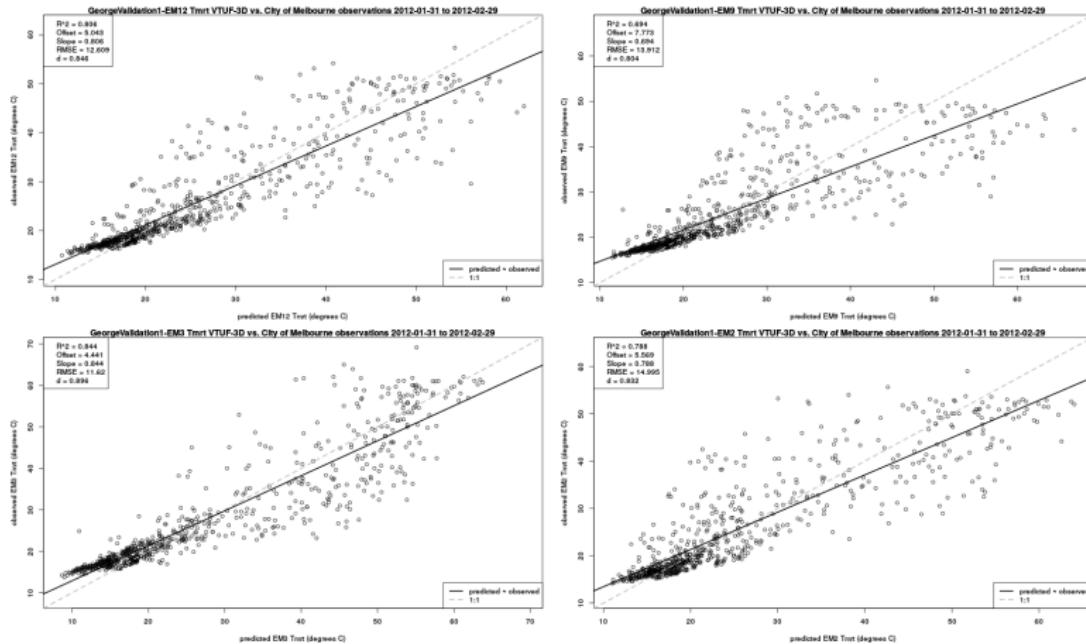


Figure : George St. point comparison of Tmrt of 4 observation stations to modelled points

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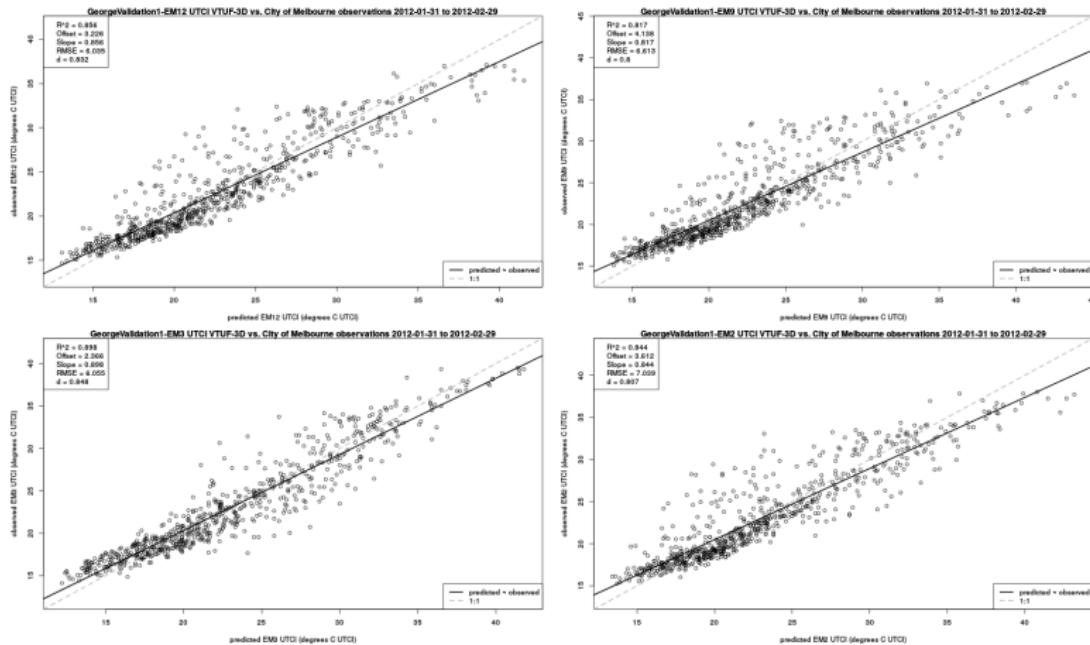
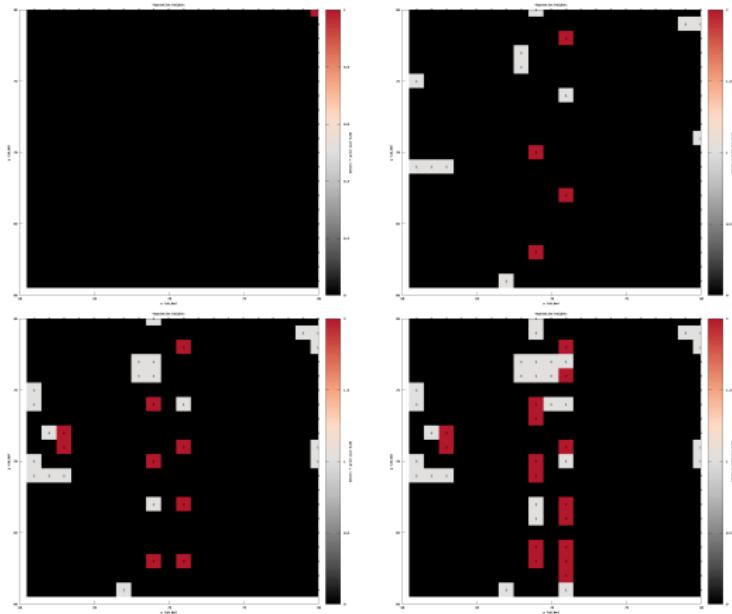


