CRC for
Water Sensitive Cities

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

Designing liveable cities through heat mitigation: tools to translate knowledge into design

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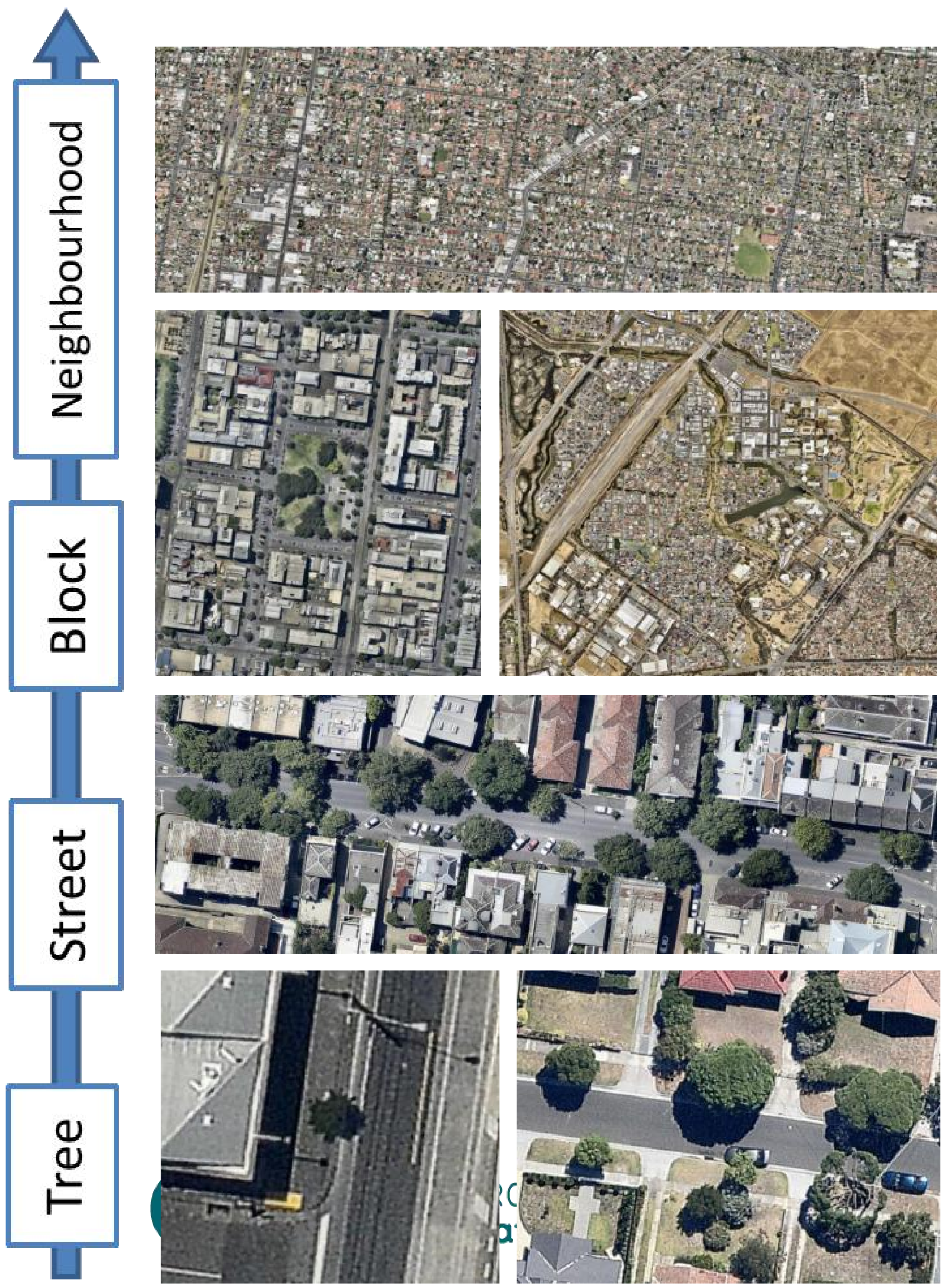
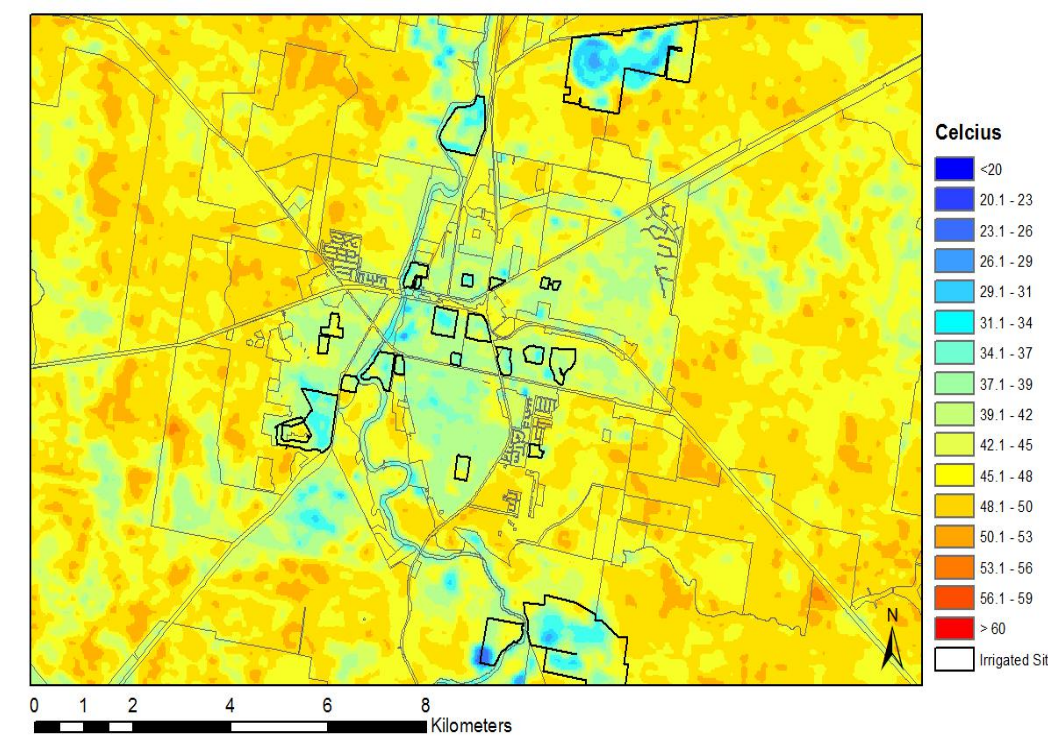
watersensitivecities.org.au

Research questions

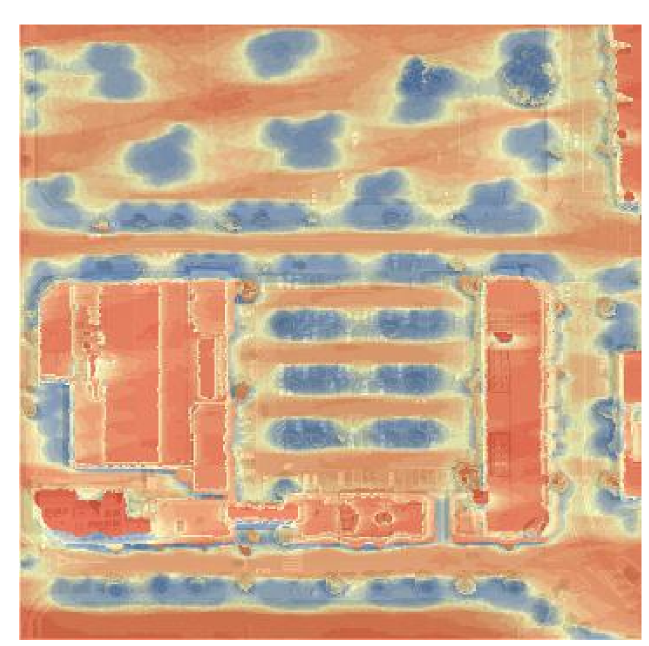
- How effective are storm water harvesting technologies, tree cover, green infrastructure and WSUD in improving urban climates **at a range of scales**?
- What are the key configurations required to reduce temperatures to save lives under heat wave conditions and to enhance human thermal comfort and liveability?



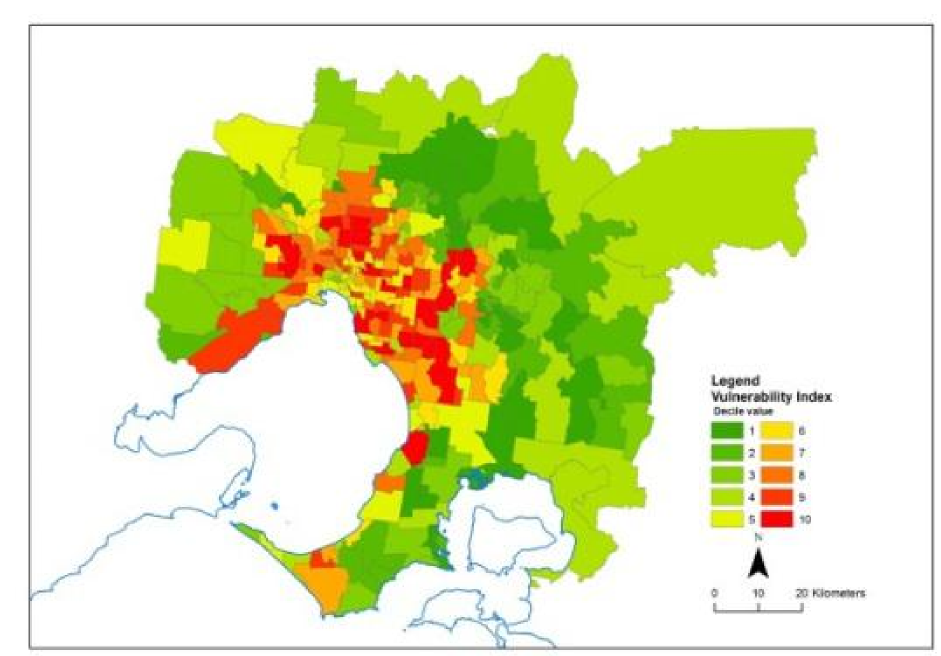
Observations



Remote sensing



Modelling

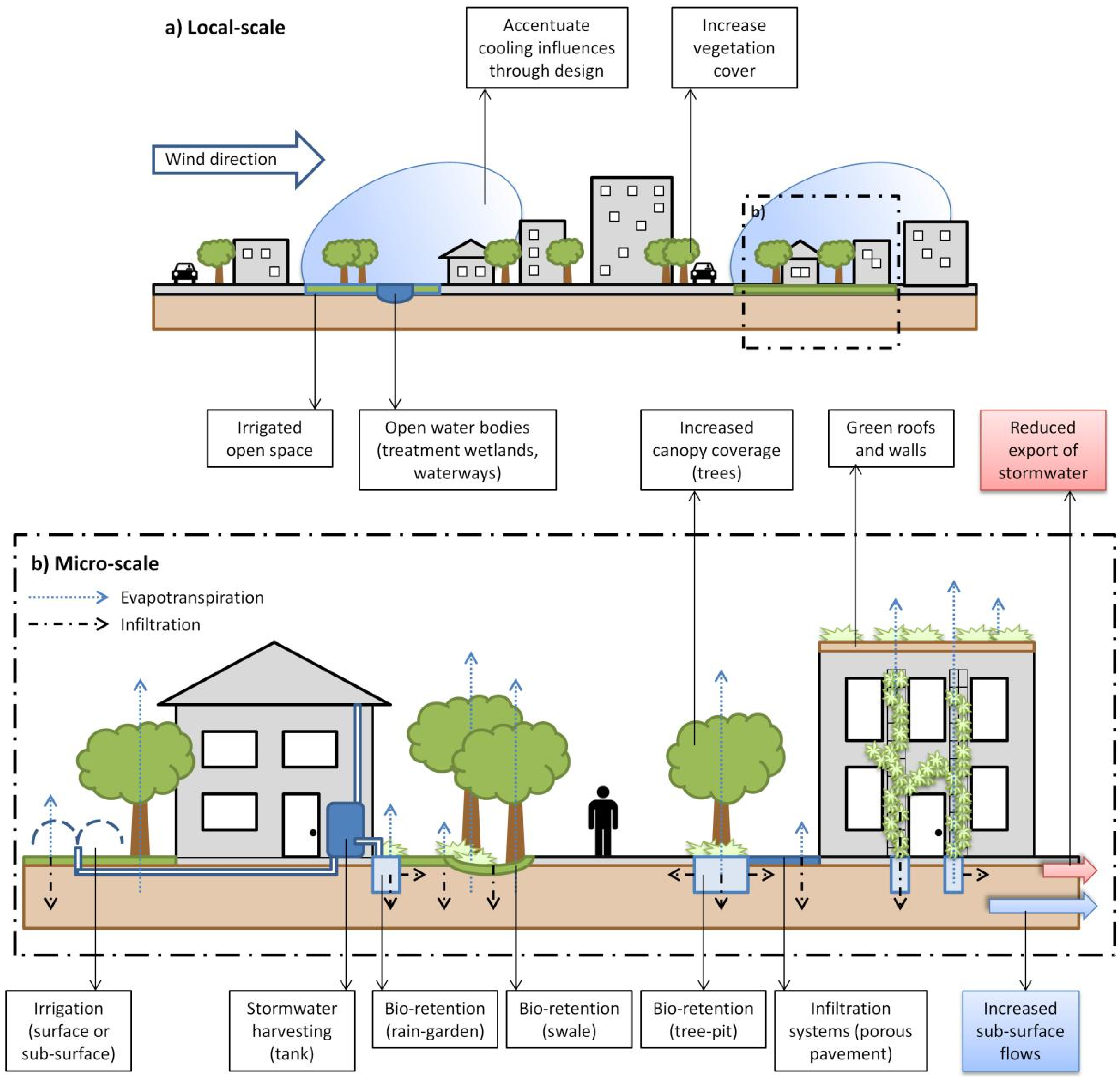


Database mapping

Urban greening for improved human thermal comfort

2 Key Goals:

- Reduced neighbourhood (local-scale) air temperature
- Improve street (micro-scale) human thermal comfort



Coutts et al 2013

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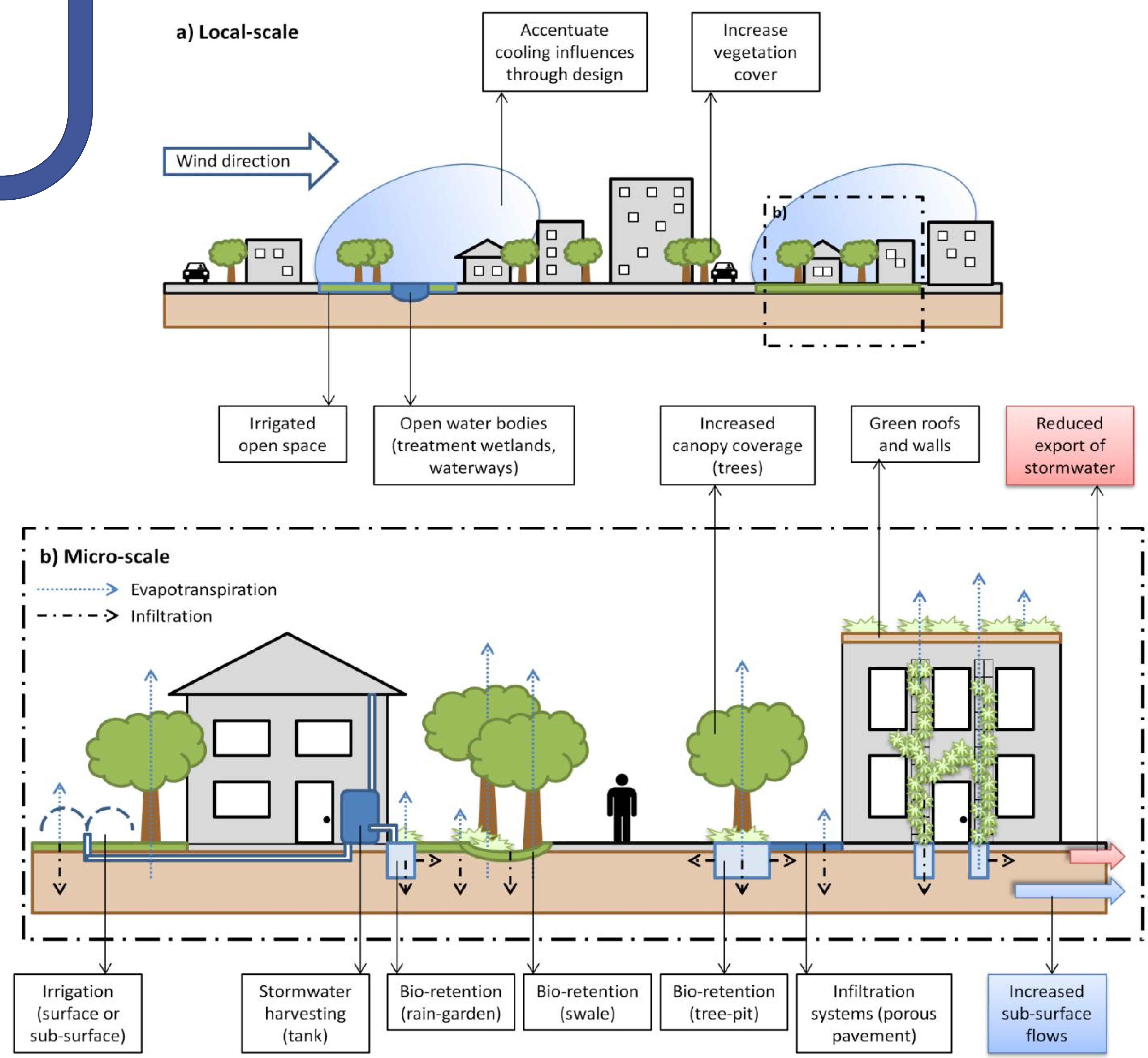
Solutions

Reduce local-scale air temperature → Limit heat-health impacts

Role of water and green infrastructure

Reduce micro-scale air temperature and *radiant* temperature

Improve human thermal comfort



Coutts, Tapper, Beringer, Loughnan, Demuzere (2013)

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Assessments of cooling solutions require modelling tools

- Modelling tools to support analysis of HTC impacts of WSUD
- Three main modelling tools for the CRC
  - VTUF−3D
  - CRC Toolkit2
  - SURFEX

