A micro-climate examination of the temperature moderating potential of increased vegetation and water in urban canyons using VTUF-3D

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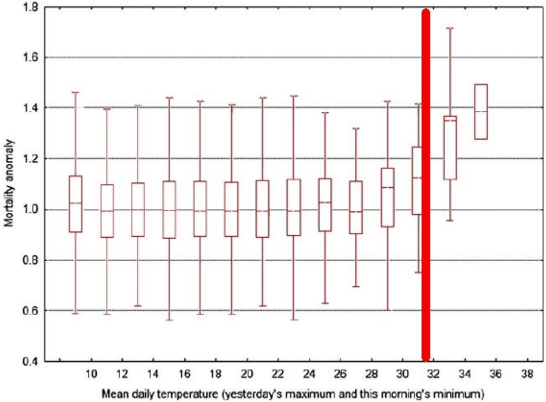
MONASH University

CRC for
Water Sensitive Cities

Introduction

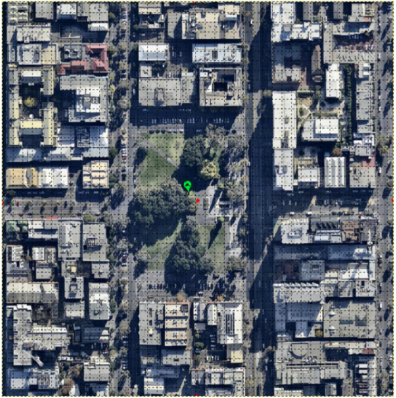
Heat health thresholds



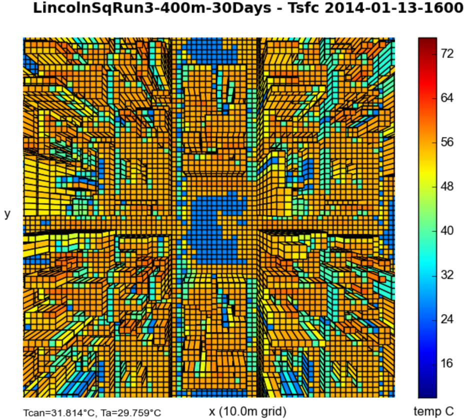
(Nicholls et al., 2008)

Trees cooling streets

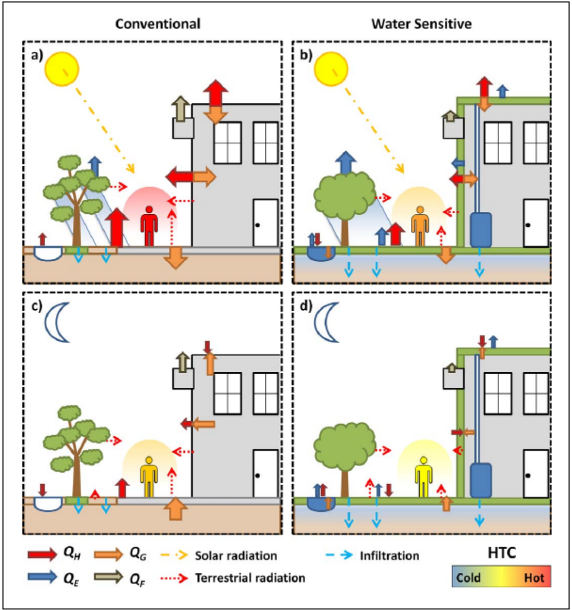
VTUF-3D, a tool to model the cooling effects of trees at a microscale



Lincoln Square, Melbourne



CRC for Water Sensitive Cities research overview



(Coutts et al., 2013)

Project B3.1 - Cities as Water Supply Catchments - Green Cities and Microclimate

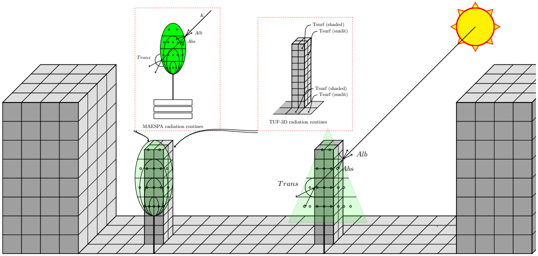
The aim of this project is to identify the climatic advantages of stormwater harvesting/reuse and water sensitive urban design at building to neighbourhood scales.

- To determine the micro-climate processes and impacts of decentralised stormwater harvesting solutions and technologies at both household and neighbourhood scales.
- To assess the impacts of these solutions on human thermal comfort and heat related stress and mortality.
- To provide stormwater harvesting strategies to improve the urban climate and benefit the carbon balance of cities.
- To project the likely impact of climate change on local urban climate, with and without stormwater resuse as a mitigation strategy.

