(Improved) micro-climate modelling assessment of the influence of water sensitive urban design on human thermal comfort: Pre-submission

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[4]University of British Columbia
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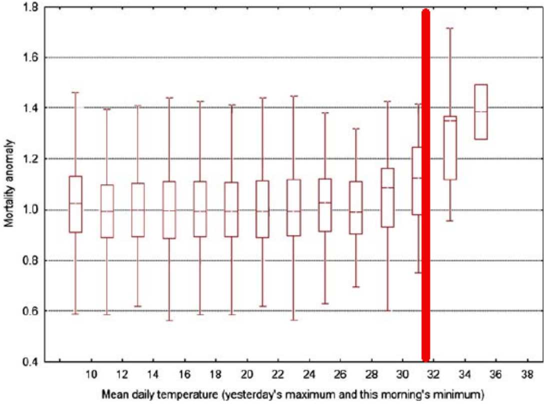
17 September 2015

Introduction

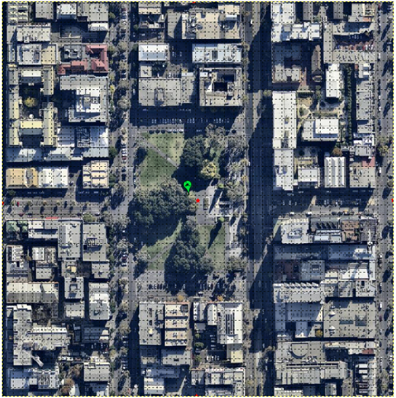
Heat health thresholds

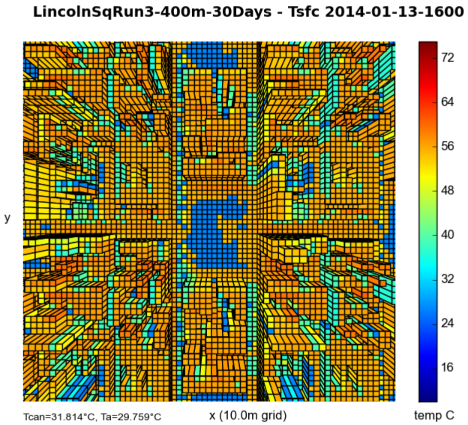


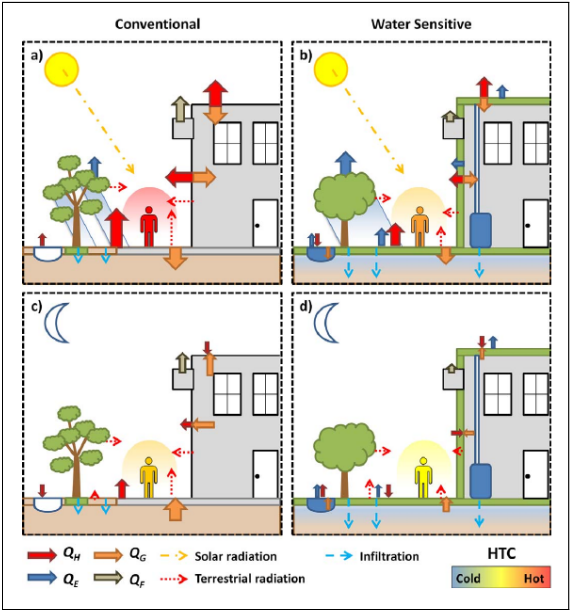
(Nicholls et al., 2008)

Trees cooling streets

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







(Coutts et al., 2013)

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

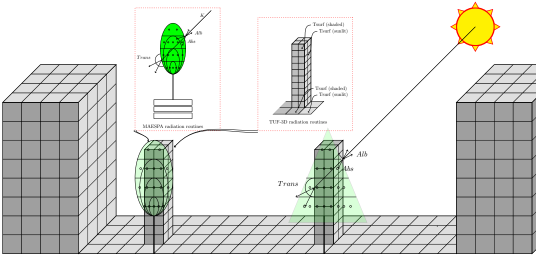
The aim of this project is to identify the climatic advantages of stormwater harvesting/reuse and water sensitive urban design at building to neighbourhood scales.

- 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

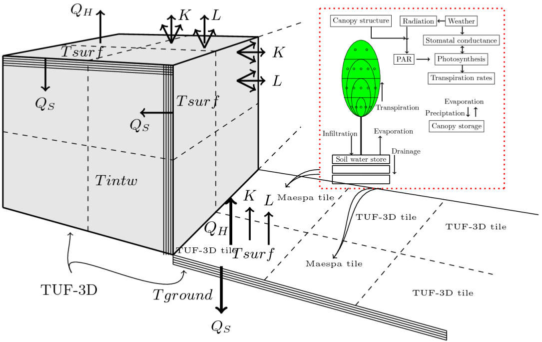
- Modifications to TUF-3D (Krayenhoff and Voogt, 2007) to resolve urban canyon radiation flux movement using placeholder vegetation structures which call MAESPA (Duursma and Medlyn, 2012) vegetation absorption, transmission, and reflection routines.
- VTUF-3D uses cube shaped structures (as TUF-3D uses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