VTUF-3D urban micro-climate model

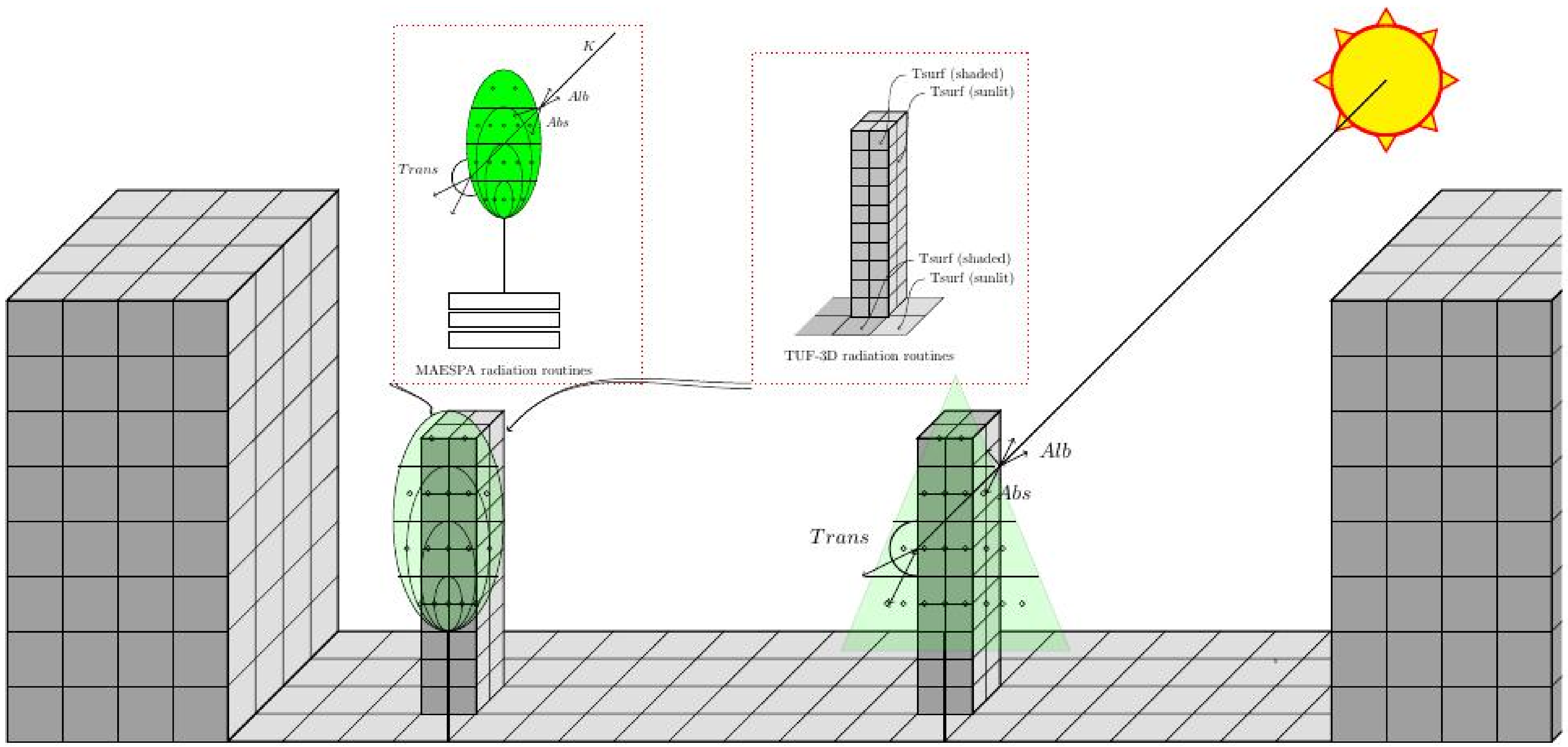
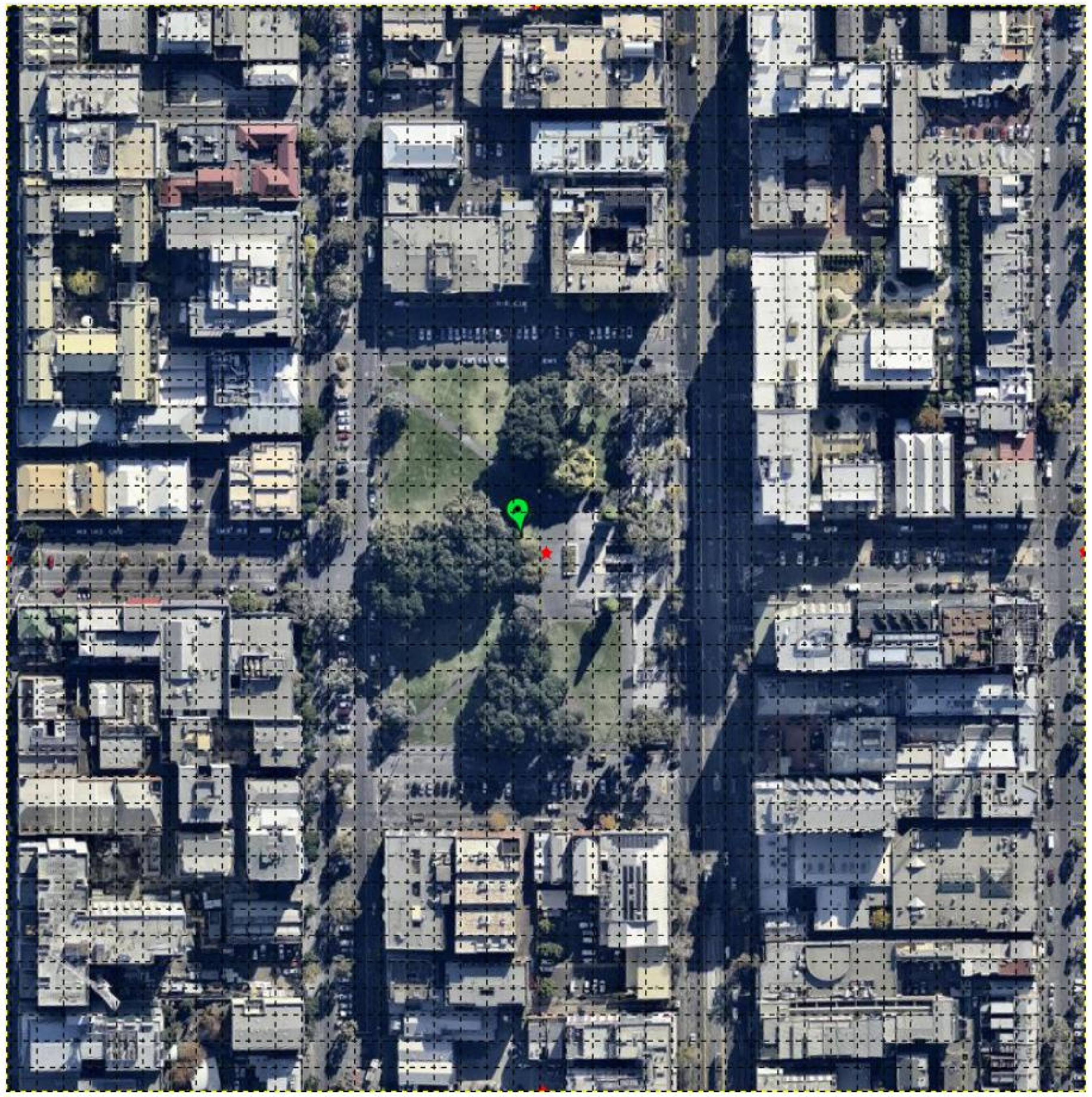


Figure 4.2: *Integration of MAESPA tree model into VTUF-3D radiation fluxes routines, in which tiled instances of MAESPA vegetation (in green) are used to calculate radiation transmission for VTUF-3D placeholder vegetation structures (in grey).*

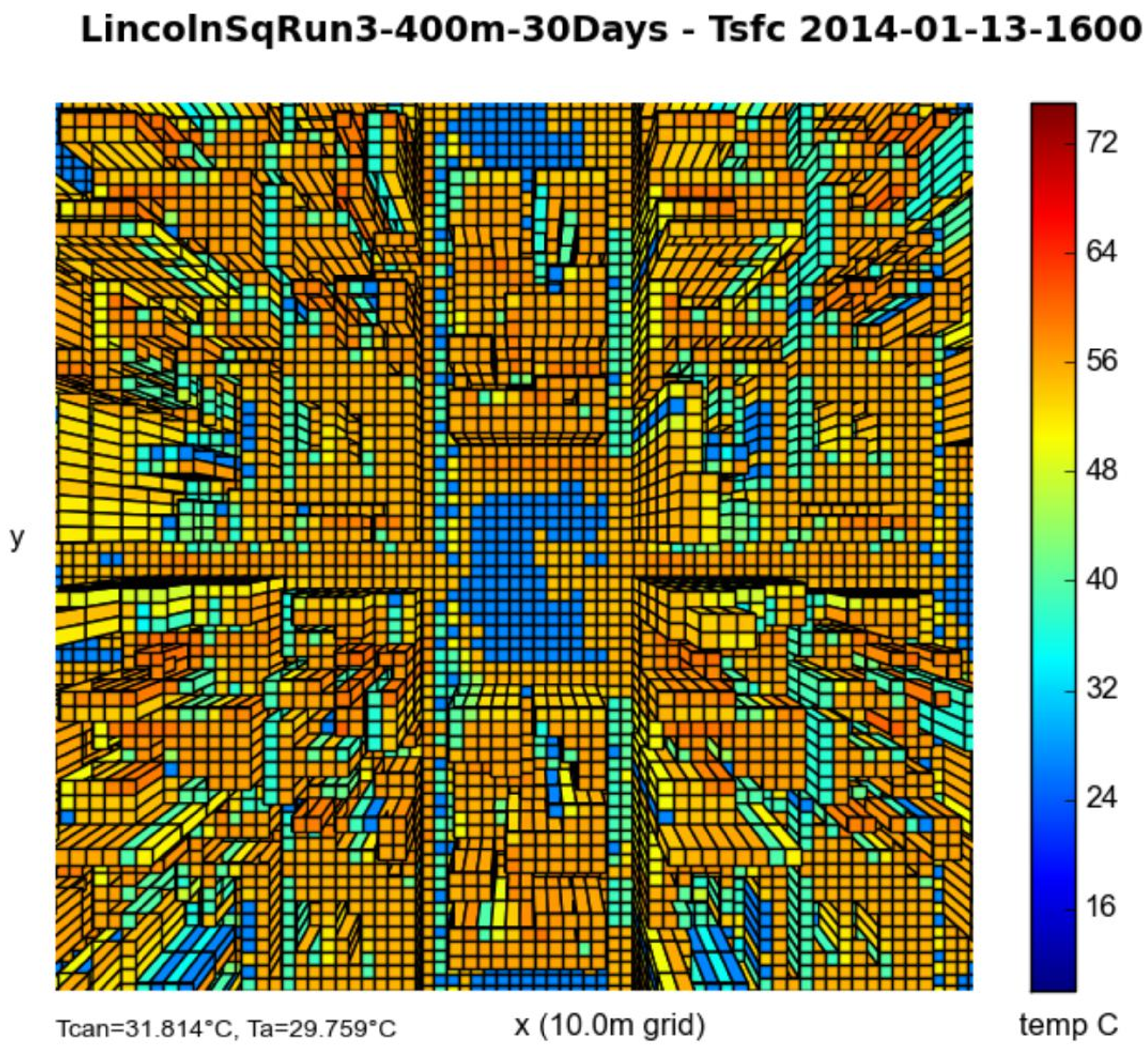
(Nice 2016)

VTUF−3D, developed to support micro−climate modelling, especially including the influences of urban vegetation and water

VTUF-3D modelling urban canopies at micro-scaled resolution

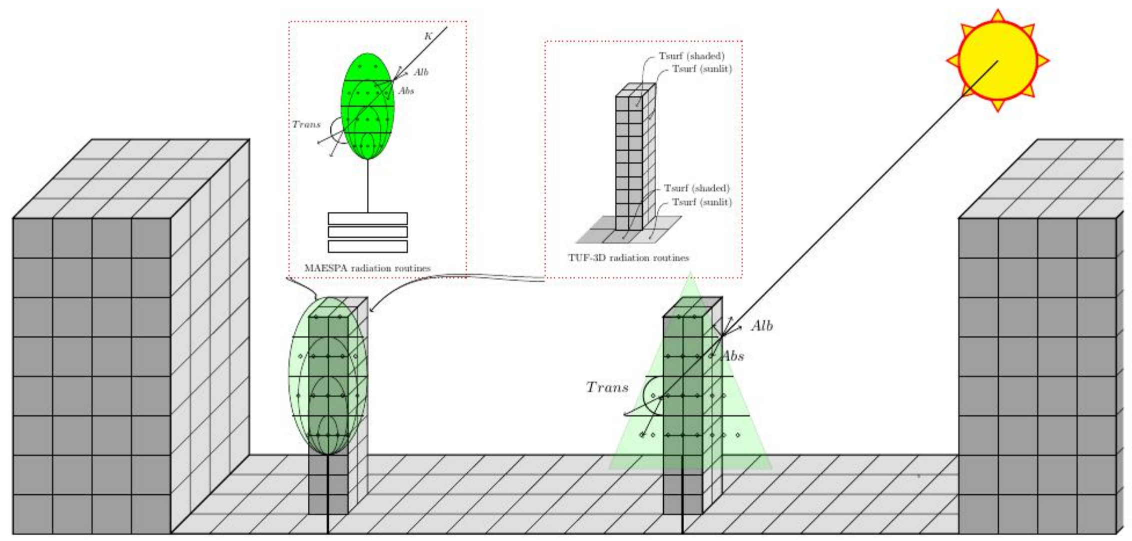


Lincoln Square, Melbourne



(Nice 2016)

VTUF−3D micro−climate model



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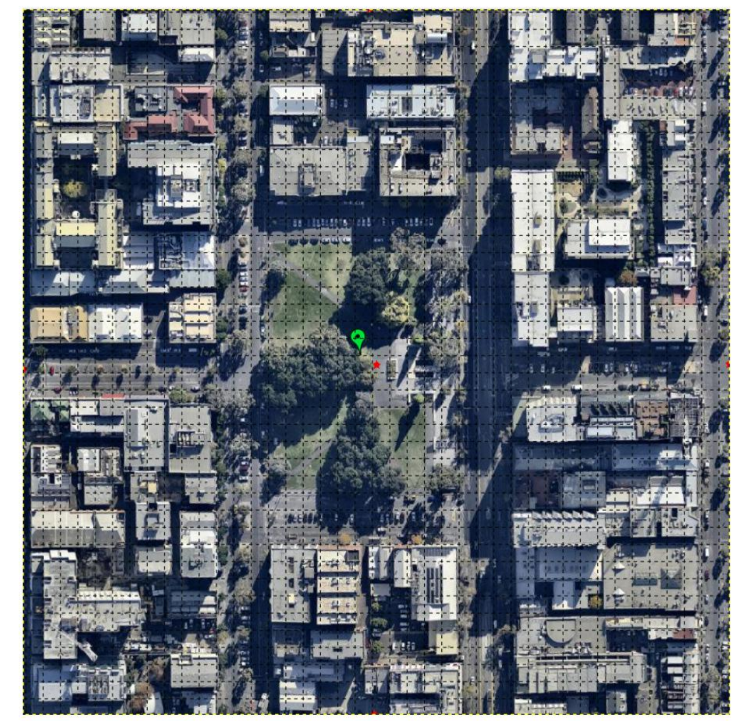
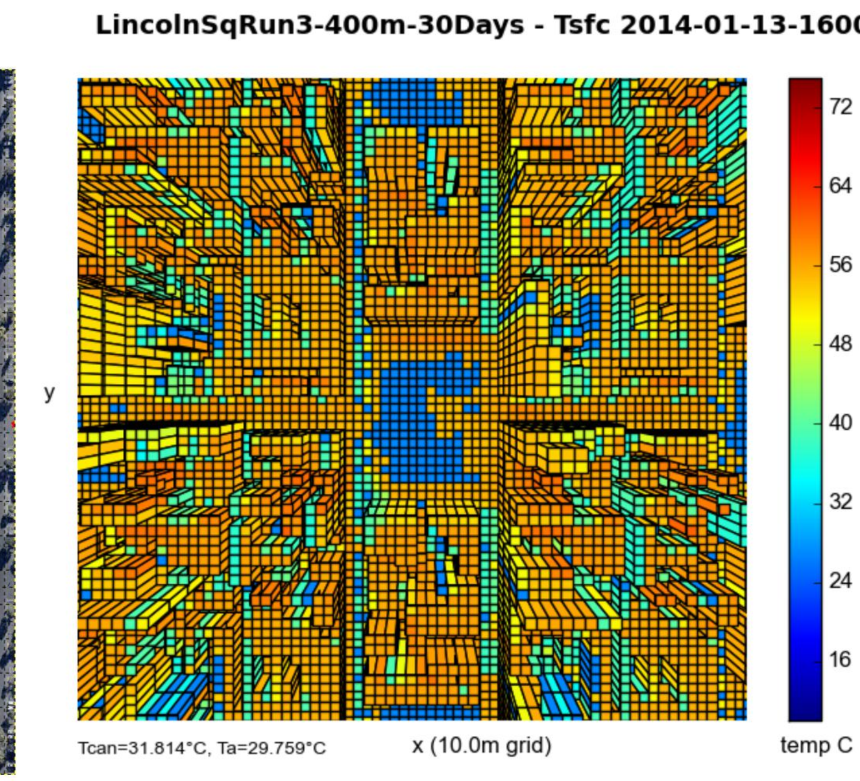
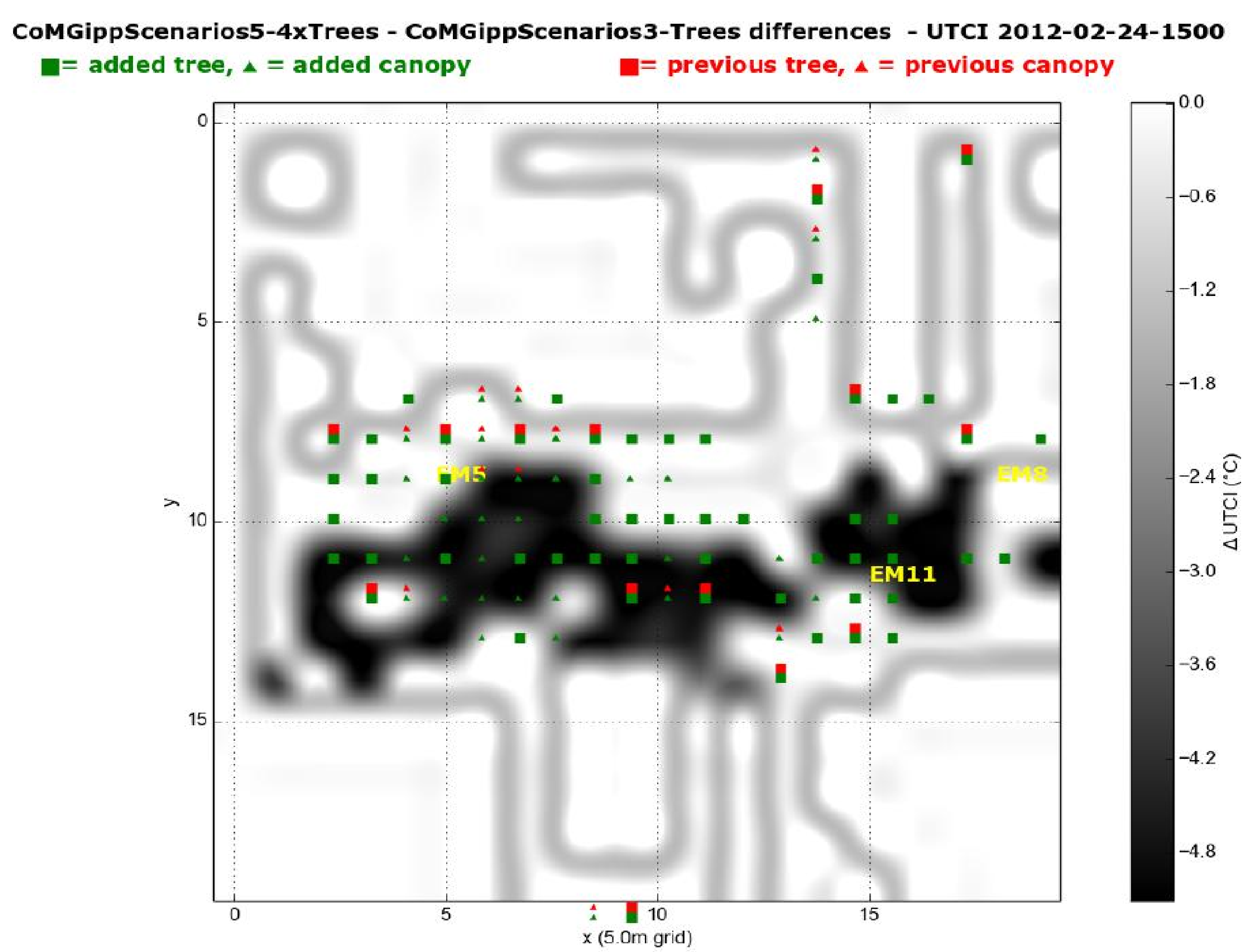