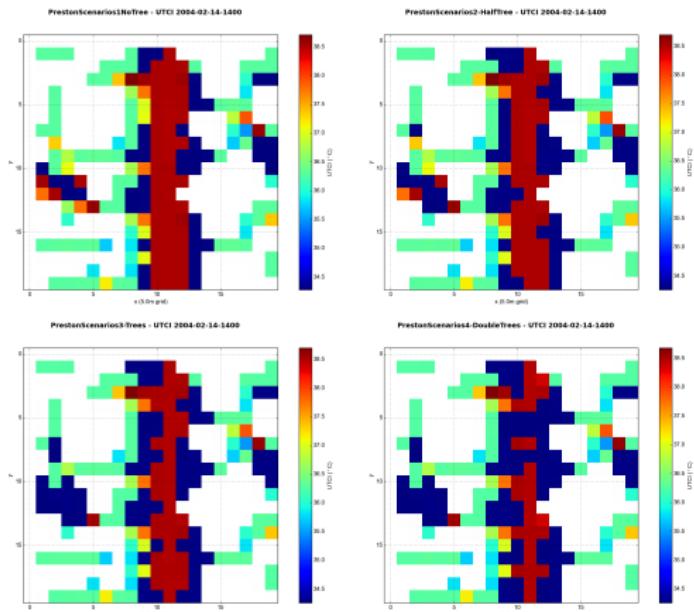
Figure : George St. point comparison of UTCI of 4 observation stations to modelled points

# Preston Scenarios-tree configurations



- 4 scenarios of zero trees, half trees, existing Preston tree canopy cover, and double trees

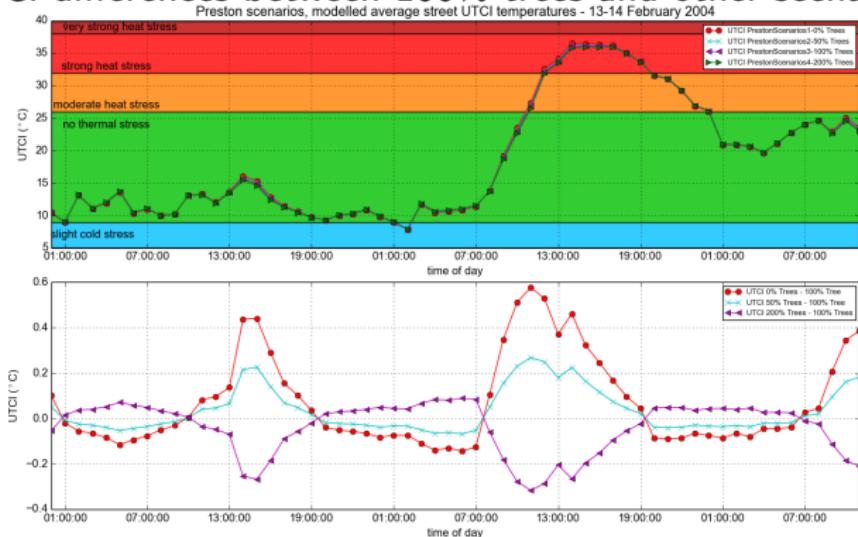
# Preston Scenarios-UTCI at 0m



- UTCI (street level, 0m, average) variations of  $0.9^{\circ}\text{C}$  between zero tree scenario and double trees
- Double trees scenario gives  $0.3^{\circ}\text{C}$  UTCI reduction over existing Preston tree canopy

