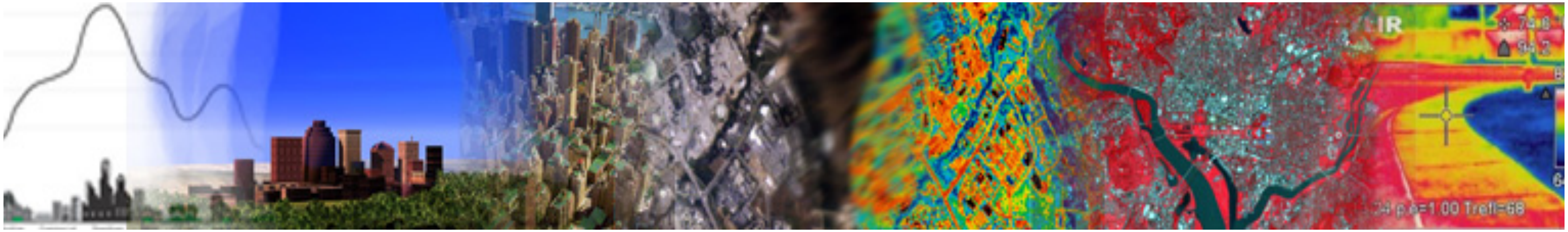
Urban Climate and Livability



Considerations from a Tropical City

FS2015 | Information Architecture of Cities, 9 March 2015

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Issue

How "sustainable"/livable/resilient are present cities and their anticipated development?

Several of urban environmental problems are directly or indirectly related to the climate of cities. Impacts of cities in terms of:

- Urban heat islands (UHI)
- Thermal comfort
- Land use change
- Carbon dioxide (CO_2) emissions
- Air pollution / air quality
- Water pollution
- Noise pollution
- Etc.

Nature of urban climates needs to be understood to be able to improve conditions and mitigate potential adverse effects such as poor air quality, high levels of heat stress which reduce productivity and human comfort, energy usage for space cooling and heating, etc.

Properties of urban areas that affect the local climate

- Radiative: Albedo, emissivity, SVF; heat absorption
- Thermal: High heat capacity, massive heat storage
- Moisture: Increased surface runoff; less evaporation
- Roughness: Increased turbulence; shelter decreases dispersion
- Emissions: Aerosols + GHG affect radiative transfer; CCN

