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

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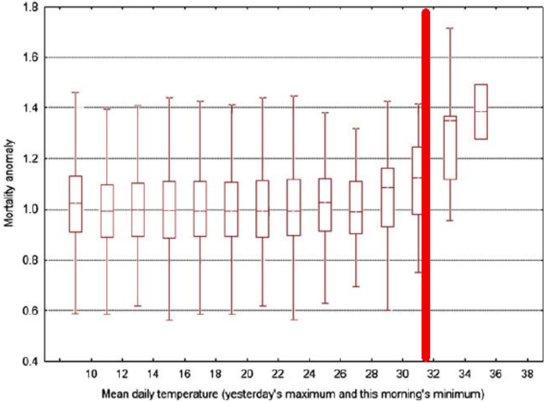
MONASH University CRC for Water Sensitive Cities

Introduction

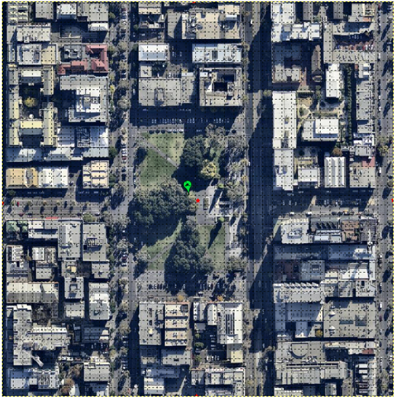
Heat health thresholds



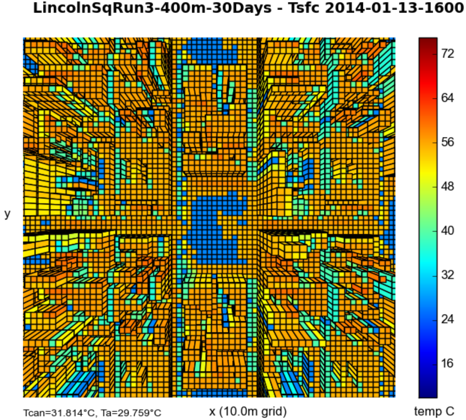
(Nicholls et al., 2008)

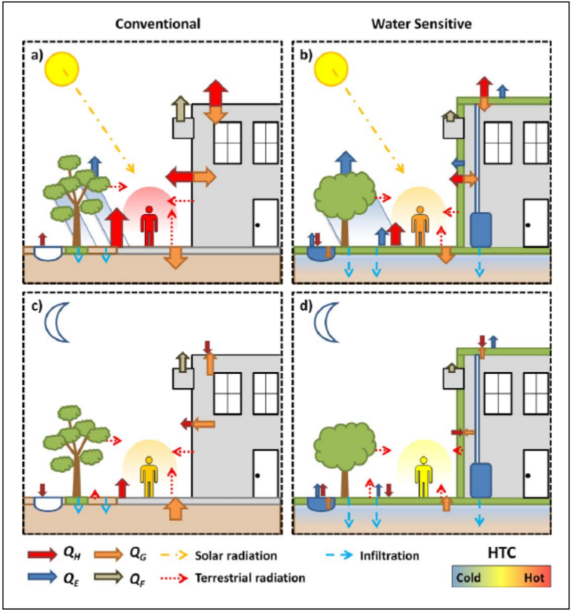
Trees cooling streets

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



Lincoln Square, Melbourne





(Coutts et al., 2013)

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

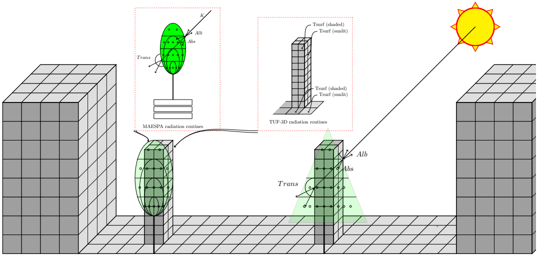
The aim of this project is to identify the climatic advantages of stormwater harvesting/reuse and water sensitive urban design at building to neighbourhood scales.