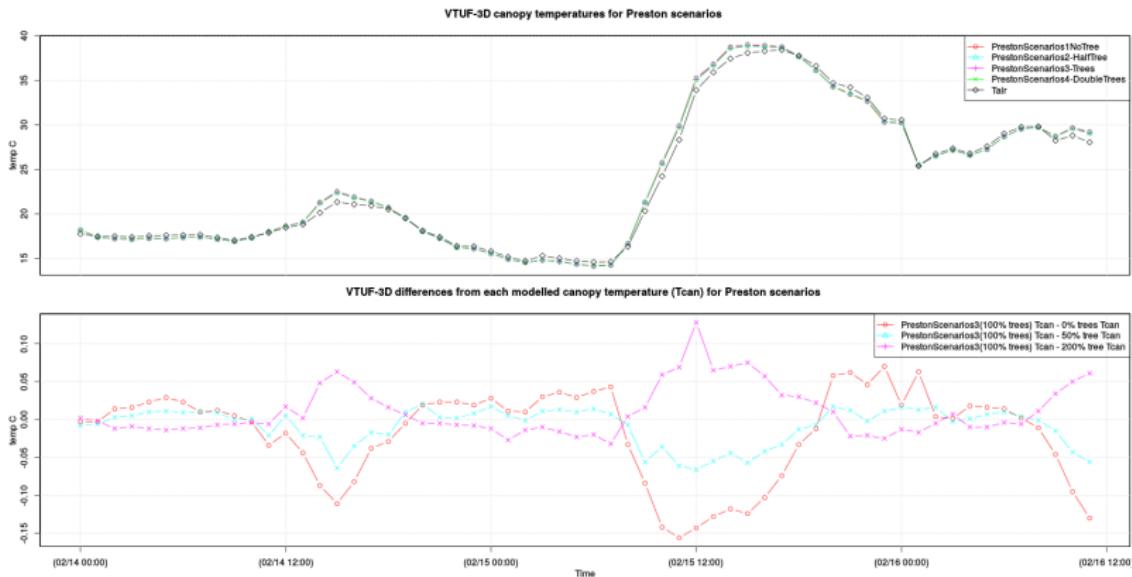
# Preston Scenarios-UTCI differences between scenarios

Modelled UTCI of 4 scenarios over 13-14 February 2004 /  
UTCI differences between 100% trees and other scenarios



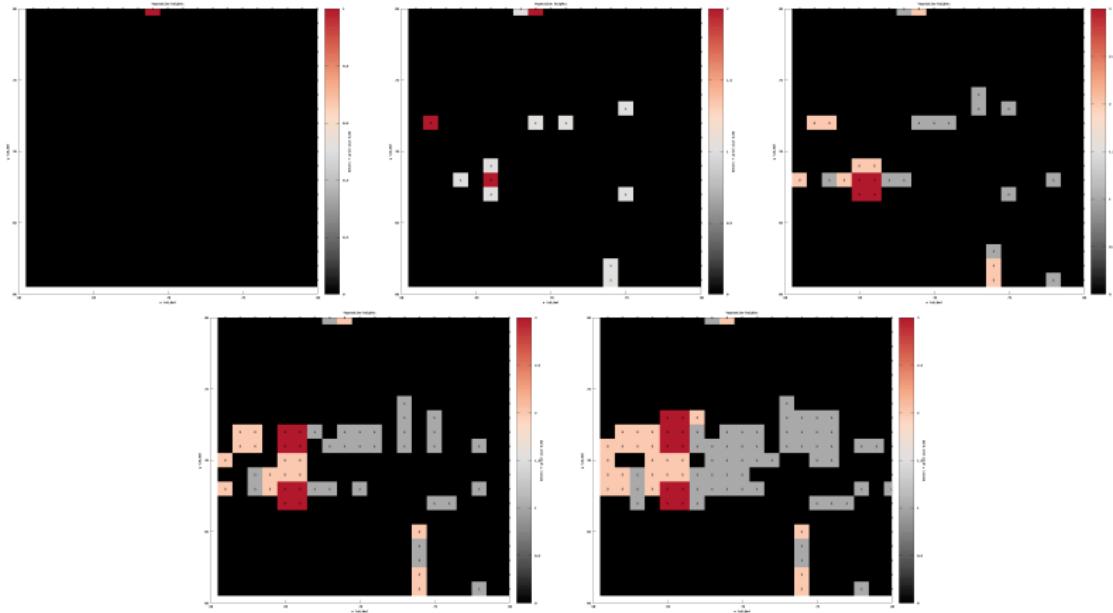
- UTCI (street level, 0m, average) variations of  $0.9^{\circ}\text{C}$  between no tree scenario and double trees
- Double trees scenario gives  $0.3^{\circ}\text{C}$  UTCI reduction over existing Preston tree canopy