Climate-relevant characteristics of urban environments

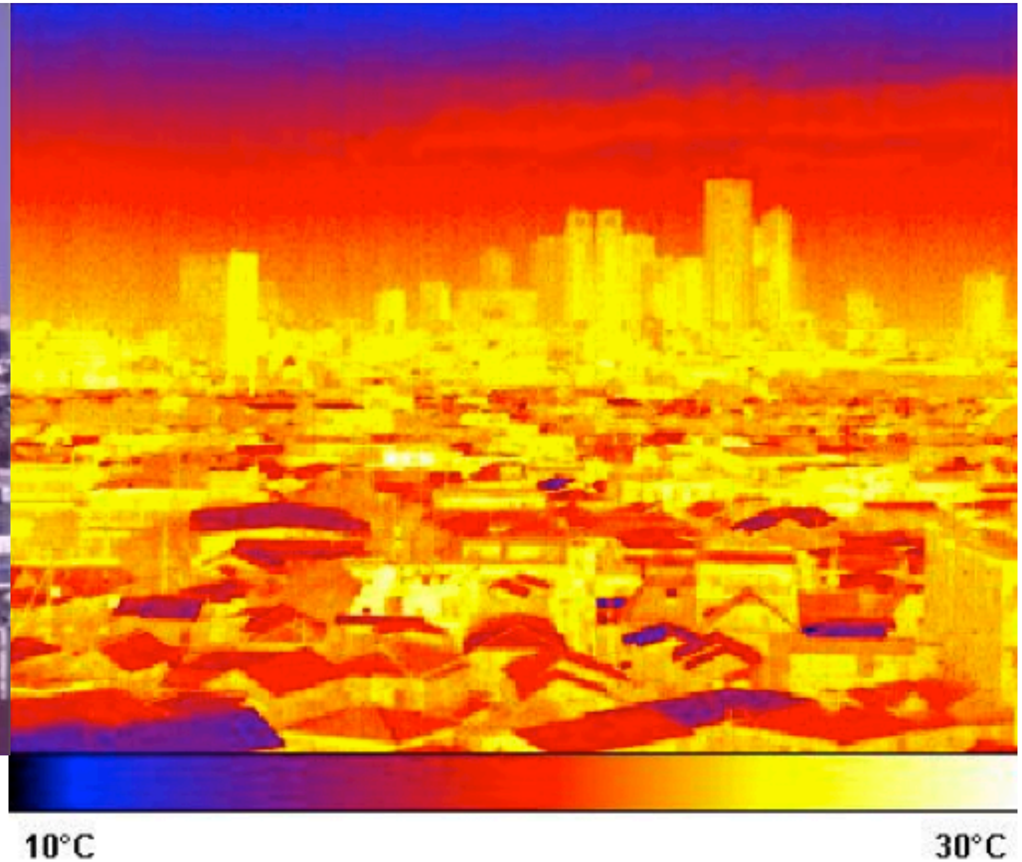
What is the result of

- extra heat sources
- relative dryness (reduced evaporation)
- shelter in the streets (reduced convection)
- obstructed horizon (less free to radiate heat away)
- multiple reflection between walls (better absorption)
- thermal inertia (the city warms and cools more slowly)
- greenhouse effect of pollution

?

Urban heat island

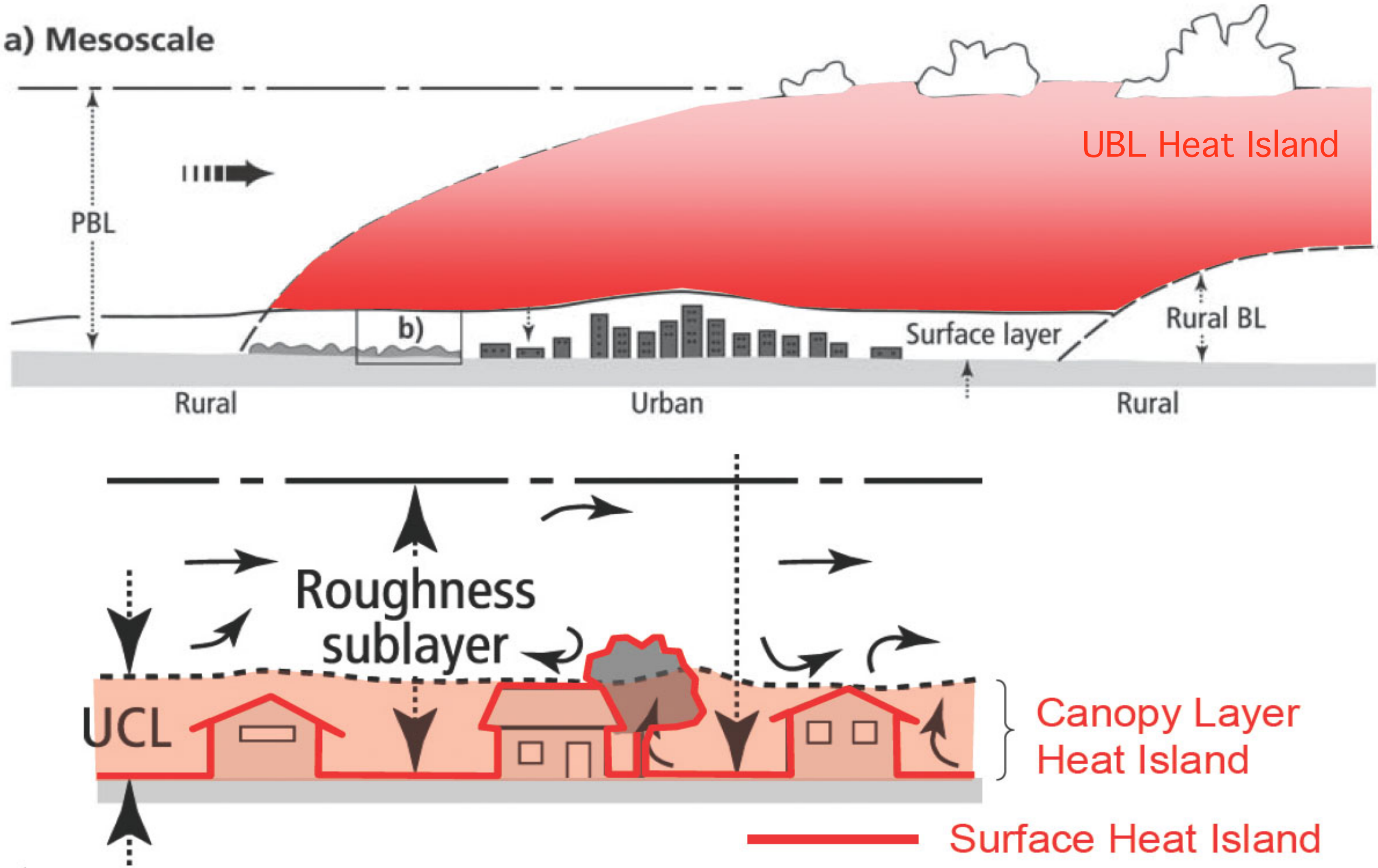
Temperature difference between city core and undeveloped surroundings with consequences for human comfort and productivity, biological activity (diseases, biodiversity, etc); most pronounced at night during calm and clear conditions.



