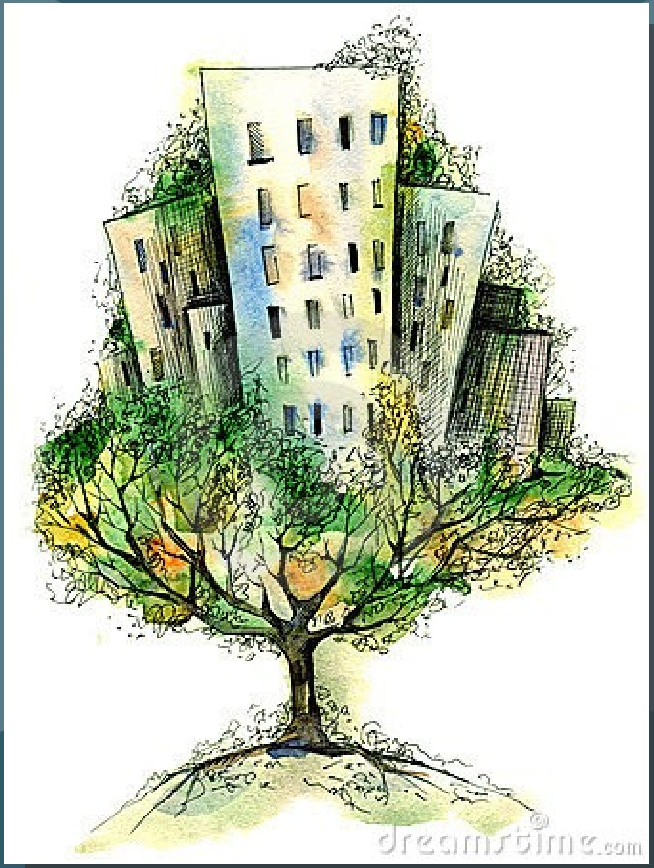
# Urban greening for improved human thermal comfort

*Kerry Nice*

*CRC for Water Sensitive Cities*
*School of Earth, Atmosphere and Environment*
*Monash University*

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An Australian Government Initiative

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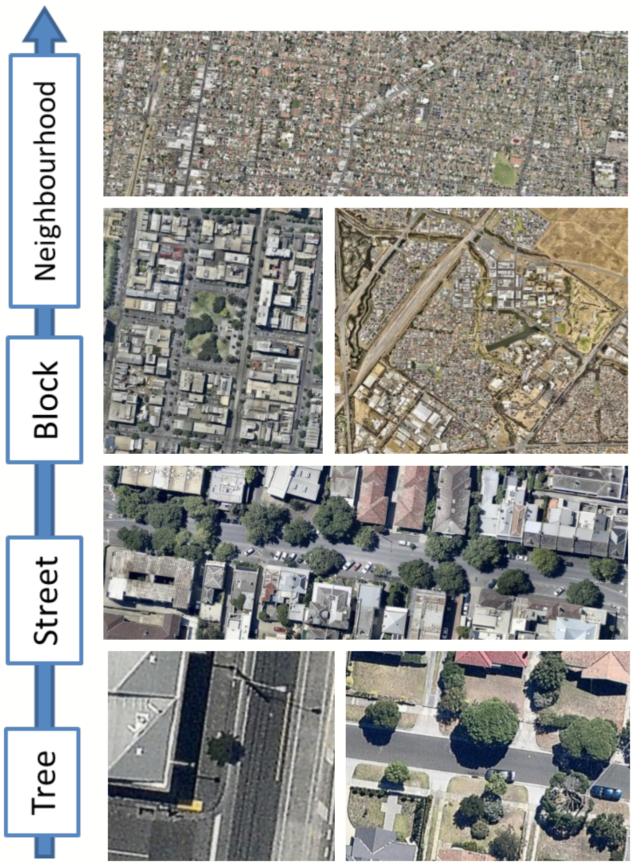
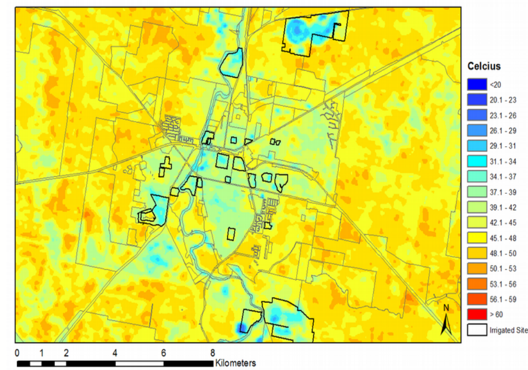
# Research questions

- 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?

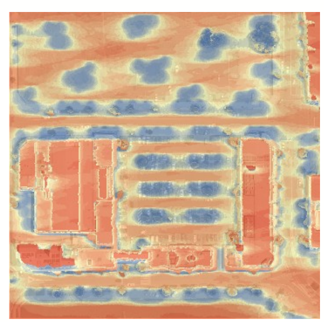


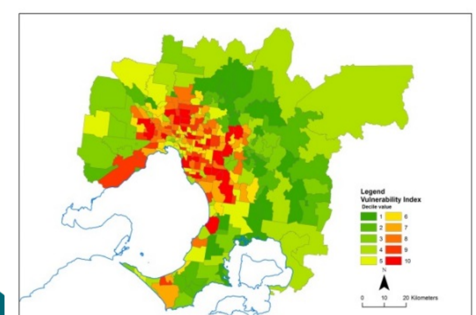


Observations



Remote sensing


Modelling



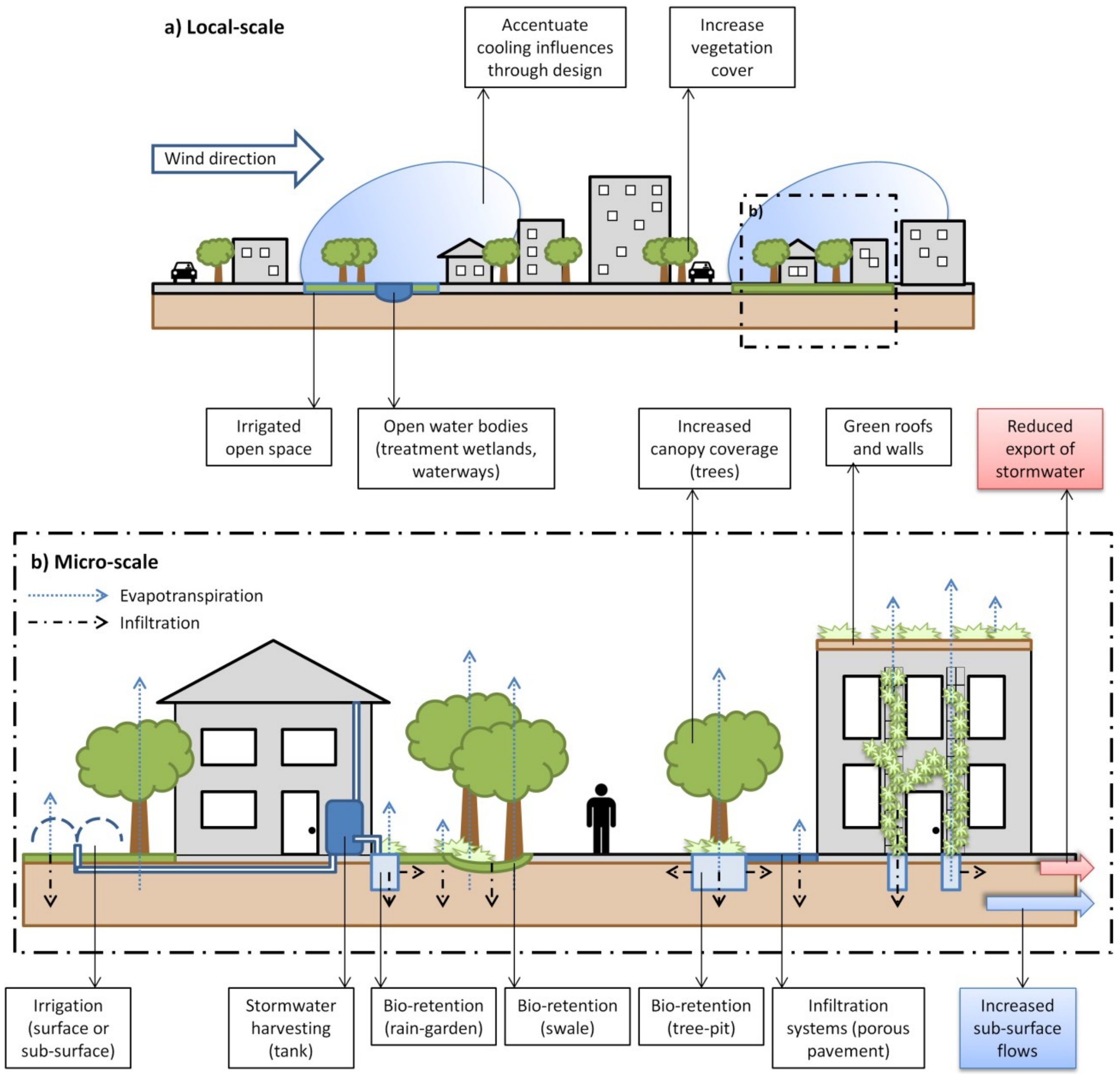
Database mapping

Cities

# 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

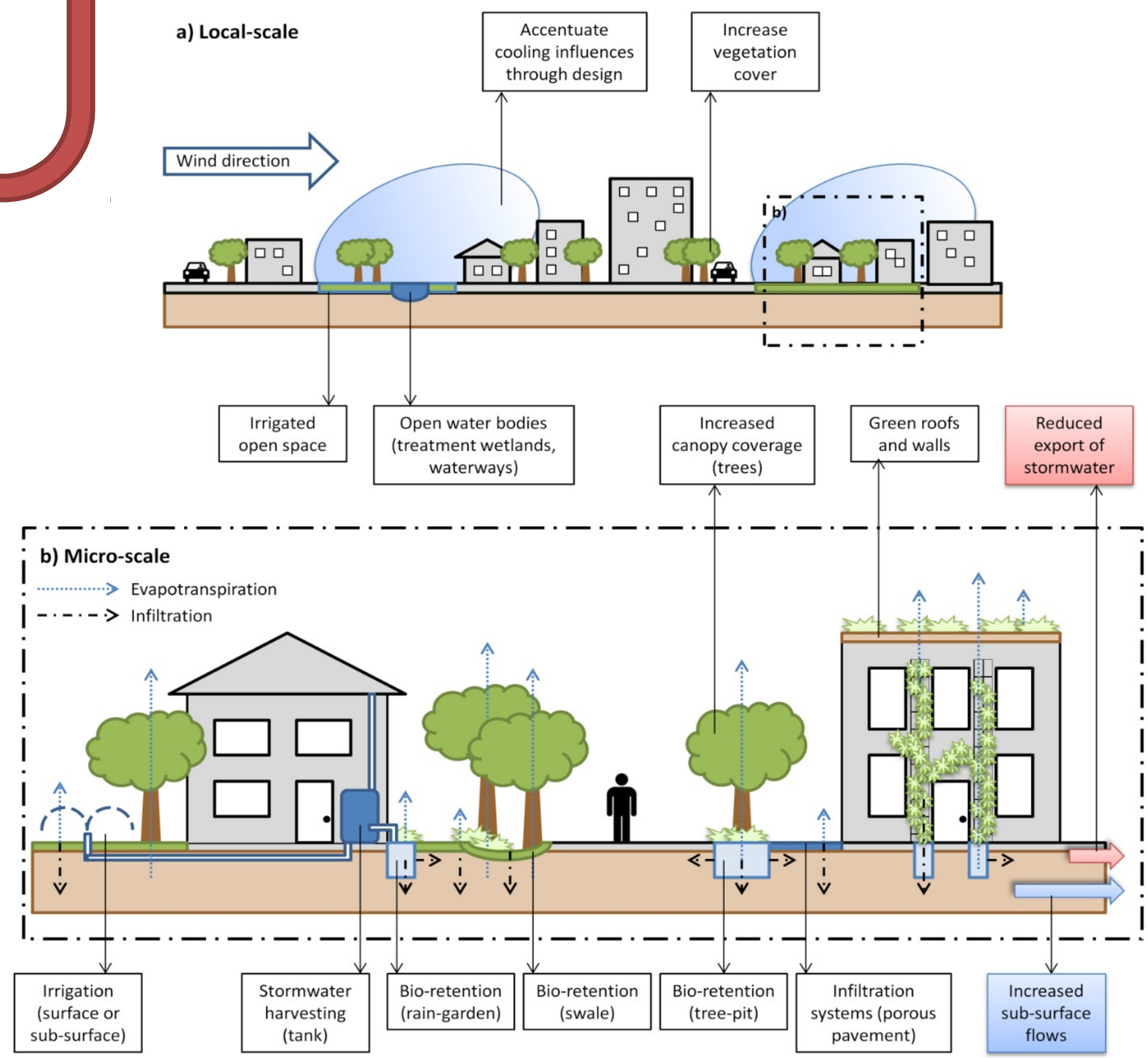
Reduce local-scale air temperature

Limit heat-health impacts

Role of water and green infrastructure

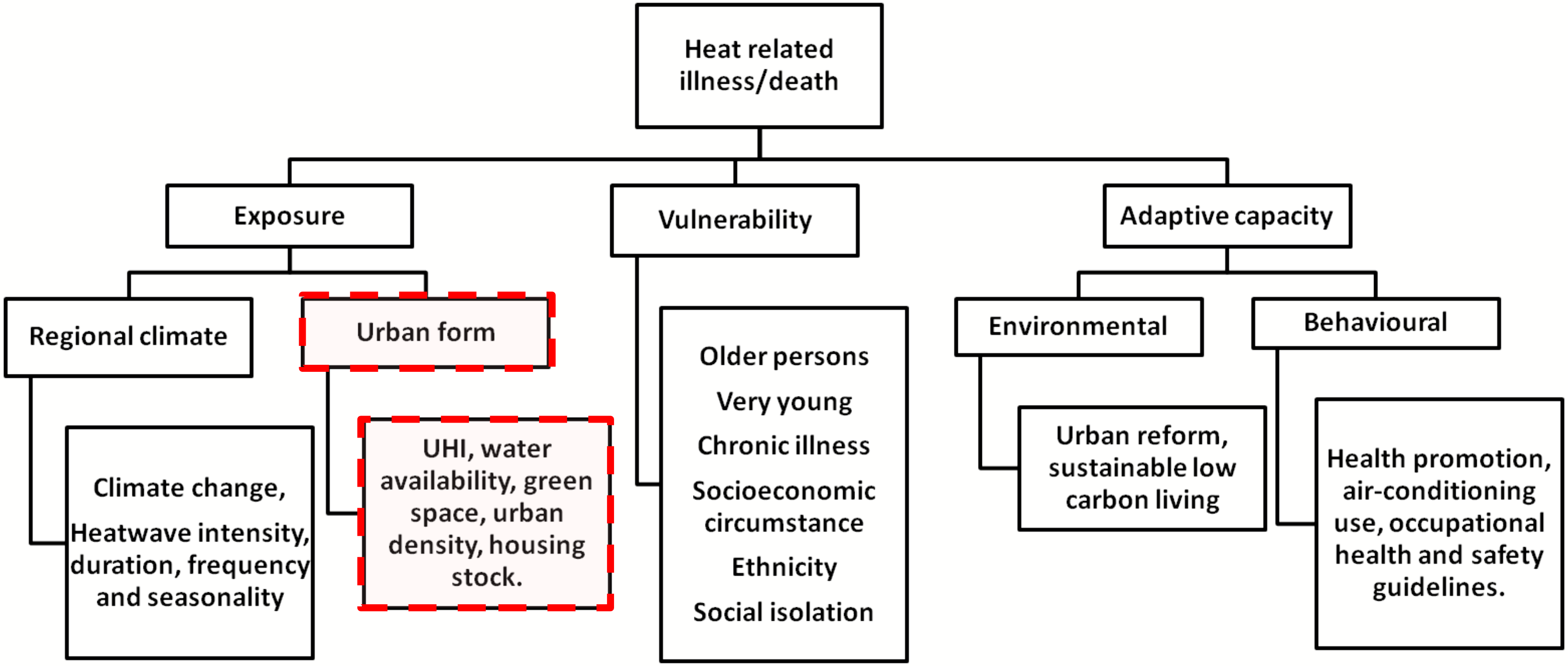
Reduce micro-scale air temperature and *radiant* temperature