# Preston Scenarios-Canopy temperatures



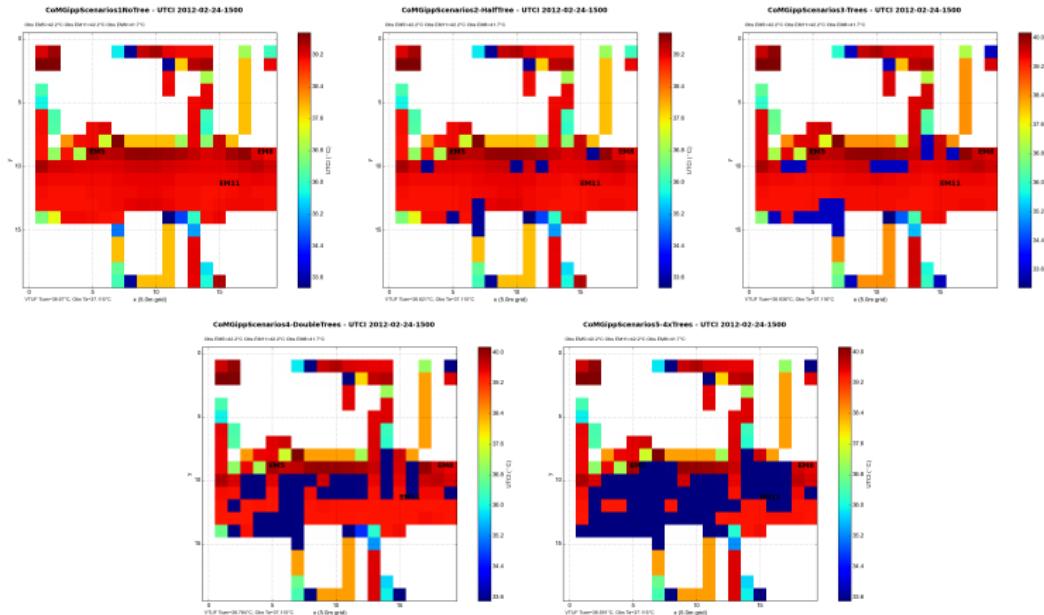
Modelled Tcan of 4 scenarios over 13-14 February 2004 /  
Tcan differences between existing tree canopy and other scenarios

# City of Melbourne Gipps St Scenarios-tree configurations



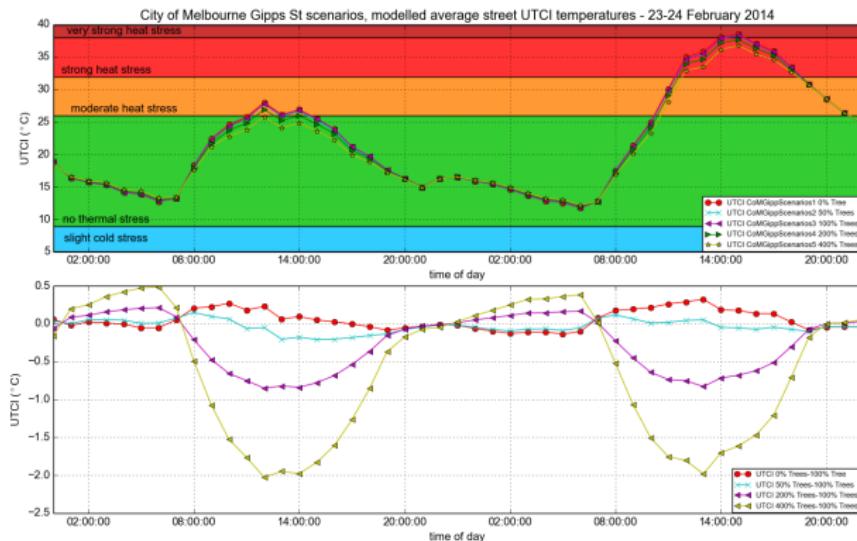
- 5 scenarios of zero trees, half normal trees, existing Gipps St tree canopy cover, double trees, and 4x trees.