Early October 1998 during late afternoon

J Voogt (UWO) and M Roth (NUS)

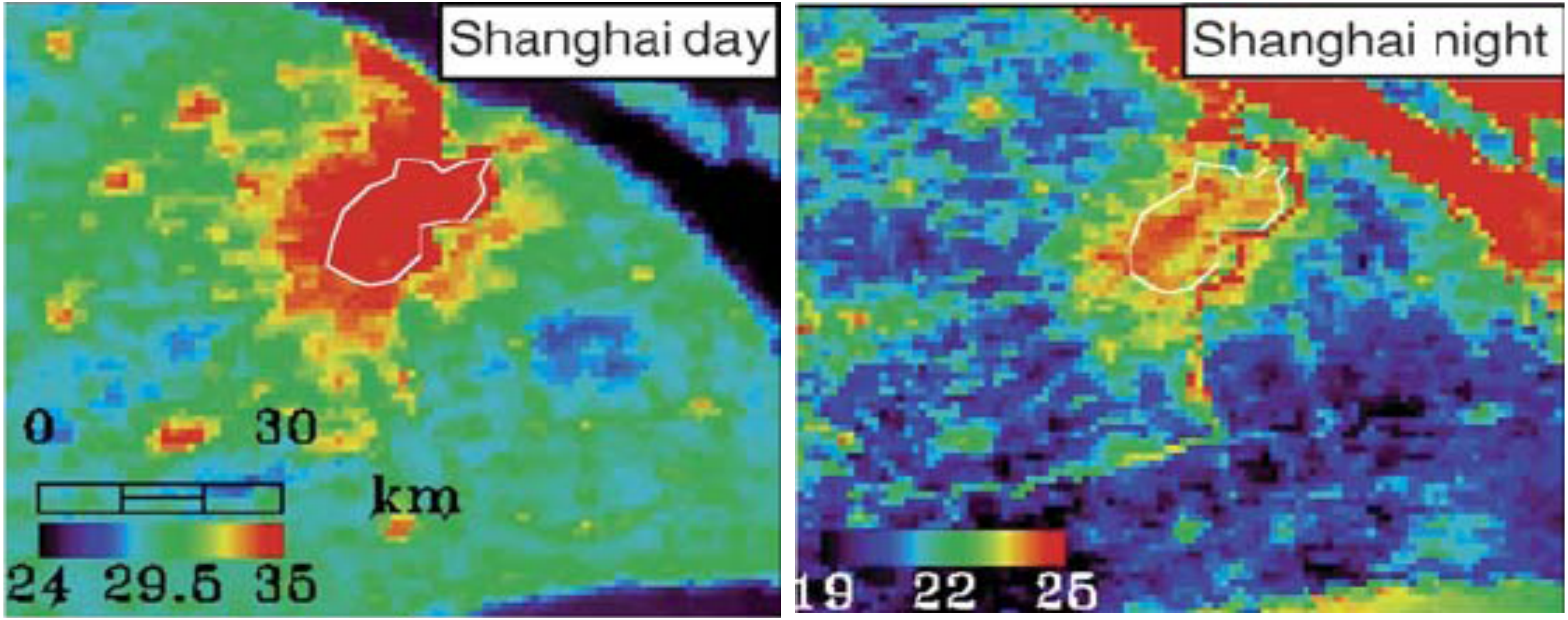
Three types of heat islands