Improve human thermal comfort




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

# Heat-health relationships




*Tapper, Coutts, Loughnan & Pankhinia (2014)*



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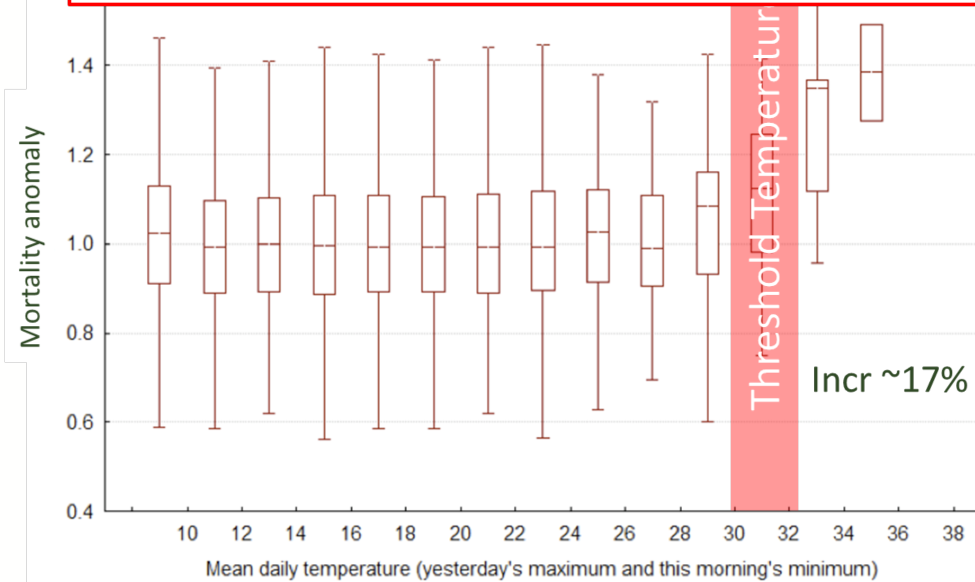
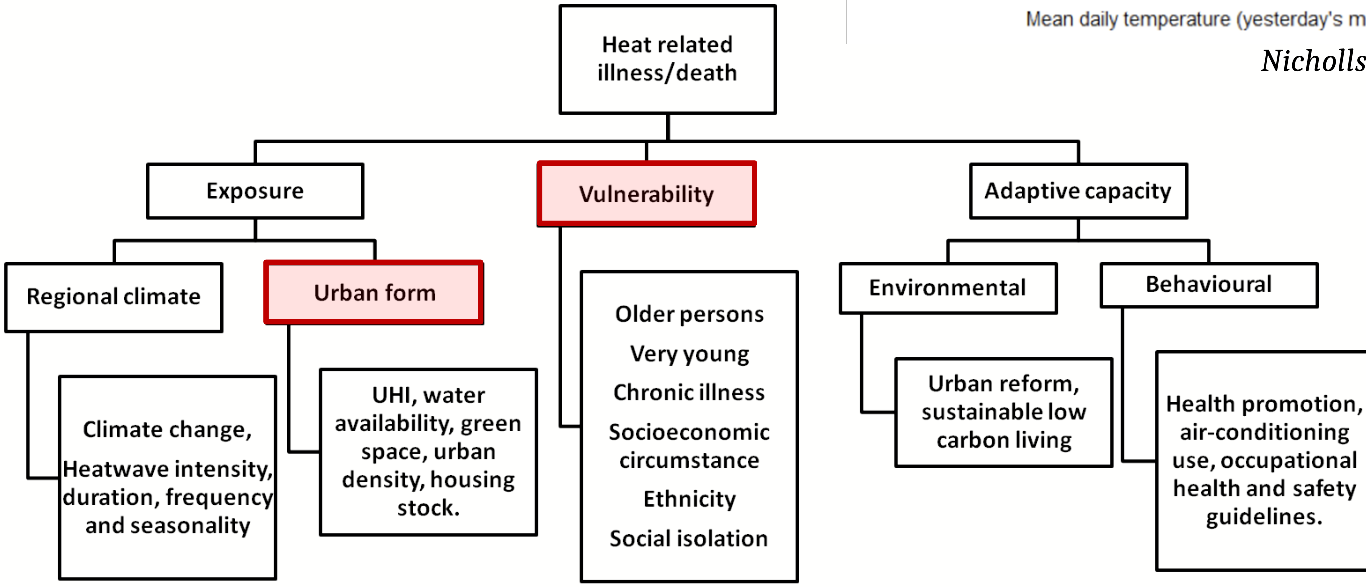
# Heat-Health Background

Suggested that even a slight temperature reduction (1-2° C) in extreme heat events (i.e. **heat mitigation**) would be sufficient to save many lives

- Melbourne – Heat Threshold for Excess Deaths in >64 year olds
- Heat-Health outcomes depend on:
  - Heat Exposure
  - Vulnerability
  - Adaptive Capacity




*Nicholls, Skinner, Loughnan & Tapper (2007)*




*Tapper, Coutts, Loughnan & Pankhinia (2014)*

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# Threshold Temperatures (Best Predictors of Mortality/Morbidity) for Australia's Capital Cities

**Table 6: Threshold temperature derived from analyses of daily all-cause mortality, daily emergency hospital admissions, daily ambulance call-outs or emergency department presentations in Australian capital cities** (number of days exceeding the temperature threshold over the record period are in parenthesis)

| City | Number of days of data | Tmax | % increase in median | Tmin | % increase in median | meanT | % increase in median | AT | % increase in median |
|---|---|---|---|---|---|---|---|---|---|
| **Brisbane** | | | | | | | | | |
| Morbidity | 2956 | 36 (55) | 2.5–12% | 26 (7) | 2.5% | 34 (2) | 9% | 40(25) | 4–11% |
| Mortality | 4007 | 36(58) | 12% | 25(11) | 5% | 31(6) | 15% | 40(9) | 8% |
| **Canberra** | | | | | | | | | |
| Morbidity | 2320 | 37 (33) | 5–10% | 20 (30) | 5% | 28 (28) | 5-8% | 38(11) | 8-10% |
| Mortality | 4007 | 33(179) | 5% | 20(43) | 2% | 28(16) | 2% | 41(4) | 5% |
| **Darwin** | | | | | | | | | |
| Morbidity | 1826 | 36 (4) | 5% | 28 (17) | 5% | 31 (19) | 7% | 35(5) | 5% |
| Mortality | 4007 | 37(11) | 5% | 29(19) | 8% | 31(94) | 3% | 47(5) | 10–20% |
| **Hobart** | | | | | | | | | |
| Morbidity | 2953 | NA | | 18 (28) | 5–20% | 27 (3) | 5% | 36(5) | 4–10% |
| Mortality | 4007 | 35(13) | 11% | 20(5) | 2% | 28(5) | 6% | 37(6) | 5–20% |
| **Melbourne** | | | | | | | | | |
| Morbidity | 3287 | 44 (5) | 3% | 26 (6) | 3% | 34 (6) | 3% | 42(10) | 2–3% |
| Mortality | 4007 | 39(23) | 2–65% | 26(9) | 5% | 28(112) | 3–13% | 36(68) | 4% |
| **Perth** | | | | | | | | | |
| Morbidity | 2007 | 43 (3) | 14% | 26 (4) | 4% | NA | | 43(8) | 2–5% |
| Mortality | 4007 | 44(3) | 30% | NA | | 32(20) | 3–10% | 45(3) | 10% |
| **Adelaide** | | | | | | | | | |
| Morbidity | 3045 | NA | | 31(4) | 5% | 39(1) | 24% | NA | |
| Mortality | 4007 | 42(21) | 2–8% | NA | | 34(2) | 8% | 43(16) | 2–10% |
| **Sydney** | | | | | | | | | |
| Morbidity | 4162 | 41(3) | 5–38% | 25(5) | 4% | 31(5) | 2% | 41(3) | 5% |
| Mortality | 4007 | 38(3) | 2–18% | 25(3) | 5% | 30(12) | 5% | 37(27) | 2–24% |

**Final report** *Loughnan, Tapper et al., 2013* **SPATIAL VULNERABILITY TO EXTREME HEAT EVENTS IN AUSTRALIAN CAPITAL CITIES.** *National Climate Change Adaptation Research Facility, Gold Coast, pp146*

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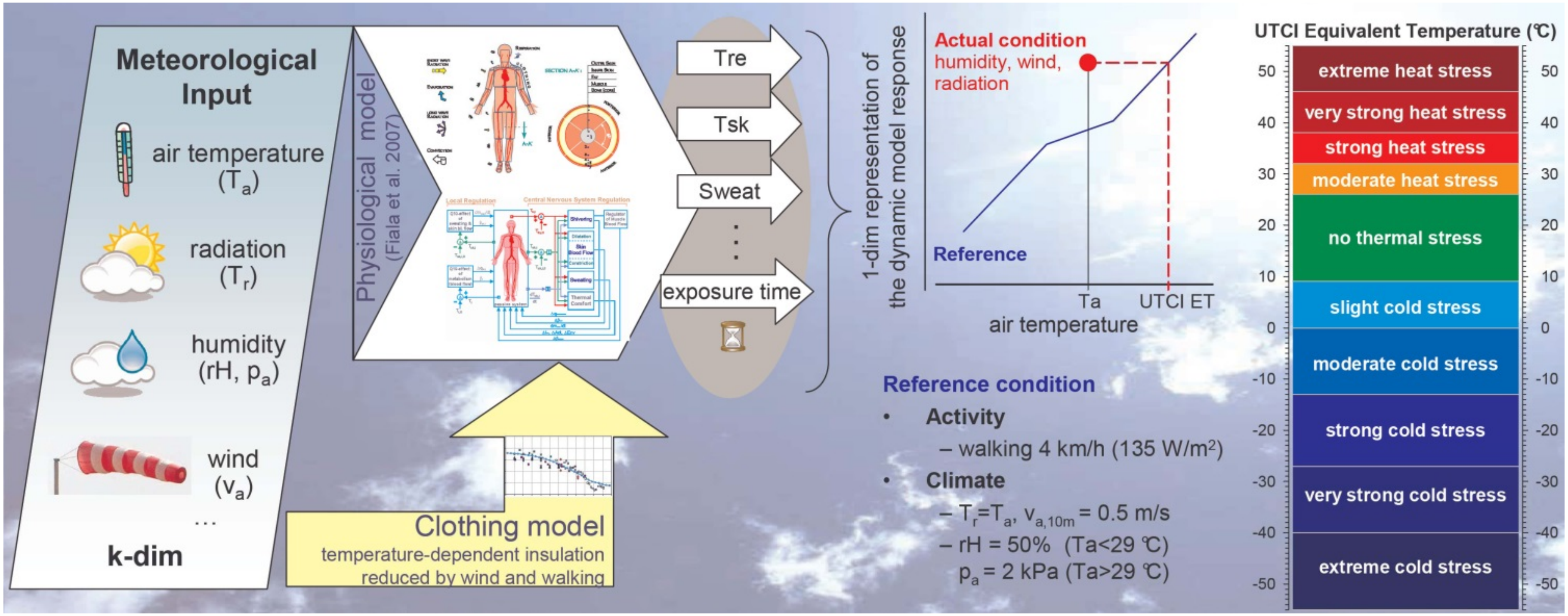
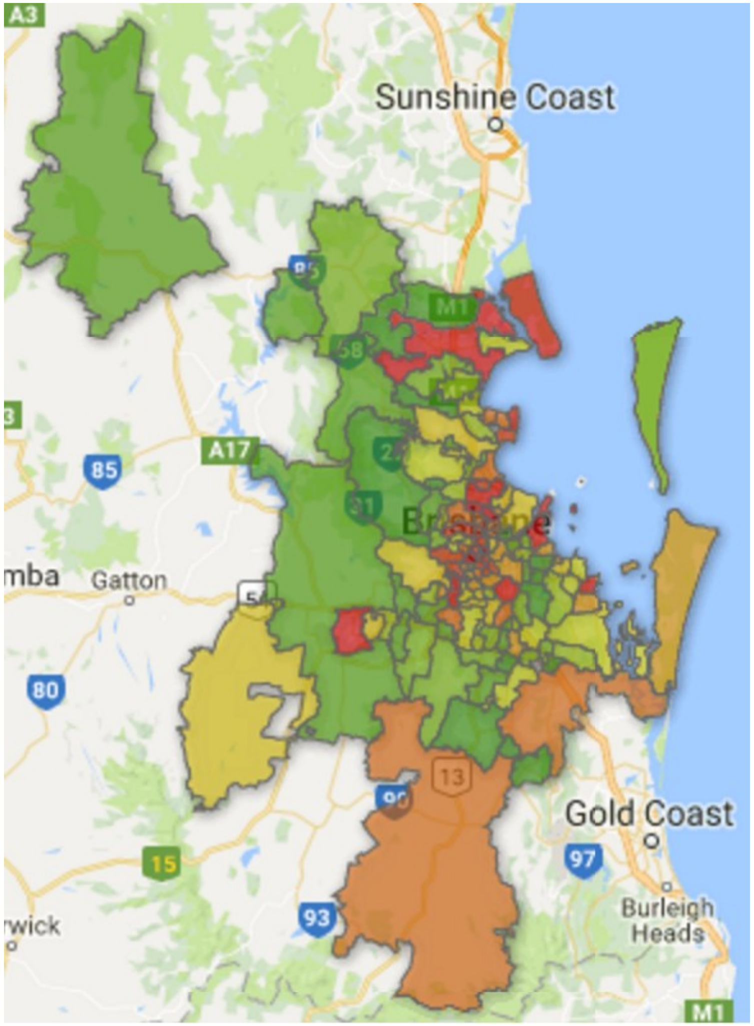
# Human thermal comfort

- Considers multiple microclimate variables
- Determined by a thermal comfort index
- Provides an assessment of heat stress
- *Mean radiant temperature* important during the day



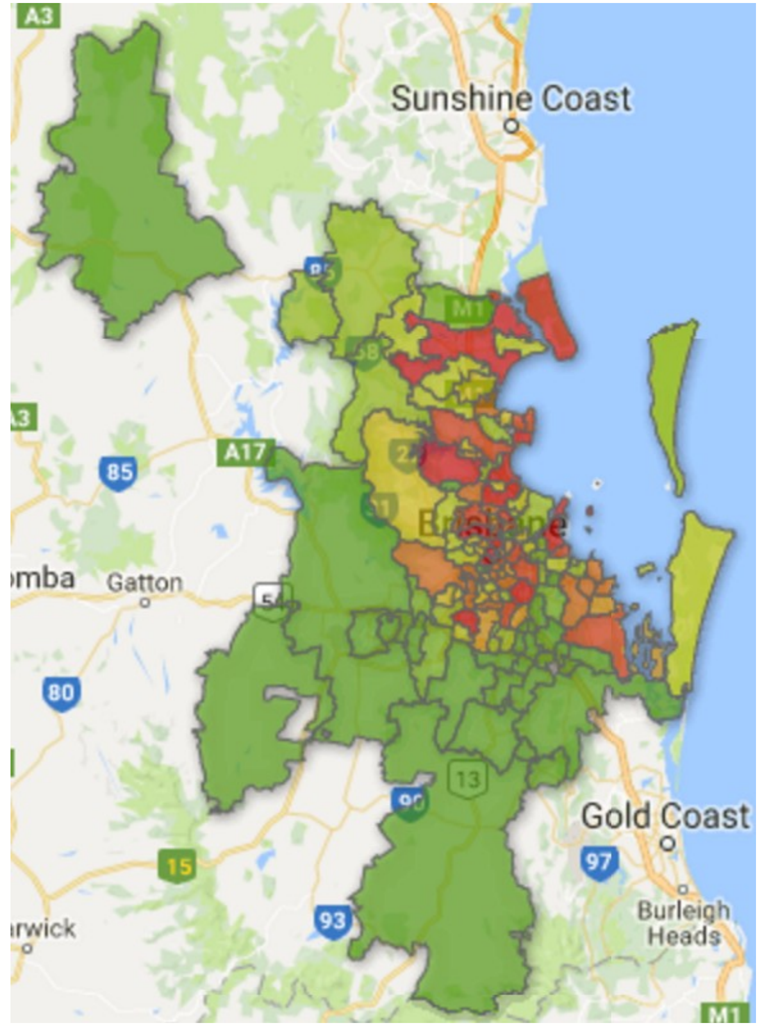

*Brode et al.*




**Vulnerability Index**

High:10

Low: 1




**Ambulance Callouts**

High:10

Low: 1

*Loughnan et al*



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# Trees must be part of the solution

- They provide shade, reducing *mean radiant temperature*
- They access water from deep layers of the soil
- Diversity of species allowing more tailored greening options
- They deliver multiple benefits
- People just ‘get’ trees


*Norton, Coutts et al (2015)*

| UGI | Green open spaces | Trees | Green roofs | Vertical greening |
|---|---|---|---|---|
| Shades canyon surfaces? | Yes, if grass rather than concrete | Yes | Shades roof, not internal canyon surfaces | Yes |
| Shades people? | Yes, if treed | Yes | No, only very intensive green roofs | No |
| Increases solar reflectivity? | Yes, when grassed | Yes | Yes, if plants healthy | Yes |
| Evapo-transpirative cooling? | Yes, with water<br>No, without water | Yes<br>(unless severe drought) | Yes, with water when hot<br>No, without water | Yes, with water when hot<br>No, without water |
| Priority locations | • Wide streets with low buildings – both sides<br>• Wide streets with tall buildings – sunny side | • Wide streets, low buildings – both sides<br>• Wide streets, tall buildings – sunny side<br>• In green open spaces | • Sun exposed roofs<br>• Poor insulated buildings<br>• Low, large buildings<br>• Dense areas with little available ground space | • Canyon walls with direct sunlight<br>• Narrow or wide canyons where trees are unviable |