Lincoln Square, Melbourne

High resolution modelling of urban areas including urban vegetation



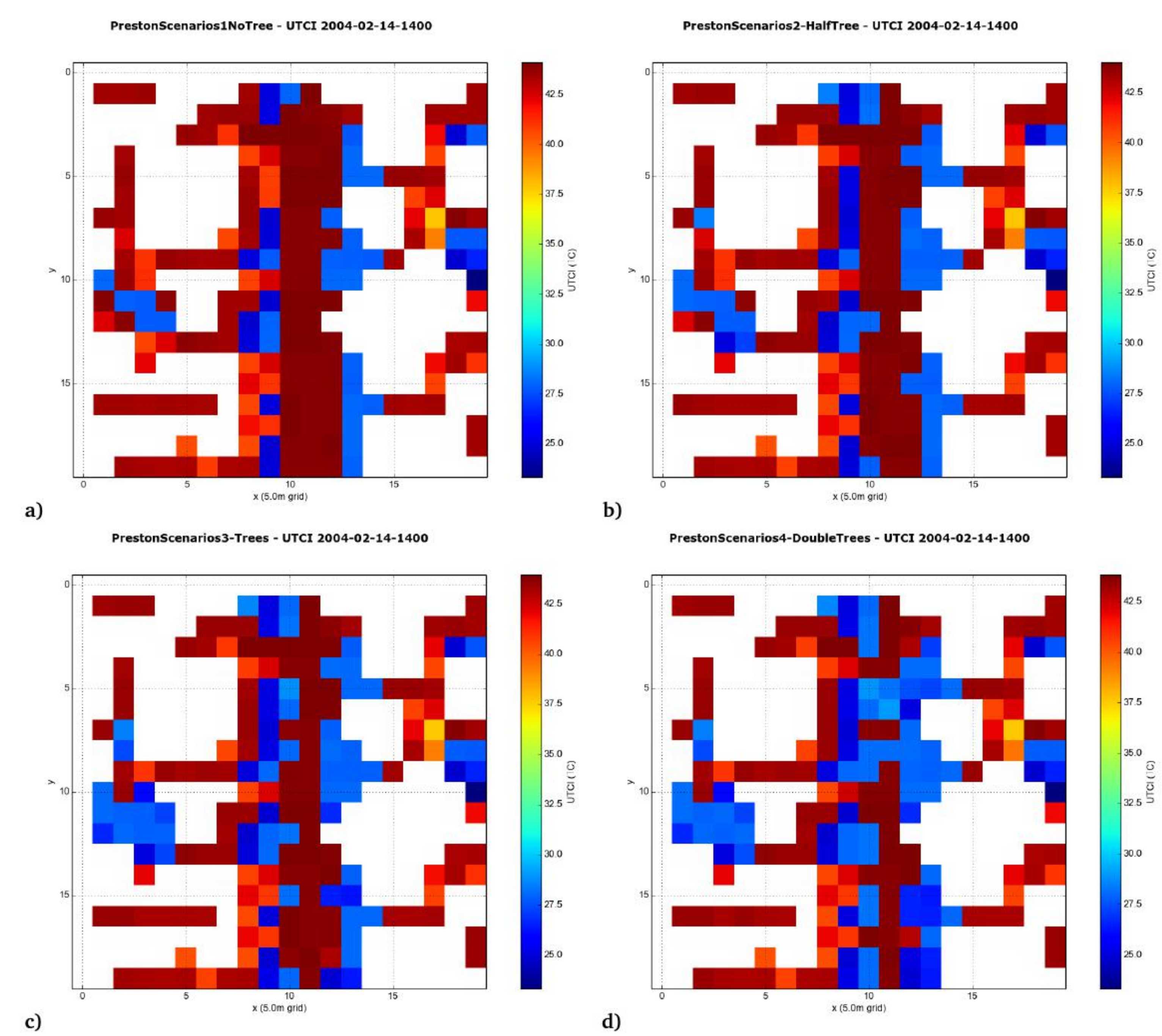
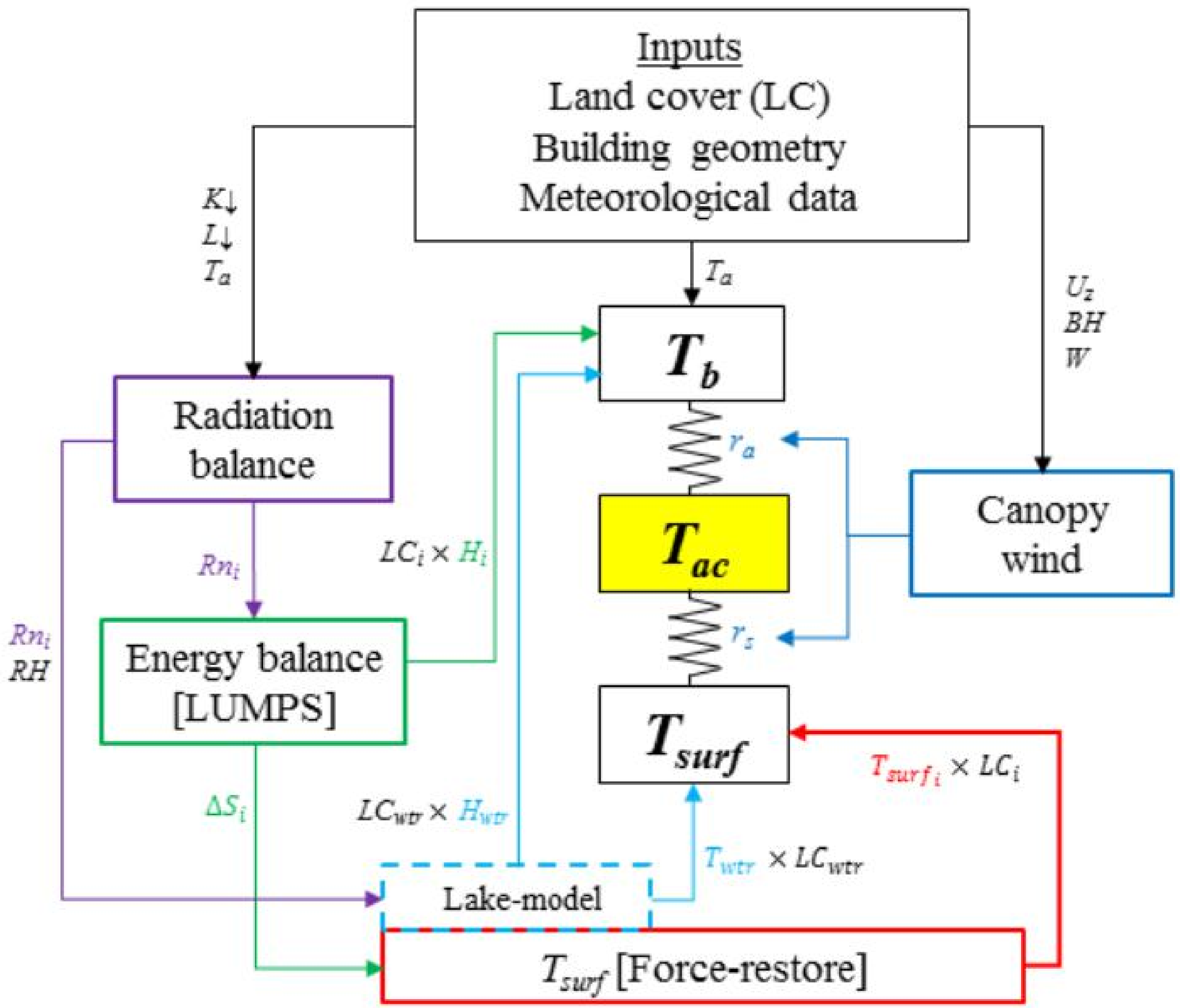


Figure 6.2: *UTCI (°C) of surfaces at 0m height for four scenarios, a) PrestonScenarios1-NoTree, b) PrestonScenarios2-HalfTree, c) PrestonScenarios3-Trees, and d) PrestonScenarios4-DoubleTrees, for modelled timestep 14 February 2004 at 2pm.*

Analysis of cooling through canopy cover scenarios

(Nice 2017)

CRC Toolkit2 micro-climate model



Developed as a simple and efficient yet robust model to account for cooling effects of urban vegetation and water at local to micro scales.

(Broadbent & Coutts 2016)

LUMPS component of Toolkit2

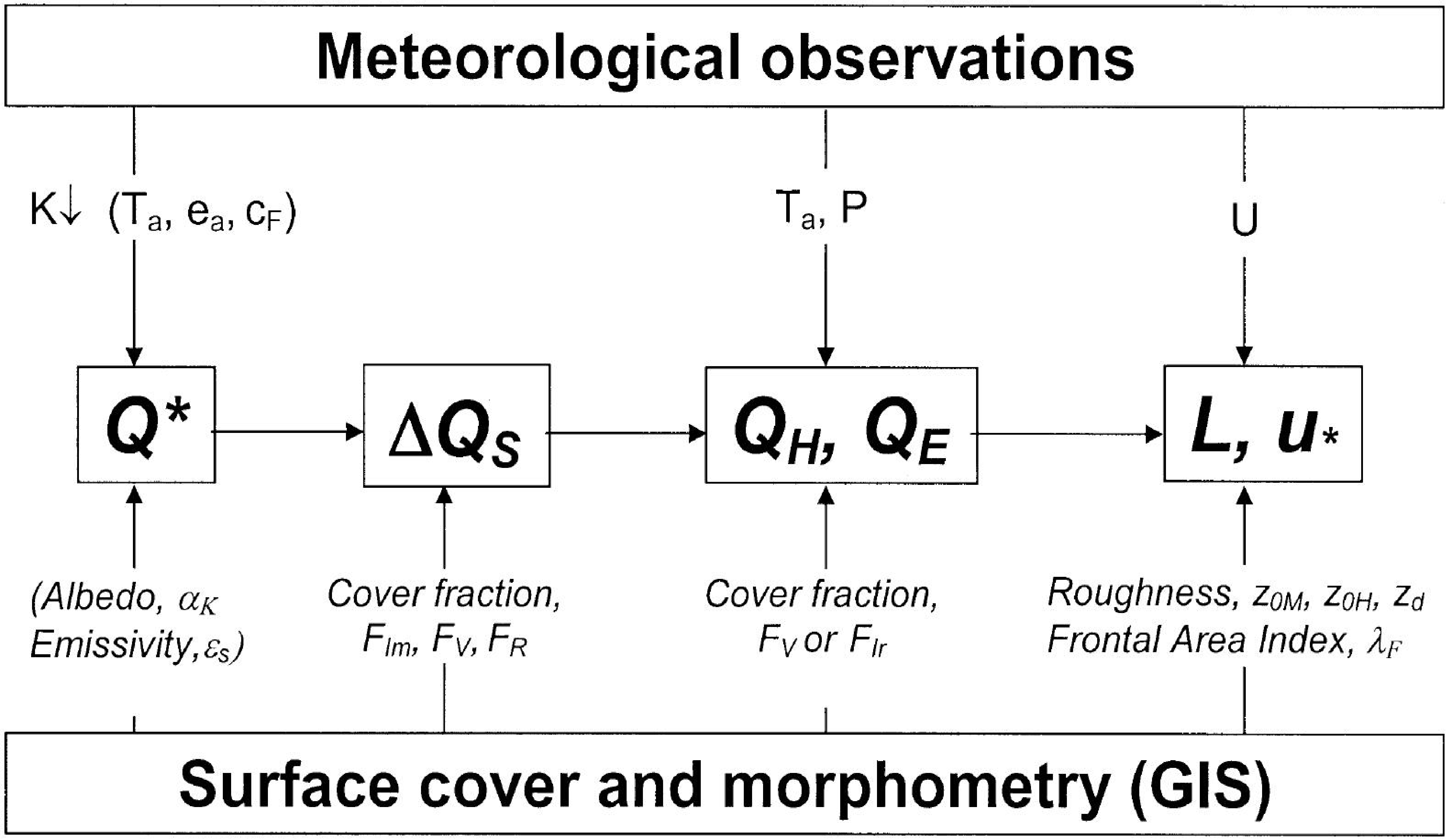
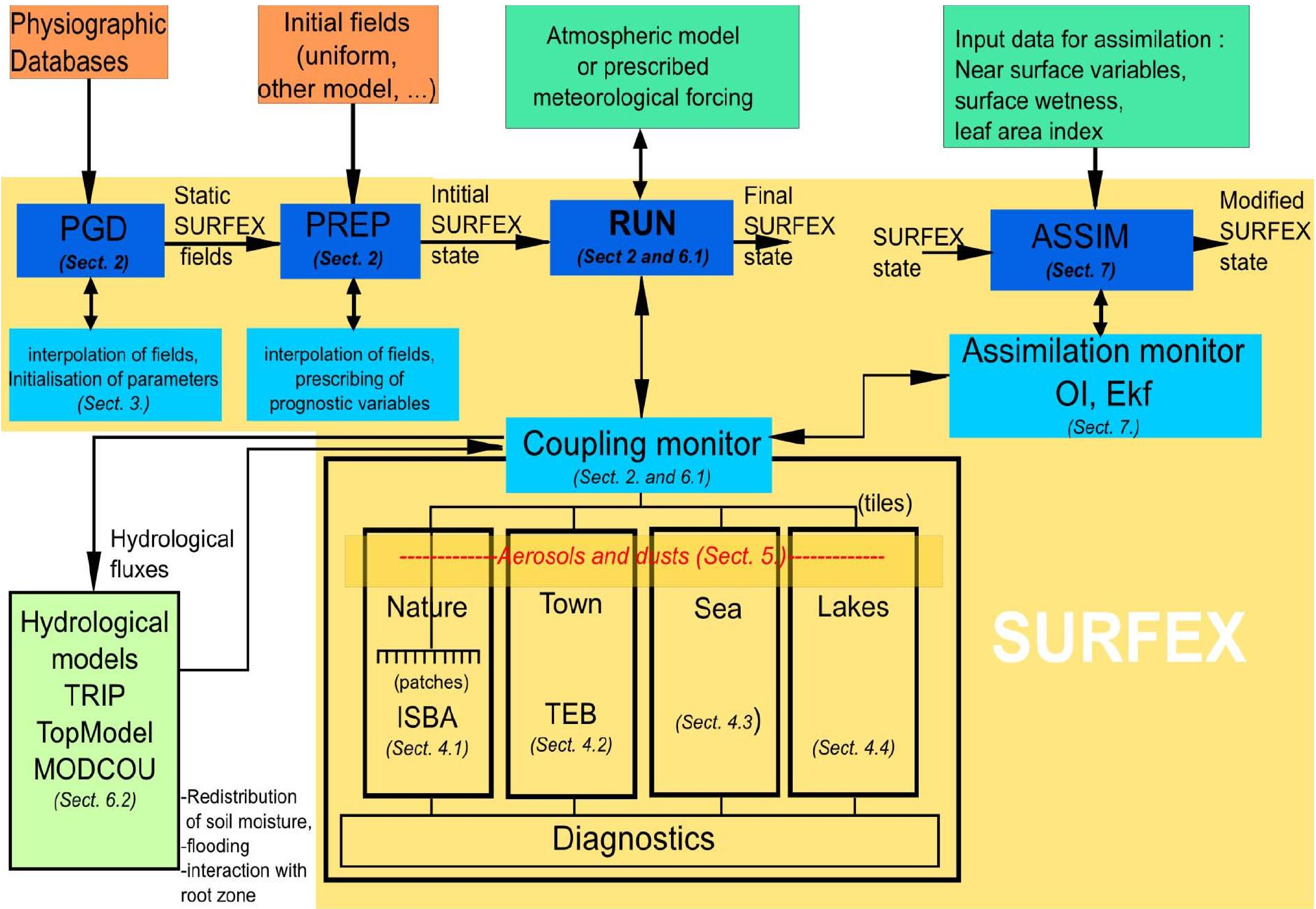


FIG. 1. Flow chart of the structure of LUMPS. Quantities in parentheses are needed only if net all-wave radiation Q^* or incoming shortwave radiation $K\downarrow$ are not measured: T_a is air temperature, e_a is actual vapor pressure, c_F is cloud fraction, P is pressure, U is wind speed, ΔQ_S is storage heat flux, Q_H is turbulent sensible heat flux density, Q_E is latent heat flux density, L is Obukhov length, and u^* is friction velocity.