(Voogt: http://www.epa.gov/hiri/index.html)

Surface temperature UHI

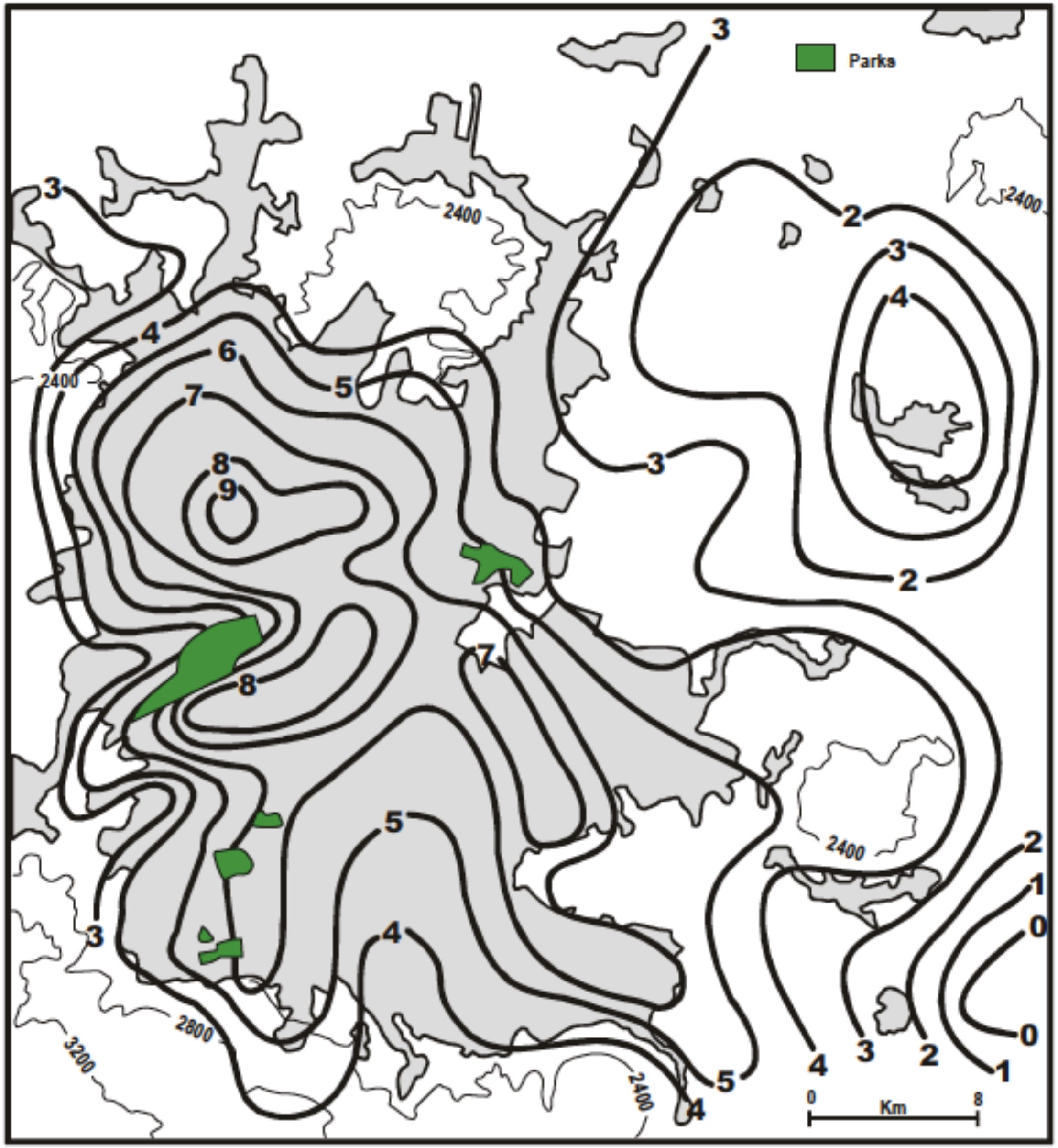
TERRA /MODIS 1 km imagery from 2001; day (10:30), night (21:30):