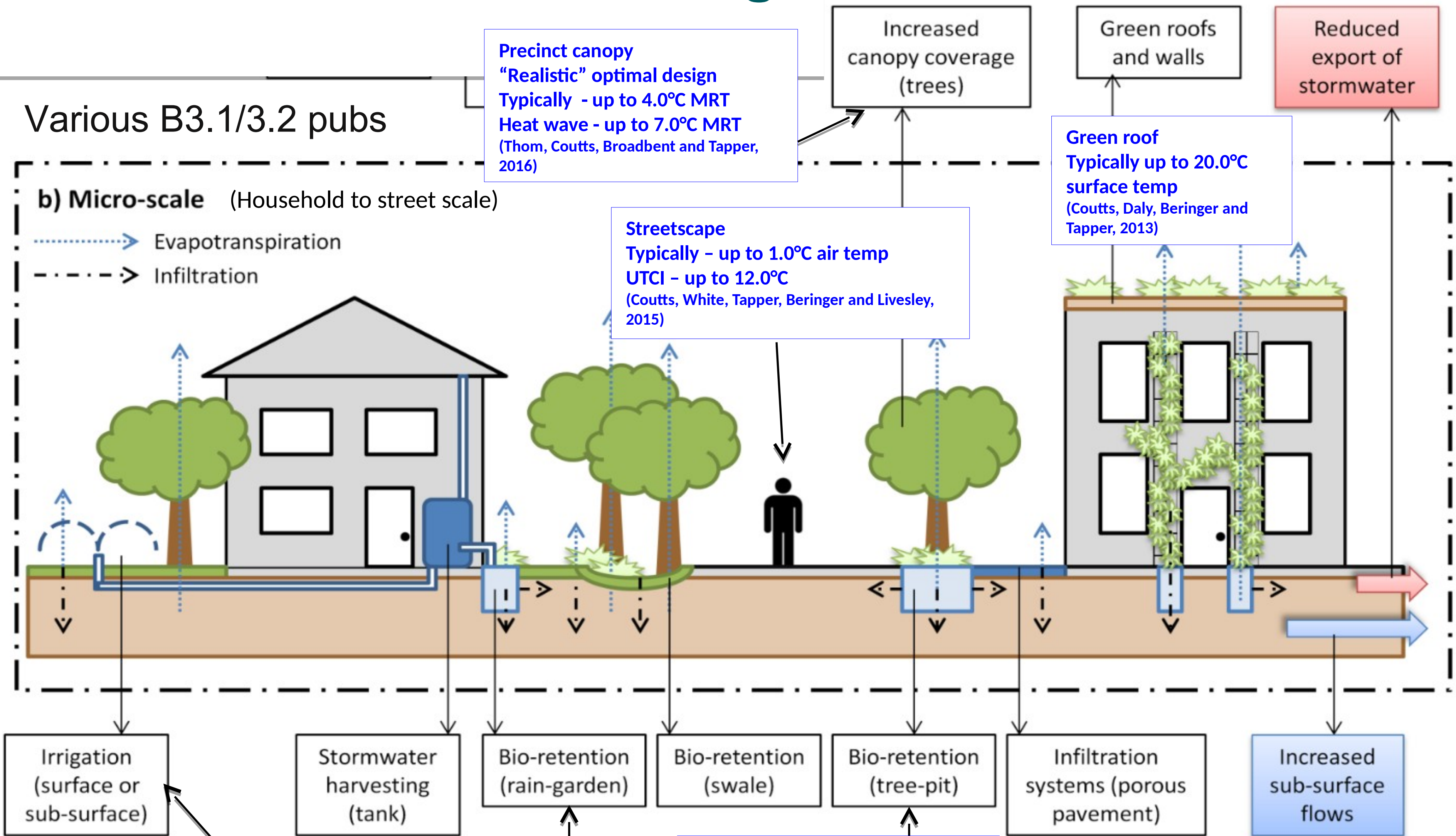
# Summertime WSUD Cooling

Various B3.1/3.2 pubs

**Precinct canopy**
**"Realistic" optimal design**
**Typically - up to 4.0°C MRT**
**Heat wave - up to 7.0°C MRT**
**(Thom, Coutts, Broadbent and Tapper, 2016)**

**Green roof**
**Typically up to 20.0°C surface temp**
**(Coutts, Daly, Beringer and Tapper, 2013)**

**Streetscape**
**Typically – up to 1.0°C air temp**
**UTCI – up to 12.0°C**
**(Coutts, White, Tapper, Beringer and Livesley, 2015)**




**Botanic Garden Irrigation**
**Heat wave – up to 3.5°C air temp**
**(Lam, Gallant and Tapper, 2017)**

**Rain-garden**
**Summer conditions**
**Surface temp – to 25°C**
**Air above and downwind (1 diameter) – up to 1.5°C**
**(Shu and Tapper, 2017)**

**Single tree**
**Typically – up to 1.2°C air temp below canopy**
**UTCI – up to 7.0°C below canopy**
**(Coutts, Moore, Thom, Tapper and White, 2017)**

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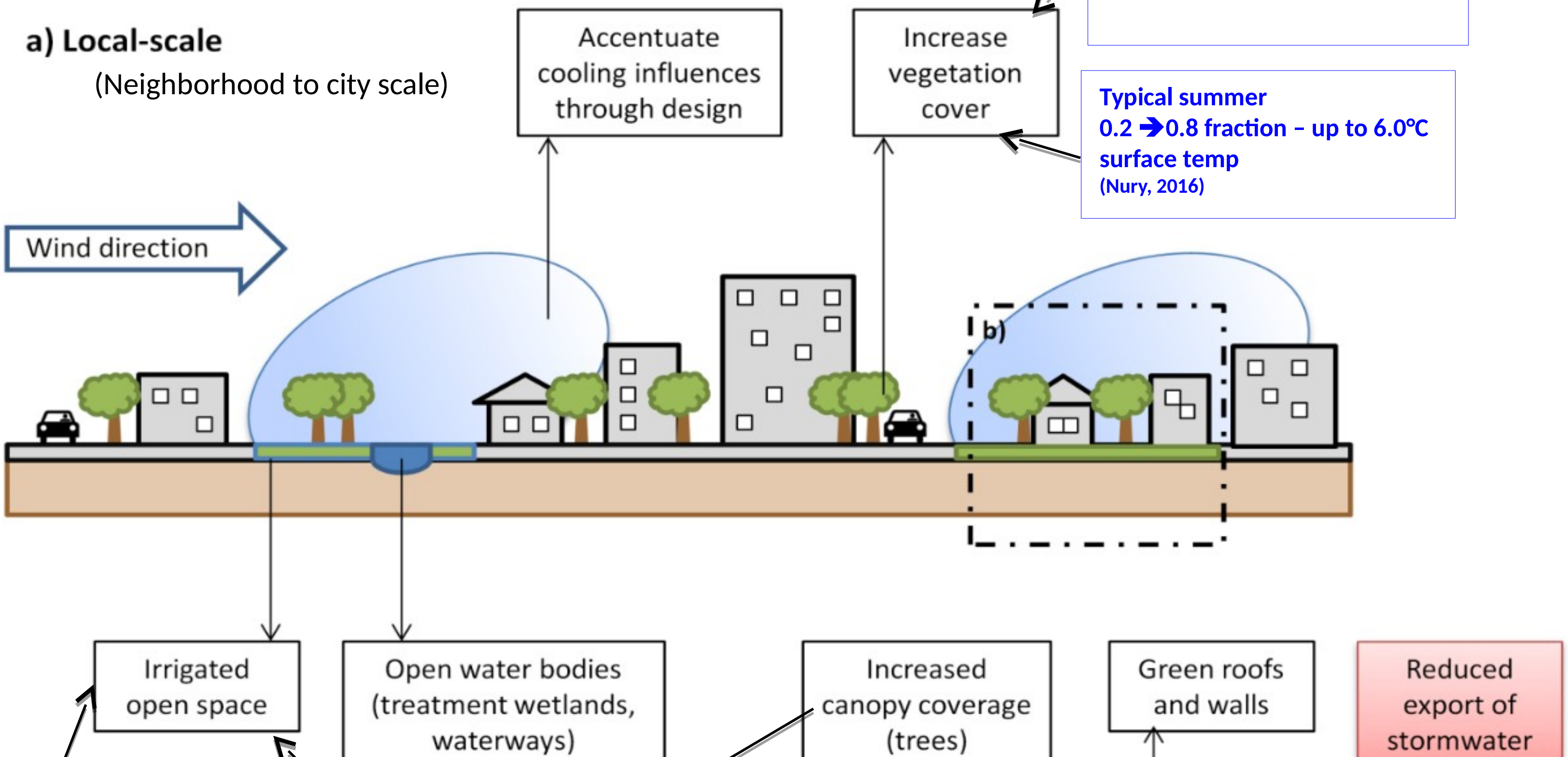
# Summertime WSUD Cooling

Various B3.1/3.2 publications

**Heat wave**
**10% - ~0.2°C air temp**
**100% - up to 1.0°C air temp**
**(Jacobs, Gallant and Tapper, 2017)**

**Typical summer**
**0.2 ➔0.8 fraction – up to 6.0°C surface temp**
**(Nury, 2016)**




**Suburban heat wave**
**Low/mod irrigation - ~0.5°C air temp**
**Very heavy irrigation - up to 2.5°C air temp**
**Up to 20°C surface temperature**
**(Broadbent, Coutts, Tapper and Demuzere, 2017)**

**Park cooling**
**Typical – light irrigation ~1.0°C air temp**
**UTCI - up to 10.0°C (Motazedian, 2016)**

**Typical summer**
**~1.0°C air temp above and downwin**
**(1 diameter)**
**(Broadbent, Coutts, Tapper and Demuzere, 20**

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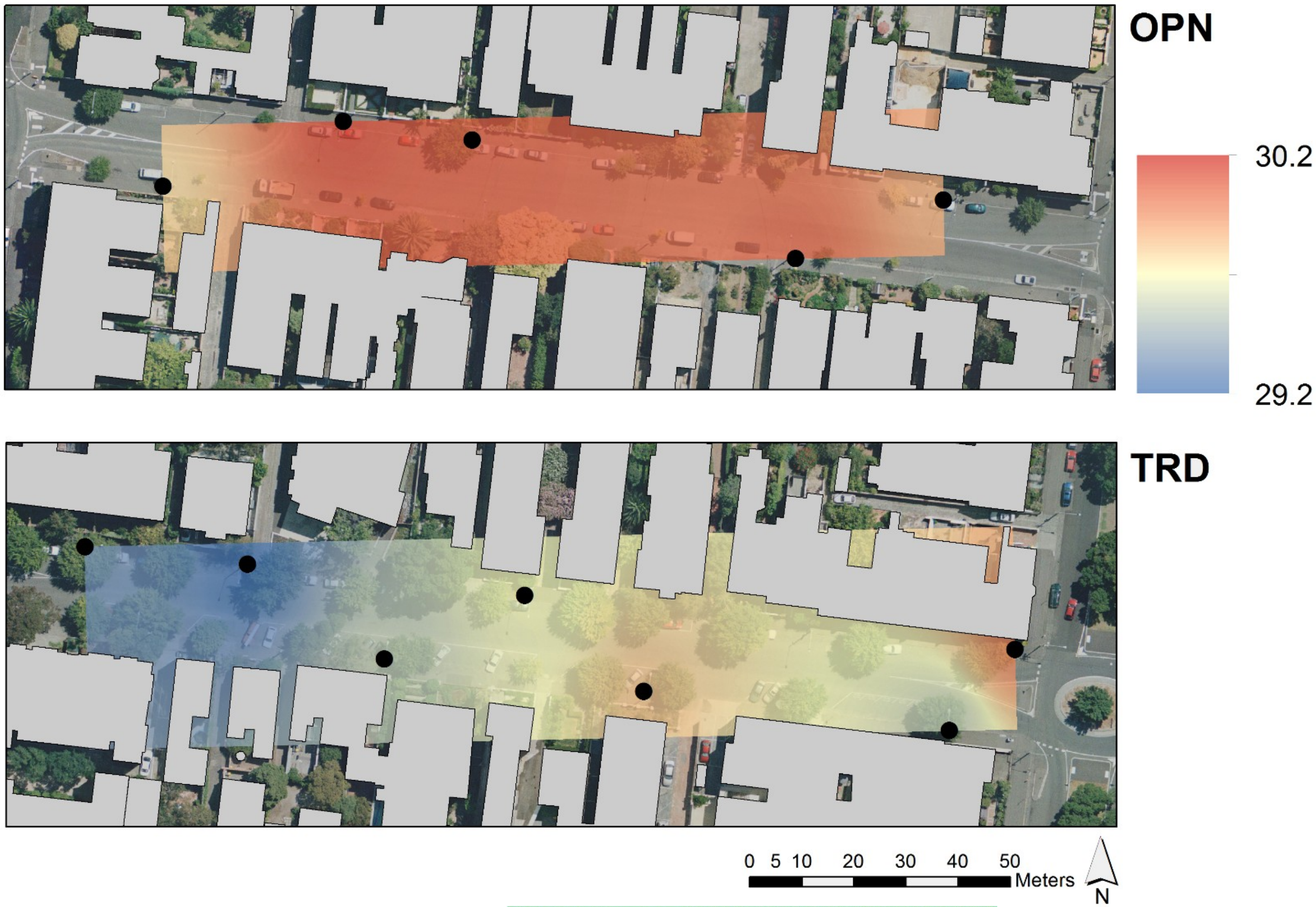
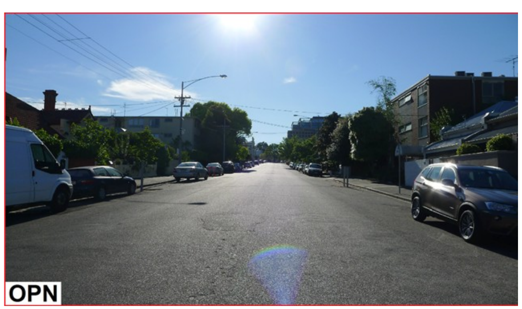
# Street tree cooling




- OPEN street vs. a TREED street
- Average daytime air temperature
- 4-12 March 2013
- 9 consecutive days exceeding 32 °C
- Differences of up to 3.1 °C among the seven stations in TRD





*Coutts, et al (2015)*

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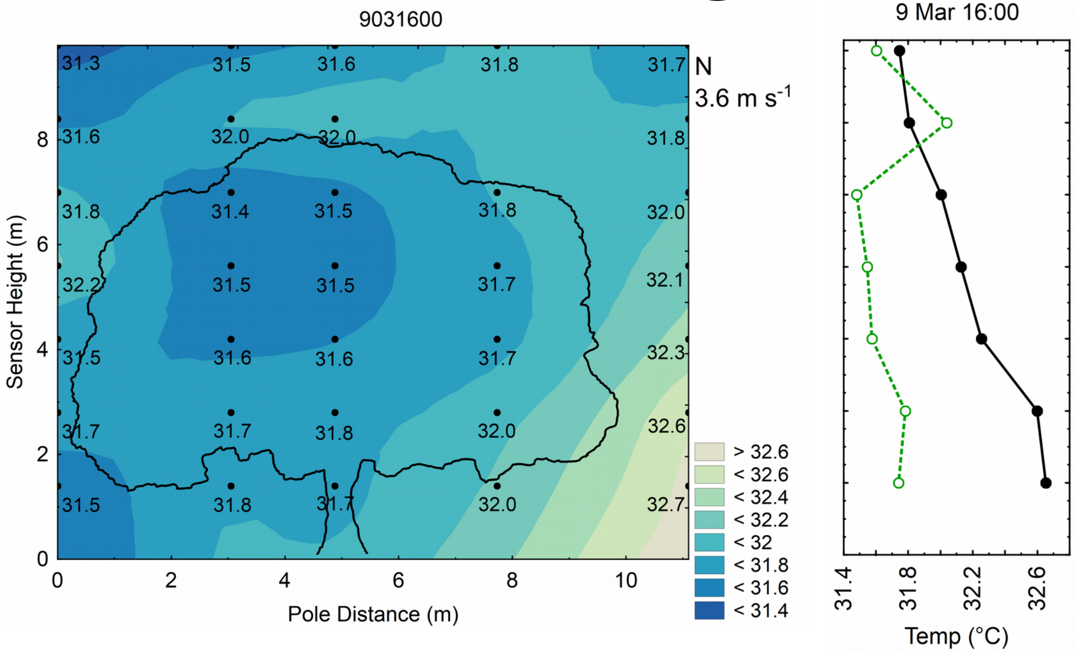
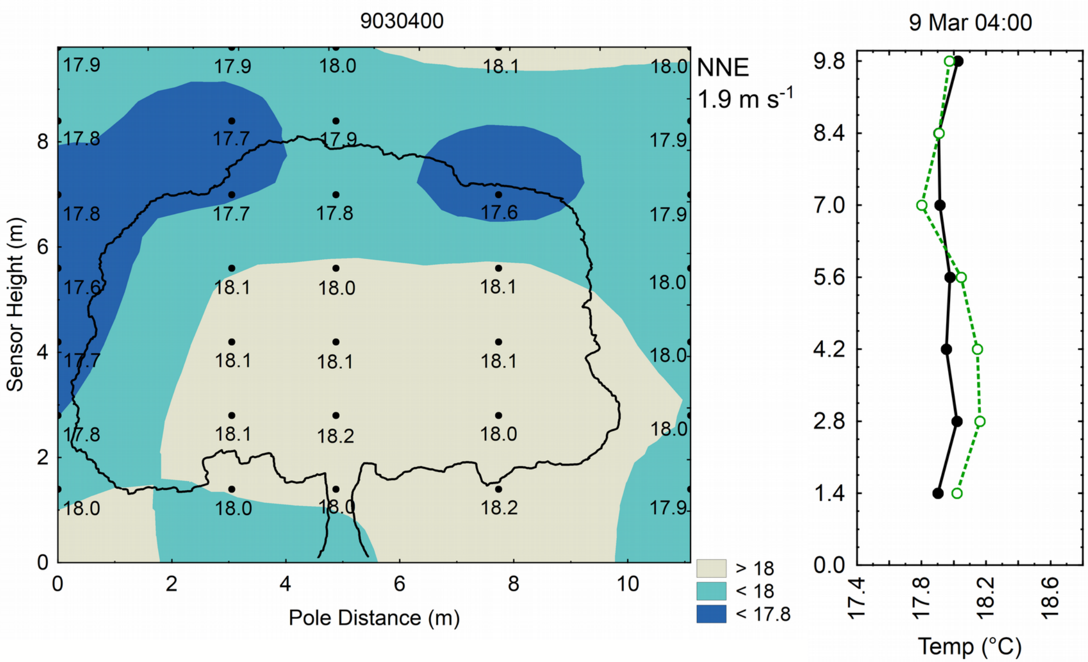
# Isolated tree cooling