(CRC for Water Sensitive Cities, 2015)

VTUF-3D energy balance modelling with MAESPA tiles

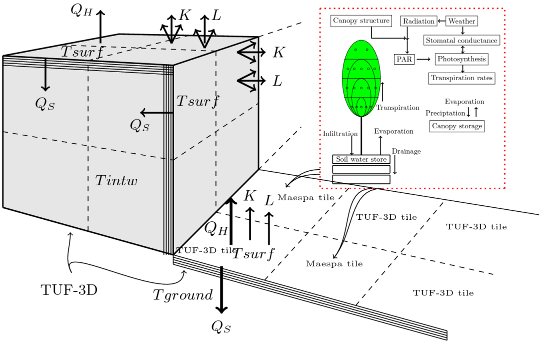
- Modifications to TUF-3D (Krayenhoff and Voogt, 2007) to resolve urban canyon radiation flux movement using placeholder vegetation structures which call MAESPA (Duursma and Medlyn, 2012) vegetation absorption, transmission, and reflection routines.
- VTUF-3D uses cube shaped structures (as TUF-3D uses 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

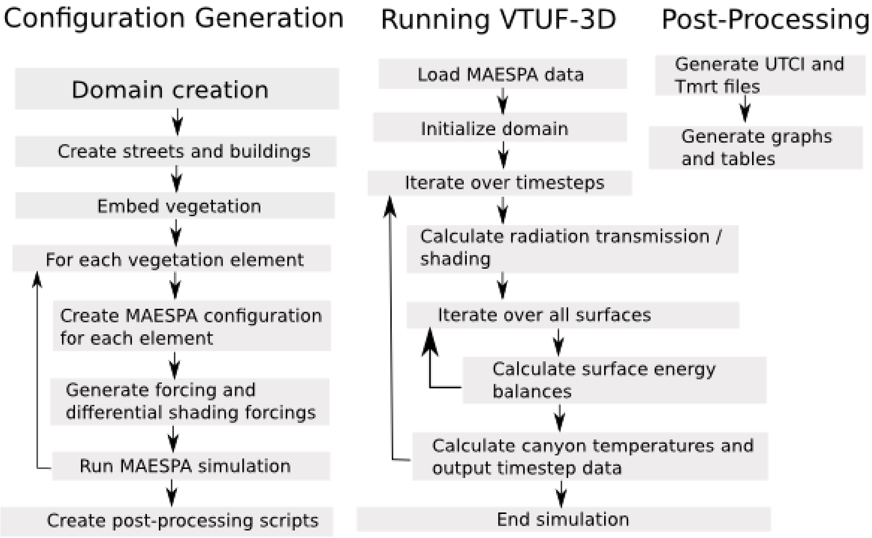
VTUF-3D energy balance modelling with MAESPA tiles

- 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

VTUF-3D process flow



MAESPA tree parameterizations common attributes

Parameter	Value
Stomatal conductance	Ball-Berry-Opti model (Medlyn et al., 2011)
Number of layers in the crown assumed when calculating radiation interception	6
Number of points per layer	12
Number of zenith angles for which diffuse transmittances are calculated	5
Number of azimuth angles for which the calculation is done	11

MAESPA olive tree (*Olea europaea*) parameterization

Parameter	Value	Source
crown radius (m)	2.5	Coutts (2014)
crown height (m)	3.75	Coutts (2014)
trunk height (m)	1.25	Coutts (2014)
leaf area index (m^2 m^{-2})	2.48	Mariscal et al. (2000)
crown shape	round	
z_{Ht} (m)	4.0	Forcing data height
z_{PD} (m)	2.5	2/3 of crown height (Grimmond and Oke, 1999)
$z_{0,Ht}$ (m)	0.375	1/10 of crown height (Grimmond and Oke, 1999

As all tree parametrizations in VTUF-3D are pluggable, individual trees are added to a domain using a specific set of configuration files with many of the physical properties scaled from a base template. Values adapted from Coutts (2014)

MAESPA olive tree (*Olea europaea*) parameterization

Parameter	Value(s)	Source
Soil reflectance (%PAR, %NIR, and %IR)	0.10, 0.05, 0.05	Levinson et al. (2007); Oke (1987)
Leaf transmittance (%PAR, %NIR, and %IR)	0.01, 0.28, 0.01	Baldini et al. (1997)
Leaf reflectance (%PAR, %NIR, and %IR)	0.08, 0.42, 0.05	Baldini et al. (1997)
Minimum stomatal conductance g0 (mol $m^{-2}s^{-1}$)	0.03	Coutts (2014)
Slope parameter g1	2.615	Coutts (2014)
# of sides of the leaf with Stomata	1	Fernández et al. (1997)
Width of leaf (m)	0.0102	
CO_2 compensation point (μmol $m^{-2}s^{-1}$)	55	Coutts (2014)
Max rate electron transport (Jmax) (μmol $m^{-2}s^{-1}$)	112.4	Coutts (2014)
Max rate rubisco activity (VCmax) (μmol $m^{-2}s^{-1}$)	81.18	Coutts (2014)
Curvature of the light response curve	0.62	Coutts (2014)
Activation energy of Jmax (KJ mol^{-1})	35350	Díaz-Espejo et al. (2006)
Deactivation energy of Jmax (J mol^{-1})	200000	Medlyn et al. (2005)
Entropy term (KJ mol^{-1})	644.4338	Medlyn et al. (2005)
Quantum yield of electron transport (mol electrons mol^{-1})	0.19	Sierra (2012)
Dark respiration (μmol $m^{-2}s^{-1}$)	0.94	Coutts (2014)
Specific leaf area (mm^2kg^{-1})	5.1	Mariscal et al. (2000)