UHI magnitude is higher during daytime compared to nighttime

(Hung *et al*, 2006)

Canopy layer (air temperature) UHI

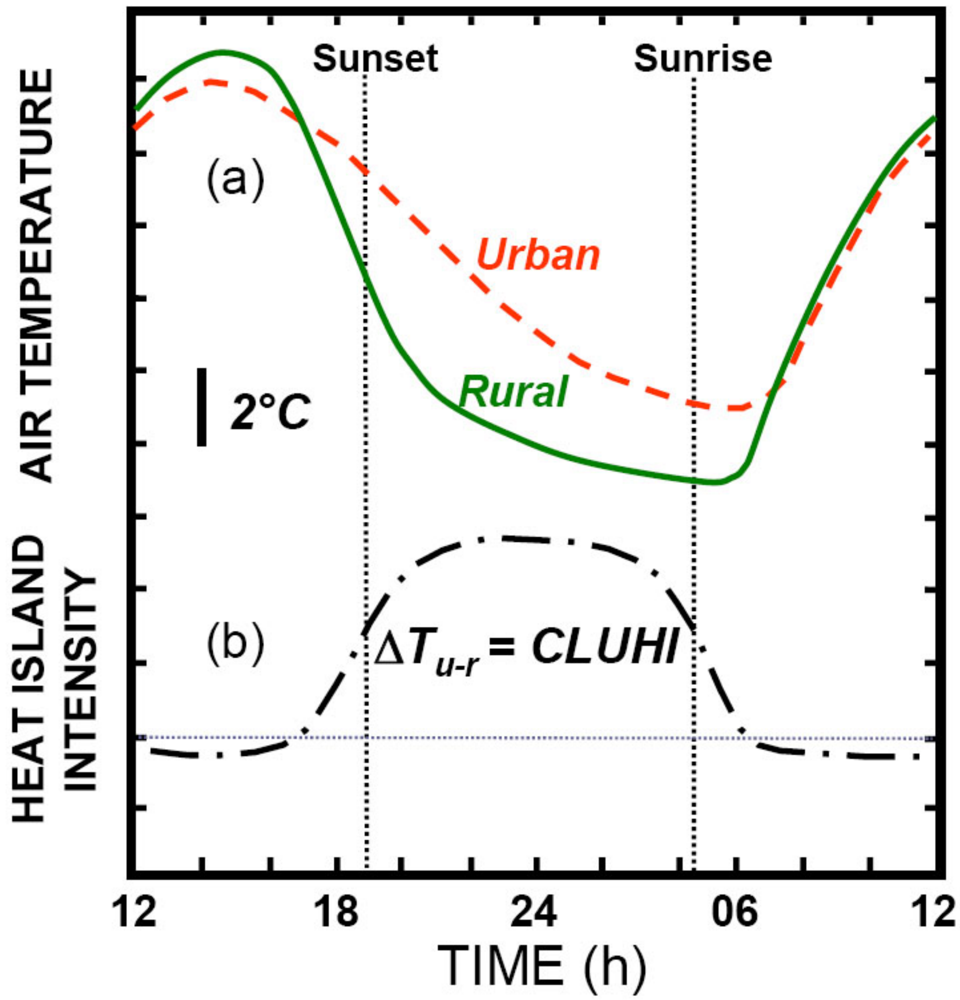


Mean minimum air temperature (nocturnal) for November 1981 in Mexico City