- Micro-scale cooling from shading
- Transpiration will add to local scale cooling
- Up to 1.2 °C difference at 1.4 metres
- Large improvements in human thermal comfort




- Slightly warmer below canopy at night of up to 0.4 °C
- Radiation trapping and emission below canopy
- Longwave cooling at canopy surface

*Coutts et al (2016)*

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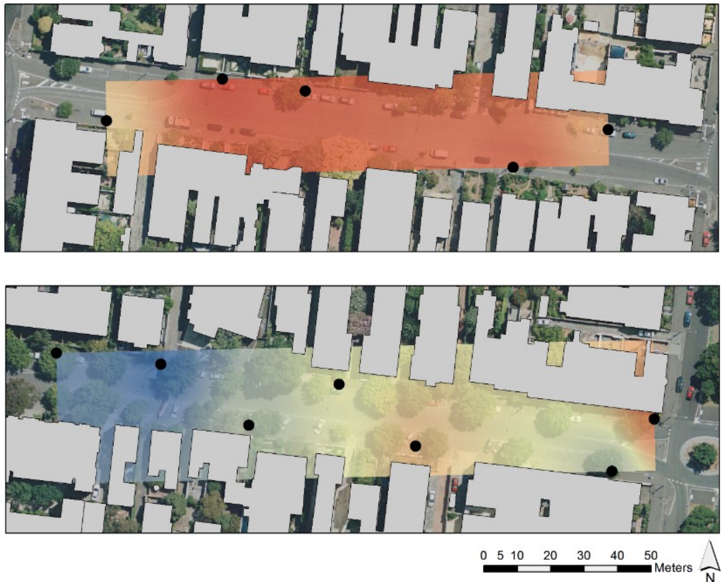
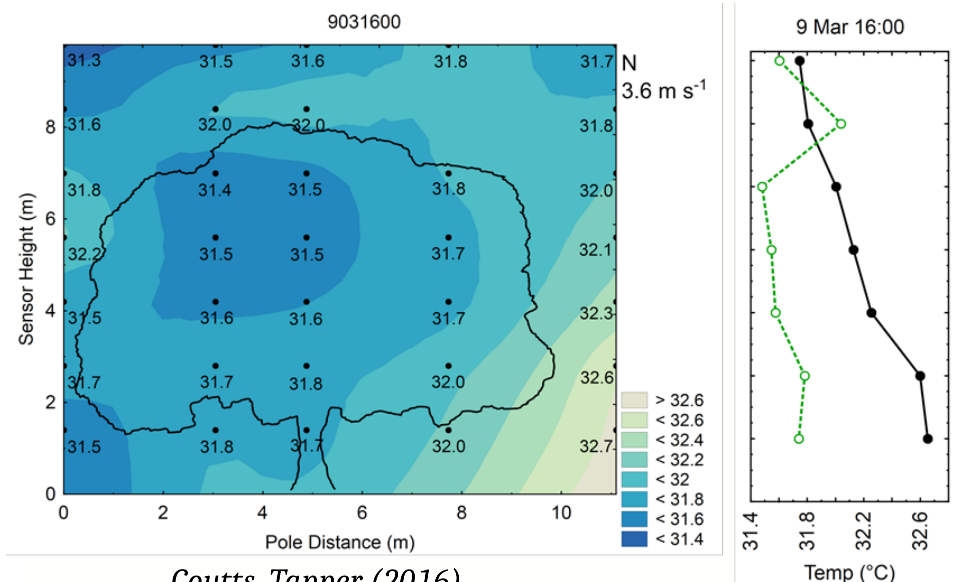
# Reduce micro-scale air temperature

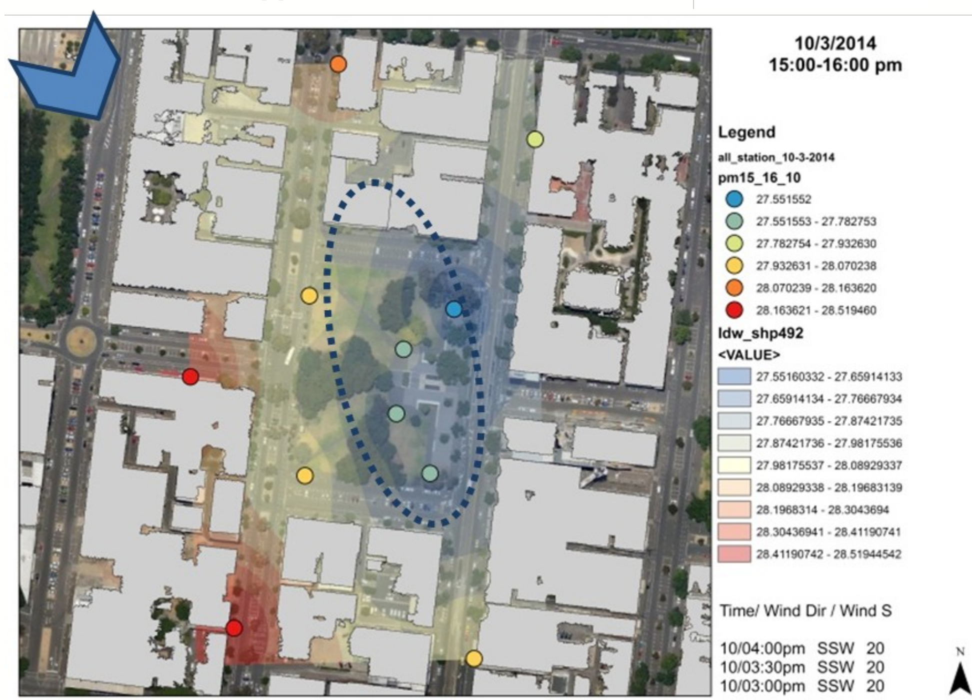



*Coutts, Livesley, Beringer, Tapper (2015)*




*Coutts, Tapper (2016)*

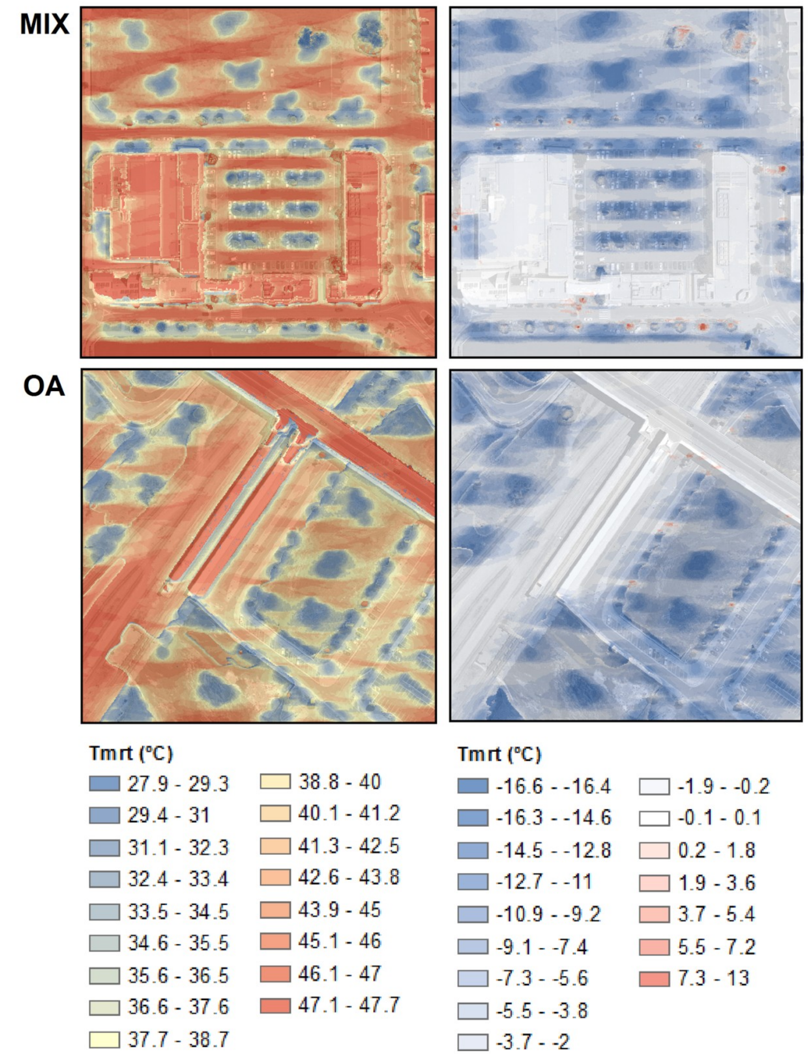
- Reductions in air temperature during the day
- Downwind cooling limited: Greening must be distributed widely
- Cooling variable in complex urban environment:
  - Type of greening
  - Urban geometry
  - Meteorology
  - Etc




*Motazedian (2015)*

# Reduce micro-scale radiant temperature

Mean radiant temperature (model)




*Thom, Coutts, Broadbent, Tapper (2016)*

*Coutts et al (2016)*

Land surface temperature (remote sensing)

- Large reductions in daytime Land SURFACE temperature from greening and irrigation
- Large reductions in daytime Mean RADIANT temperature due to shade

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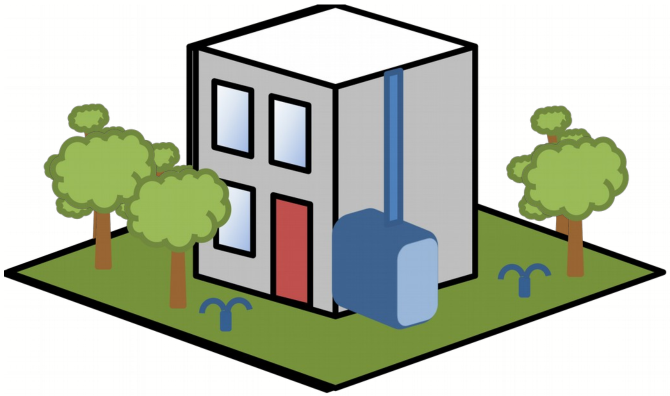
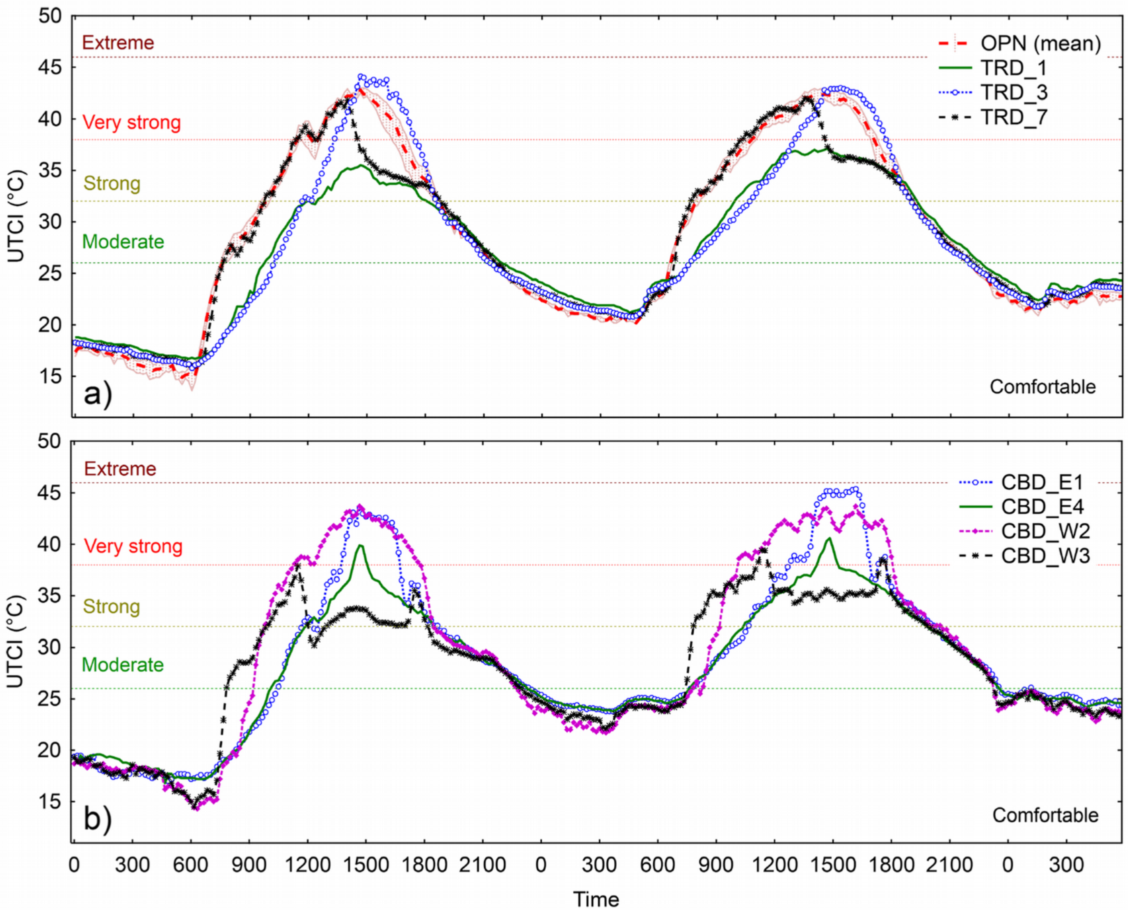
# Improve human thermal comfort - Streetscape

- Large improvements in daytime human thermal comfort from trees. Critical that trees are present where possible in greening scenarios






*Coutts, Livesley, Beringer, Tapper (2015)*

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# Reducing heat-health costs with trees

- Economic benefit of street trees – City of Monash
- Street trees only (private veg left unchanged)
- Also valued carbon uptake and storage, air quality and stormwater

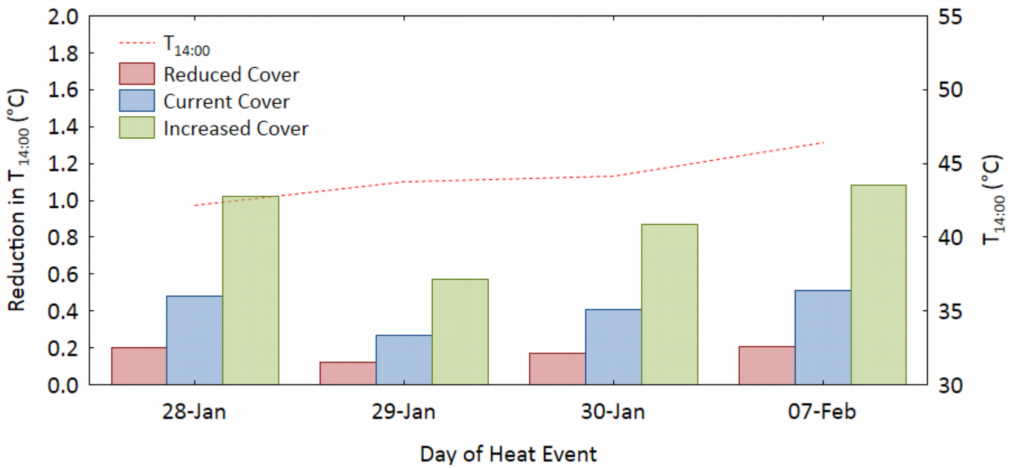
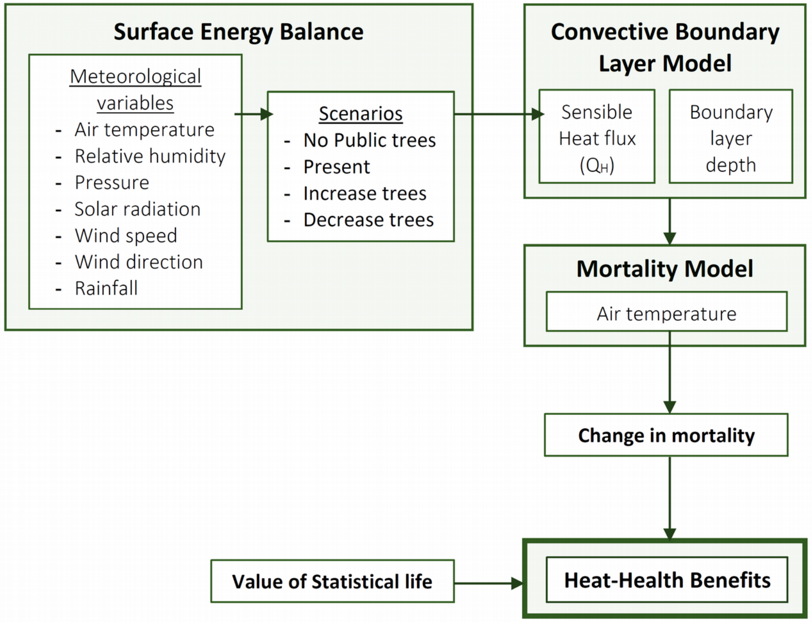



**Figure 4.12:** Illustrates the change in temperature ($T_{14:00}$) attributed to three tree cover scenarios: (i) the current tree population, (ii) a 50 % reduction in public trees, and (iii) a 100 % increase in public trees (left axis). $T_{14:00}$ measured at Moorabbin Airport on the four most extreme days of the 2009 heatwave is displayed on the right axis.