MAESPA brushbox tree (*Lophostemon Confertus*) parameterization

Parameter	Value	Source
crown radius (m)	2.5	Coutts et al. (2016)
crown height (m)	3.75	Coutts et al. (2016)
trunk height (m)	1.25	Coutts et al. (2016)
leaf area index (m^2 m^{-2})	2.0	Wright and Westoby (2000)
crown shape	round	
z_{Ht} (m)	4.0	Forcing data height
z_{PD} (m)	2.5	2/3 of crown height (Grimmond and Oke, 1999)
$z_{0,Ht}$ (m)	0.375	1/10 of crown height (Grimmond and Oke, 1999

MAESPA brushbox tree (*Lophostemon Confertus*) parameterization, tree dimensions for 5x5m grid (rescale for taller/shorter), values adapted from Coutts et al. (2016)

MAESPA brushbox tree (*Lophostemon Confertus*) parameterization

Parameter	Value(s)	Source
Leaf reflectance (%PAR, %NIR, and %IR)	0.04, 0.35, 0.05	Fung-yan (1999)
Minimum stomatal conductance g0 (mol $m^{-2}s^{-1}$)	0.01	Coutts et al. (2016)
Slope parameter g1	3.33	Coutts et al. (2016)
# of sides of the leaf with Stomata	1	Beardsell and Considine (1987)
Width of leaf (m)	0.05	Coutts et al. (2016)
CO_2 compensation point (μmol $m^{-2}s^{-1}$)	53.06	Coutts et al. (2016)
Max rate electron transport (μmol $m^{-2}s^{-1}$)	105.76	Coutts et al. (2016)
Max rate rubisco activity (μmol $m^{-2}s^{-1}$)	81.6	Coutts et al. (2016)
Curvature of the light response curve	0.61	Coutts et al. (2016)
Activation energy of Jmax (KJ mol^{-1})	35350	Bernacchi et al. (2001)
Deactivation energy of Jmax (J mol^{-1})	200000	Medlyn et al. (2005)
Entropy term (KJ mol^{-1})	644.4338	Medlyn et al. (2005)
Quantum yield of electron transport (mol electrons mol^{-1})	0.06	Coutts et al. (2016)
Dark respiration (μmol $m^{-2}s^{-1}$)	1.29	Coutts et al. (2016)
Specific leaf area (mm^2kg^{-1})	25.3	Wright and Westoby (2000)

MAESPA grass parameterization

Parameter	Value	Source
crown radius (m)	2.5	Radius of 5x5m grid
crown height (m)	0.2	Simmons et al. (2011)
trunk height (m)	0.01	
stem diameter (m)	0.2	
leaf area index (m^2 m^{-2})	7.13	ave. from Bijoor et al. (2014)
crown shape	box	
z_{Ht} (m)	4.0	Forcing data height
z_{PD} (m)	0.066	2/3 of crown height (Grimmond and Oke, 1999)
$z_{0,Ht}$ (m)	0.02	1/10 of crown height(Grimmond and Oke, 1999)