(Redrawn from Jauregui 1986)

UHI genesis

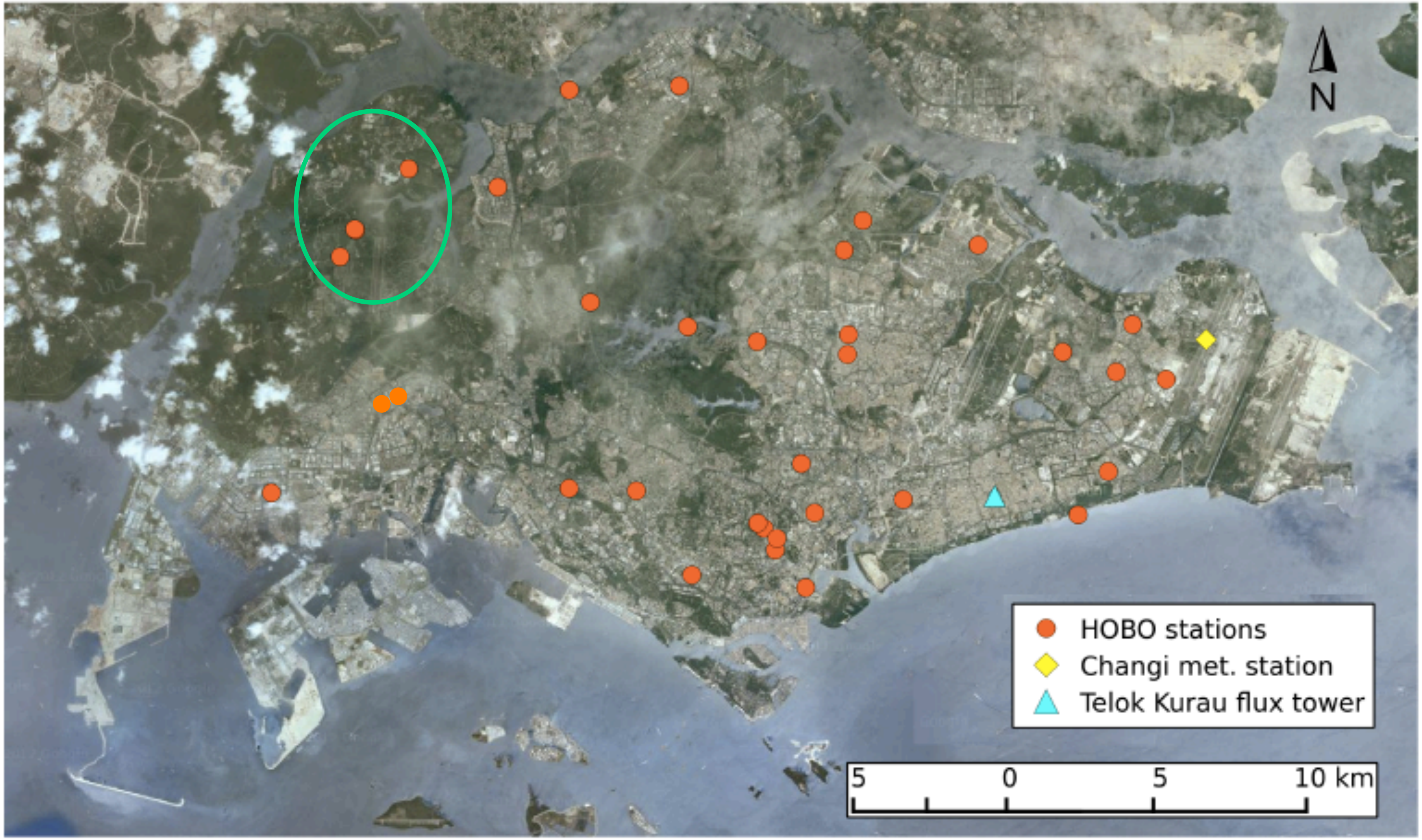
UHI forms in the air due to a difference in the cooling between urban and rural areas. Maximum cooling differential is achieved during clear and calm conditions.