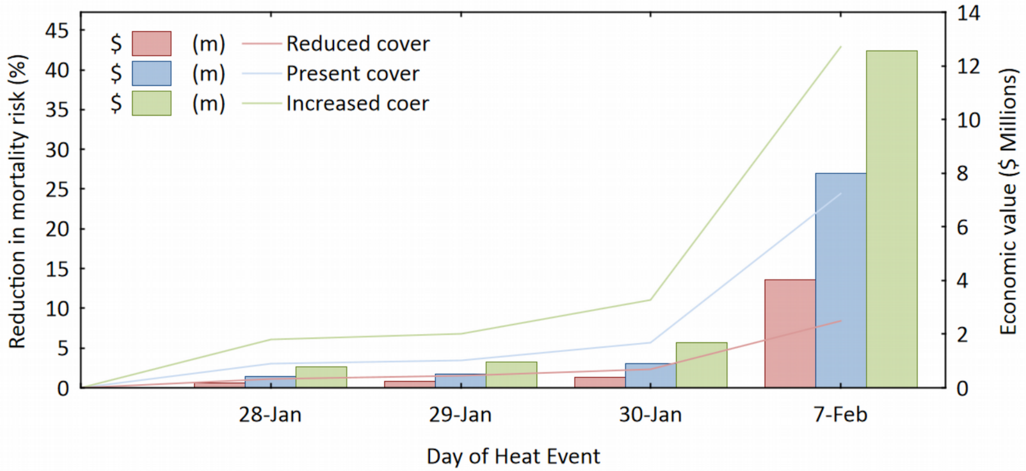
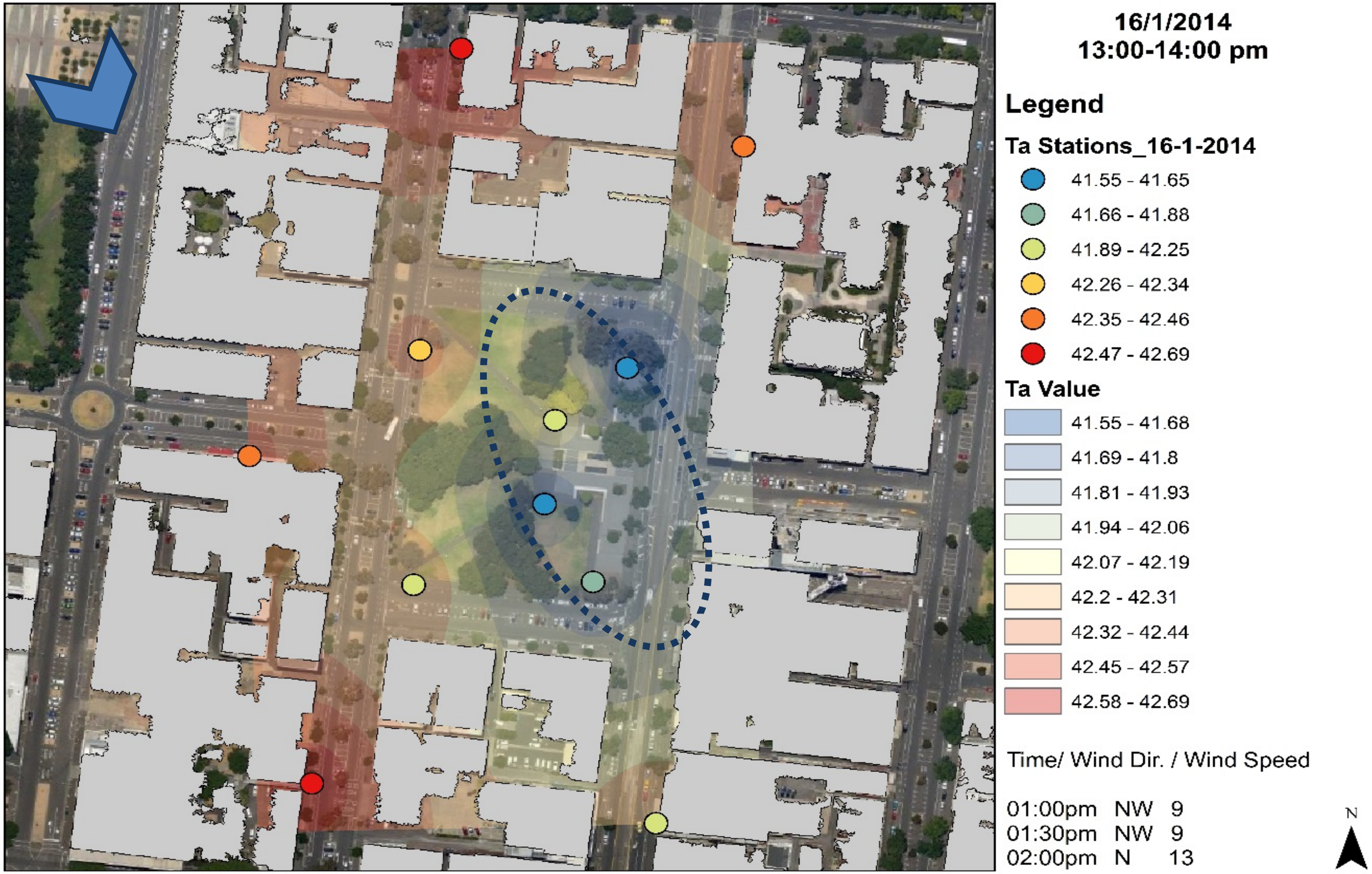




**Figure 4.13:** Illustration of the reduction in predicted mortality (ΔM) during an extreme heat event (left axis). Here canopy cover scenarios are: (i) present tree population, (ii) increased tree population, and (iii) reduced tree population. The associated economic value ($) is indicated in bars for each scenario (right axis) based on the recommended VSL for Australian policy analysis ($ 4.2 million) (Australian Government, 2014).

*Thom (2015); Thom, Coutts and Tapper (2016)*

# Green open space cooling




*Motazedian, Coutts, Tapper (2016)*



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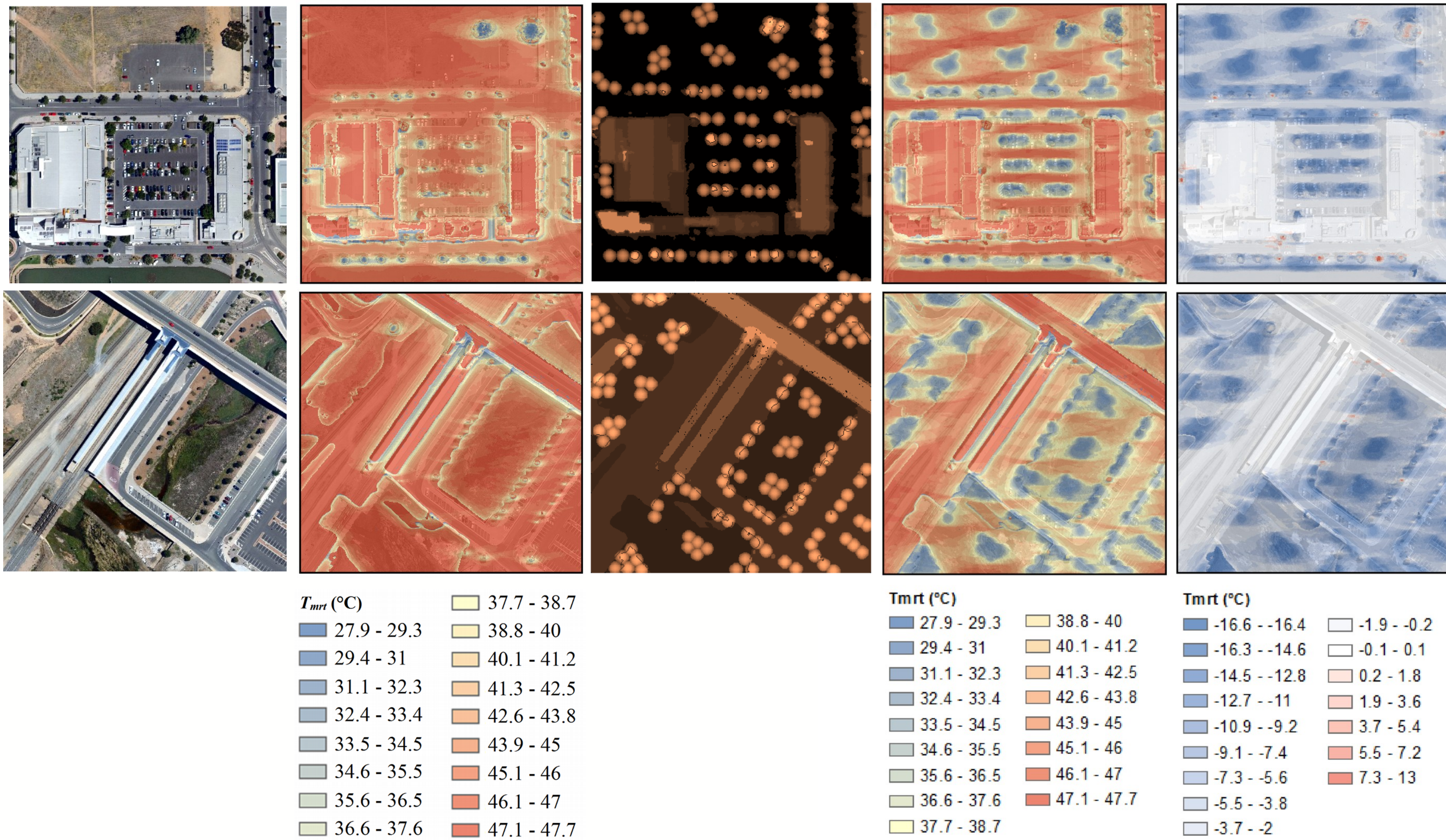
# Trees reduce *mean radiant temperature*




*Thom, Coutts et al (2016)*



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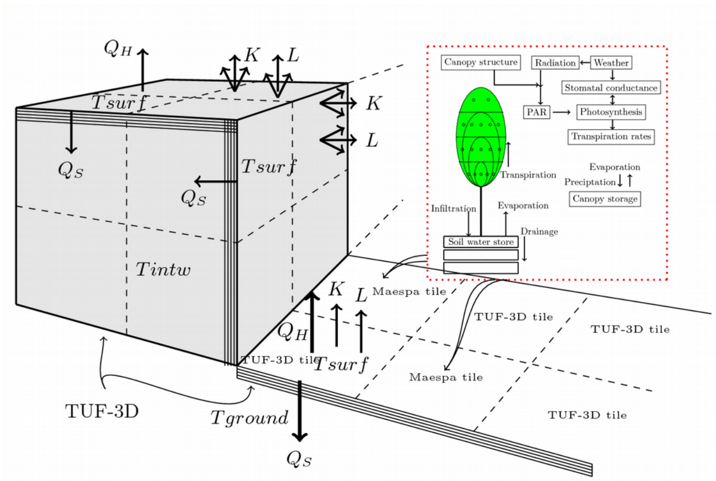
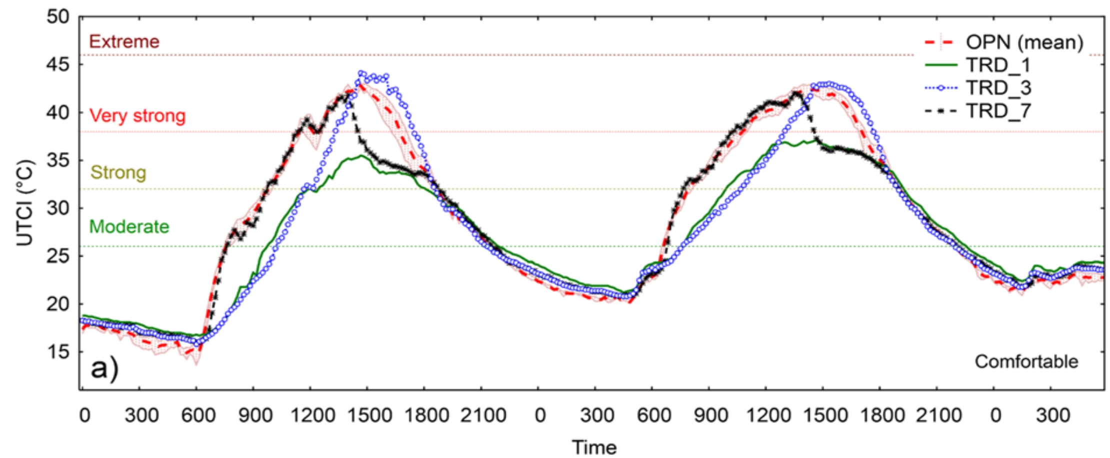
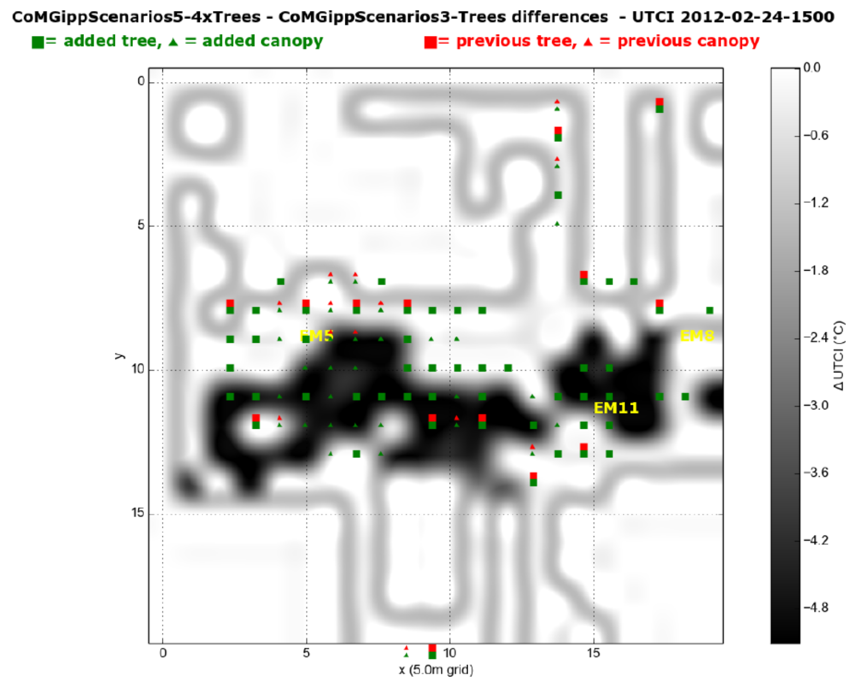
# Trees improve human thermal comfort