- 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

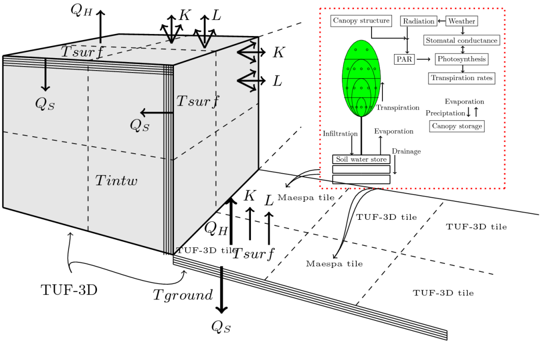
- Modifications to TUF-3D (Krayenhoff and Voogt, 2007) to resolve urban canyon radiation flux movement using placeholder vegetation structures which call MAESPA (Duursma and Medlyn, 2012) vegetation absorption, transmission, and reflection routines.
- VTUF-3D uses cube shaped structures (as TUF-3D uses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

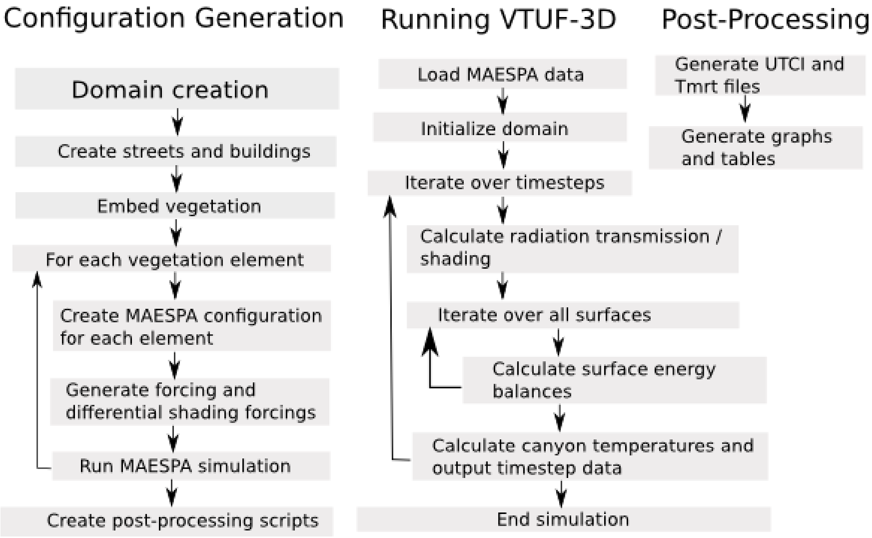
VTUF-3D energy balance modelling with MAESPA tiles

- 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
crown radius (m)	2.5
crown height (m)	3.75
trunk height (m)	1.25
leaf area index	2.48
crown shape	round
zht (m)	4.0
zpd (m)	1.6
z0ht (m)	3.0

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
Leaf reflectance (%PAR, %NIR and %IR)	0.082, 0.49, 0.05	Baldini et al. (1997)
Minimum stomatal conductance g0 (mol/m^{2}s)	0.0213	Coutts (2014)
Slope parameter g1	3.018	Coutts (2014)
# of sides of the leaf with Stomata	2	
Width of leaf (m)	0.0102	
CO_2 compensation point (μmol/m ^{2}s)	46	Sierra (2012);56= Coutts (2014)
Max rate electron transport (μmol/m^{2}s)	135.5	135.5=Sierra (2012);134=Coutts (2014)
Max rate rubisco activity (μmol/m^{2}s)	82.7	82.7=Sierra (2012);94=Coutts (2014)
Curvature of the light response curve	0.9	Sierra (2012)
Activation energy of Jmax (KJ/mol)	35350	Díaz-Espejo et al. (2006)
Deactivation energy of Jmax (J/mol)	200000	Medlyn et al. (2005)
XX Entropy term (KJ/mol)	644.4338	
Quantam yield of electron transport (mol electrons/mol)	0.2	
Dark respiration (μmol/m^{2}s)	1.12	Sierra (2012);1.79=Coutts (2014)
Specific leaf area	5.1	3.65=Villalobos et al. (1995);5.1=Mariscal et al. (2000)