MAESPA grass layer as a box tree on the ground covering the plot area

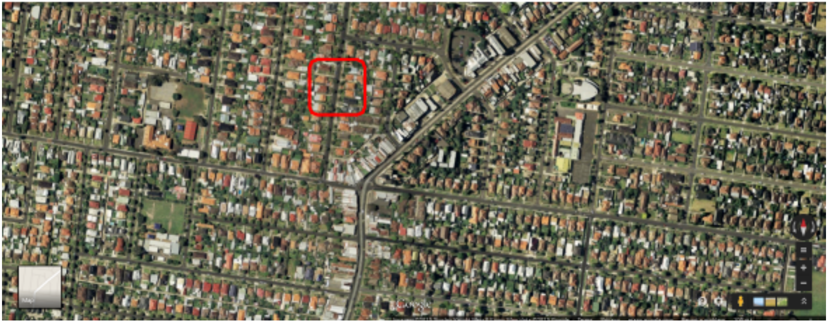
MAESPA grass parameterization

Parameter	Value(s)	Source
Soil reflectance (%PAR, %NIR, and %IR)	0.10 0.05 0.05	Observed, Levinson et al. (2007), Oke (1987)
Leaf transmittance (%PAR, %NIR, and %IR)	0.05 0.45 0.01	C3 grasses, from Katjacnik et al. (2014)
Leaf reflectance (%PAR, %NIR, and %IR)	0.05 0.65 0.08	C3 grasses, from Katjacnik et al. (2014)
Minimum stomatal conductance g0 (mol $m^{-2}s^{-1}$)	0.0	De Kauwe et al. (2015)
Slope parameter g1	5.25	C3 grasses, from De Kauwe et al. (2015)
# of sides of the leaf with Stomata	2	Green et al. (1990)
Width of leaf (m)	0.006	Rademacher and Nelson (2001)
CO_2 compensation point (μmol $m^{-2}s^{-1}$)	57	Brown and Morgan (1980) at 25 degrees
Max rate electron transport (μmol $m^{-2}s^{-1}$)	80.95	Tall Fescue from Yu et al. (2012)
Max rate rubisco activity (μmol $m^{-2}s^{-1}$)	36.14	Tall Fescue from Yu et al. (2012)
Curvature of the light response curve	0.7	Gilmanov et al. (2007)
Activation energy of Jmax (KJ mol^{-1})	65300	Bernacchi et al. (2001)
Deactivation energy of Jmax (J mol^{-1})	200000	Medlyn et al. (2005)
Entropy term (KJ mol^{-1})	644.4338	Medlyn et al. (2005)
Quantum yield of electron transport (mol electrons mol^{-1})	0.05	Monson et al. (1982)
Dark respiration (μmol $m^{-2}s^{-1}$)	0.6	Estimated for Tall Fescue from Yu et al. (2012)
Specific leaf area (mm^2kg^{-1})	23.16	Average from Table 1 in Bijoor et al. (2014) for 3 turfgrasses.

MAESPA grass layer as a box tree on the ground covering the plot area

Model testing and validation using Preston dataset

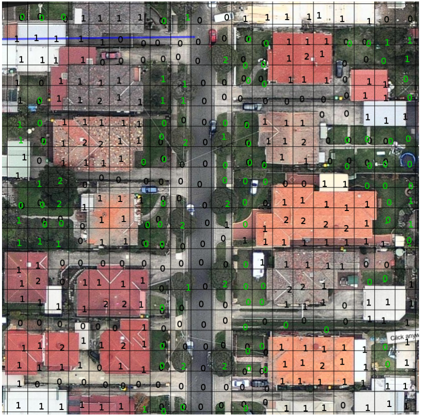
- Preston - homogeneous, medium density.
- Data set contains complete flux observations recorded 2003-2004, allowing validation of surface energy balances
- Modelled area, (500x500m) chosen is representative of overall area observed by flux tower



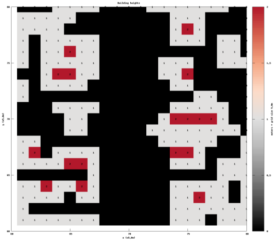
Adapted from Google Maps (2015)

Model testing and validation using Preston dataset

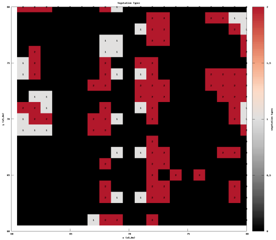
Mix of vegetation types: grass (19.5%), olive and brushbox trees (16.0%). Medium density area (45.2% buildings). 19.3% impervious surfaces.



Digitization of Preston suburban street, Oakhill Ave. (1=building heights, 1=vegetation heights)
Adapted from Nearmap (2015).



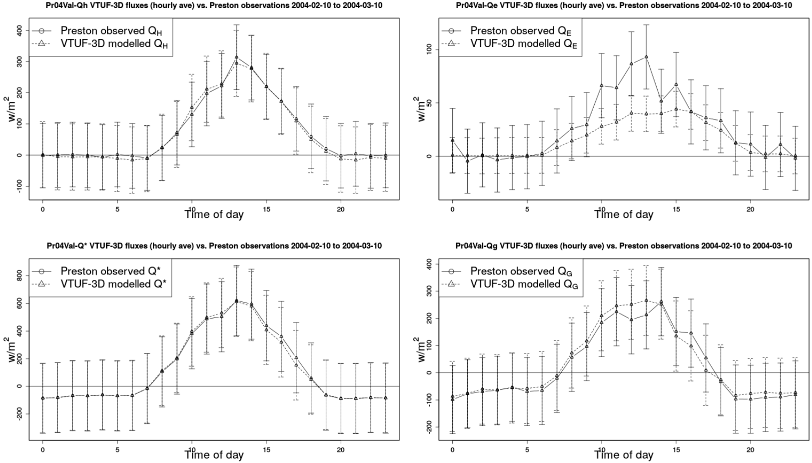
Building heights (0, 5, 10m)