# City of Melbourne Gipps St Scenarios-UTCI at 0 meters



- UTCI (averaged at 0m height) maximum variations of  $1.0^{\circ}\text{C}$  between Gipps St. zero tree scenario and double trees.

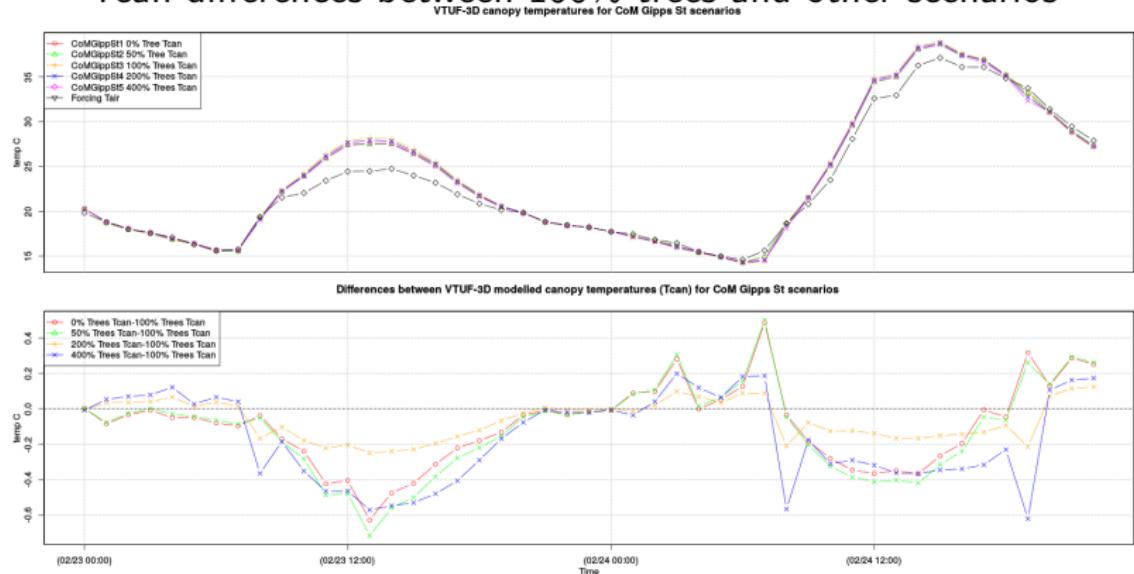
# City of Melbourne Gipps St Scenarios-UTCI differences between scenarios



- UTCI (averaged at 0m height) maximum variations of  $1.0^{\circ}\text{C}$  between Gipps St. zero tree scenario and double trees, while  $2.3^{\circ}\text{C}$  between zero and 4x tree scenario.

# City of Melbourne Gipps St Scenarios-Canopy temperatures

Modelled Tcan of 4 scenarios over 23-24 February 2014 /  
Tcan differences between 100% trees and other scenarios



Canopy temperature differences range from 0.2°C to 0.4°C .

- Preliminary modelling with VTUF-3D shows UTCI temperature reductions of up to  $1.0^{\circ}\text{C}$  between varying tree cover scenarios (or perhaps even over  $2^{\circ}\text{C}$  in some scenarios) and canopy temperature differences of  $0.2^{\circ}\text{C}$  to  $0.4^{\circ}\text{C}$ .
- Completion of vegetation parameterizations (grass as well as a variety of common street trees, in addition to the olive and brushbox parameterizations)
- Completion of validation scenarios
  - Hughesdale
  - Smith St
- Sensitivity study building on and adding variations of validation scenarios to examine impact to human thermal comfort of placement and quantity of trees in urban areas

# Bibliography

- Duursma, R.A. and Medlyn, B.E. (2012), MAESPA: a model to study interactions between water limitation, environmental drivers and vegetation function at tree and stand levels, with an example application to [CO<sub>2</sub>] × drought interactions. *Geoscientific Model Development*, 5(4):pp. 919–940.
- Krayenhoff, E.S. and Voogt, J.A. (2007), A microscale three-dimensional urban energy balance model for studying surface temperatures. *Boundary-Layer Meteorology*, 123(3):pp. 433–461.
- Nicholls, N., Skinner, C., Loughnan, M. and Tapper, N. (2008), A simple heat alert system for Melbourne, Australia. *International Journal of Biometeorology*, 52(5):pp. 375–84.