MAESPA tree parameterization

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

MAESPA olive tree (*Olea europaea*) parameterization

- Tree dimensions for 5x5m grid (rescale for taller/shorter):
  crown radius = 2.5m, crown height = 3.75m
  trunk height = 1.25m, leaf area index=2.48
  crown shape = round, zht=4.0, zpd=1.6, z0ht=3.0
- Leaf reflectance 3 wavelengths 0.082, 0.49, 0.05 (Baldini et al 1997)
- Minimum stomatal conductance g0 = 0.0213 (From Smith St. data)
- Slope parameter g1 = 3.018 (From Smith St data)
- # of sides of the leaf with Stomata = 2
- Width of leaf (metres) = 0.0102
- CO2 compensation point = 46 (Sierra 2012) (56 @ Smith St.)
- Max rate electron transport=135.5 (135.5 @ Sierra 2012) (134 @ Smith St.)
- Max rate rubisco activity = 82.7 (82.7 @ Sierra 2012) (94 @ Smith St.)
- Curvature of the light response curve =0.9 (Sierra 2012)
- Activation energy of Jmax = 35350 (Diaz-Espejo et al 2006)
- Deactivation energy of Jmax = 200000 (Medlyn et al 2005)
- XX Entropy term = 644.4338
- Quantam yield of electron transport = 0.2
- Dark respiration= 1.12 (Sierra 2012) (1.79 @ Smith St.)
- Specific leaf area=5.1 (3.65=Villalobos et al 1995;5.1=Mariscal et al 2000)

MAESPA brushbox tree (*Lophostemon Confertus*) parameterization

- Tree dimensions for 5x5m grid (rescale for taller/shorter):
  crown radius = 2.5m, crown height = 3.75m
  trunk height = 1.25m, leaf area index =2.0
  crown shape = round, zht=4.0, zpd=1.6, z0ht=3.0
- Leaf reflectance 3 wavelengths 0.04, 0.35, 0.05 (Fung-yan 1999)
- Minimum stomatal conductance g0 = 0.01 (Determined from Melbourne Cemetery Tree)
- Slope parameter g1 = 3.33 (Determined from Melbourne Cemetery Tree)
- # of sides of the leaf with Stomata = 1 (Beardsell and Consodine)
- Width of leaf (metres) = 0.05
- CO2 compensation point = 53.06 (CO2 curves)
- Max rate electron transport=105.76 (CO2 curves)
- Max rate rubisco activity = 81.6 (CO2 curves)
- Curvature of the light response curve =0.61 (PAR curves)
- Activation energy of Jmax = 35350 (Bernacchi et al 2001)
- Deactivation energy of Jmax = 200000 (Medlyn et al 2005)
- XX Entropy term = 644.4338
- Quantam yield of electron transport = 0.06 (PAR curves)
- Dark respiration= 1.29 (PAR curves)
- Specific leaf area=25.3 (25.3=Wright and Westoby 2000)

MAESPA grass parameterization

- Stomatal conductance - Ball-Berry-Opti model (Medlyn et al., 2011)
- Dimensions for grass vegetation for 5x5m grid
    - crown shape = box
    - crown radius = 2.5m
    - crown height = 0.1m
    - trunk height = 0.1m
    - leaf area index=1.47 (Bremer and Ham 2005)
- nolay = 6 (Number of layers in the crown assumed when calculating radiation interception.)
- pplay = 12 (Number of points per layer)
- nzen = 5 (Number of zenith angles for which diffuse transmittances are calculated.)
- naz= 11 (Number of azimuth angles for which the calculation is done.)

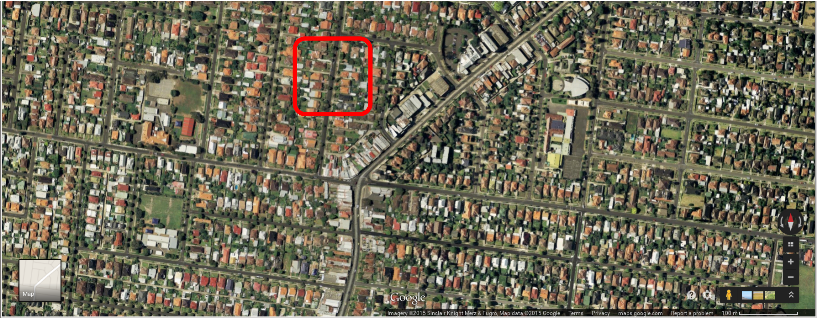
VTUF-3D validation matrix

Scenario	Ta	Tcan	UTCI	ET	Energy balance
Preston (Coutts et al., 2007)					
Gipps/George St, Melbourne (Coutts et al., 2015)					
Lincoln Sq, Melbourne (Motazedian, 2015)					
Hughesdale					
Smith St, Melbourne (Gebert et al., 2012)					