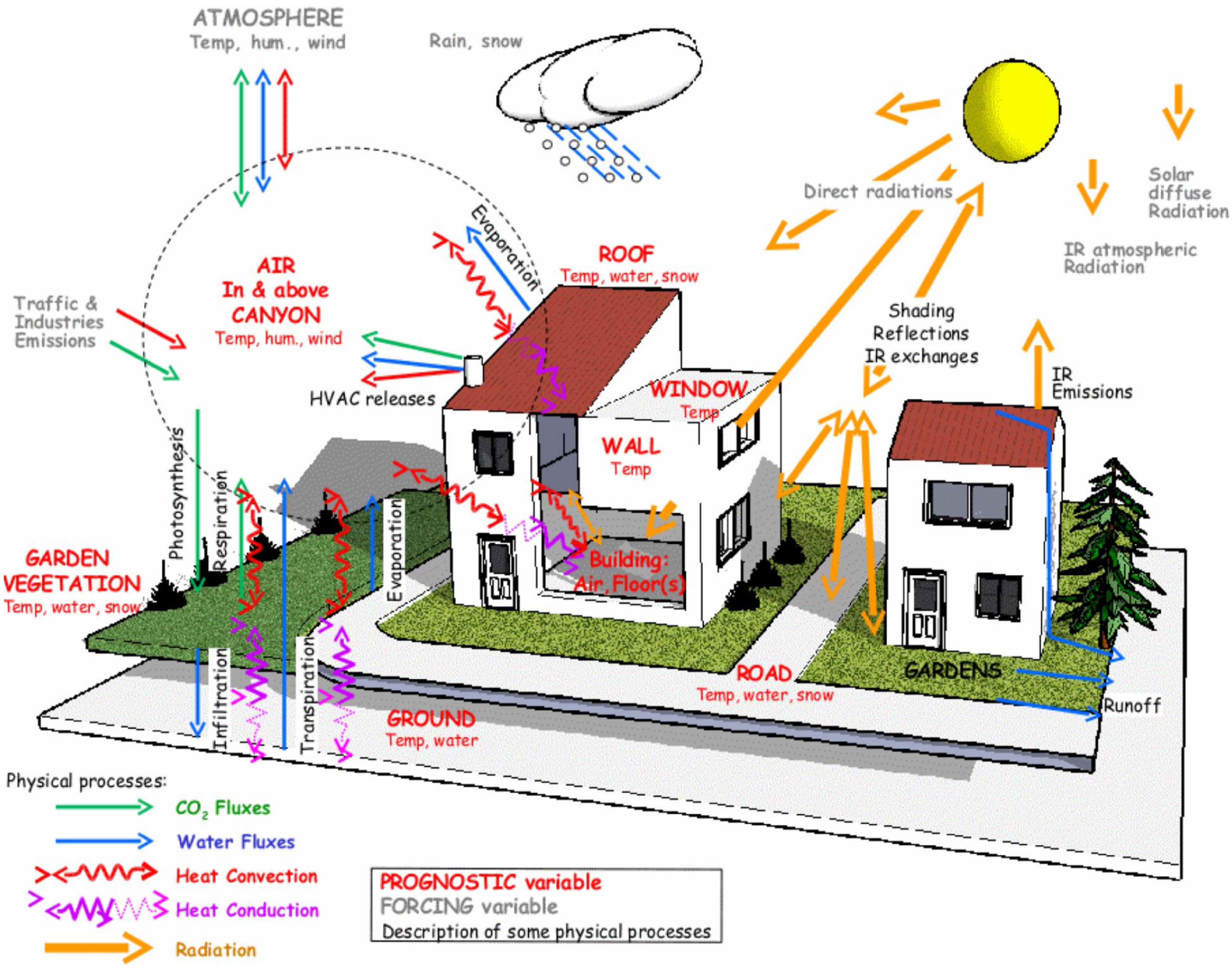
(Grimmond & Oke 2002)

SURFEX



(Masson et al. 2013)

SURFEX – Town energy balance (TEB) module

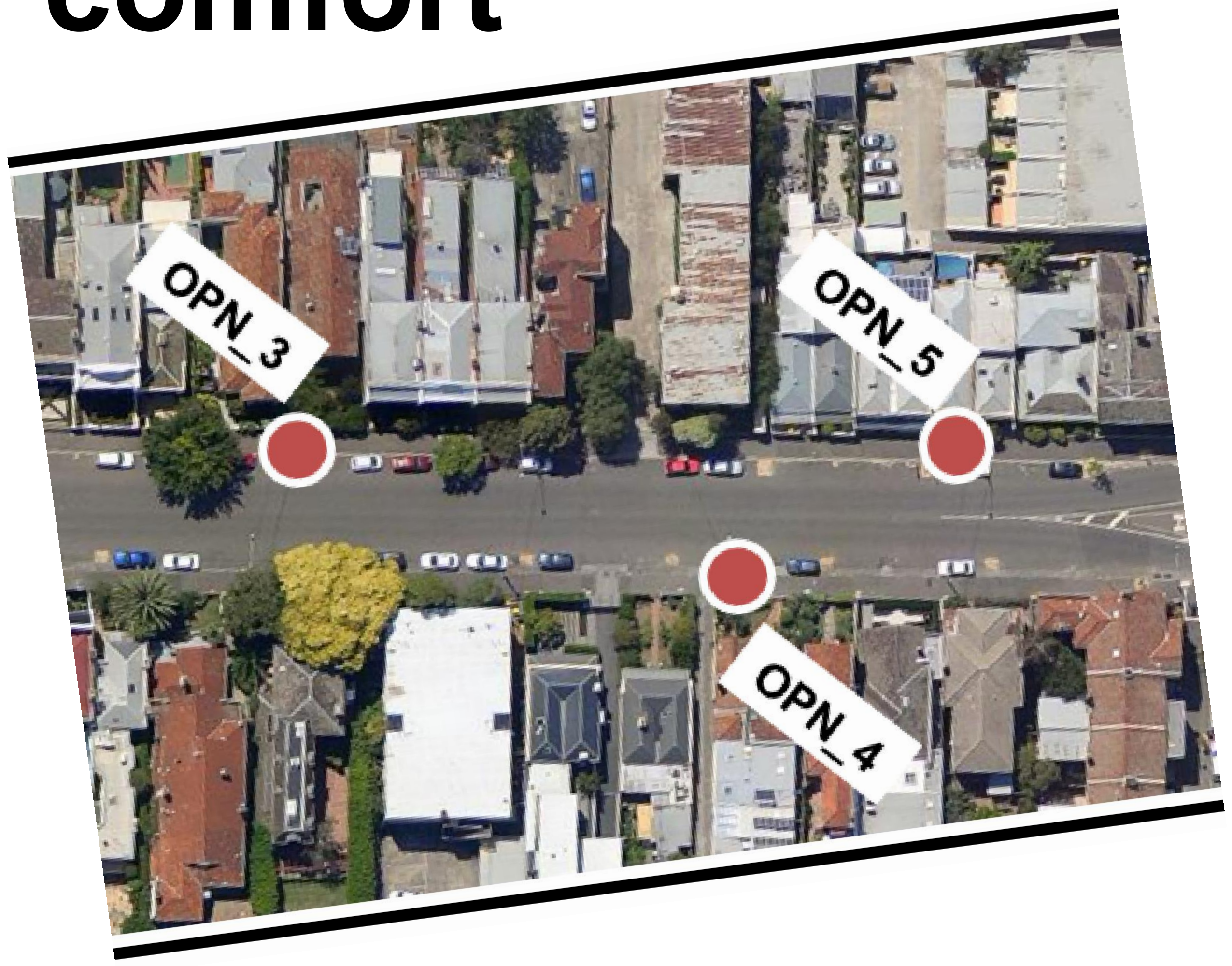


(Masson et al. 2013)

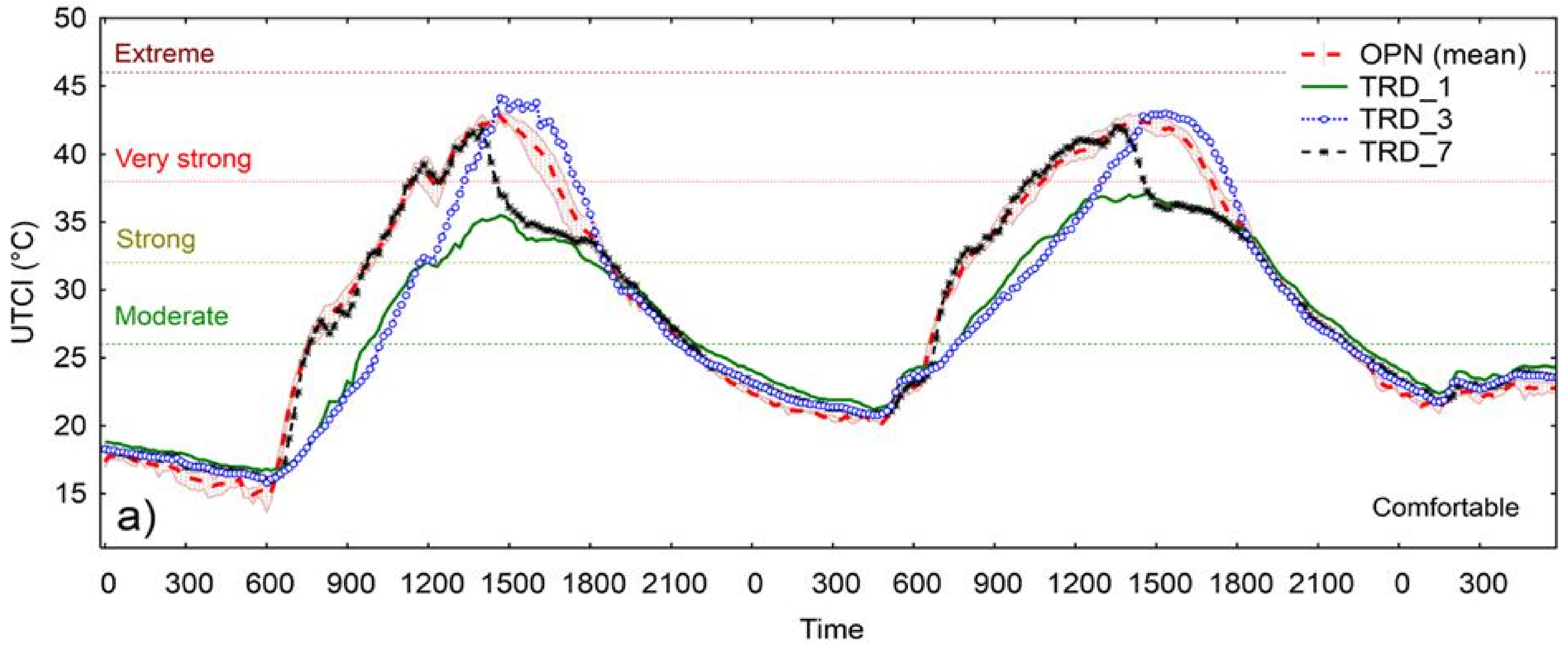
Application of modelling tools in assessing HTC impacts of WSUD

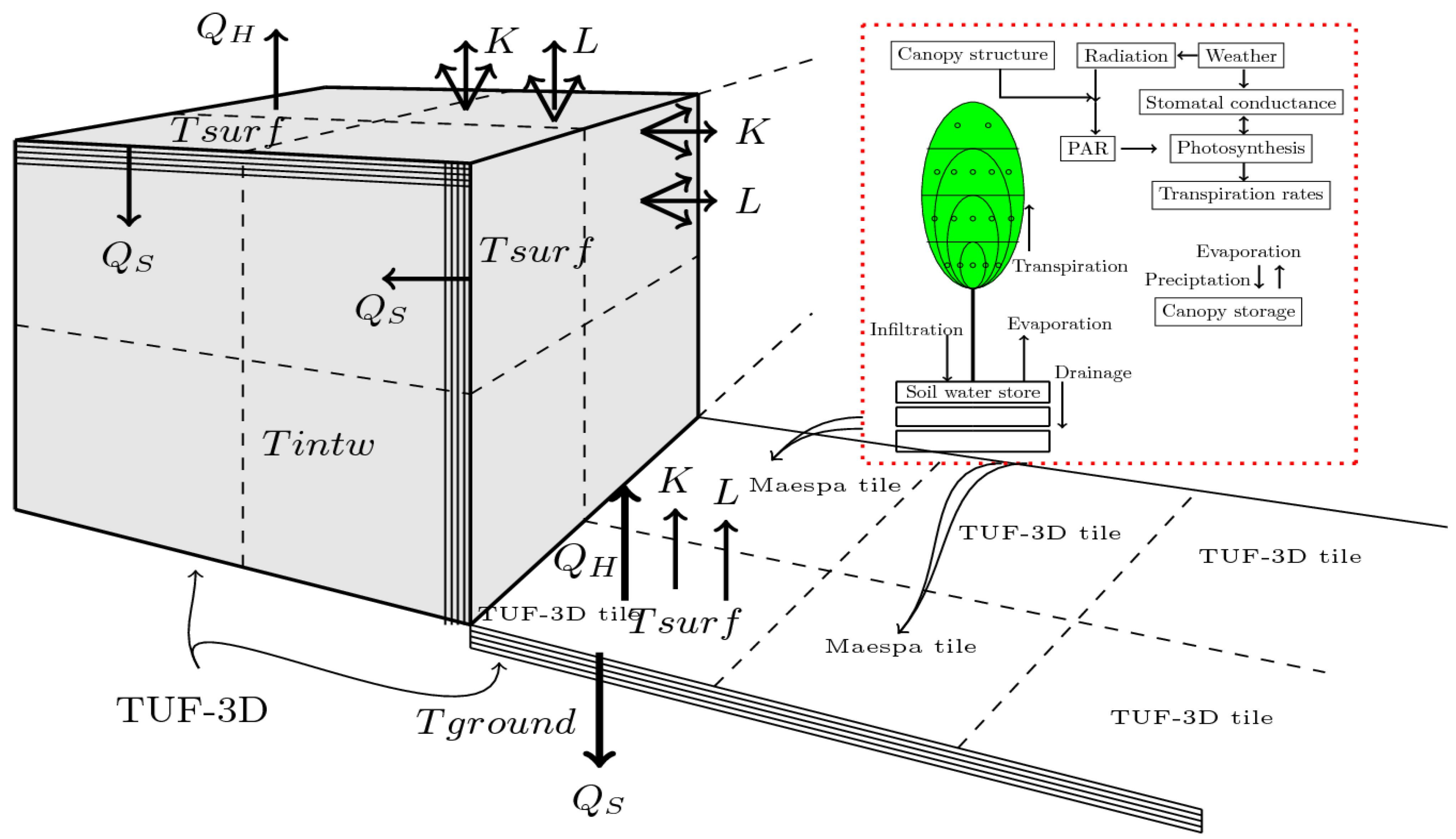
- How have these three models been used to examine this issue?
  - VTUF−3D
  - CRC Toolkit2
  - SURFEX

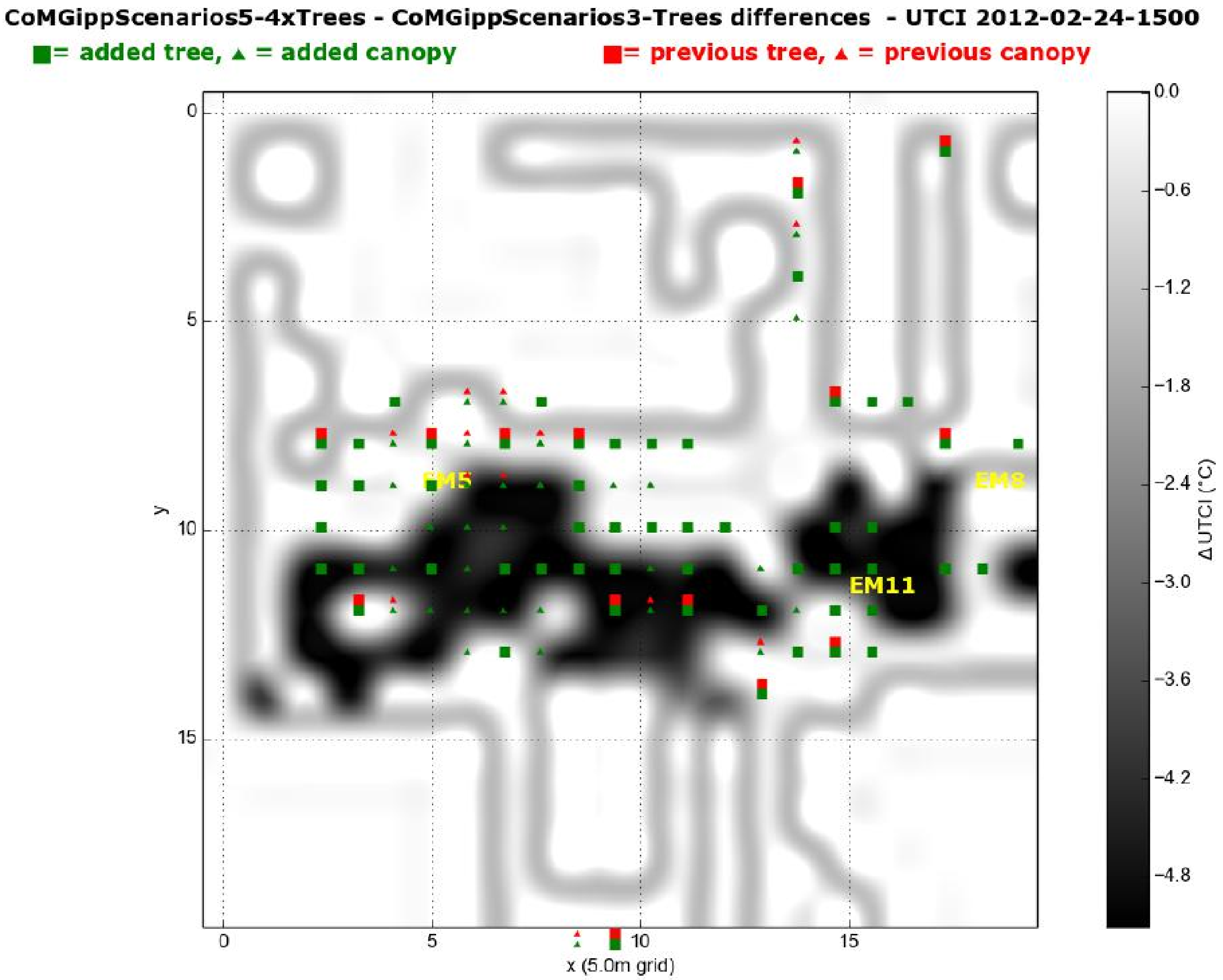
VTUF-3D- Examining how trees improve human thermal comfort



(Coutts et al., 2015).