*Nice, 2016*



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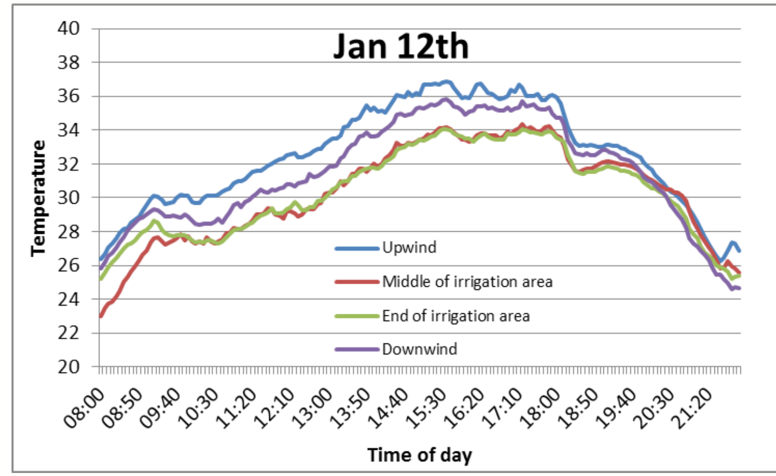
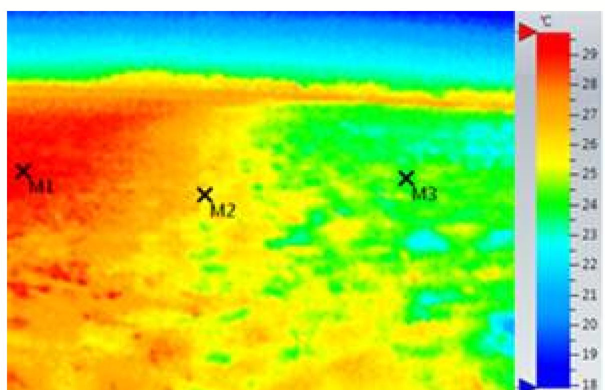
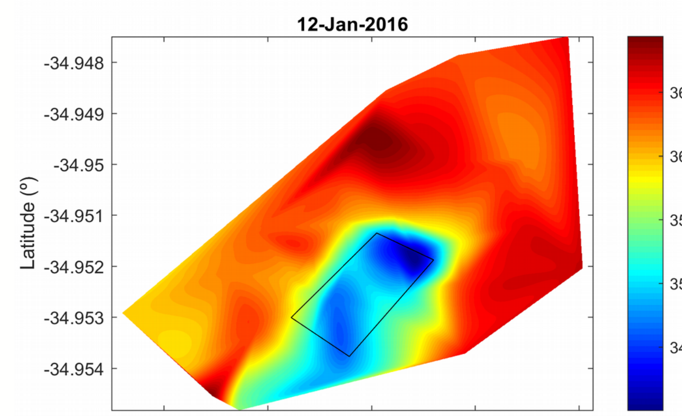
# Irrigation study at Adelaide Airport


(Ingleton 2017)

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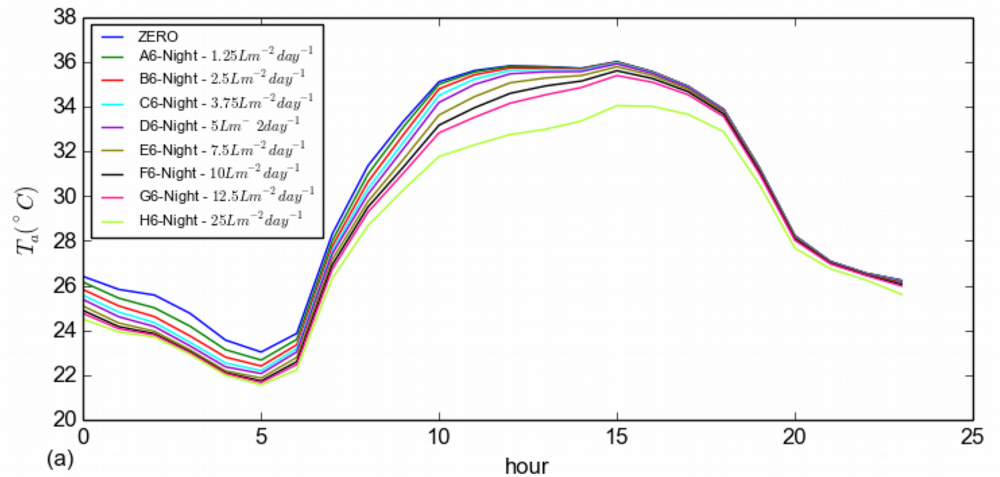
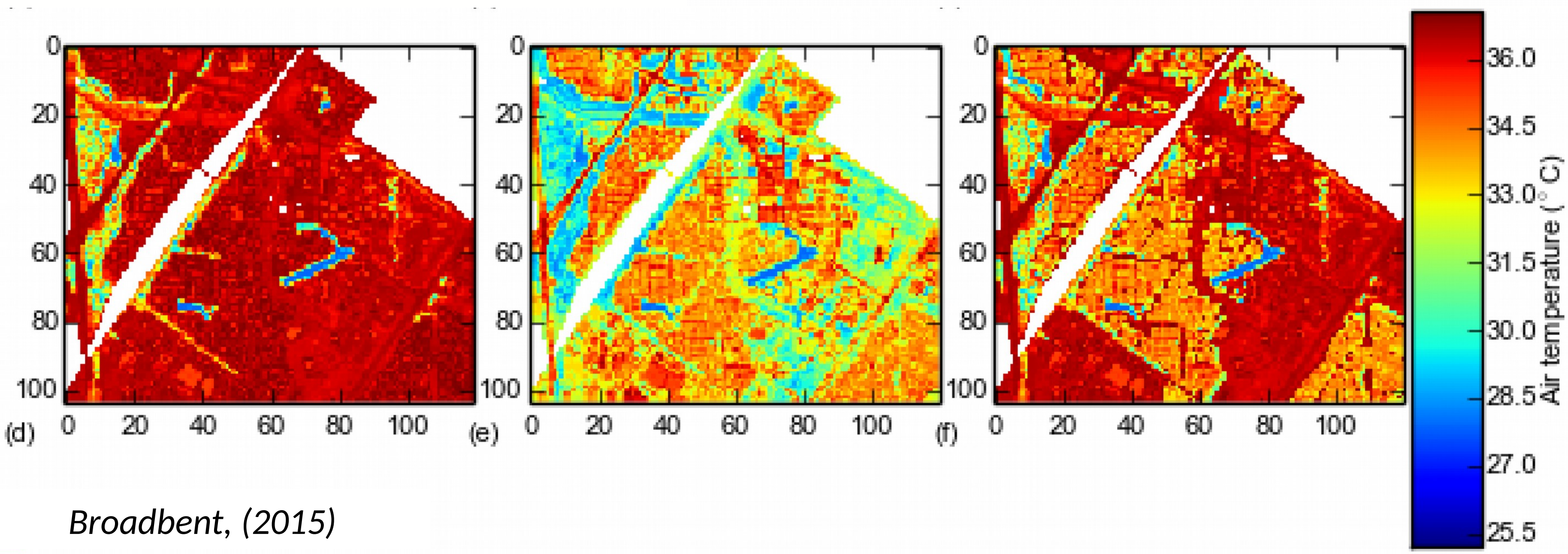
# Irrigation cooling

- Explored various irrigation scenarios




*Broadbent, (2015)*

# 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

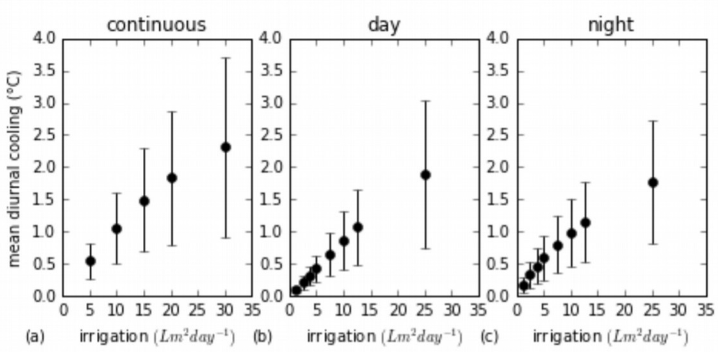



Figure 7: Heatwave average diurnal cooling (with standard deviations) for (a) continuous, (b) day, and (c) night irrigat

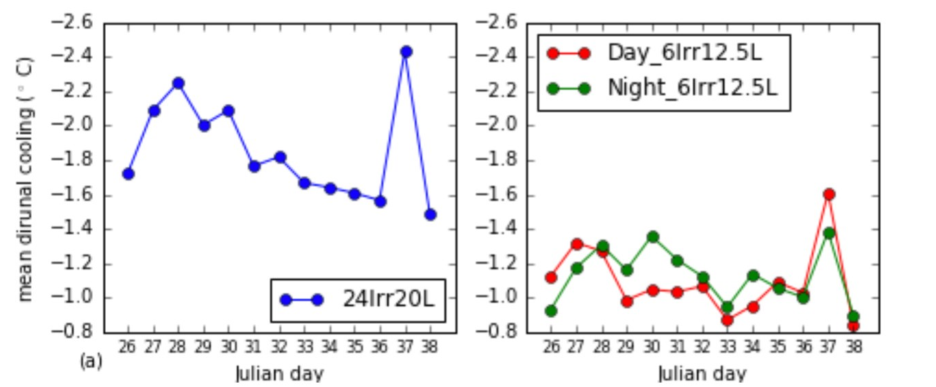



Figure 8: The mean diurnal cooling on each day of the heatwave for (a) 24Irr20L and (b) Day/Night_6Irr12.5L scenarios.

*Broadbent, Coutts, Demuzere and Tapper (2017)*

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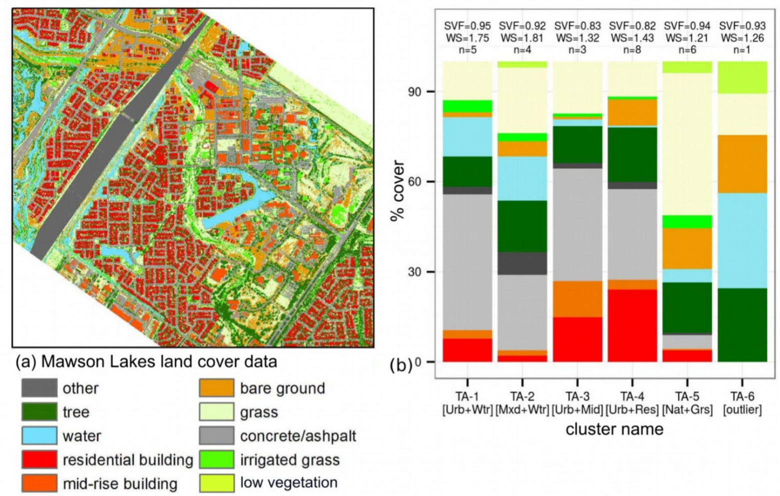
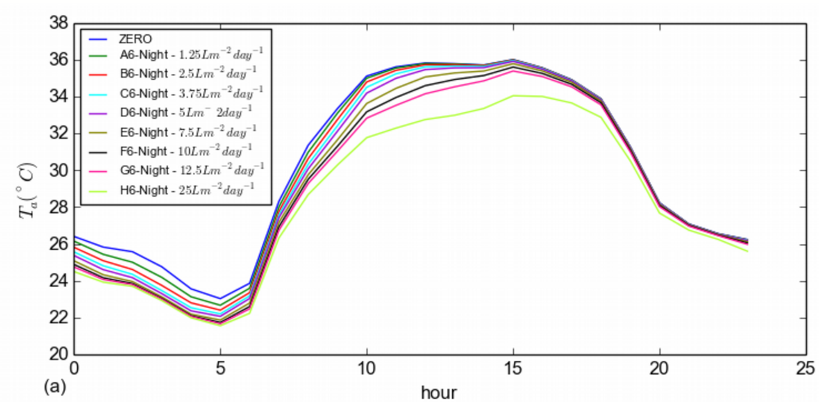
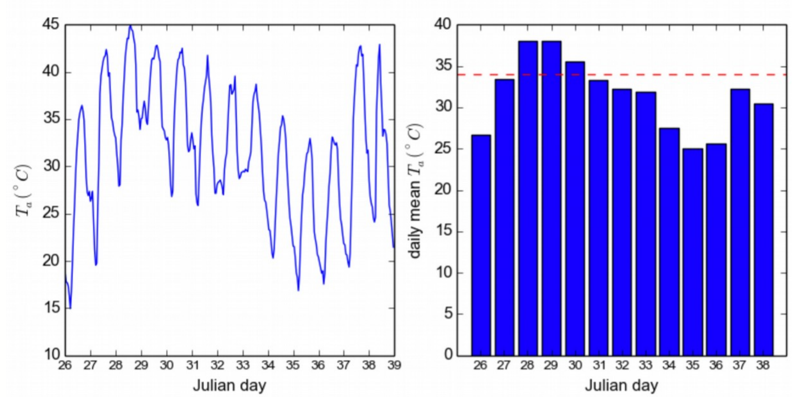
# Landscape irrigation for cooler cities and suburbs – Example from Mawson Lakes, Adelaide

- 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)*

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# Landscape irrigation - Mawson Lakes, Adelaide

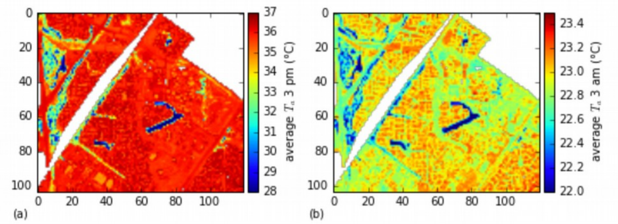



Figure 6: The spatial representation of the heatwave average (a) 3 pm and (b) 3 am $T_a$ (2 m) across the Mawson Lakes domain for the base case (no irrigation) simulation. The x and y axis are labelled by cell number.

Modelled Heatwave Temp

## 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

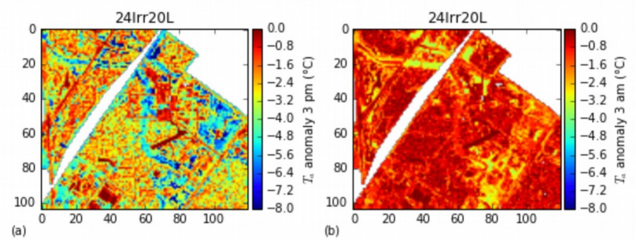
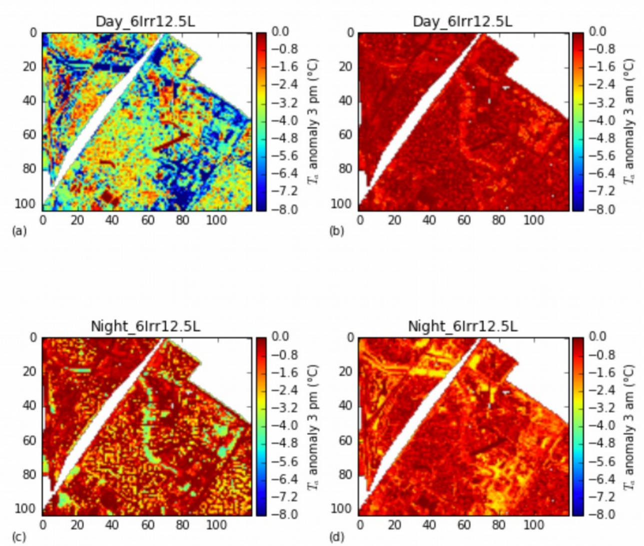



Figure 9: Spatial representation of cooling from 24Irr20L at (a) 3 pm and (b) 3 am on Julian day 37. The x and y axis are labelled by cell number.

24h20L 3pm/3am Cooling




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.