A variety of observation data allows validations of a number of different aspects of the model

Model testing and validation using Preston dataset

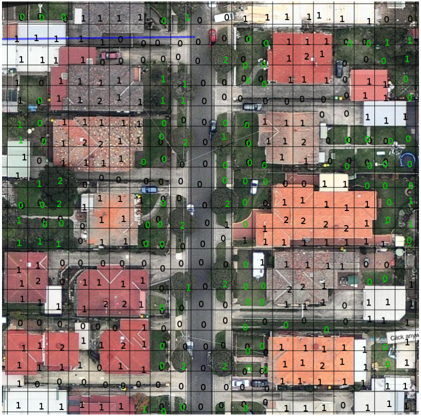
- Preston - homogeneous, medium density.
- Data set contains complete flux observations recorded 2003-2004, allowing validation of surface energy balances
- Modelled area, (500x500m) chosen is representative of overall area observed by flux tower



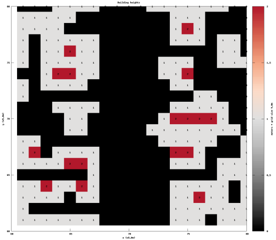
(Google 2015)

Model testing and validation using Preston dataset

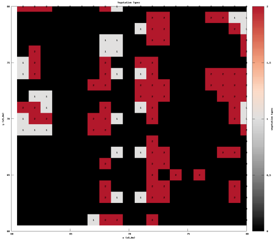
Mix of vegetation types: grass (18.5%), olive and brushbox trees (7.25%). Medium density area (46.75% buildings). 27.5% impervious surfaces.



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



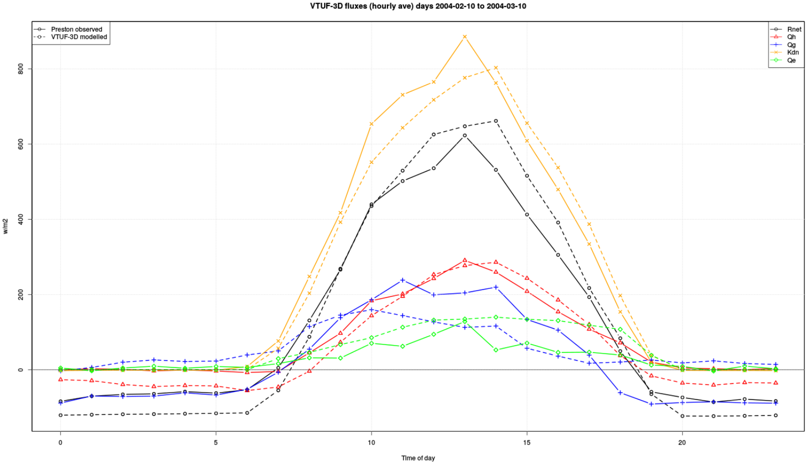
Building heights (0, 5, 10m)



Vegetation heights (0, 5, 10m)

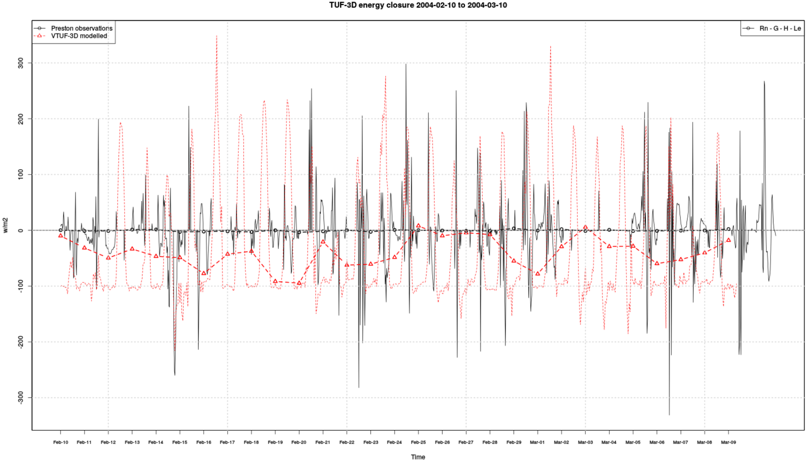
Model testing and validation using Preston dataset

30 day hourly average flux comparisons to Preston flux observations



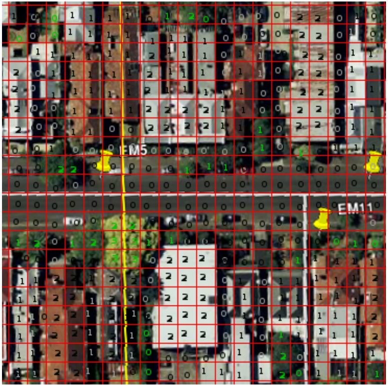
Model testing and validation using Preston dataset