MAESPA brushbox tree (*Lophostemon Confertus*) parameterization

Table : MAESPA brushbox tree (*Lophostemon Confertus*) parameterization, tree dimensions for 5x5m grid (rescale for taller/shorter), values adapted from Coutts (2015b)

Parameter	Value
crown radius (m)	2.5
crown height (m)	3.75
trunk height (m)	1.25
leaf area index	2.0
crown shape	round
zht (m)	4.0
zpd (m)	1.6
z0ht (m)	3.0

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^2s)	0.01	Coutts (2015b)
Slope parameter g1	3.33	Coutts (2015b)
# of sides of the leaf with Stomata	1	Beardsell and Considine (1987)
Width of leaf (m)	0.05	
CO_2 compensation point ($\mu mol/m^2s$)	53.06	Coutts (2015b)
Max rate electron transport ($\mu mol/m^2s$)	105.76	Coutts (2015b)
Max rate rubisco activity ($\mu mol/m^2s$)	81.6	Coutts (2015b)
Curvature of the light response curve	0.61	Coutts (2015b)
Activation energy of Jmax (KJ/mol)	35350	Bernacchi et al. (2001)
Deactivation energy of Jmax (J/mol)	200000	Medlyn et al. (2005)
XX Entropy term (KJ/mol)	644.4338	
Quantam yield of electron transport (mol electrons/mol)	0.06	Coutts (2015b)
Dark respiration ($\mu mol/m^2s$)	1.29	Coutts (2015b)
Specific leaf area	25.3	Wright and Westoby (2000)

MAESPA grass parameterization

Parameter	Value	Source
crown radius (m)	2.5	
crown height (m)	0.2	Simmons et al. (2011)
trunk height (m)	0.01	
stem diameter (m)	0.2	
leaf area index	7.13	ave from Bijoor et al. (2014)
crown shape	box	
zht (m)	4.0	
zpd (m)	0.066	
z0ht (m)	0.02	

MAESPA grass layer as a box tree on the ground covering the plot area, values adapted from Coutts (2015a)