Nice, 2016

VTUF-3D- HTC impacts of urban canopy cover

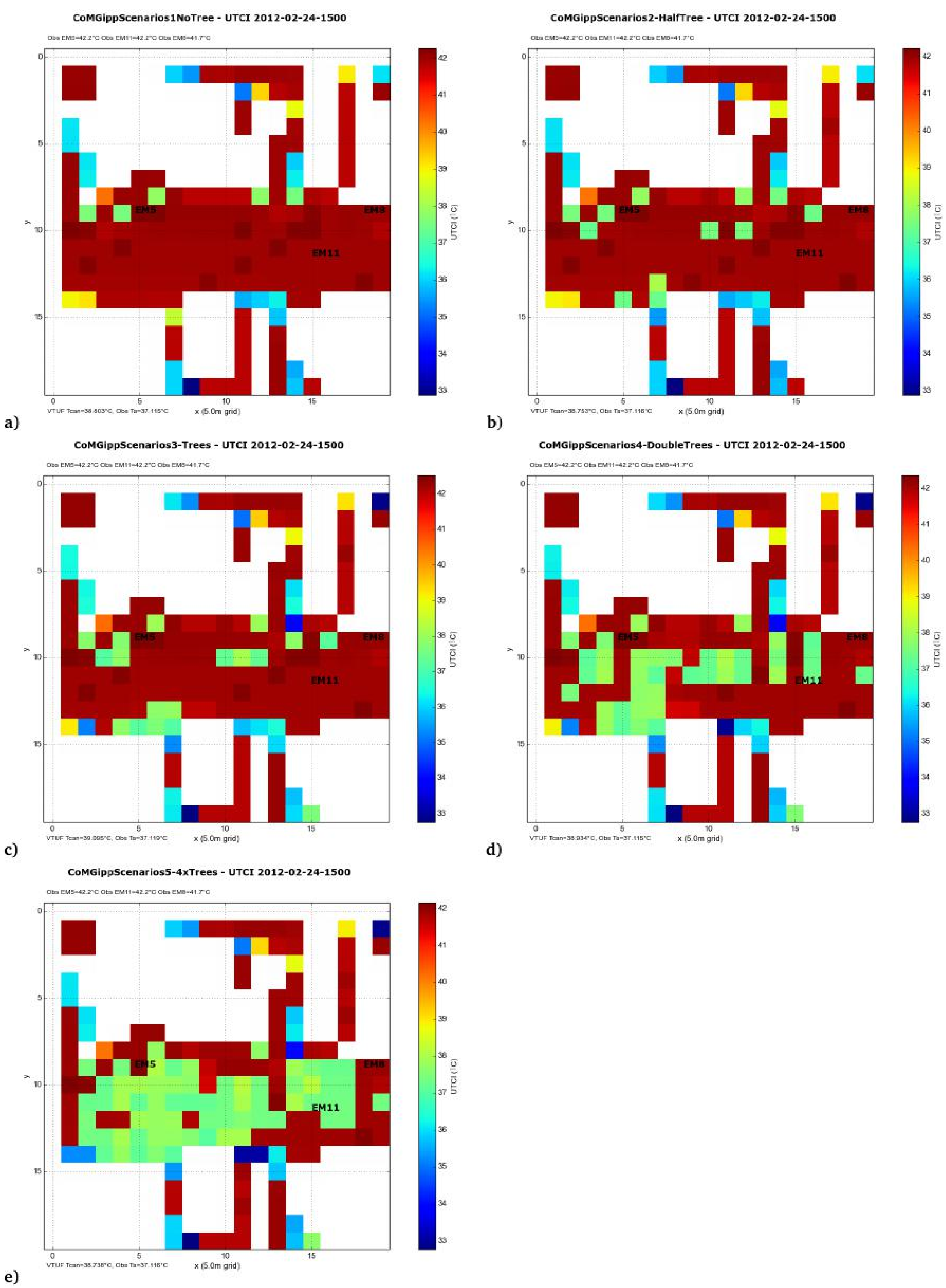
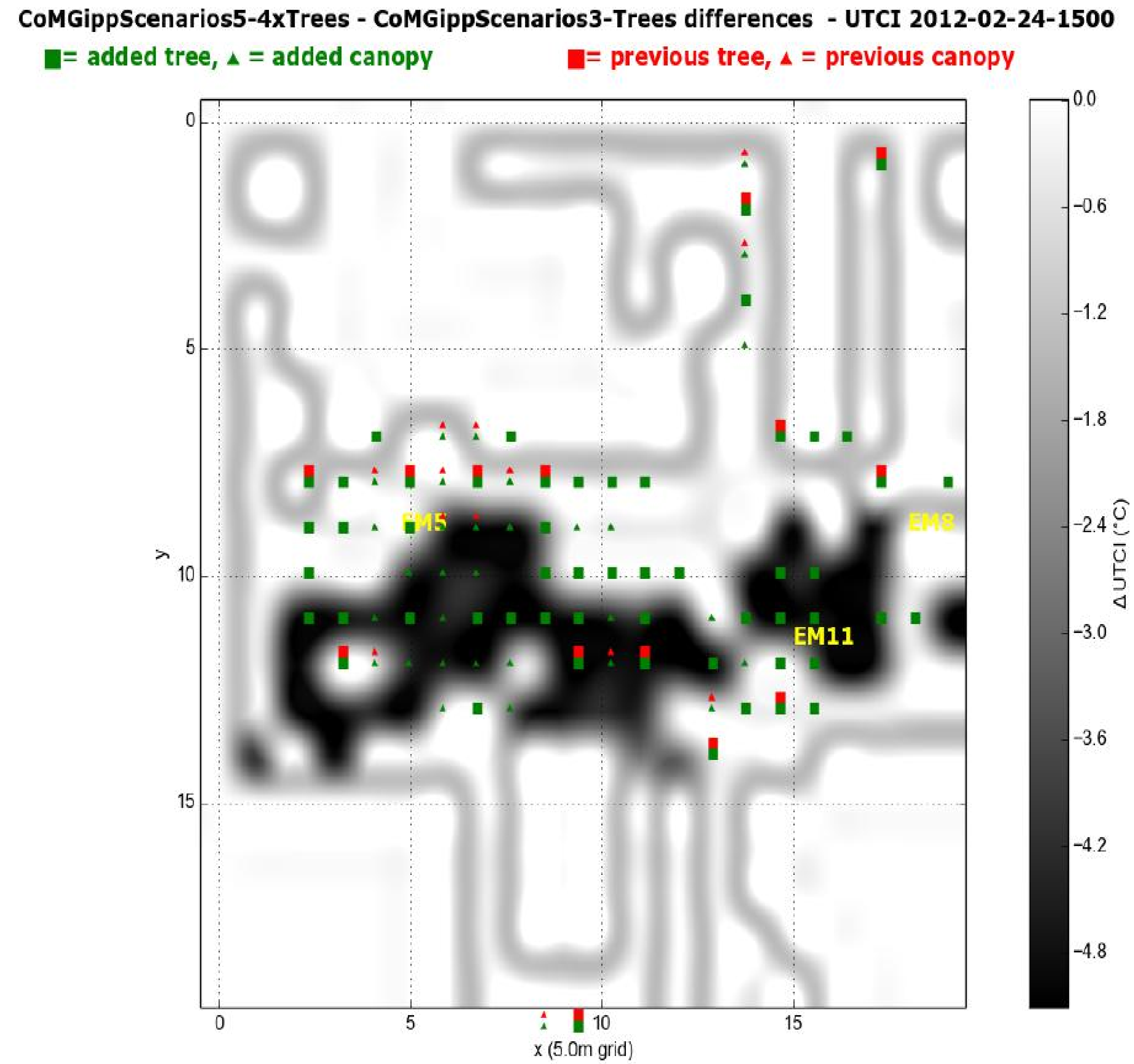


Figure 6.7: *UTCI (°C) of surfaces at 0m height for five scenarios, a) CoMGippScenarios1-NoTree, b) CoMGippScenarios2-HalfTree, c) CoMGippScenarios3-Trees, d) CoMGippScenarios4- DoubleTrees, and e) CoMGippScenarios5-4xTrees, for modelled timestep 24 February 2012 3pm.*



- Elimination of trees – average UTCI increases by 0.4C
- Double trees – UTCI reductions of over 2.0C
- Highly localised decreases of over 4C UTCI under canopy

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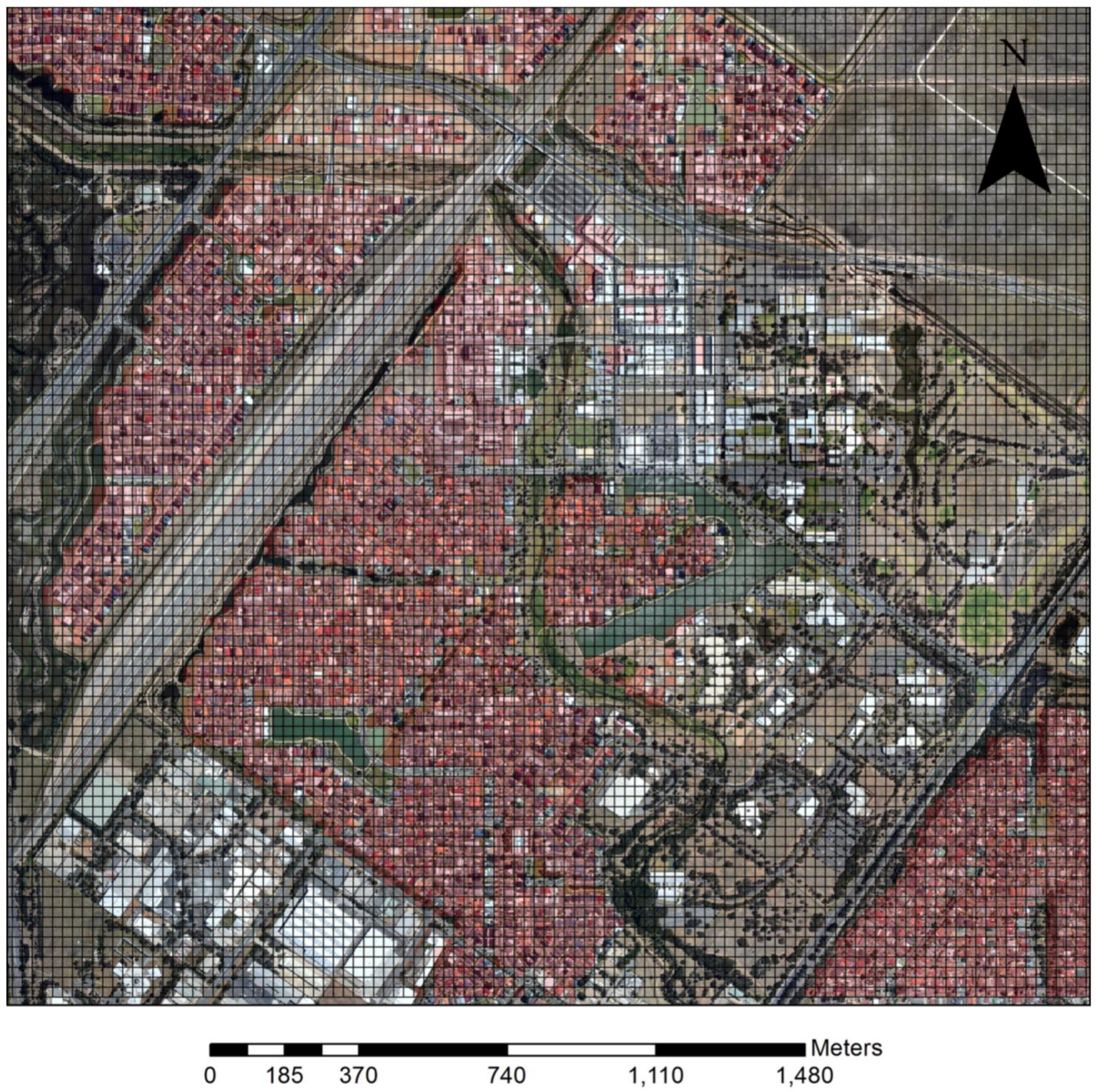
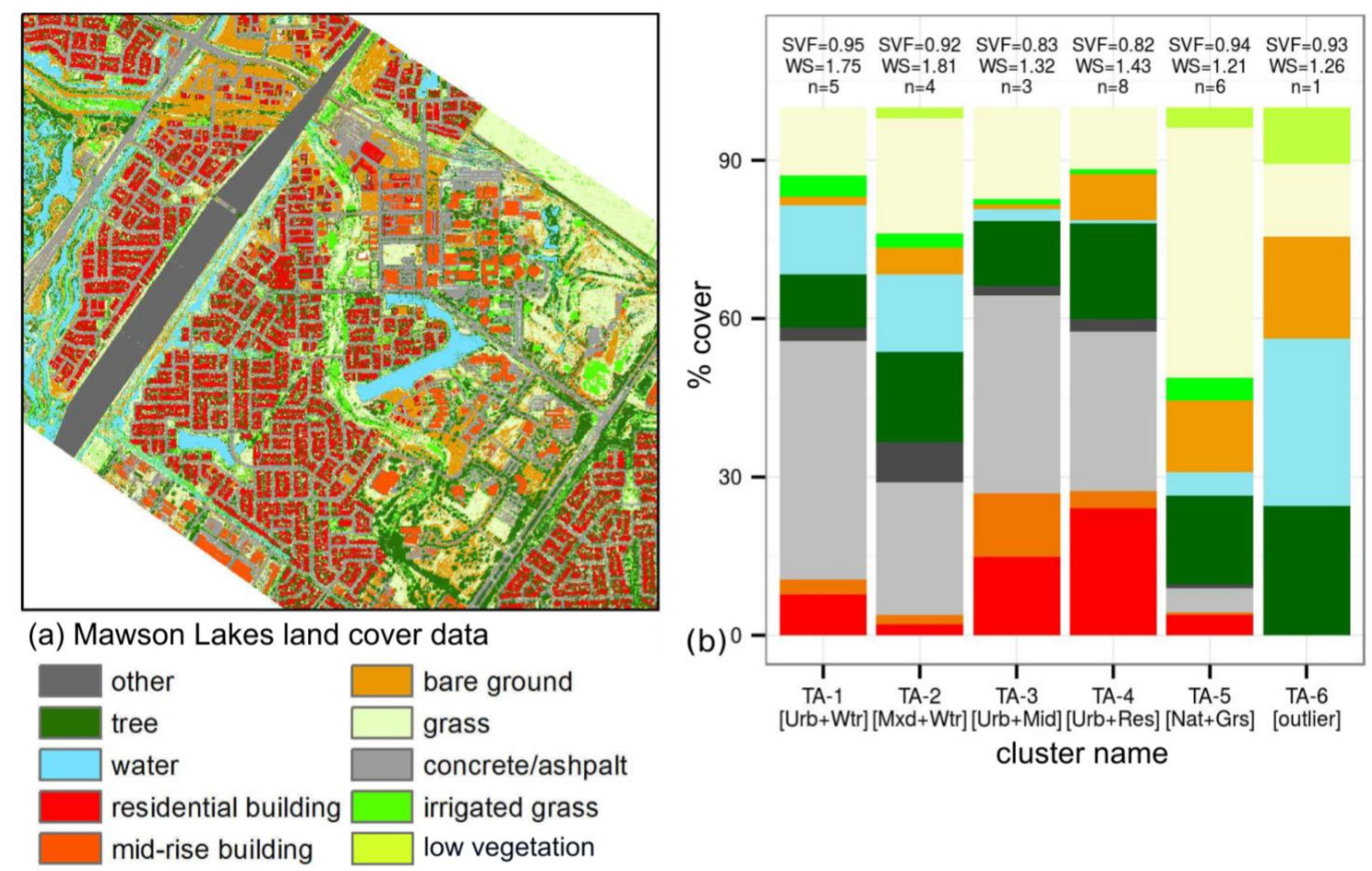
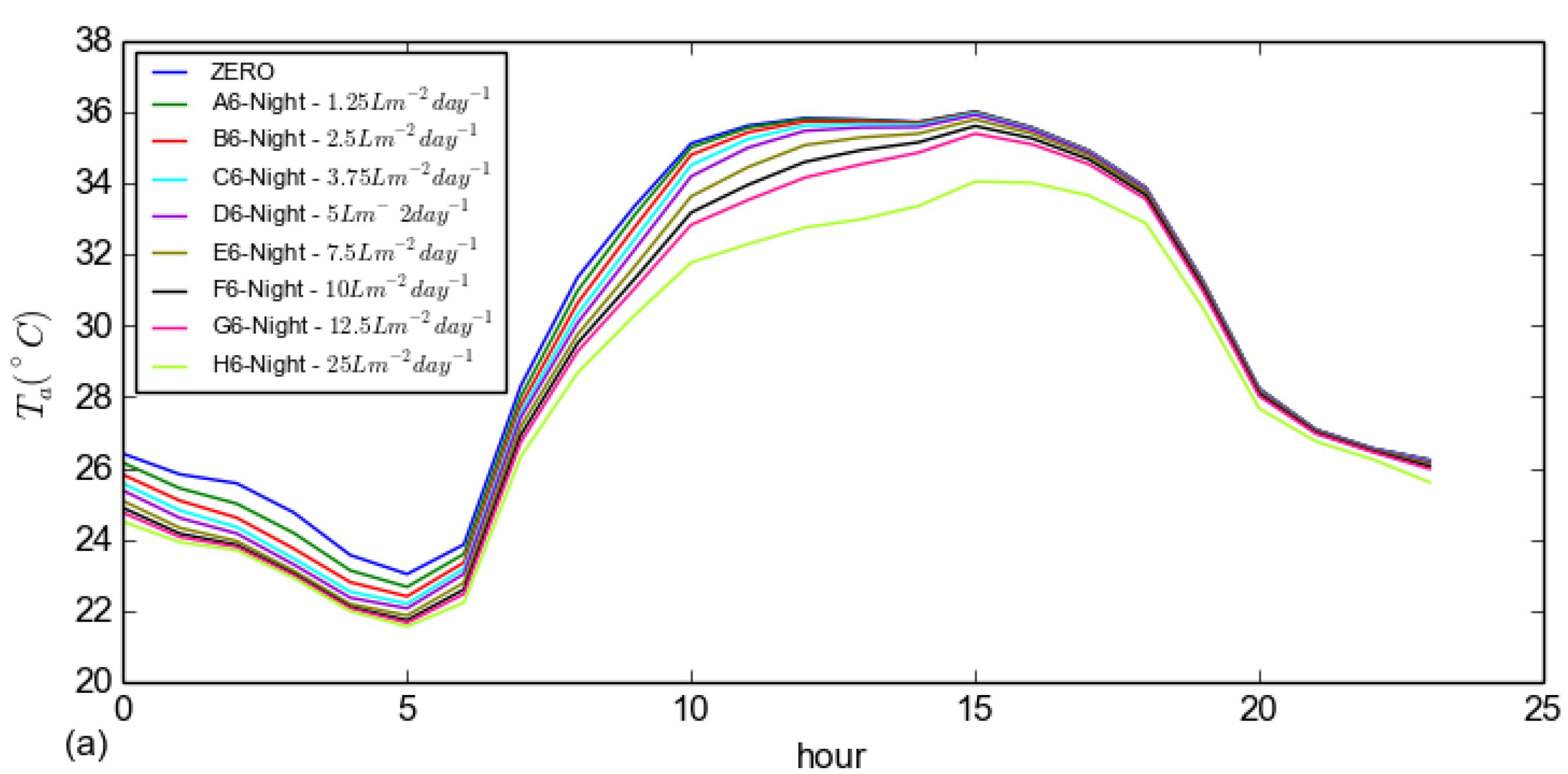
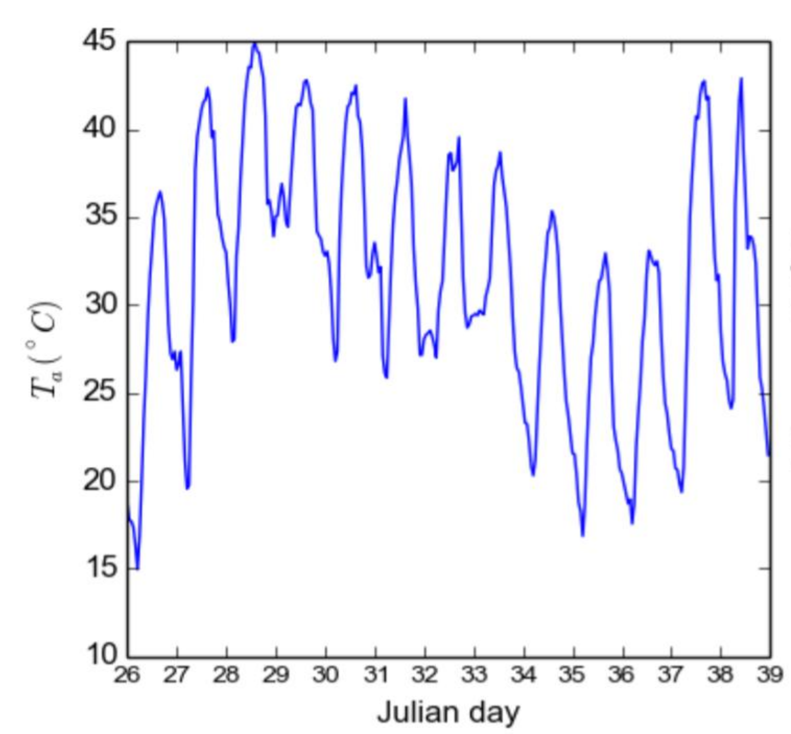
Landscape irrigation for cooler cities and suburbs – Example from Mawson Lakes, Adelaide

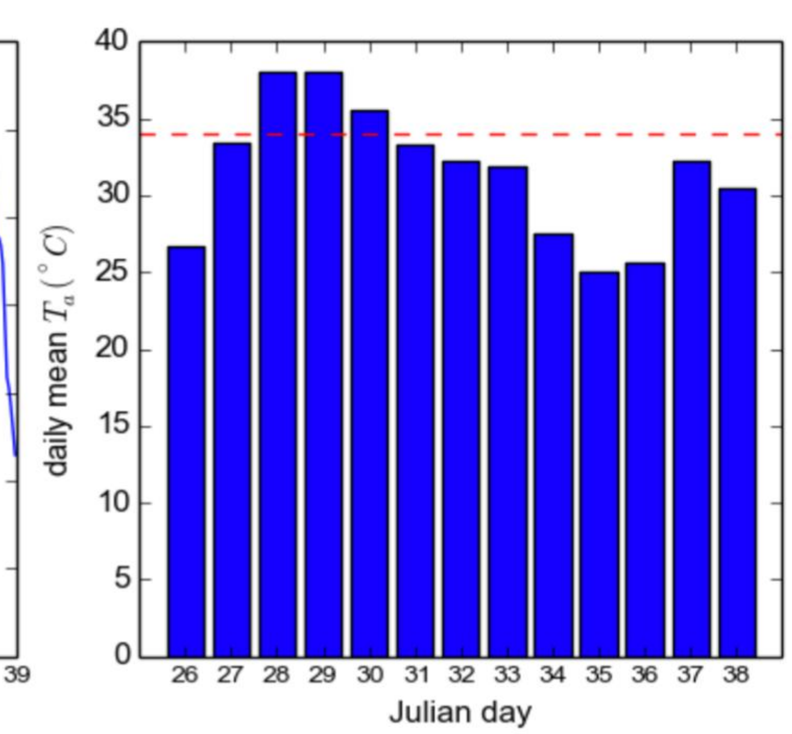


- Used an observation-validated SURFEX model to assess impact of irrigation during 2009 heatwave
- A range of irrigation scenarios simulated