Vegetation heights (0, 5, 10m)

Model testing and validation using Preston dataset

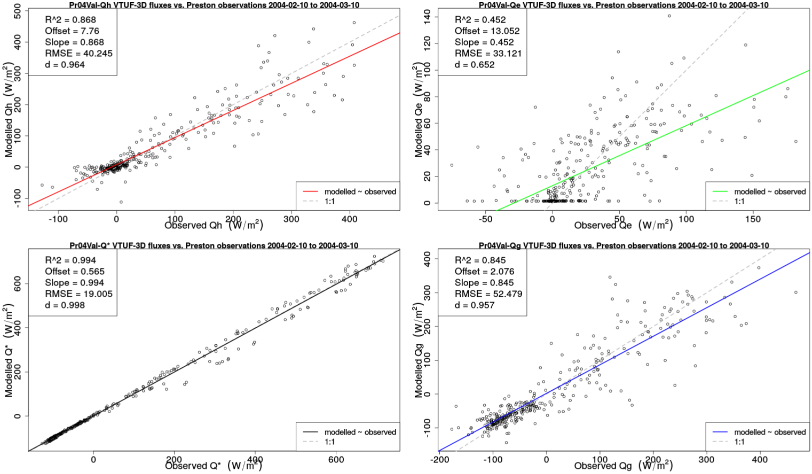
30 day hourly average flux comparisons to Preston flux observations



Pr04Val run 30 day hourly average VTUF-3D flux comparisons to Preston flux observations for the period 10 February-10 March 2004

Model testing and validation using Preston dataset

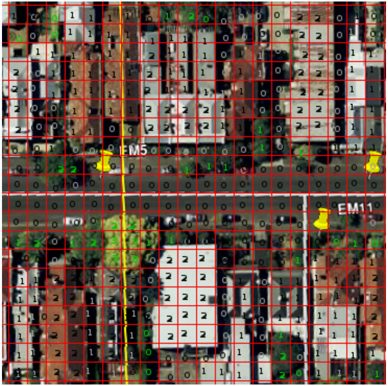
30 day hourly flux comparisons to Preston flux observations



Pr04Val scenario modelled vs. observations for Q_H, Q_E, Q^*, and Q_G fluxes for the period 10 February-10 March 2004.

Model testing and validation using City of Melbourne, George and Gipp St datasets

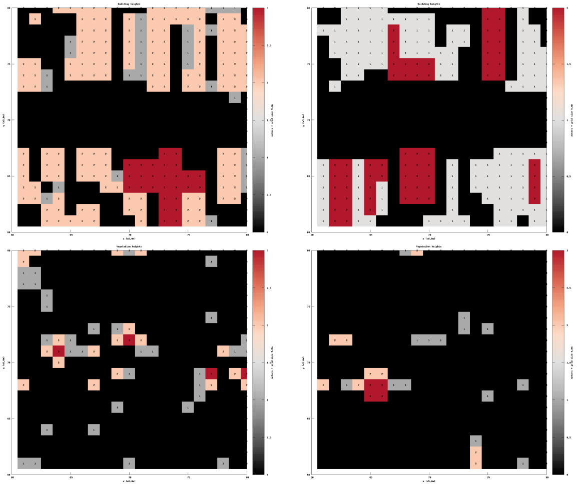
Shallow urban canyons (ave building heights 7 and 8m, H:W 0.32 and 0.27) with varying canopy cover (45% and 12%)



Validation against 4 and 3 observation stations located on street

Model testing and validation using City of Melbourne, George and Gipp St datasets