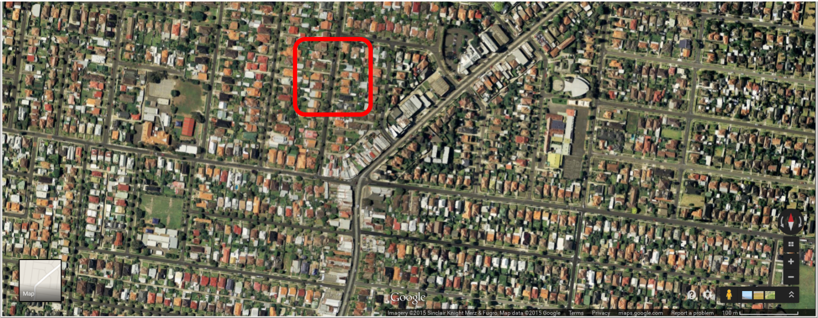
MAESPA grass parameterization

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)	0.01 0.28 0.01	Olive: Baldini et al. (1997) (Adaxial side of leaf)
Leaf reflectance (%PAR, %NIR and %IR)	0.05 0.42 0.08	Olive: Baldini et al. (1997) (Adaxial side of leaf)
Minimum stomatal conductance g0 (mol/m^2s)	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	
Width of leaf (m)	0.006	Rademacher and Nelson (2001)
CO_2 compensation point ($\mu mol/m^2s$)	57	Brown and Morgan (1980) @ 25 degrees
Max rate electron transport ($\mu mol/m^2s$)	80.95	Tall Fescue from Yu et al. (2012))
Max rate rubisco activity ($\mu mol/m^2s$)	36.14	Tall Fescue from Yu et al. (2012))
Curvature of the light response curve	0.9	
Activation energy of Jmax (KJ/mol)	35350	Bernacchi et al. (2001)
Deactivation energy of Jmax (J/mol)	200000	Medlyn et al. (2005)
XX Entropy term (KJ/mol)	644.4338	
Quantam yield of electron transport (mol electrons/mol)	0.19	PAR curves; PSICO2=Absorb*8*0.5
Dark respiration ($\mu mol/m^2s$)	0.6	Estimated for Tall Fescue from Yu et al. (2012)
Specific leaf area	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

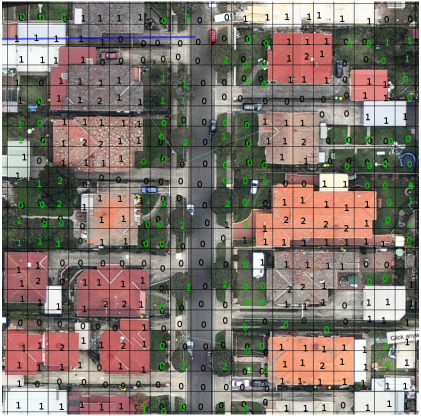
- Preston - homogeneous, medium density.
- Data set contains complete flux observations recorded 2003-2004, allowing validation of surface energy balances
- Modelled area, (500x500m) chosen is representative of overall area observed by flux tower



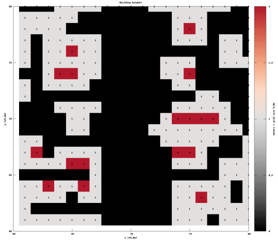
(Google 2015)

Model testing and validation using Preston dataset

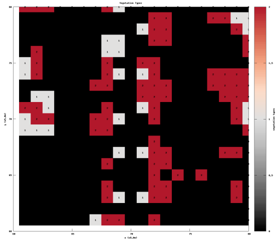
Mix of vegetation types: grass (18.5%), olive and brushbox trees (7.25%). Medium density area (46.75% buildings). 27.5% impervious surfaces.



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



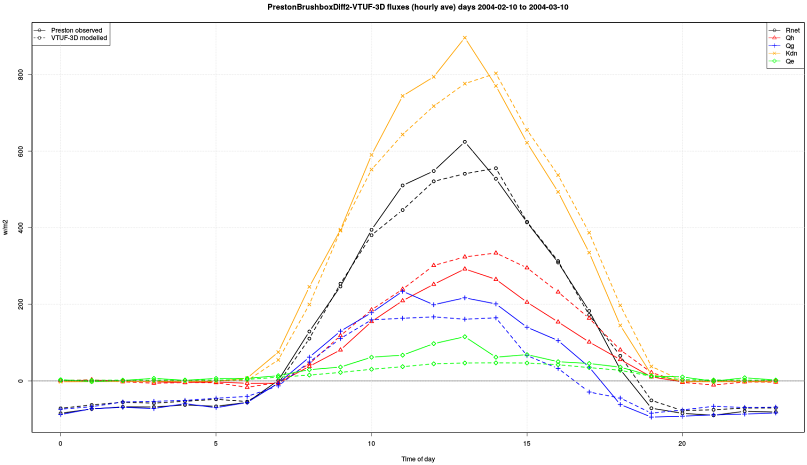
Building heights (0, 5, 10m)