Energy closure, $Q* - Qg - Qh - Qe = 0$



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

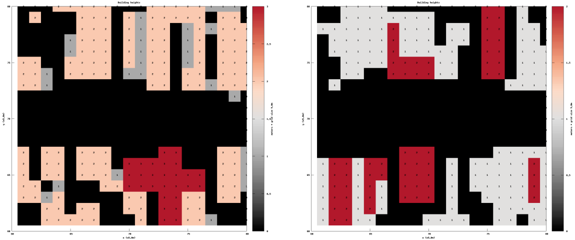
Shallow urban canyons (ave building heights 7 and 8m, H:W 0.32 and 0.27) with varying canopy cover (45% and 12%)

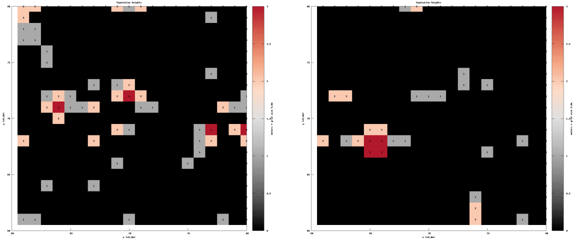


Validation against 4 and 3 observation stations located on street

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

Building heights - George St, Gipp St

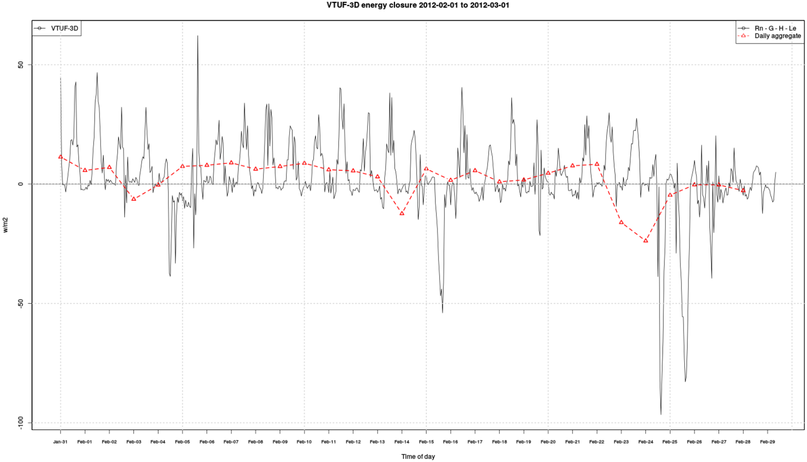




Vegetation cover - George St, Gipp St

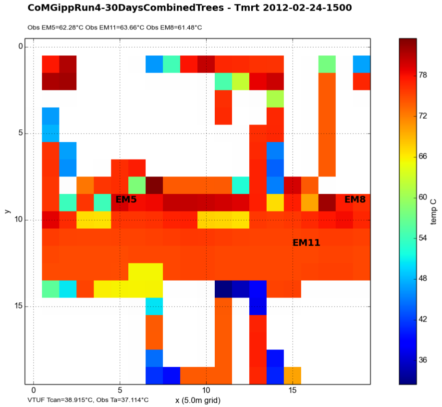
Model testing and validation using City of Melbourne, George and Gipp St datasets

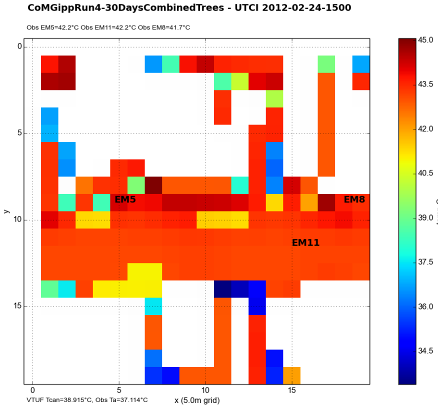
Energy closure of Gipp St



Model testing and validation using City of Melbourne, Gipp St dataset

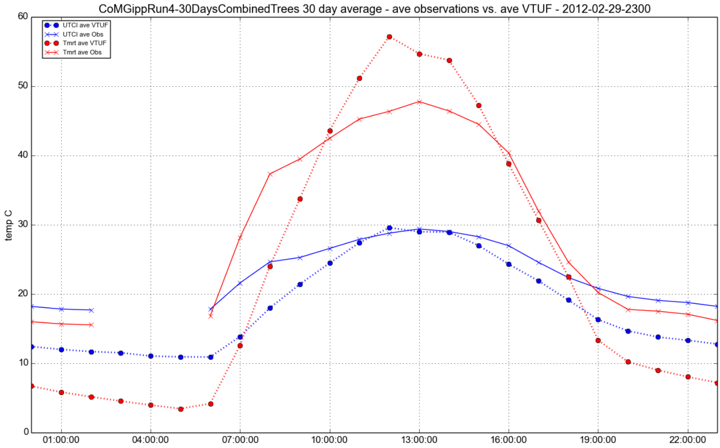
Results of Tmrt and UTCI for 24 February 2014 1500.