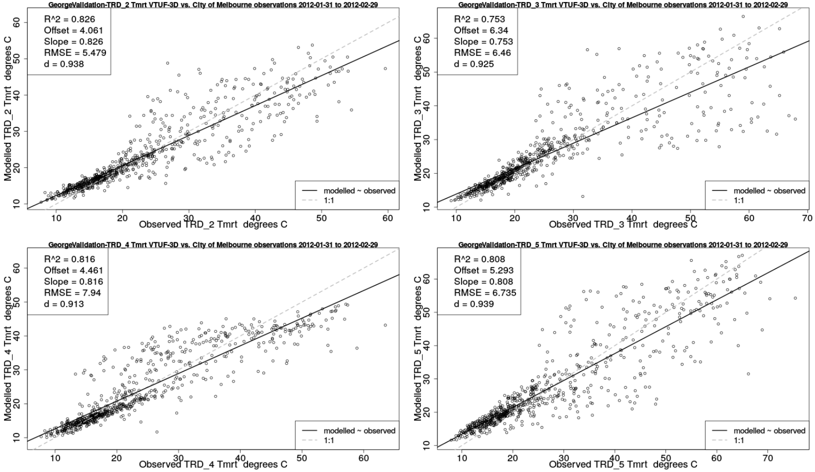
Building heights - George St, Gipp St



Vegetation cover - George St, Gipp St

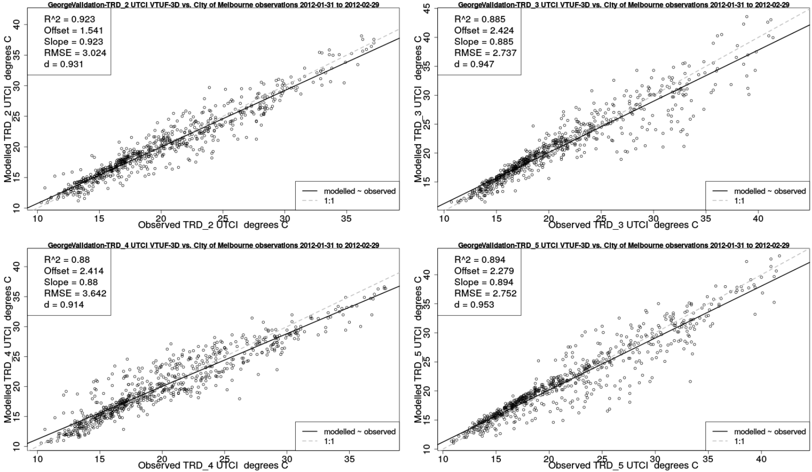
Model testing and validation using City of Melbourne, George and Gipp St datasets

30 day comparison of predicted T_{mrt} to observed - George St

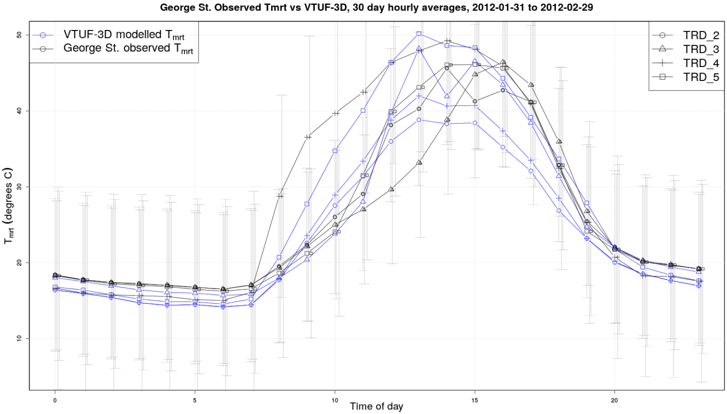


Model testing and validation using City of Melbourne, George and Gipp St datasets

30 day comparison of predicted UTCI to observed - George St

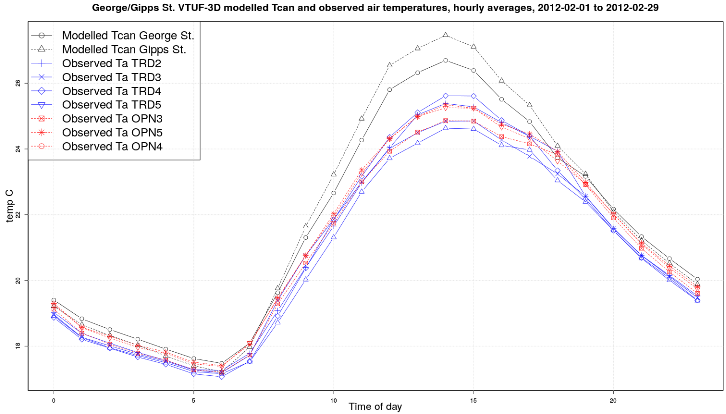


Model testing and validation using City of Melbourne, George and Gipp St datasets



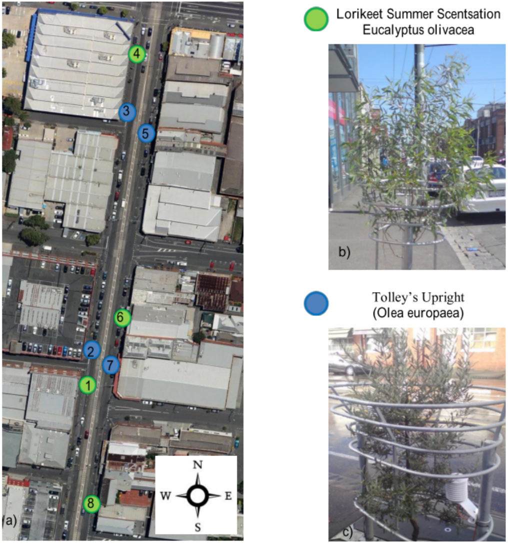
George St. scenario four observation stations (TRD_2, TRD_3, TRD_4, and TRD_5) values of T_{mrt} aggregated into hourly averages over 30 days compared to modelled points.