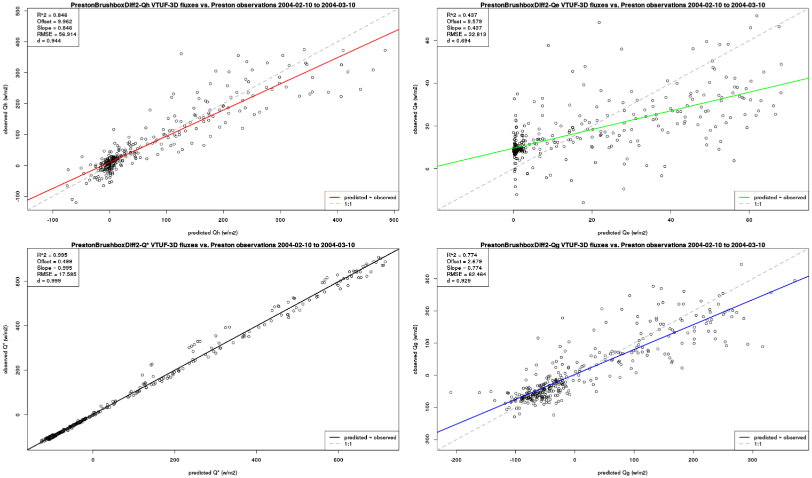
Vegetation heights (0, 5, 10m)

Model testing and validation using Preston dataset

30 day hourly average flux comparisons to Preston flux observations

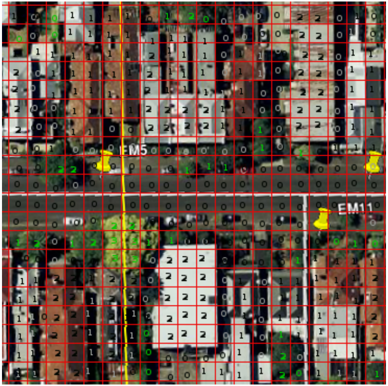


30 day hourly flux comparisons to Preston flux observations



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

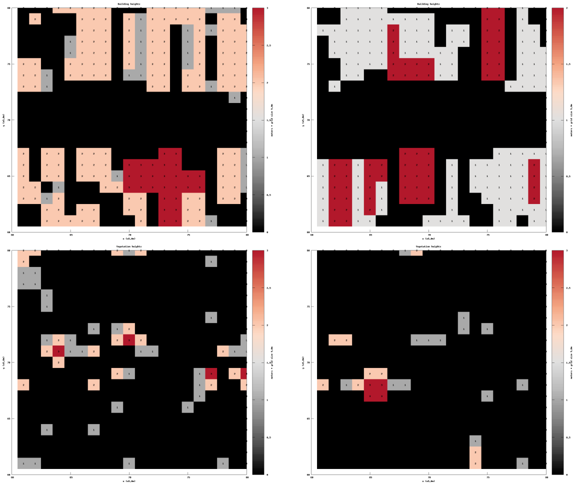
Shallow urban canyons (ave building heights 7 and 8m, H:W 0.32 and 0.27) with varying canopy cover (45% and 12%)