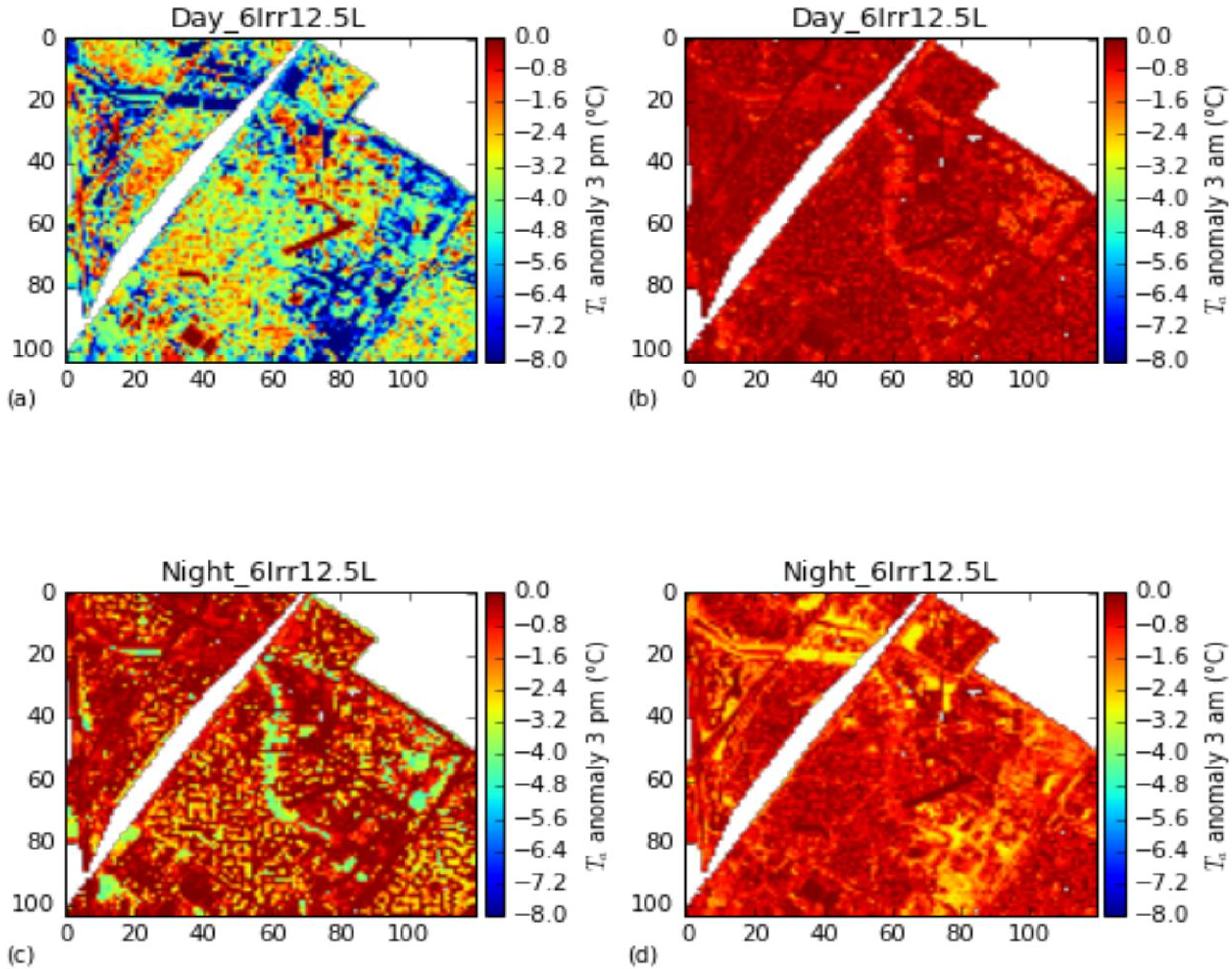






Broadbent, Coutts, Demuzere and Tapper (2017)

SURFEX modelling irrigation schemes

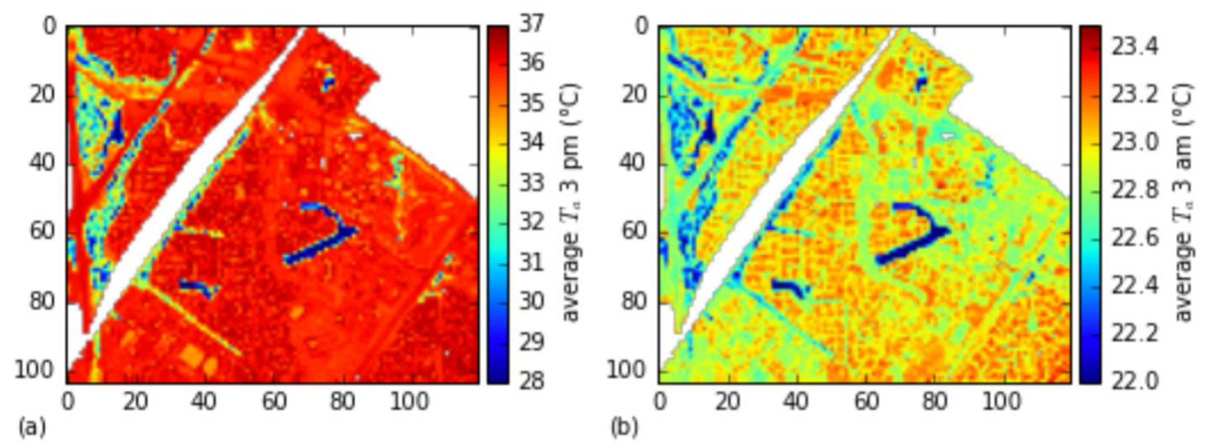


(Broadbent 2017)

Landscape irrigation - Mawson Lakes, Adelaide

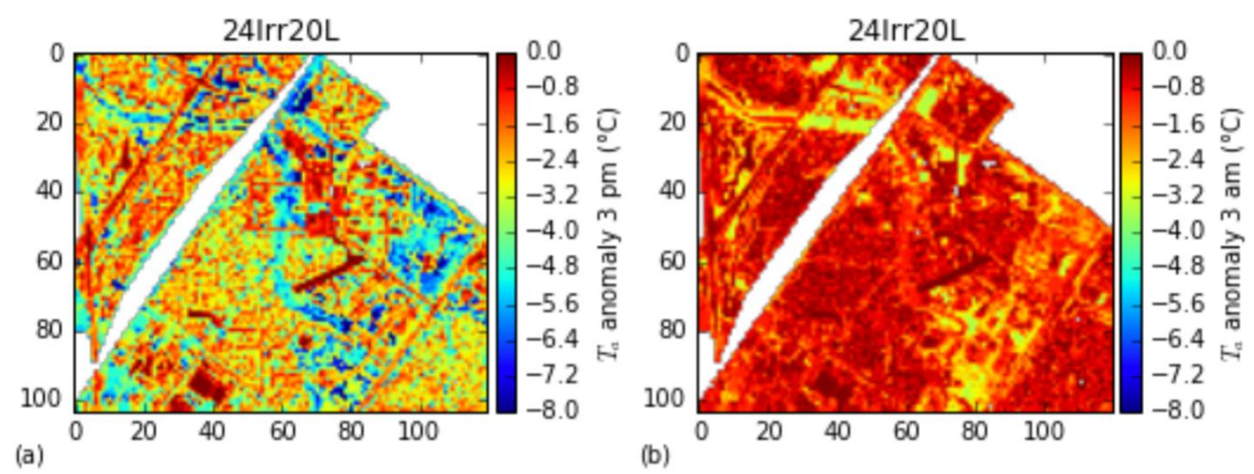
Spatial Patterns

- Significant spatial variation within the domain due to pervious fraction and vegetation type (see left and below)
- For continuous irrigation, more cooling during day than night – LHF especially large



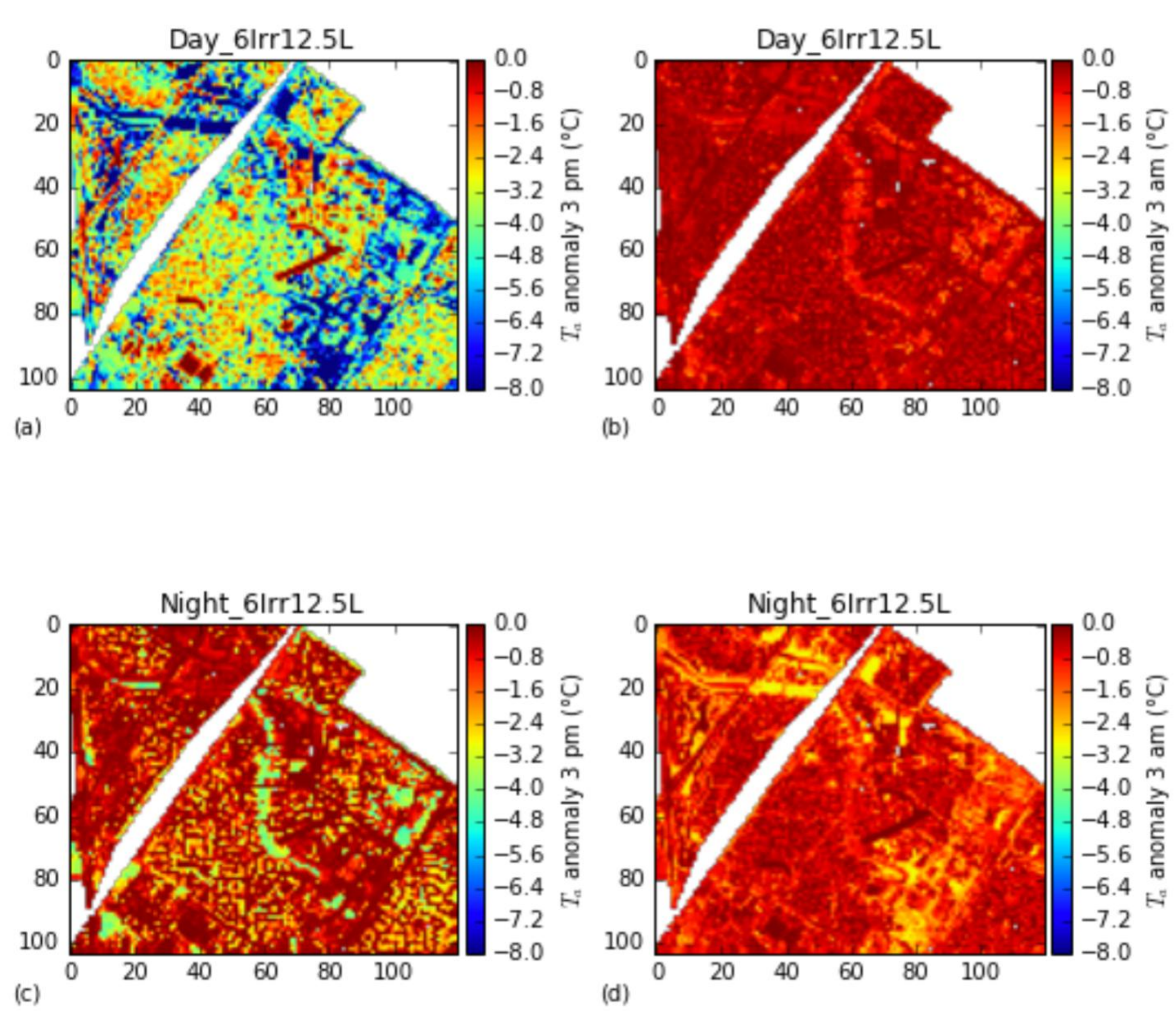
Modelled Heatwave Temp

Figure 6: The spatial representation of the heatwave average (a) 3 pm and (b) 3 am T_a (2 m) across the Mawson Lakes domain for the base case (no irrigation) simulation. The x and y axis are labelled by cell number.



24h20L 3pm/3am Cooling

Figure 9: Spatial representation of cooling from 24Irr20L at (a) 3 pm and (b) 3 am on Julian day 37. The x and y axis are labelled by cell number.



Day 37 3pm/3am Cooling (12.5L applied)

Day 37 3pm/3am Cooling (12.5L applied)

Figure 10: Spatial representation of cooling from Day/Night.6Irr12.5L scenario at (a/c) 3 pm and (b/d) 3 am on Julian day 37. The x and y axis are labelled by cell number.

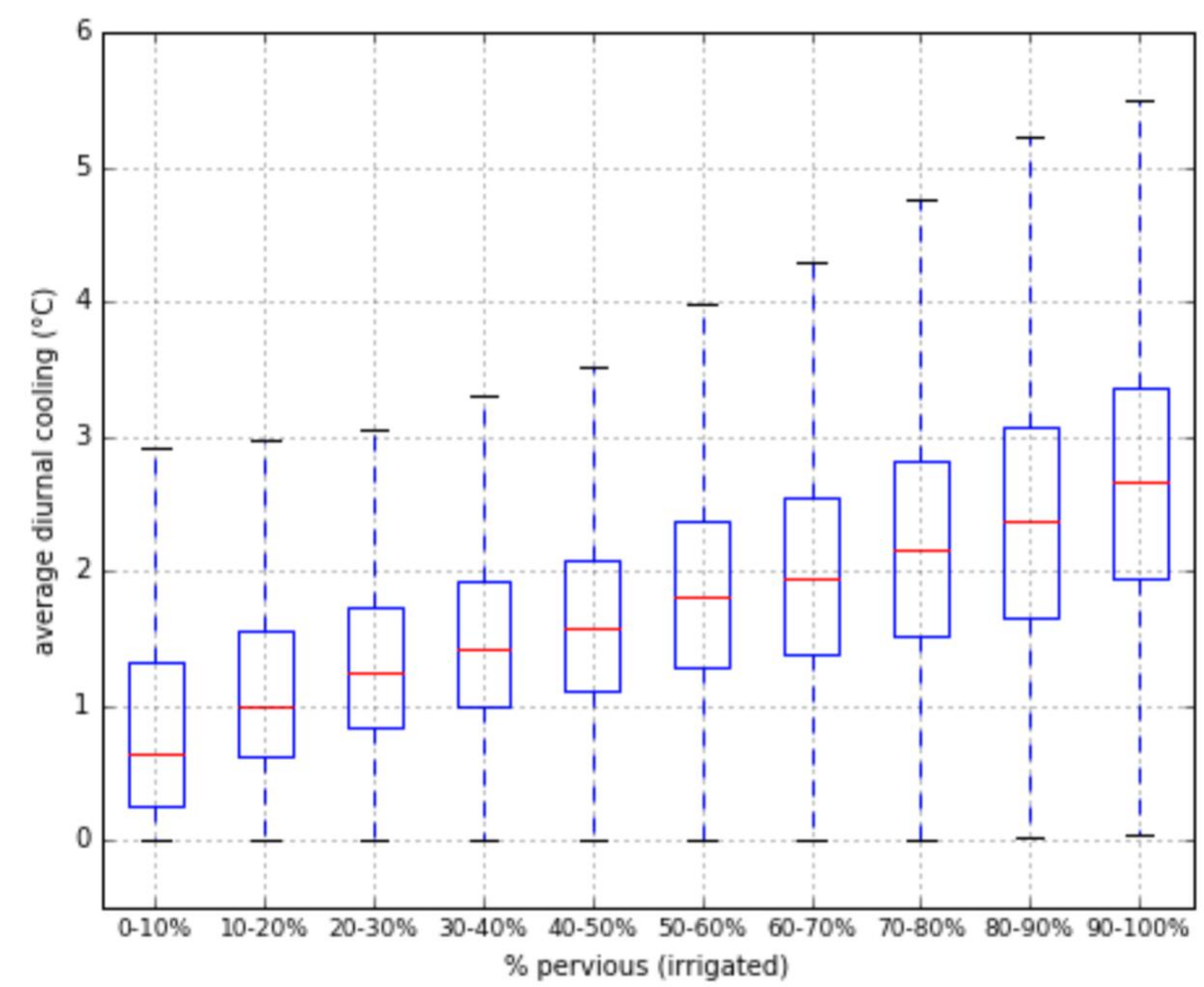


Figure 11: The daily cooling (24Irr20L scenario) for each grid cell during the heatwave period grouped by pervious (irrigated) fraction. Average cooling increases at a near linear rate, but does diminish slightly above 90% perviousness. The boxes represent the inter-quartile range and the whiskers represent 1.5 × inter-quartile range.

Broadbent, Coutts, Demuzere and Tapper (2017)

Landscape irrigation - Mawson Lakes, Adelaide

Temporal Patterns

Table 1: A description of irrigation scenarios used in this study.

Scenario	Hourly irrigation (L m^{-2} hr^{-1})	Daily irrigation (L m^{-2} d^{-1})	Water-use (domain)* (ML d^{-1})	Water-use (residential) (ML d^{-1})
24Irr5L	0.21	5	17.6	3.8
24Irr10L	0.42	10	35.1	7.6
24Irr15L	0.63	15	52.7	11.5
24Irr20L	0.83	20	70.2	15.3
24Irr30L	1.25	30	105.3	22.9
Day_6Irr1.25L | Night_6Irr1.25L	0.21	1.25	4.4	1.0
Day_6Irr2.5L | Night_6Irr2.5L	0.42	2.50	8.8	1.9
Day_6Irr3.75L | Night_6Irr3.75L	0.63	3.75	13.2	2.9
Day_6Irr5L| Night_6Irr5L	0.83	5.00	17.6	3.8
Day_6Irr7.5L | Night_6Irr7.5L	1.25	7.50	26.3	5.7
Day_6Irr10L | Night_6Irr10L	1.67	10.0	35.1	7.6
Day_6Irr12.5L | Night_6Irr12.5L	2.08	12.5	43.9	9.6
Day_6Irr25L | Night_6Irr25L	4.17	25.0	87.8	19.2

day scenarios = 11 am–5 pm

night scenarios = 11 pm–5 am

ML = mega-litres

*note that these simulations are hypothetical and in reality irrigation would be conducted selectively. We irrigated the whole domain to assess the effect of irrigation across the entire suburban environment.