Model testing and validation using City of Melbourne, George and Gipp St datasets



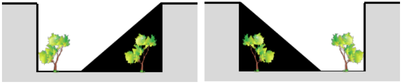
George/Gipps St. modelled T_{can} compared to observed T_a of George St. 4 treed canopy stations and Gipps St. 3 open canopy stations, hourly averages over February 2012 modelled period.

Model testing and validation using Smith St dataset

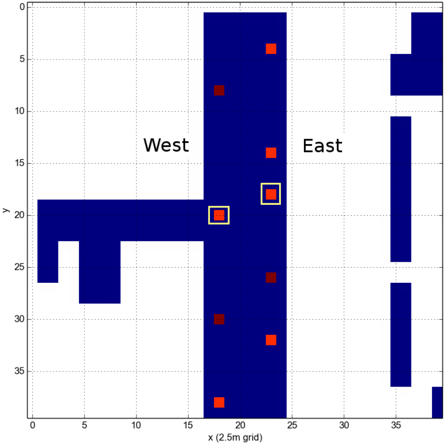


Validations using isolated tree physiology data (Gebert et al., 2012)

Model testing and validation using Smith St dataset

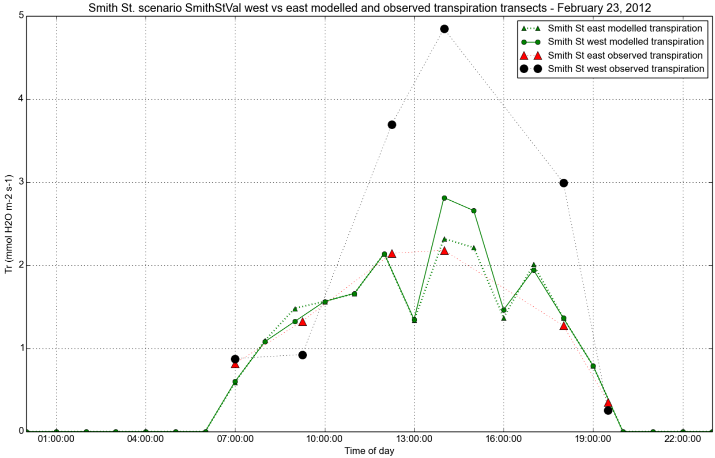


Effects of urban canyon shadowing



Extraction of modelled Q_E values for Smith St. olive trees.

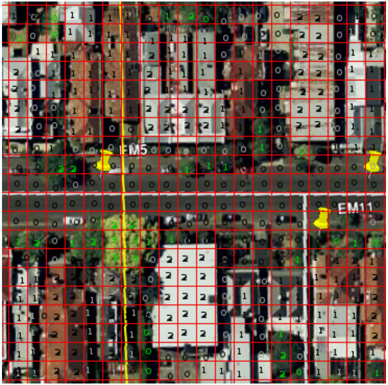
Smith St observed vs modelled east/west energy fluxes



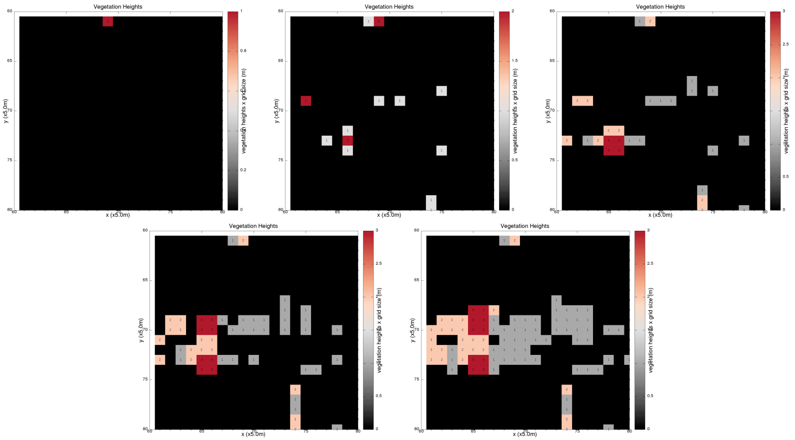
VTUF-3D SmithStVal validation showing modelled transpiration along each west and east tree location for 23 February 2012. Also shown, observed transpiration values for the same tree location.