Validation against 4 and 3 observation stations located on street

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

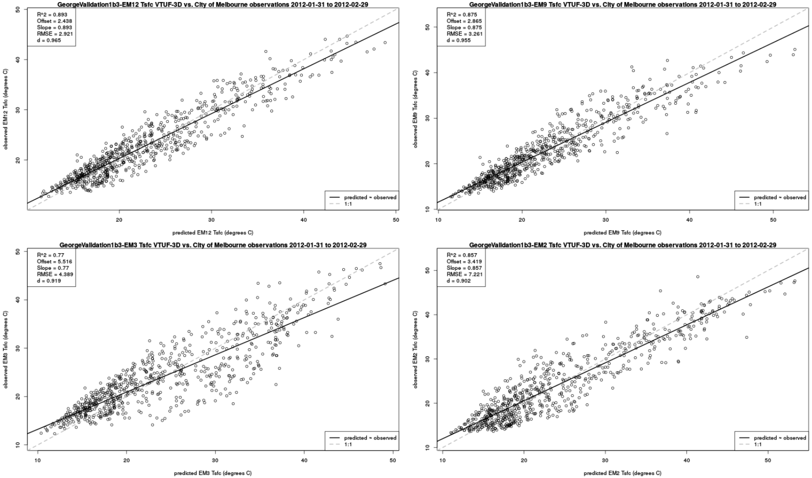
Building heights - George St, Gipp St



Vegetation cover - George St, Gipp St

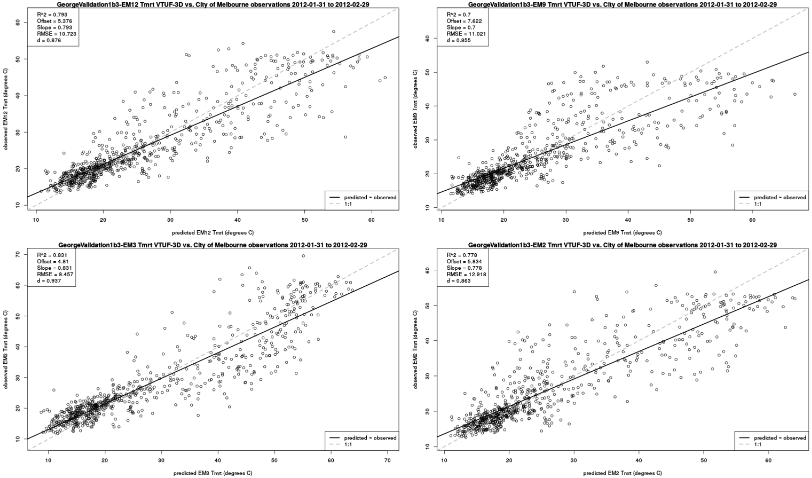
Model testing and validation using City of Melbourne, George and Gipp St datasets

30 day comparison of predicted Tsfc to observed - George St



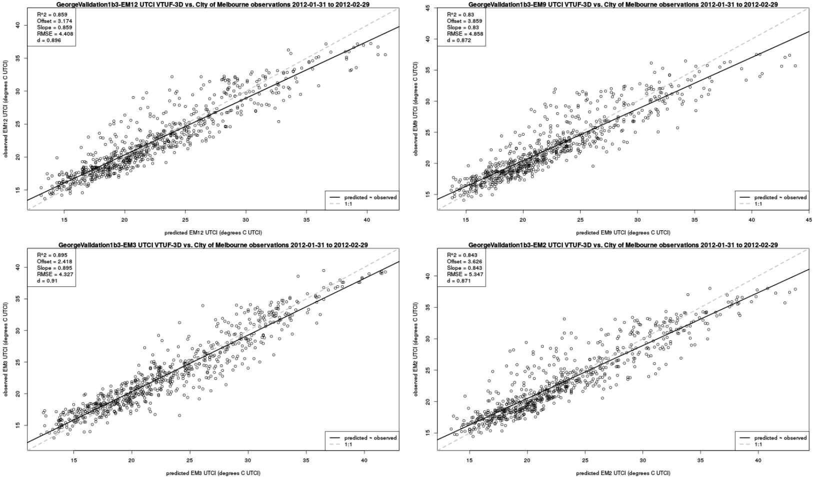
Model testing and validation using City of Melbourne, George and Gipp St datasets