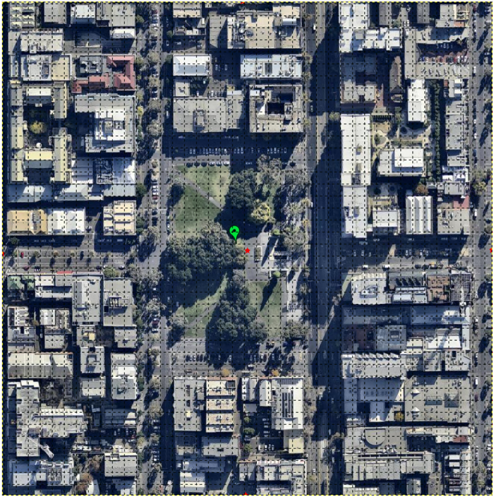


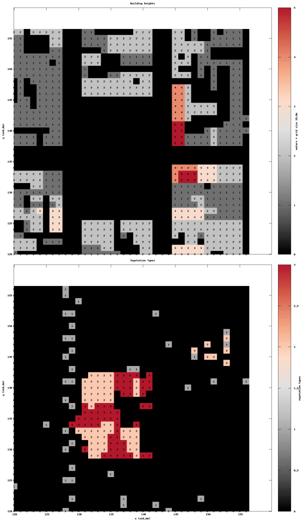
Model testing and validation using City of Melbourne, Gipps St dataset

Averaged comparison of 3 observations stations to modelled points



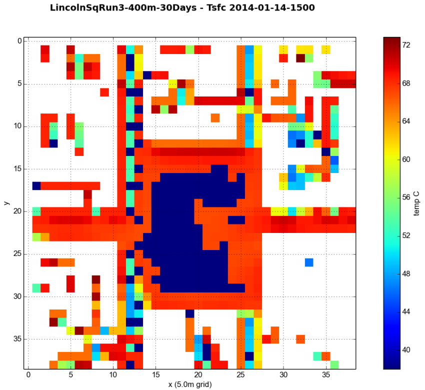
Model testing and validation using Lincoln Sq dataset





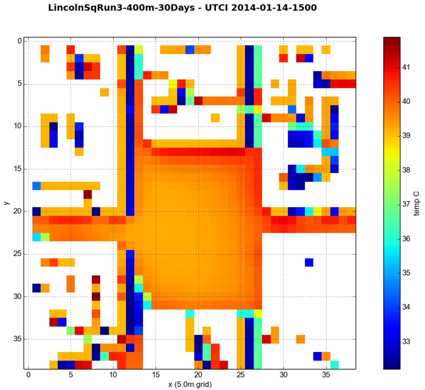
Melbourne urban square, mix of open grass and mature trees within dense urban canyon

Model testing and validation using Lincoln Sq dataset



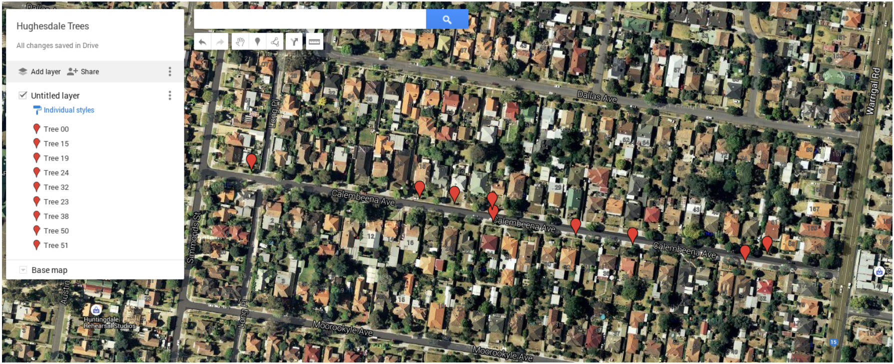
Comparisons of modelled Tsfc to observed transits

Model testing and validation using Lincoln Sq dataset



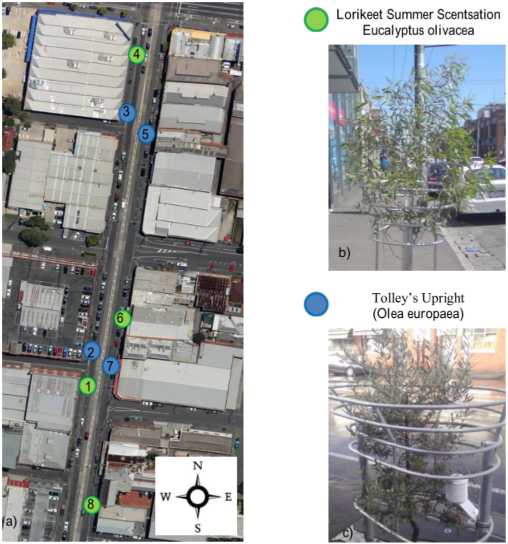
Comparisons of modelled UTCI to observed transits