- Continuous irrigation average cooling of up to 2.3°C (30L/m2/day)
- Non-linear (20L/m2/day may be optimal)
- Bigger impact on hotter days
- Night irrigation marginally less effective than day irrigation

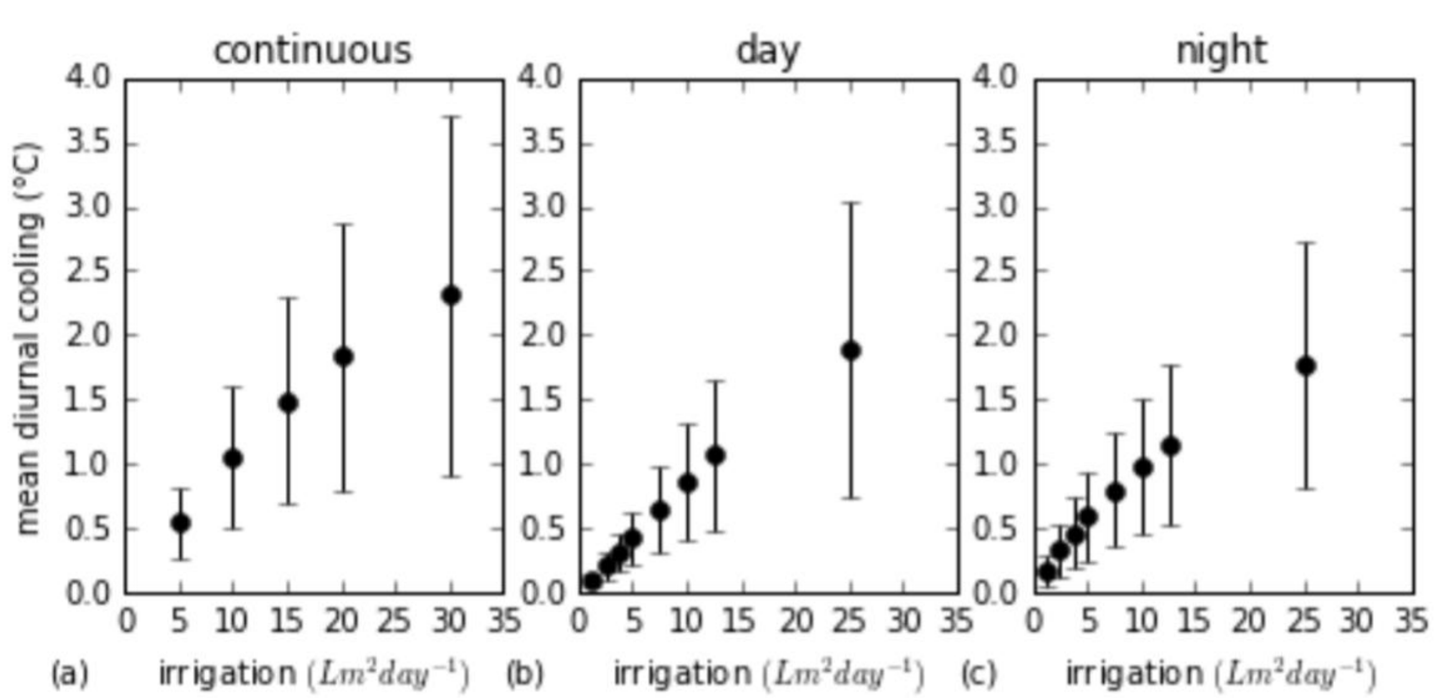


Figure 7: Heatwave average diurnal cooling (with standard deviations) for (a) continuous, (b) day, and (c) night irrigat

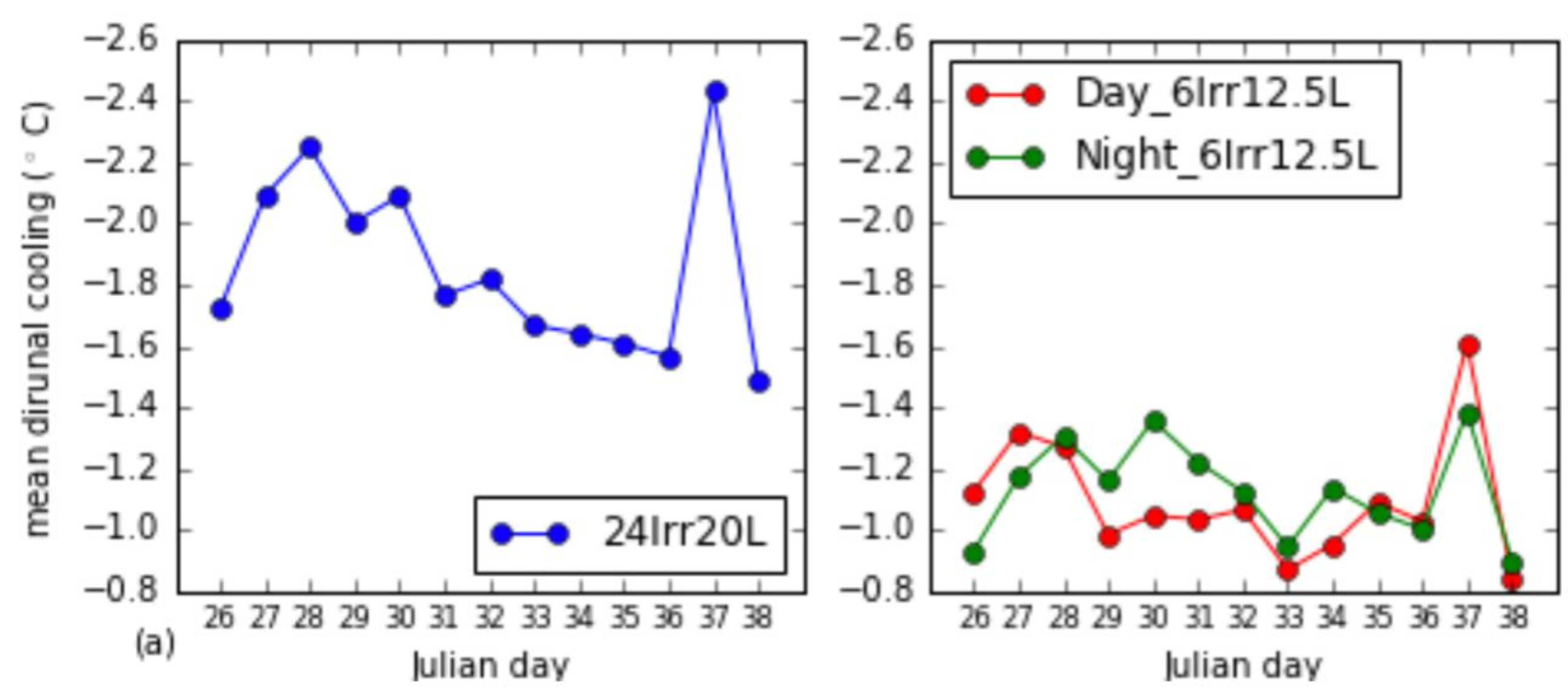
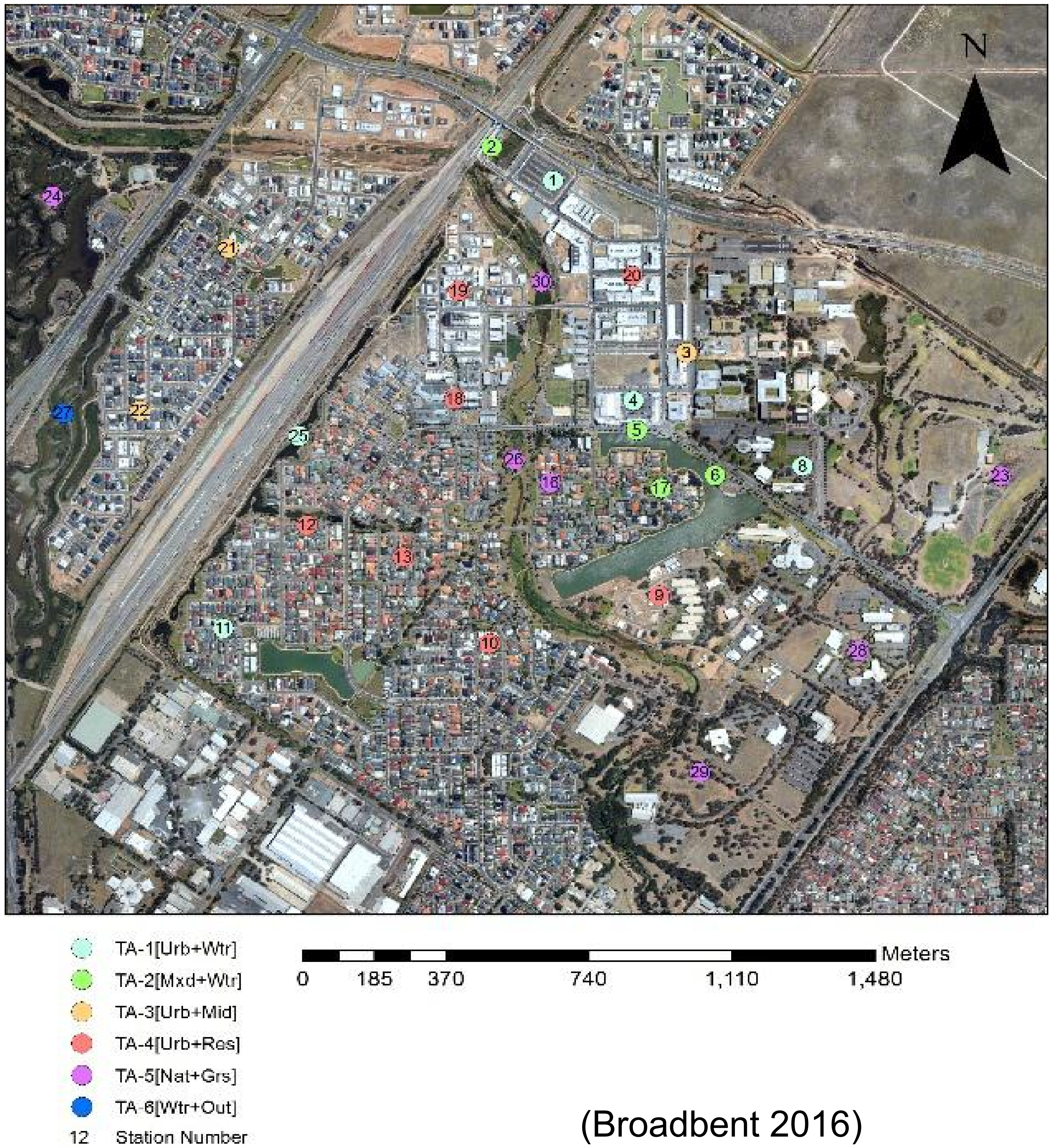


Figure 8: The mean diurnal cooling on each day of the heatwave for (a) 24Irr20L and (b) Day/Night_6Irr12.5L scenarios.

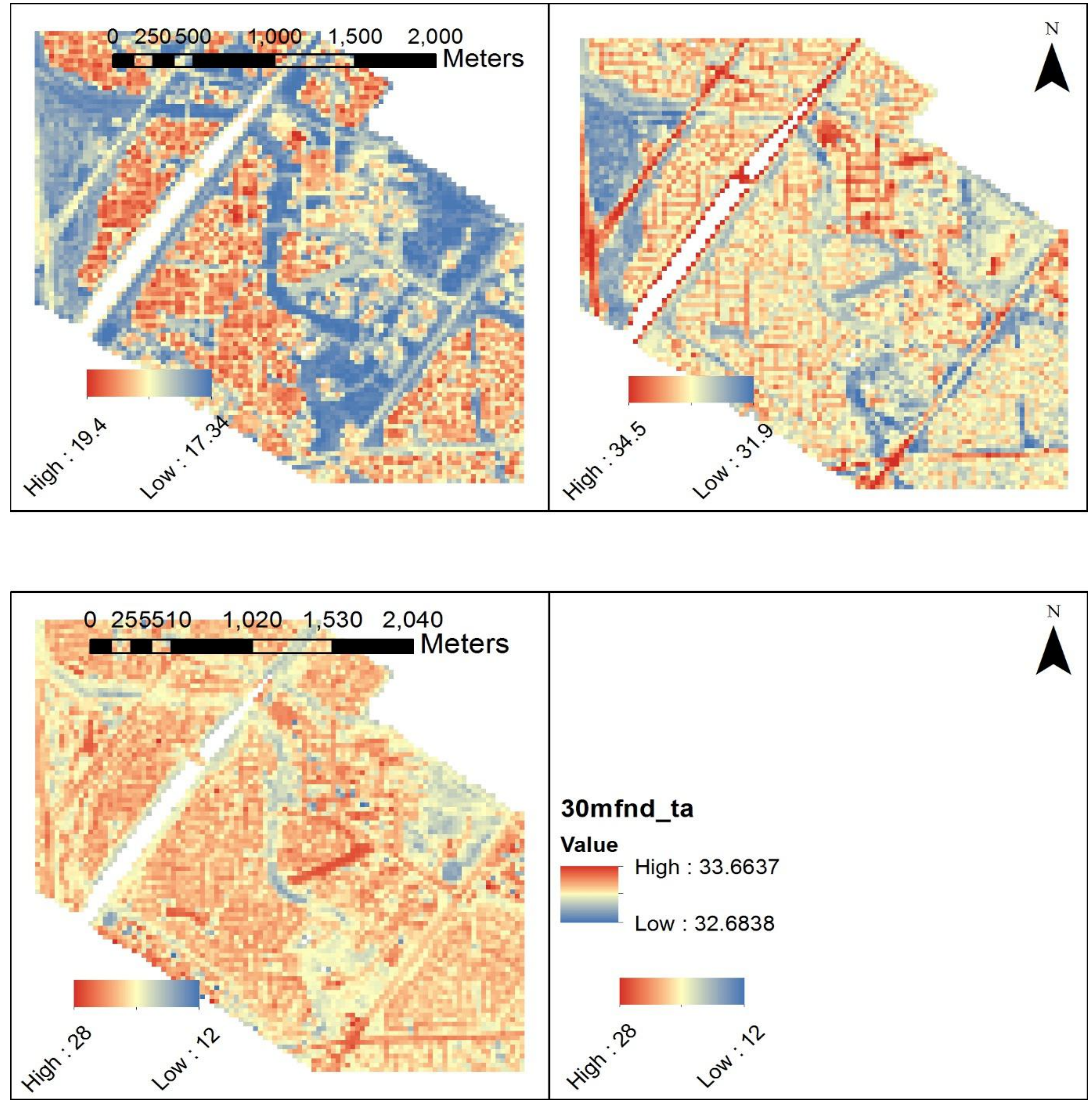
Broadbent, Coutts, Demuzere and Tapper (2017)

CRC Toolkit2 modelling analysis of Mawson Lakes

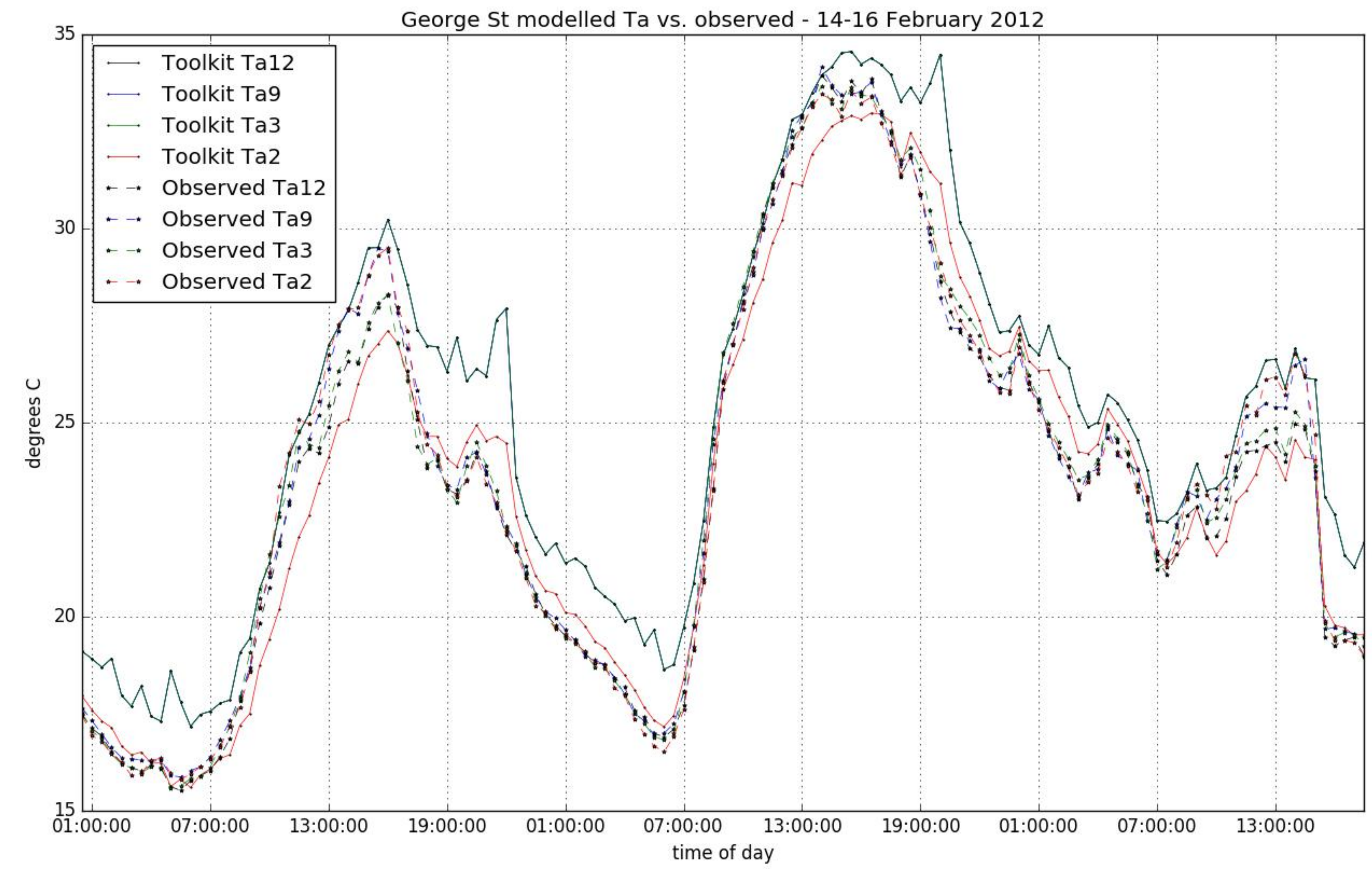
Cooling effects of WSUD features on air temperatures

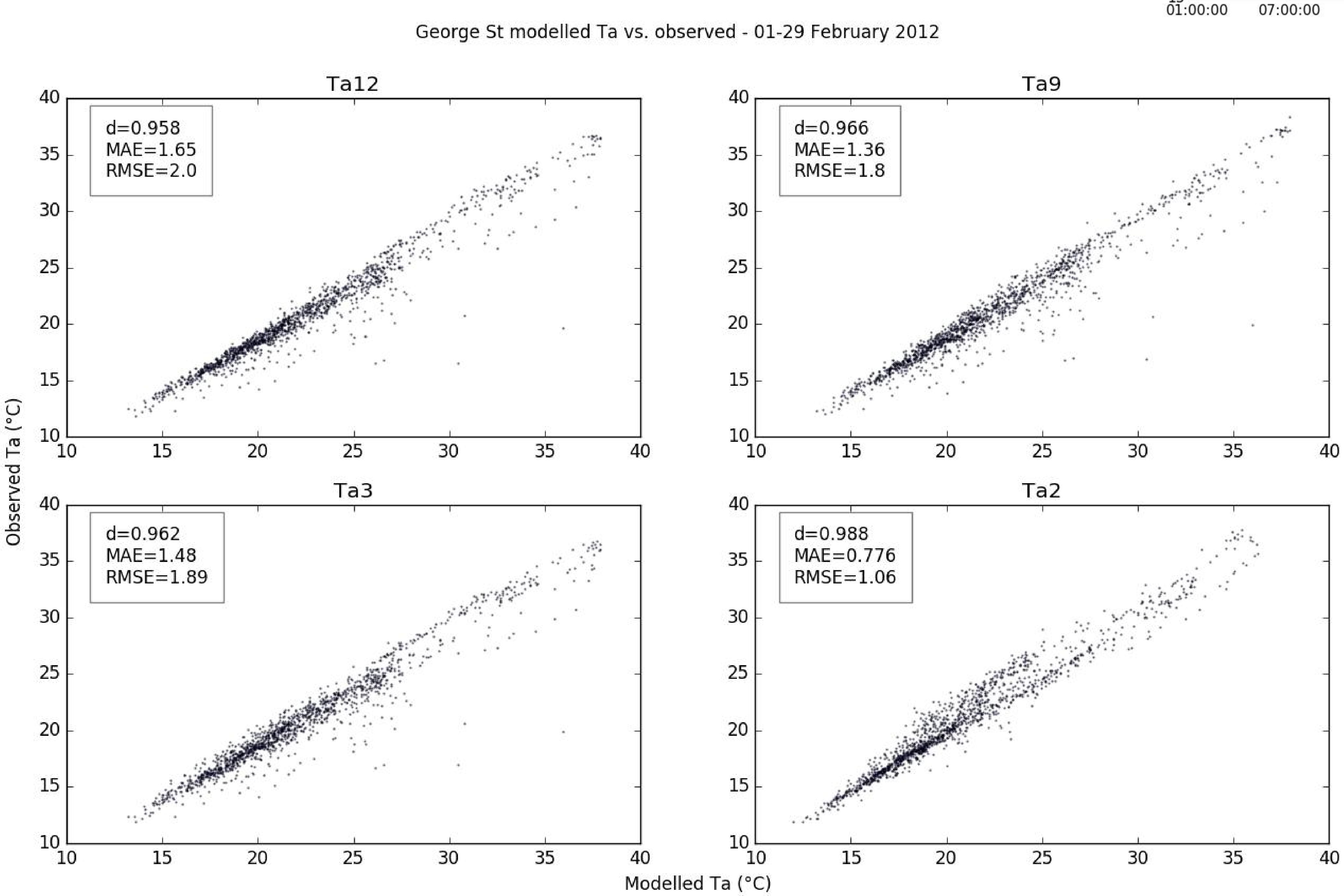


(Broadbent 2016)