30 day comparison of predicted Tmrt to observed - George St

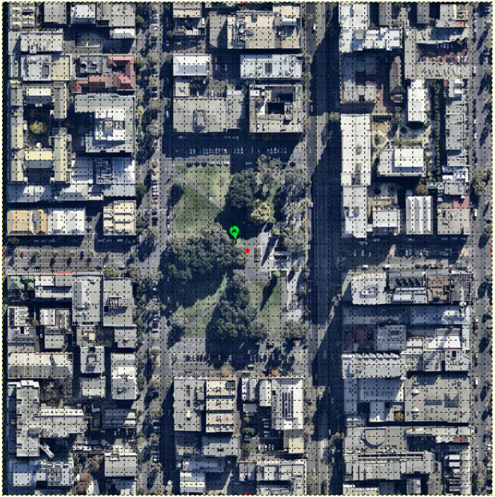


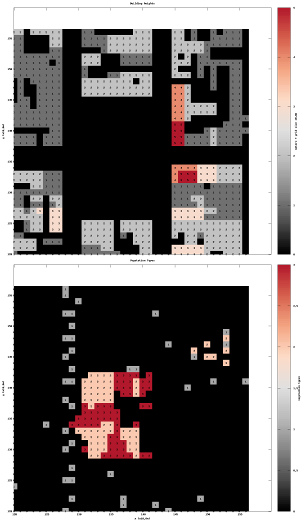
Model testing and validation using City of Melbourne, George and Gipp St datasets

30 day comparison of predicted UTCI to observed - George St



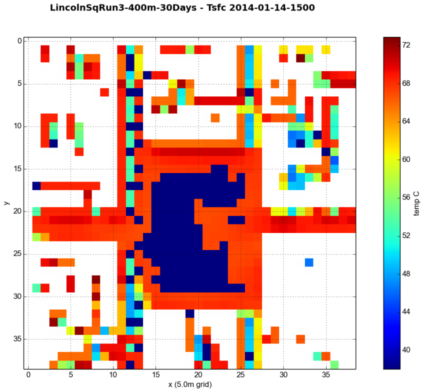
Model testing and validation using Lincoln Sq dataset





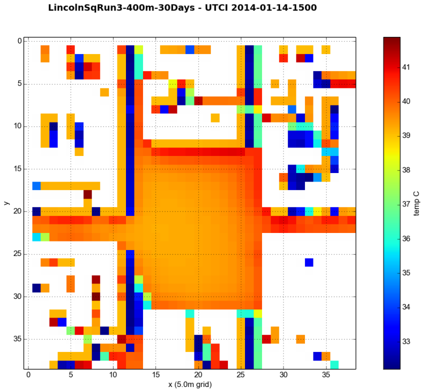
Melbourne urban square, mix of open grass and mature trees within dense urban canyon

Model testing and validation using Lincoln Sq dataset



Comparisons of modelled Tsfc to observed transits

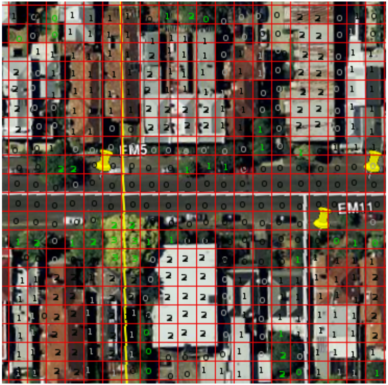
Model testing and validation using Lincoln Sq dataset



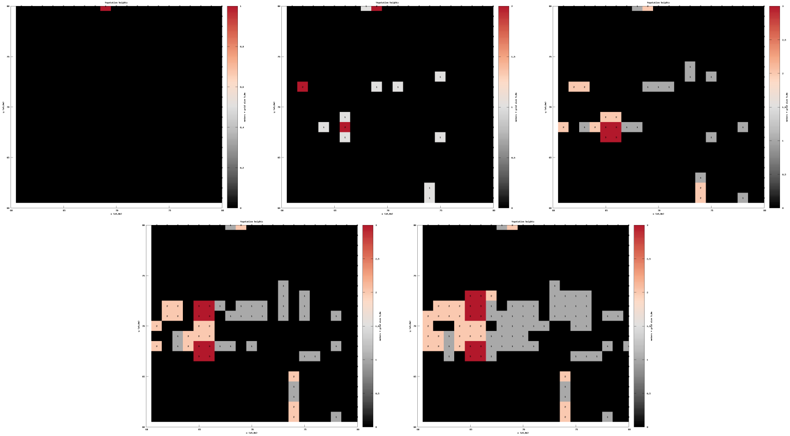
Comparisons of modelled UTCI to observed transits