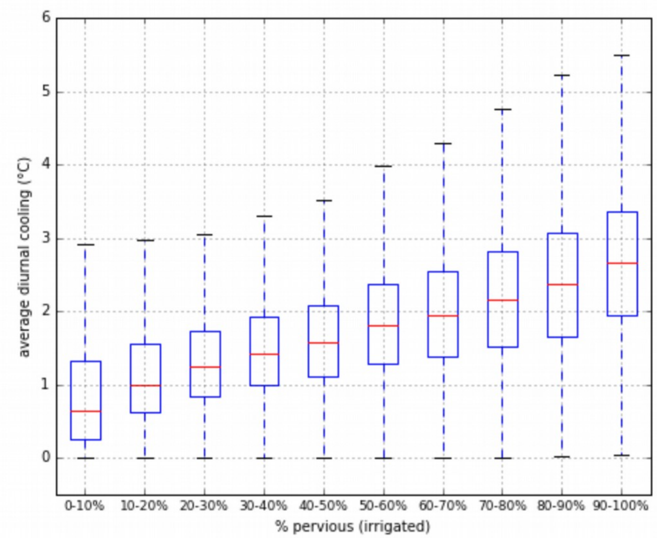



Figure 11: The daily cooling (24Irr20L scenario) for each grid cell during the heatwave period grouped by pervious (irrigated) fraction. Average cooling increases at a near linear rate, but does diminish slightly above 90% perviousness. The boxes represent the inter-quartile range and the whiskers represent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

*Broadbent, Coutts, Demuzere and Tapper (2017)*

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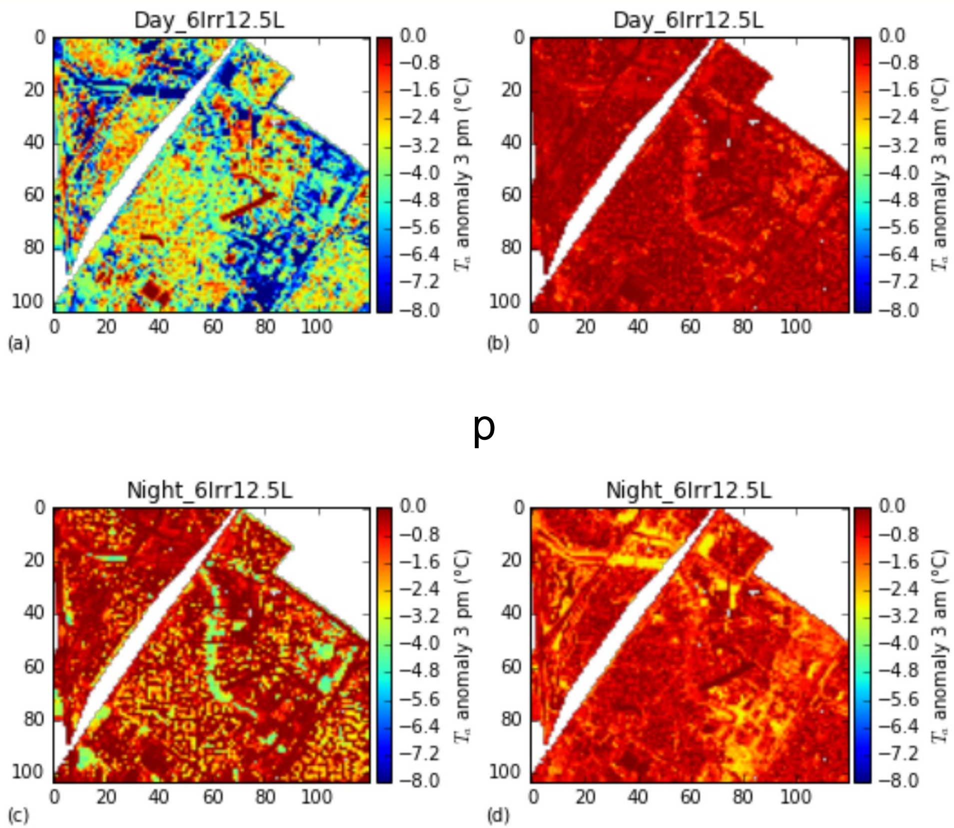
# SURFEX modelling irrigation schemes




(Broadbent 2017)

# Water and trees

*City of Melbourne, 2012*

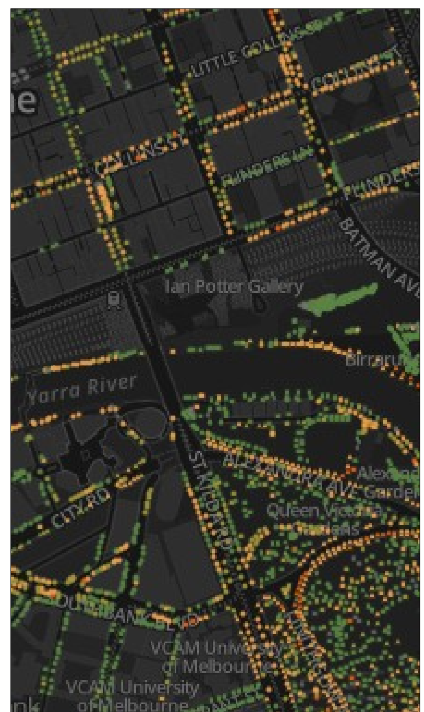
Trees can be extremely beneficial for urban climate BUT:

- They must have full canopies to provide shade
- Be actively transpiring to provide evaporative cooling

A lack of water compromises this

(Whitlow and Bassuk, 1988):

- Low soil water availability:
  - High stormwater runoff
  - Drought
  - Water restrictions
  - Reduced infiltration:
    - Hydrophobic soils
    - Compacted soils




City branches out to replace drought-hit trees

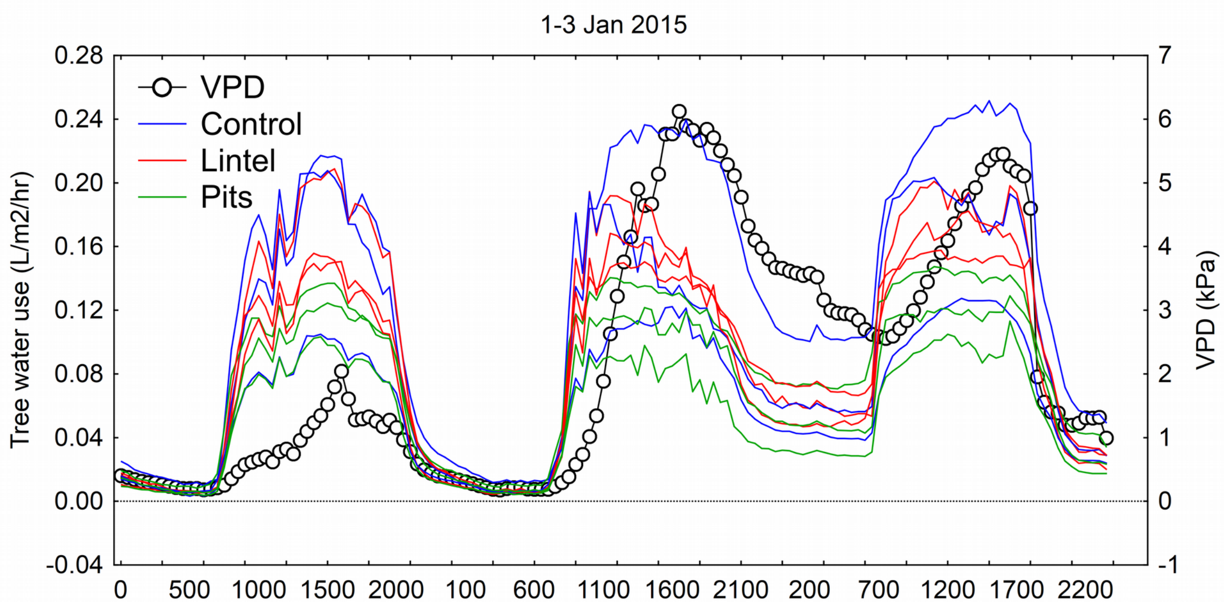
Dewi Cooke
May 11, 2010

Comments 17

Extreme weather and the ravages of time have left many of Melbourne's trees in need of replacement. *Photo: Justin McManus*

MELBOURNE will look to such countries as Spain, Chile and the US for replacements of thousands of drought-ravaged trees

# Passive irrigation of street trees




- Evidence of stomatal control on water loss
- Water transport at night
- No clear evidence of benefit of passive irrigation – issues with treatments
- 2015/16 summer???

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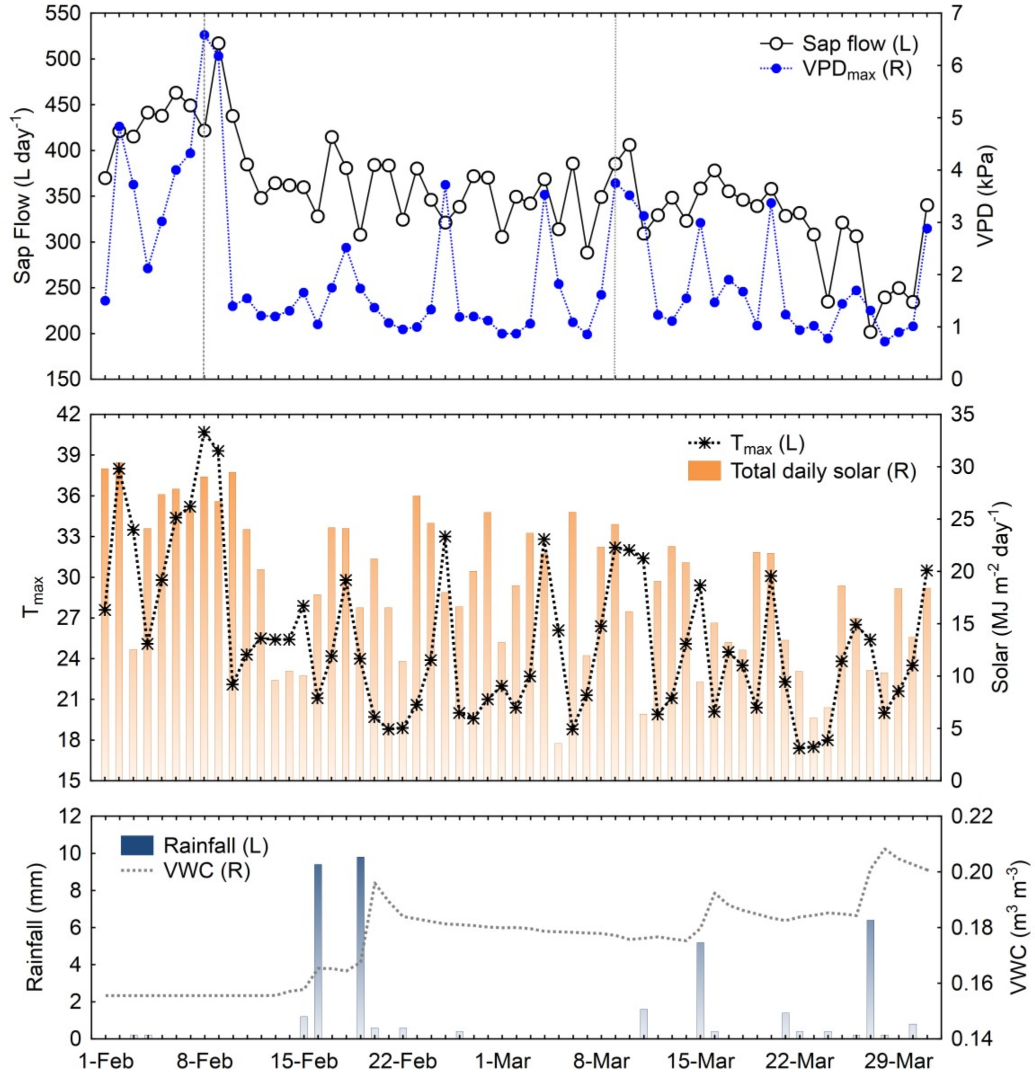
*Coutts, Thom, Szota, Livesley, (2015)*

# Water use of an isolated tree

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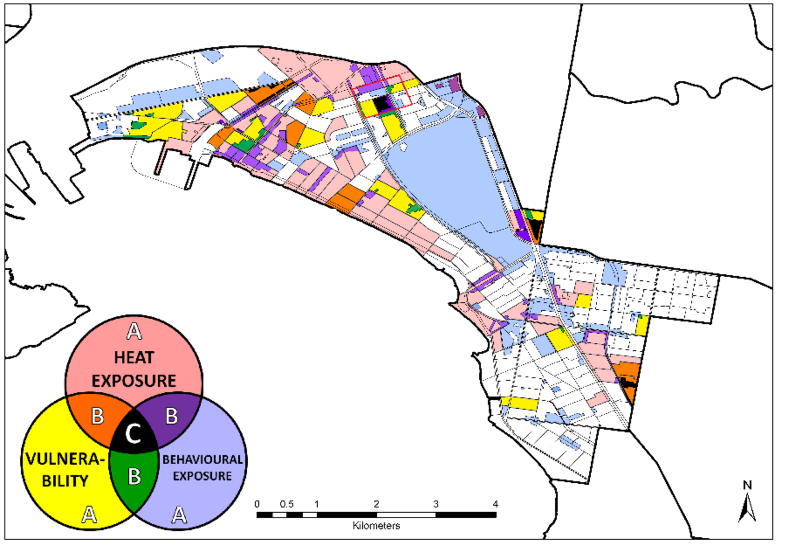
*Coutts et al 2016*

# Key interventions

- Existing street trees should be protected & maintained
  - Passive and active irrigation in built up areas
  - Maintain healthy canopies for shading
- More trees should be planted
  - Prioritise canopy cover in areas of high solar exposure
  - Highly localised benefit so trees must be distributed
  - Tree species should be diverse
  - Water should be supplied
- ‘Right tree, right place’
  - Consider light, water availability, climate, etc




*Norton, B. A., Coutts, et al 2015.*



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# Prioritising tree placement

- **Wide open streets** should be targeted as they are exposed to larger amounts of solar radiation during the day (Norton et al., 2015).
- **East-west oriented streets** were targeted as they are exposed to more solar radiation during the day (Ali-Toudert and Mayer, 2006).
- **North facing walls** (in the Southern Hemisphere) in east-west streets , and **west facing walls** to provide shading from the afternoon sun when Ta peaks.
- Trees should be **clustered together** - more effective at reducing Tmrt than isolated trees (Streiling and Matzarakis, 2003) and can help protect them from intense radiative loads (Oke, 1988).
- Employ a **'Savanah' type landscape** arrangement (as suggested by Spronken-Smith [1994] in relation to urban parks) of **clustered trees** interspersed **with open areas** to provide daytime shading while allowing nocturnal cooling and ventilation (Spronken-Smith and Oke, 1998)

*Thom, Coutts et al 2016*

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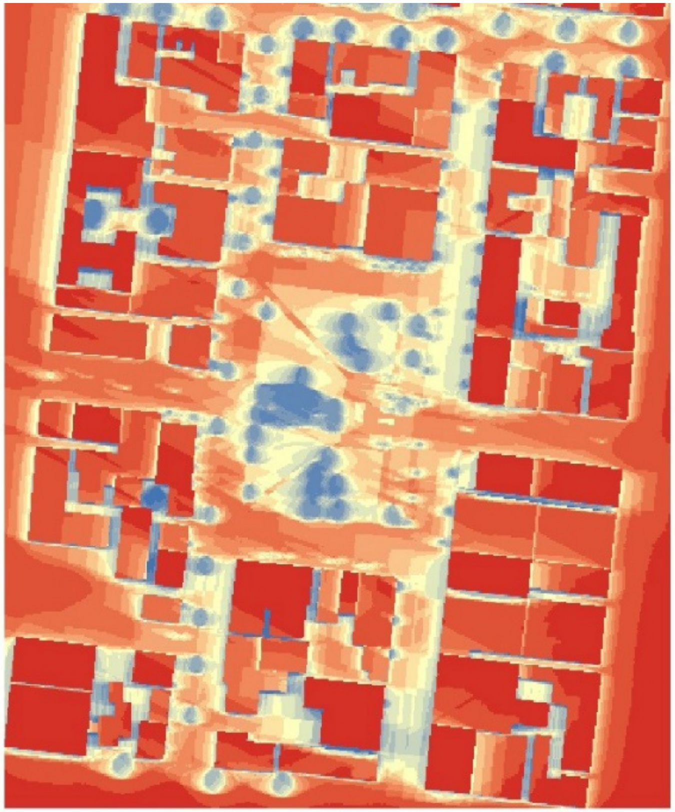
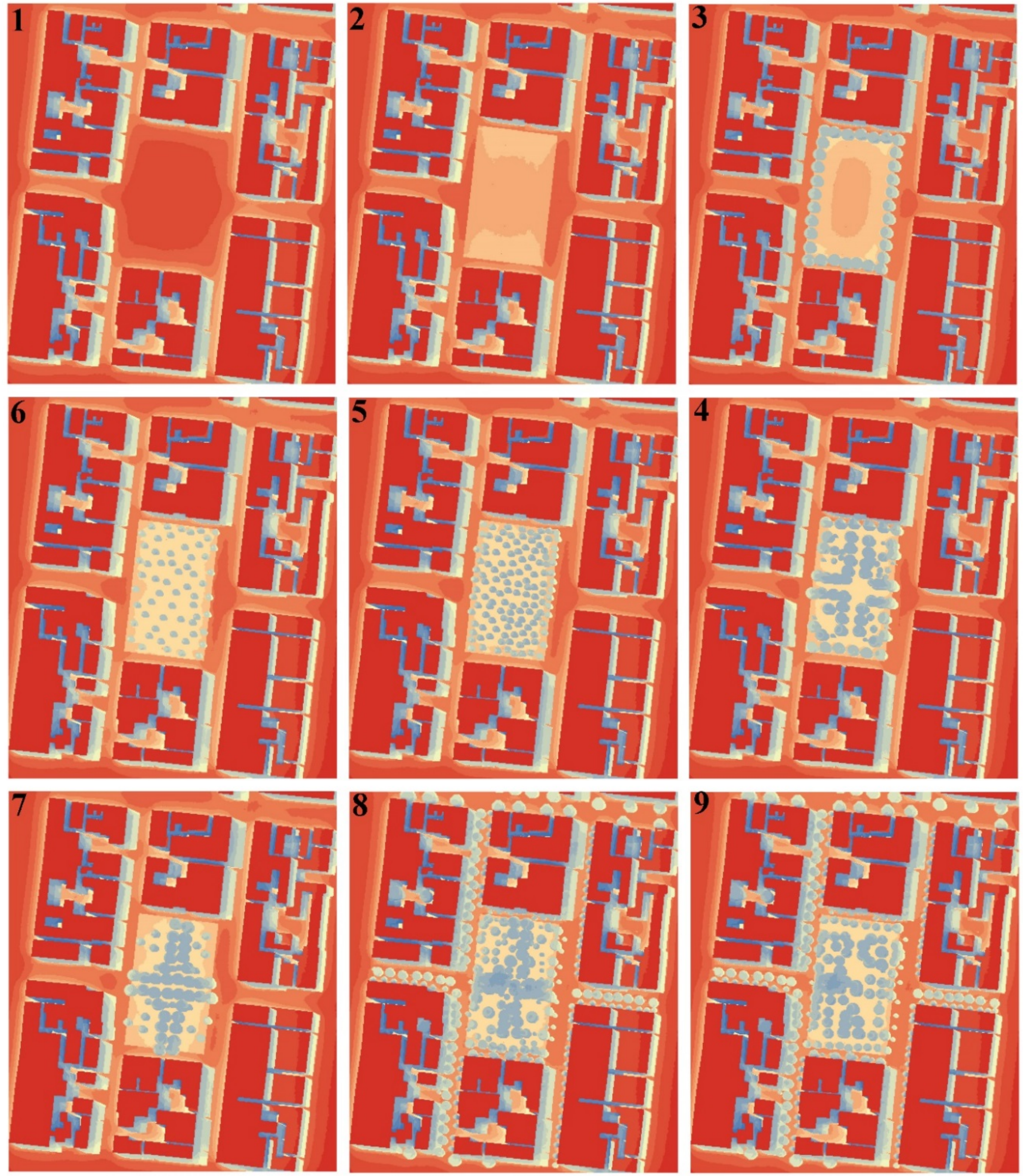
## Current