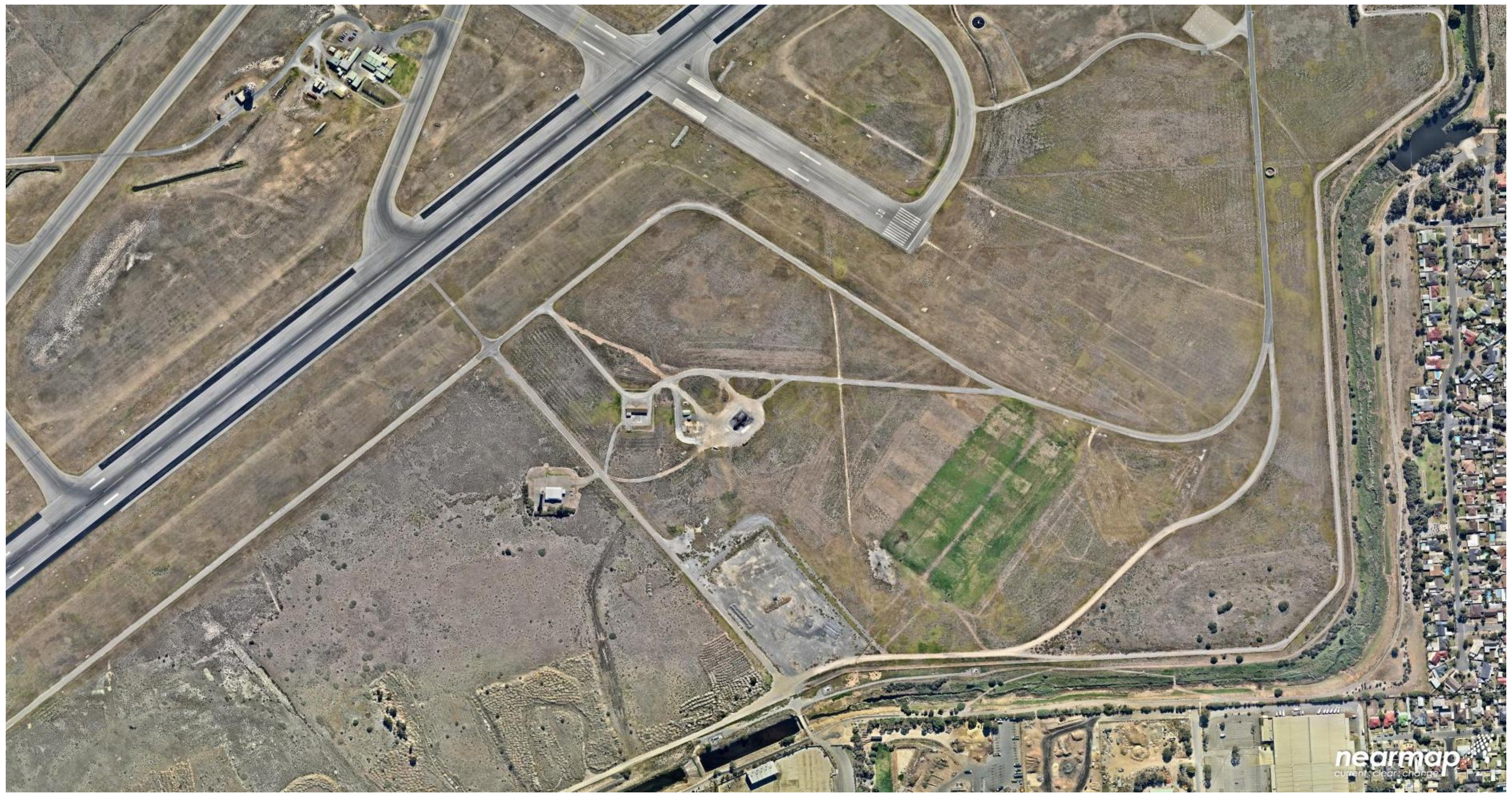
Validation of Toolkit2 air temperature predictions

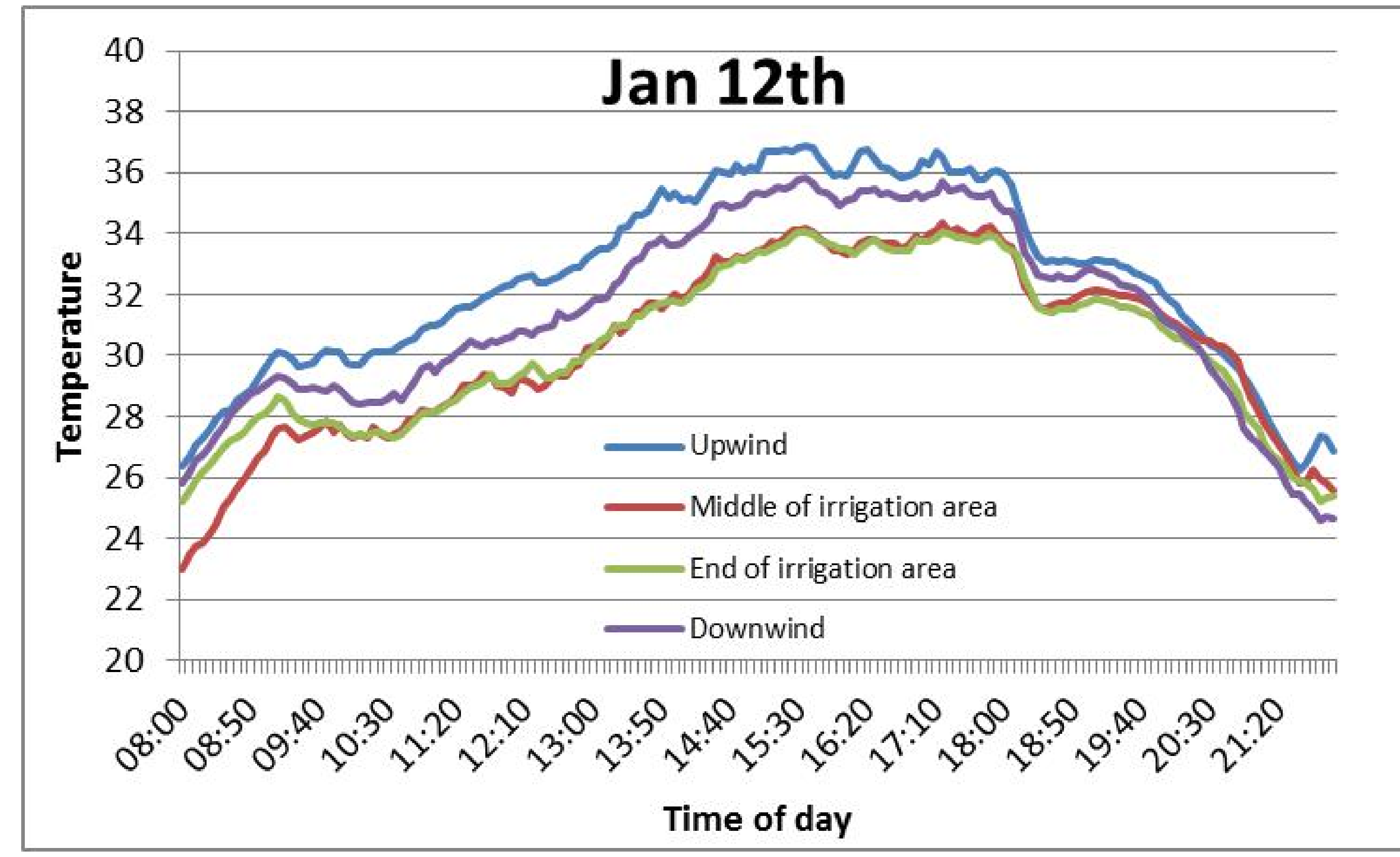


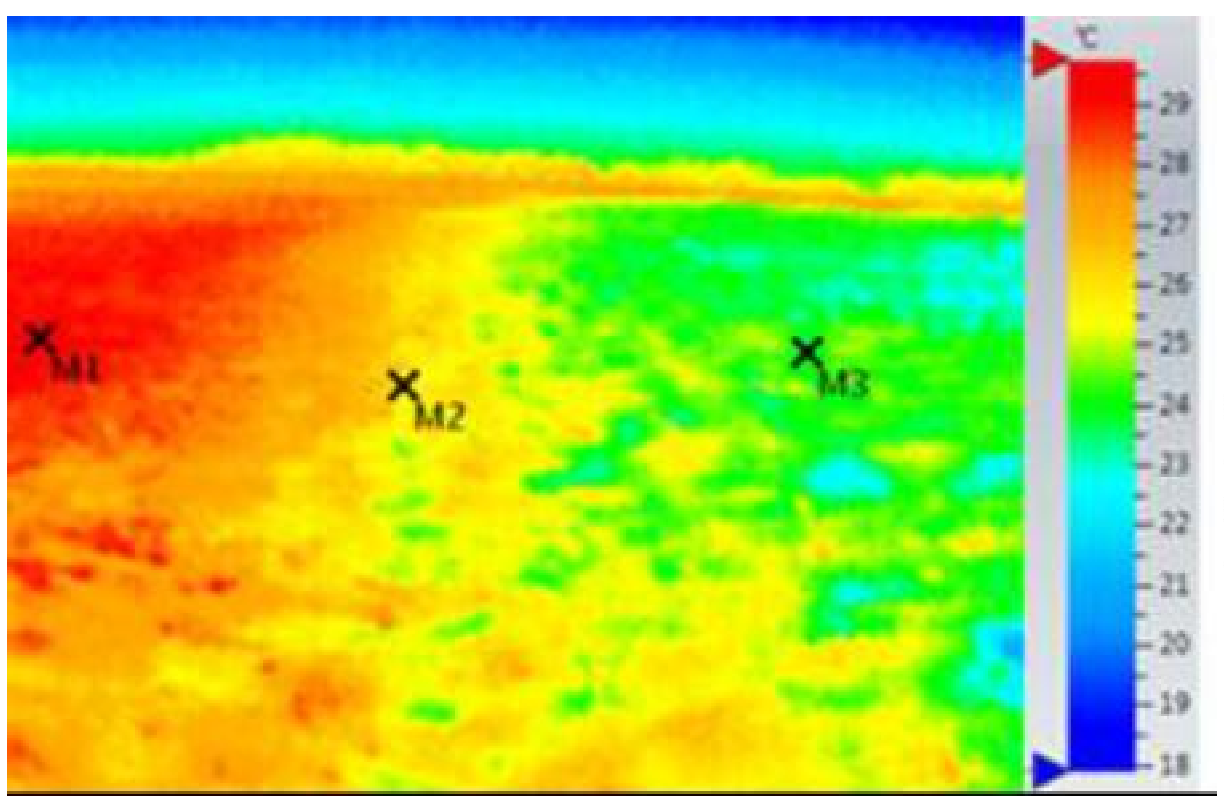


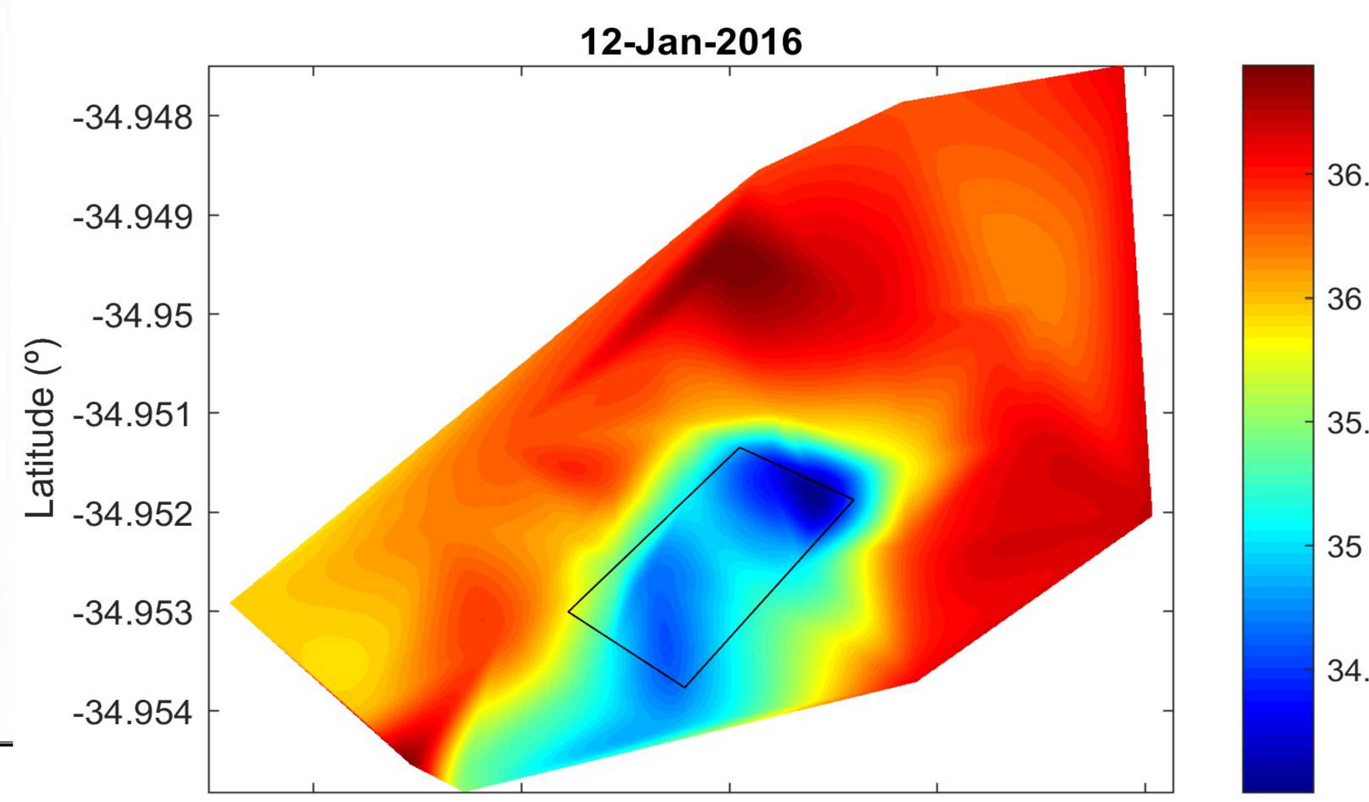
- Validation against George St. observations within the street canyon
- Comparisons of observed values at 4 locations
- Comparison over 2 days (above)
- Comparison over 30 days (left)

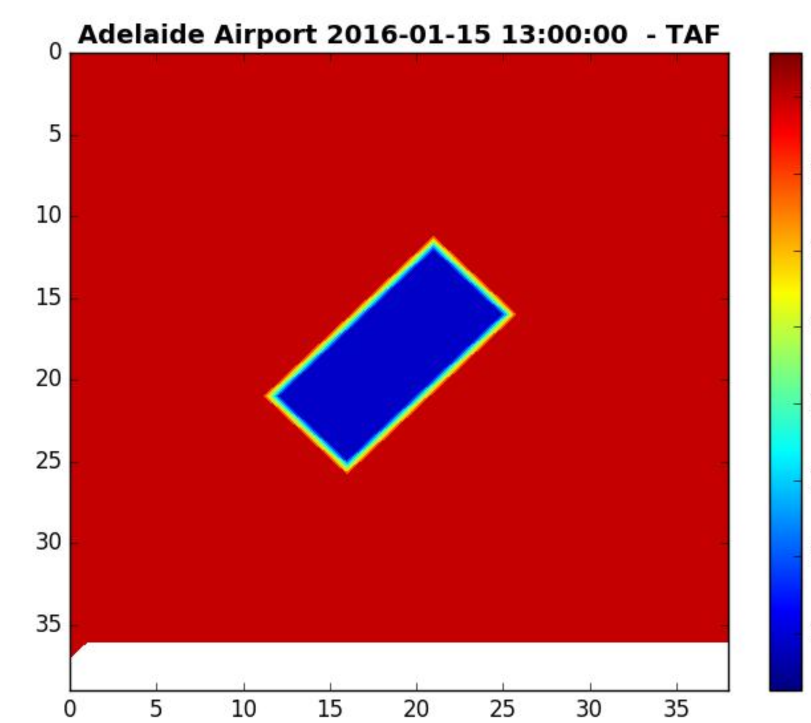
Toolkit2 - Irrigation study at Adelaide Airport











(Ingleton 2017)

What's next: Preview of future modelling related tasks

- IRP2 WP6 – Economic benefits of urban cooling
- Modelling four scenarios using Toolkit2 and SURFEX to determine the amount of temperature moderation expected from each scenario
- Literature review identifies financial benefits of UHI mitigation
- Climate modelling output (temperature reductions of the four scenarios) to be used in economic modelling

- Integration of Toolkit2 climate model with CRC Toolkit

- Rename Toolkit2?
  - TARGET – **T**he **A**ir–temperature **R**esponse to **G**reen–infrastructure **E**valuation **T**ool

Overview of study area

Case study area is ~ 3770 ha new growth area adjacent to the existing urban area

Future growth will deliver 21,000 new homes along with employment areas, community and recreational facilities.

Two major waterway corridors and open space network across the area

Average rainfall of 587 mm annually

Stormwater runoff generated off hard surfaces (the urban excess) is currently 10,300 ML/yr. This will increase to 15,540 ML/yr by 2030

Wastewater produced is currently 2,487 ML. This will increase to 5,247ML/yr by 2030

- 873 ML/yr of recycled water used for agriculture.

Economic modelling of financial benefits of cooling based on four scenarios

Four scenarios are proposed for modelling	**Victorian policy setting**
No regulation	Landscape features in the absence of any regulation (e.g. stormwater pollutant load reductions, Building Codes) – no precinct scale WSUD – minimal irrigation: when undertake potable mains used
Current regulation	Landscape features required for current regulatory settings (Clause 56:07 of the Victorian Planning Provisions and 6 star building code) – precinct scale wetlands – 30 % uptake of rainwater tanks used to irrigate private gardens
Proposed changes for regulation	Landscape features that could be used to deliver the anticipated changes to regulation (which are likely to introduce % reduction in flow volume) for both BPEM and Building Codes – precinct scale wetlands – significant stormwater harvesting at lot and/or precinct scale
Targeted UHI mitigation scenario	−Landscape features required to achieve a significant reduction in UHI effect (such as the often-stated 2 degree C cooling scenario) – active irrigation of street trees, active promotion of stormwater losses through infiltration and/or evapotranspiration, significant inclusion of urban greening

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Thank you.