Model testing and validation using Hughesdale dataset



Validations in medium density urban area using tree physiology data

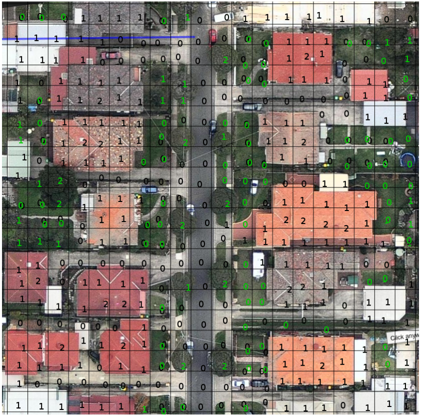
Model testing and validation using Smith St dataset



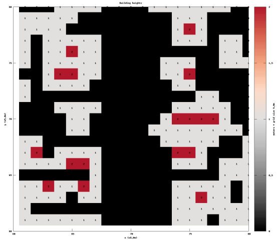
Validations using isolated tree physiology data (Gebert et al., 2012)

Scenarios using Preston dataset

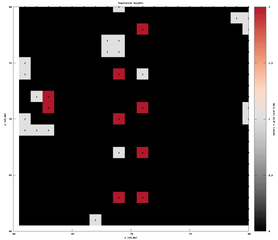
Mix of vegetation types: grass (18.5%), olive and brushbox trees (7.25%). Medium density area (46.75% buildings). 27.5% impervious surfaces.



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

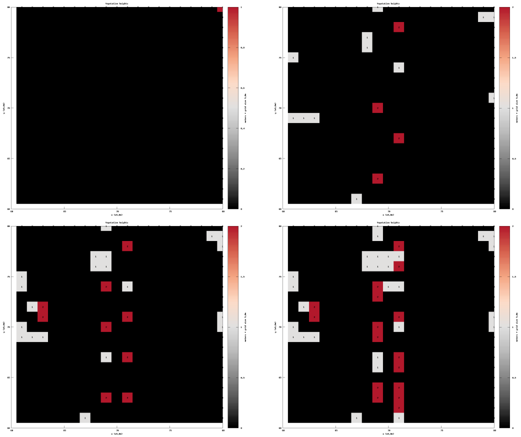


Building heights (0, 5, 10m)



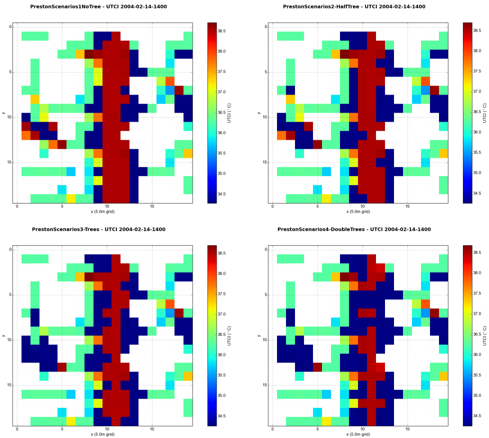
Vegetation heights (0, 5, 10m)

Preston Scenarios-tree configurations



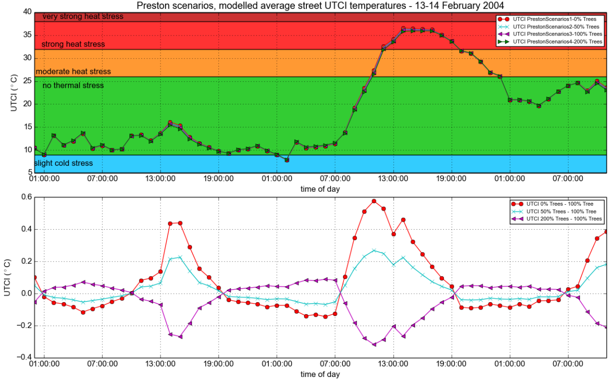
- 4 scenarios of zero trees, half trees, existing Preston tree canopy cover, and double trees

Preston Scenarios-UTCI at 0m



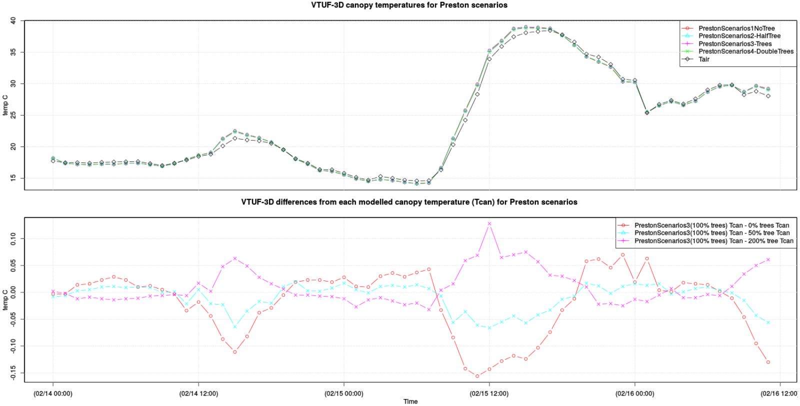
- UTCI (street level, 0m, average) variations of 0.9°C between zero tree scenario and double trees
- Double trees scenario gives 0.3°C UTCI reduction over existing Preston tree canopy