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%)

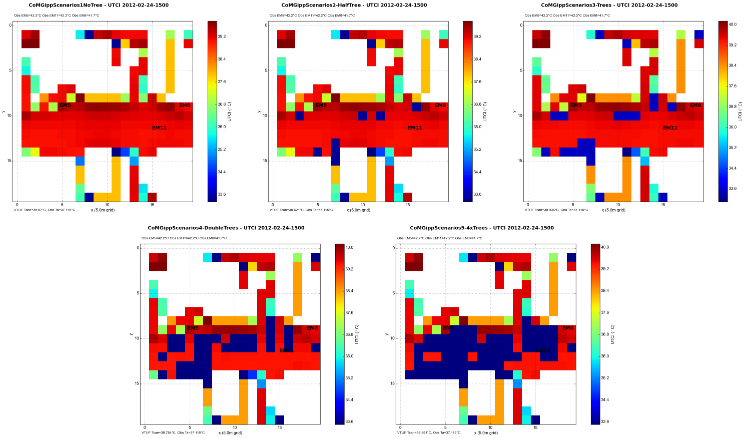


City of Melbourne Gipps St Scenarios-tree configurations



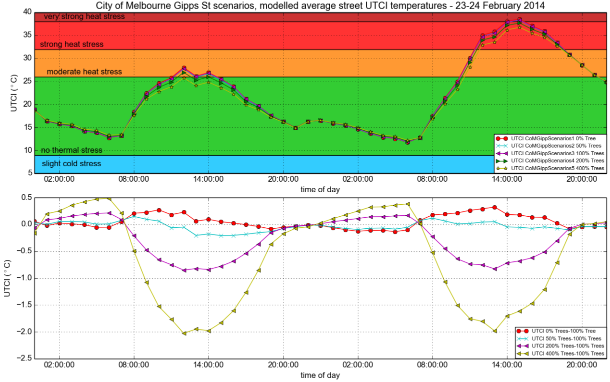
- 5 scenarios of zero trees, half trees, existing Gipps St tree canopy cover, double trees, and 4x trees.

City of Melbourne Gipps St Scenarios-UTCI at 0 meters



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

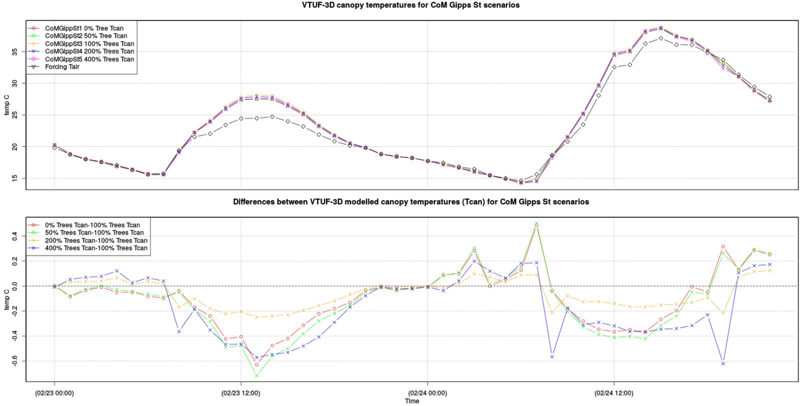
City of Melbourne Gipps St Scenarios-UTCI differences between scenarios



- UTCI (averaged at 0m height) maximum variations of 1.0°C between Gipps St. zero tree scenario and double trees. Variation of over 2.2°C UTCI between 0 tree and 4x trees.

City of Melbourne Gipps St Scenarios-Canopy temperatures

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



Canopy temperature 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
    - Smith St
- Case study of Smith St and its isolated trees
- 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

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Thank you. Questions?

MONASH University

CRC for Water Sensitive Cities