## Scenarios



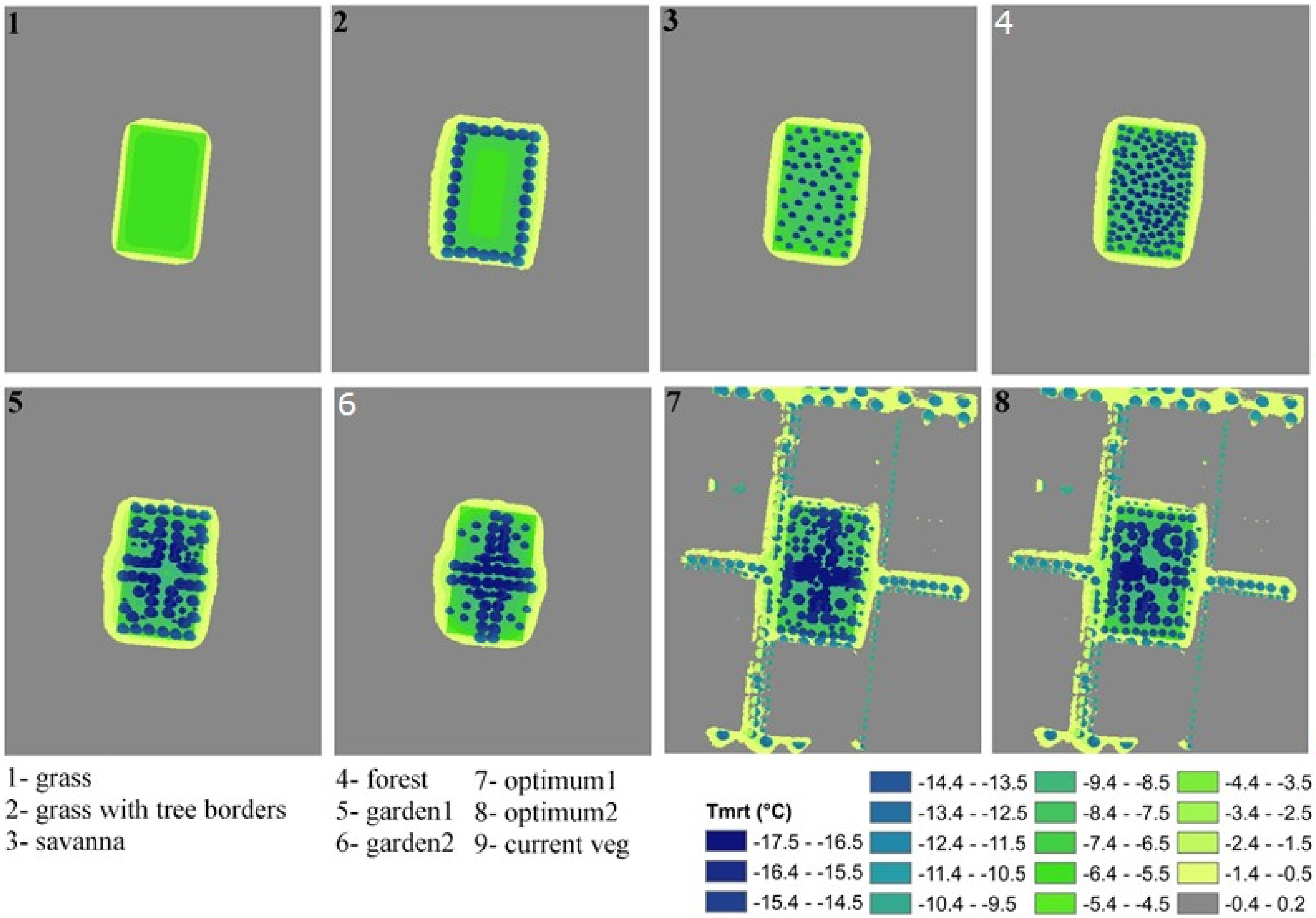

1- base case
2- grass
3- grass with tree borders
4- savanna
5- forest
6- garden1
7- garden2
8- optimum1
9- optimum2
10- current veg

Tmrt (°C)

37.8 - 40.1
40.2 - 41.2
41.3 - 42.3
42.4 - 43.6
43.7 - 44.7
44.8 - 45.7
45.8 - 46.8
46.9 - 47.9
48 - 49.8
49.9 - 52.2
52.3 - 53.8
53.9 - 55.1
55.2 - 56.6
56.7 - 57.8
57.9 - 59.1
59.2 - 60.3
60.4 - 61.6
61.7 - 62.3

*Motazedian, 2016*

Mean $T_{mrt}$ difference at 3pm during heatwaves (13-17th January)




| Scenarios | 24th-29th December $\Delta T_{mrt}$ | 13th-17th January at 15:00 $\Delta T_{mrt}$ |
|---|---|---|
| Current | -- | -- |
| Base case | -- | -- |
| Future build-current tree | -1.0 | -1.0 |
| Grass | -0.3 | -0.5 |
| Grass with Tree borders | -0.4 | -0.9 |
| Savanna | -0.6 | -0.8 |
| Forest | -0.8 | -0.9 |
| Garden 1/ Multi-use | -0.9 | -1.1 |
| Garden 2/ Multi-use | -0.8 | -1.0 |
| Optimum design 1 | -1.8 | -1.8 |
| Optimum design 2 | -1.5 | -1.8 |



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*Motazedian, 2016*

# Limiting heat health impacts

*Thom (2015)*

- Economic benefit of street trees – City of Monash
- Mortality benefits ($)
- Street trees only (private veg left unchanged)
- Also valued carbon uptake and storage, air quality and stormwater

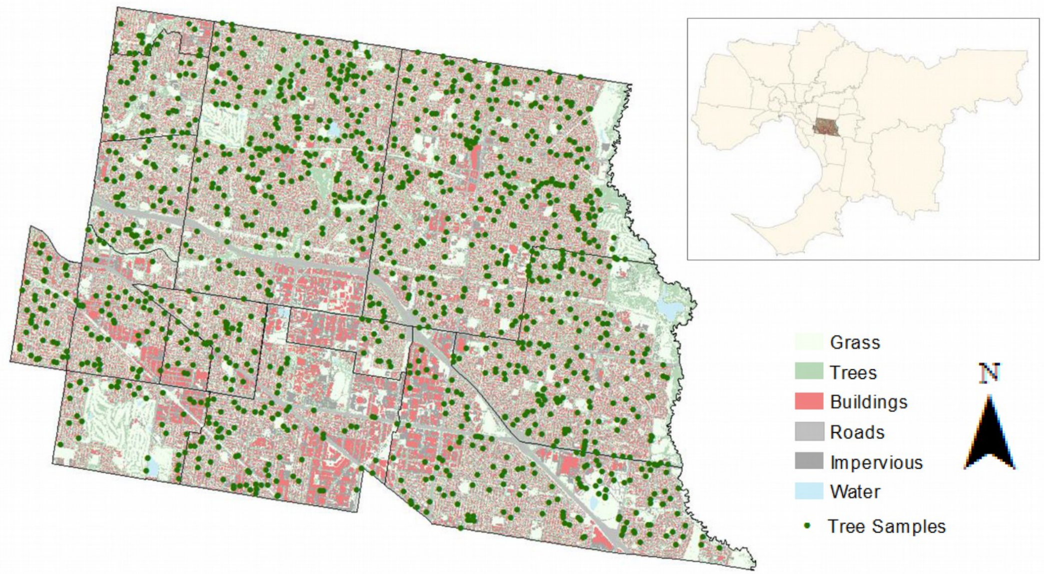
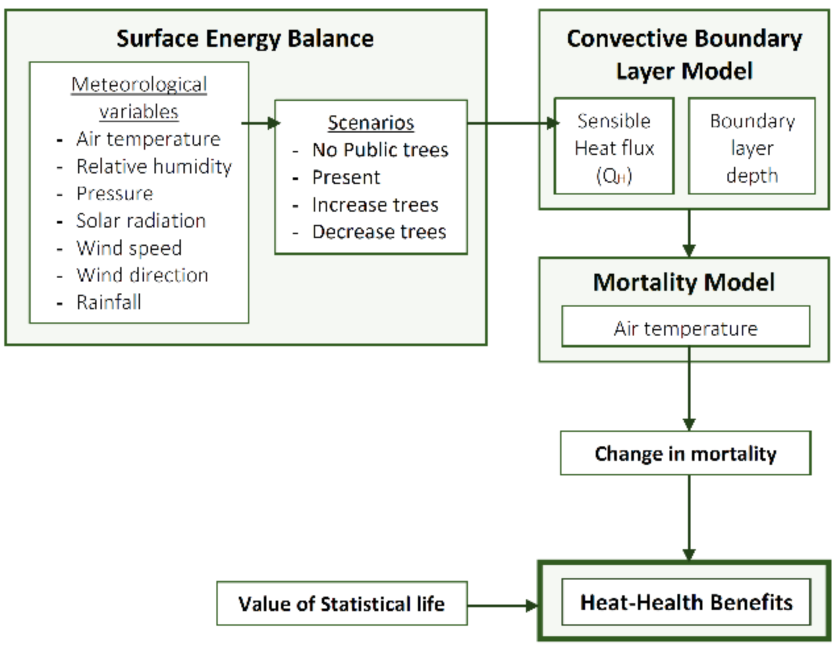
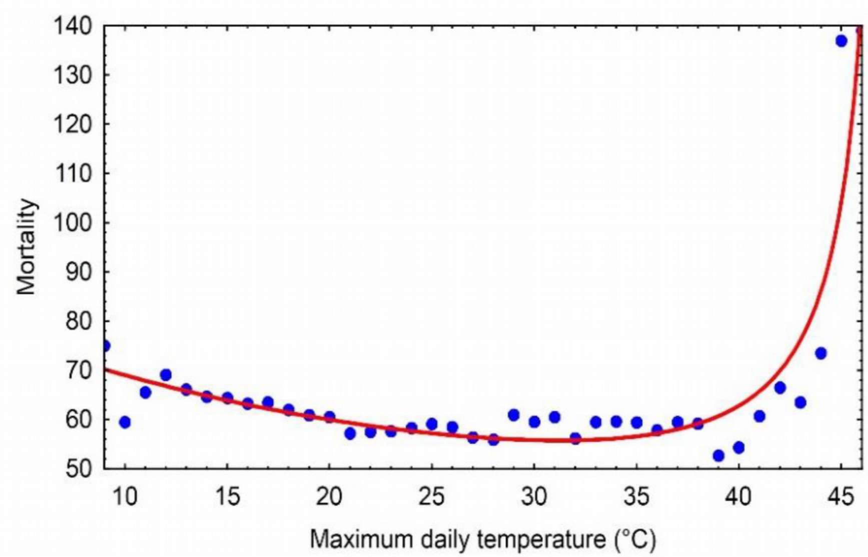



**Figure 3.6:** Street trees selected by stratified random sampling process (1 284) for field measurement in the City of Monash, Melbourne. Associated land cover around sample trees is illustrated.



# Limiting heat health impacts

*Thom (2015)*

**Scenarios**

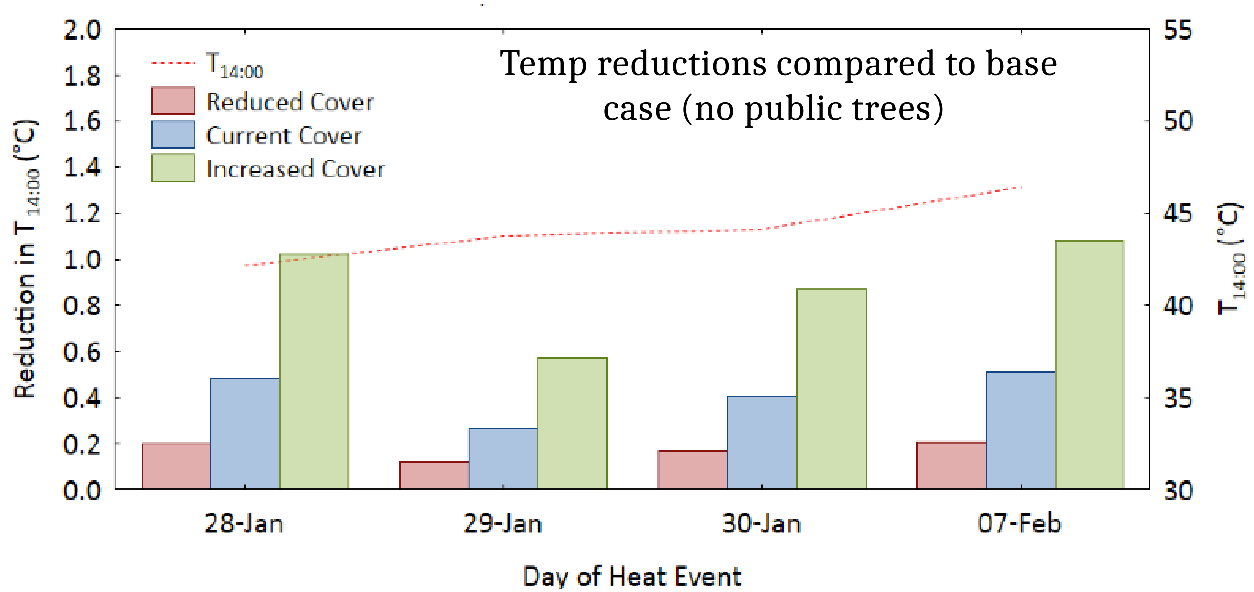
- No street trees (base case) (17%)
- Current street trees (24%)
- Less street trees (20%)
- More street trees (32%)

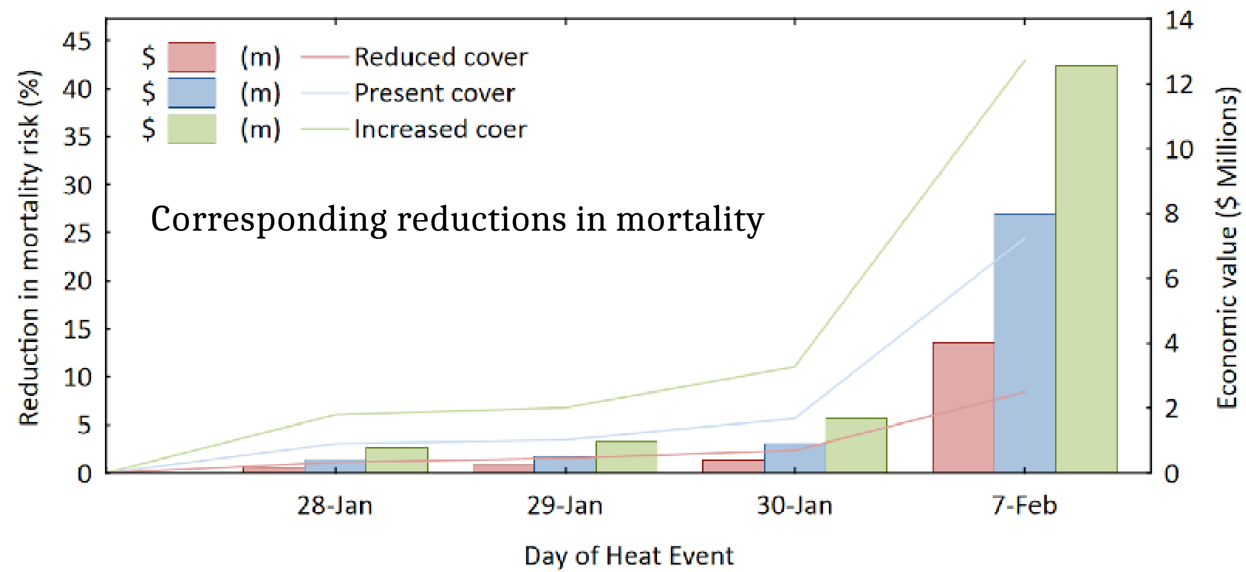
**Mortality benefits over 4 day period:**

- Current tree cover delivers ~0.5°C benefits = $9.78 million
- Doubling of cover provides a further ~0.5°C benefits (~1.0°C total over base case) =$16.01 million

**Total value of current urban forest**

- **$12.85 million**



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