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°C between no tree scenario and double trees
- Double trees scenario gives 0.3°C UTCI reduction over existing Preston tree canopy

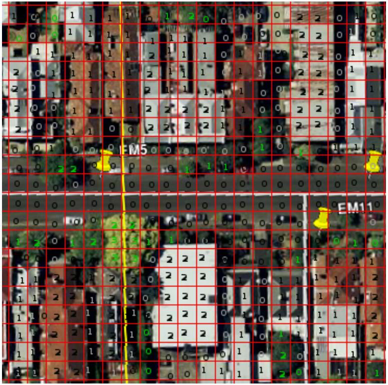
Preston Scenarios-Canopy temperatures



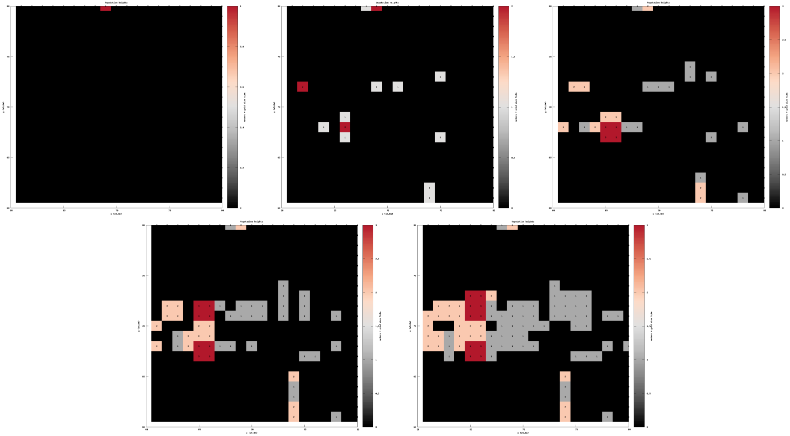
Modelled Tcan of 4 scenarios over 13-14 February 2004 / Tcan differences between normal trees and other scenarios

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%)

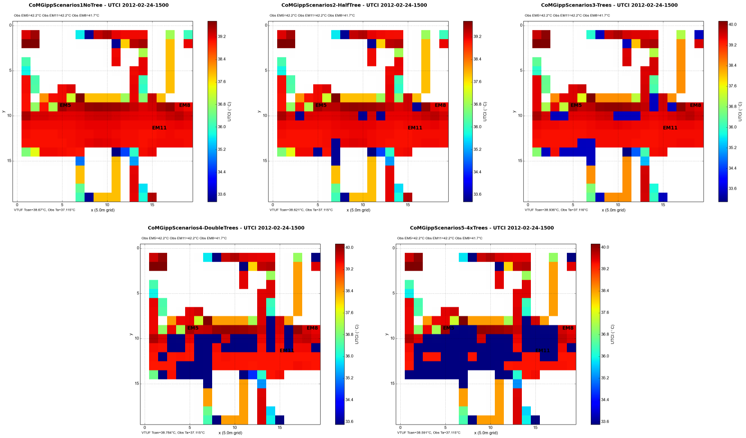


City of Melbourne Gipps St Scenarios-tree configurations



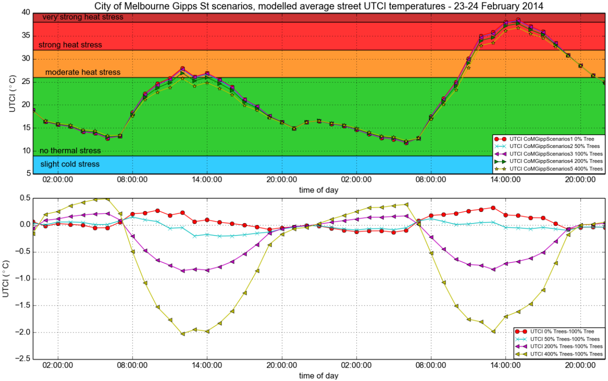
- 5 scenarios of zero trees, half trees, existing Gipps St tree canopy cover, double trees, and 4x trees.

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.

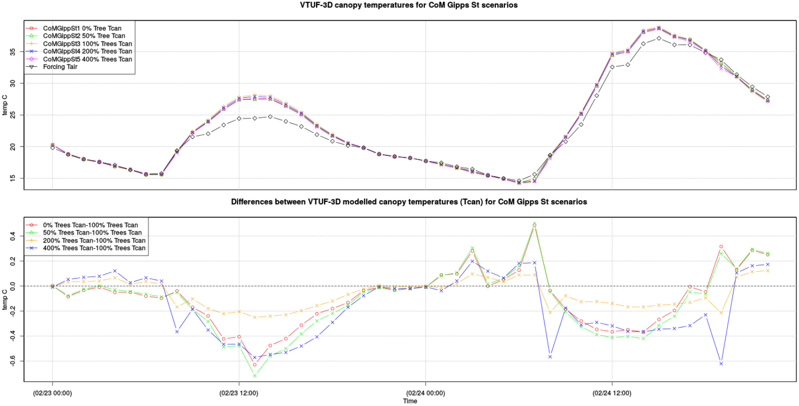
City of Melbourne Gipps St Scenarios-UTCI differences between scenarios



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

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 .