Scenarios using City of Melbourne, George and Gipps St datasets

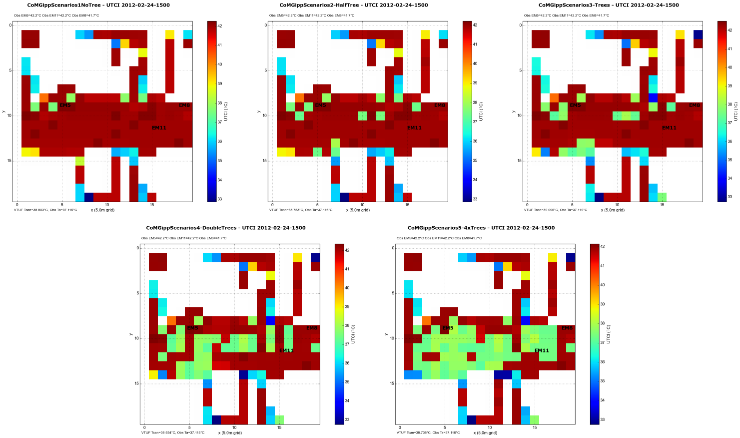
Shallow urban canyons (ave building heights 7 and 8m, H:W 0.32 and 0.27) with varying canopy cover (45% and 12%)



City of Melbourne Gipps St Scenarios-tree configurations

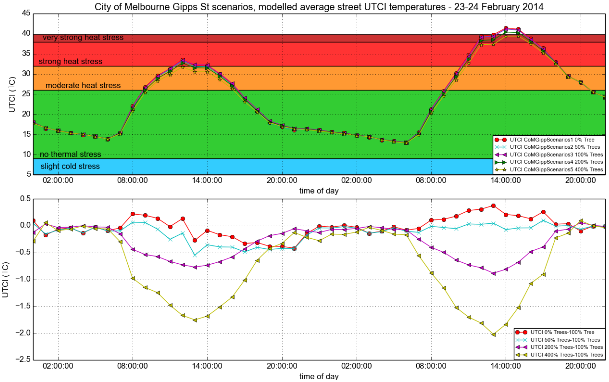


- 5 scenarios of zero trees, half trees, existing Gipps St tree canopy cover, double trees, and 4x trees.



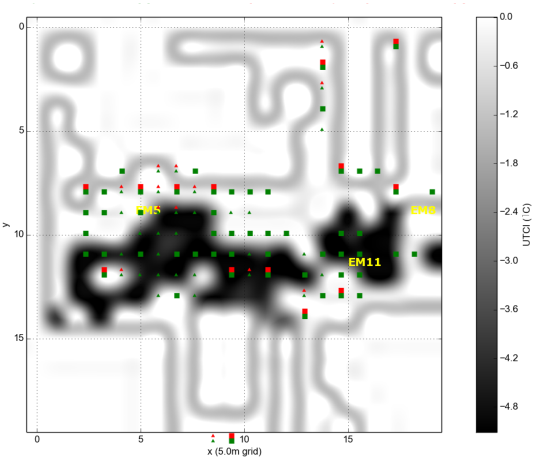
- UTCI (averaged at 0m height) maximum variations of 1.0°C between Gipps St. zero tree scenario and double trees.

City of Melbourne Gipps St Scenarios-UTCI differences between scenarios



- UTCI (averaged at 0m height) maximum variations of 1.0°C between Gipps St. zero tree scenario and double trees. Variation of over 2.5°C UTCI between 0 tree and 4x trees.

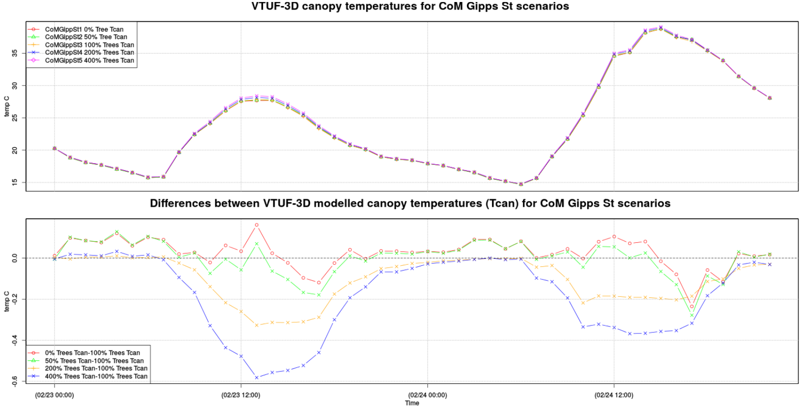
City of Melbourne Gipps St Scenarios-UTCI differences between scenarios



- Differences (at 0m height) between Gipps St. existing canopy and 4x canopy showing localised cooling effects of 4-5°C UTCI

City of Melbourne Gipps St Scenarios-Canopy temperatures

Modelled T_{can} of 4 scenarios over 23-24 February 2014 / T_{can} differences between normal trees and other scenarios



Canopy temperature (average air temperature of urban canyon) differences range from 0.2°C to 0.4°C .

Future work

- Addition of vegetation parameterizations (a variety of common street trees) adding to existing olive, brushbox, and grass parameterizations
- Completion of validation scenarios
  - Hughesdale
  - Other climate zones / winter time
- Adding user friendly graphics interface to VTUF-3D to make it accessible to a wider user group
- 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
- Research fellowship at University of Melbourne - Walkability, urban design, and micro-climates

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Thank you. Questions?

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