Sensitivity scenarios

A final set of scenarios will be built to examine the different variables in urban vegetation. These will be built using an idealized urban canyon. In these scenarios, the following variables will be varied to determine their individual impact on HTC:

- tree height,
- leaf area index,
- number of trees,
- tree placement (side of street, grouping or solitary),
- soil moisture.

Open tasks

Model

Storage fluxes? Are they correct? Time of day/night response? Switch to OHM?
Energy balance closures (losing energy for high vegetation configurations).
Revisit how Maespa fluxes are distributed and validate them.
Inner tree shading. All trees are modelled at 100% direct radiation. Interim fix could be to model each tree 3 times, 0%, 50%, and 100% direct radiation. Then use the specific value based on the FBEAM value falling on the tree during the timestep.
Check that Qh actually feeds into Tcan. The calculation of Tcan seems to be very circular in the code.
Finish implementation of tree transmission, absorption, and reflections.
Are Maespa flux values actually needed as they can be calculated from the Tsfc.
There is 0 Maespa transpiration at night. See ICUC9 UCP10 (Linden 2015)
Extend Maespa to model WSUD things (swales, biofiltration, etc).
Configuration GUI (and automated analysis).
OpenFoam air flows

Configuration

Add back in 8 degree rotation.
Are the grass parameterizations correct? Qe should be 35% of net (trees 20-40%) (ICUC9 ICP11 Ngao 2015)
Add in extra tree types.
Is the soil moisture correct?
Configure Maespa to model WSUD things (swales, biofiltration, etc).
Create overall simplified configuration, model running, and analysis toolkit for non-modellers.

Analysis

Are calculations of Tmrt correct? Which then feed into UTCI calculations.
Check energy balance closure at points of interest.
Winter validation?
Sensitivity study: Evaluate tree height, LAI, # of trees, tree placement, soil moisture.

Future work

- 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
- 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

Thesis outline

The thesis will follow the following outline:

- Chapter 1: Introduction
- Chapter 2: Literature review and identification of key modelling processes
- Chapter 3: Methodology
- Chapter 4: Modifications to TUF-3D urban micro-climate model to support assessments of WSUD influences on HTC at a micro-scale in urban canyons.
- Chapter 5: Validation and assessment of improved performance of the VTUF-3D model to model urban areas.
- Chapter 6: A systematic assessment of WSUD scenarios and urban morphologies using newly improved VTUF-3D model in support of HTC at a micro-climate level in urban areas.
- Chapter 7: Discussion.
- Chapter 8: Conclusion.
- Chapter 9: References.

Date	Progress/Events
January 2012	Cities as Water Supply Catchments, Project 3: Green Cities and Micro-climate report, 'Urban climate model selection for modelling WSUD features'
February 2012	7th International Conference on Water Sensitive Urban Design presentation, 'The micro-climate of a mixed urban parkland environment'
April 2012	Official candidature start date
April-October 2012	Literature review and planning
May 2012	Cities as Water Supply Catchments Industry Partner Workshop presentation, 'Urban climate model selection for modelling WSUD features'
August 2012	ICUC8 Conference presentation, 'A consideration of Water Sensitive Urban Design (WSUD) modelling strategies'
October 2012	Confirmation of candidature
February 2014	AMS 2014 conference poster, 'An urban micro-climate model for assessing impacts of Water Sensitive Urban Design'
October 2012-March 2015	'Modifications to TUF-3D urban micro-climate model to support assessments of WSUD influences on HTC at a micro-scale in urban canyons.' (Chapter 4)
July 2014	Mid-candidature
October 2014	An urban micro-climate model for assessing impacts of Water Sensitive Urban Design. In: Water Sensitive Cities Conference 2014. 21-23 October, 2014 - Melbourne, Australia. Poster
July 2015	VTUF-3D: An urban micro-climate model to assess temperature moderation from increased vegetation and water in urban canyons. In: ICUC9 - 9th International Conference on Urban Climate 2015. 20-24 July 2015 - Toulouse, France. Presentation
September 2015	VTUF-3D: An urban micro-climate model to assess temperature moderation from increased vegetation and water in urban canyons. In: 2nd Water Sensitive Cities Conference 2015. 8-9 September 2015 - Brisbane, Australia. Poster / Presentation
March 2015 - October 2015	'Validation and assessment of improved performance of the VTUF-3D model to model urban areas.' (Chapter 5)
October 2015 - December 2015	'A systematic assessment of WSUD scenarios and urban morphologies using newly improved VTUF-3D model in support of HTC at a micro-climate level in urban areas.' (Chapter 6)
October 2015-January 2016	Writing
January 2016	Submission

Bibliography

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Thank you. Questions?