(Oke 1982)

Canopy layer UHI in Singapore

~40 HOBO sensors between 2008-2014 (~2 m)



Li (2013)

69D
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669B


SFQ5628X
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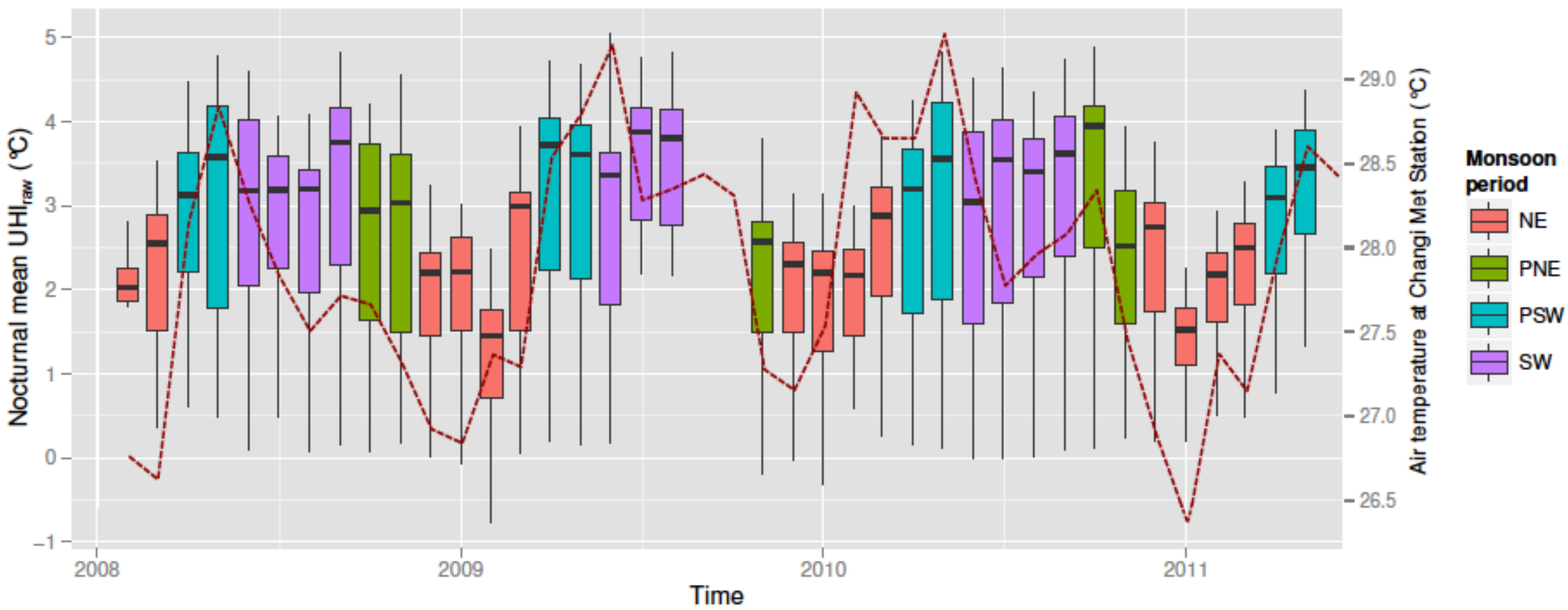
Seasonal variability of canopy layer UHI, Singapore

Boxplot of mean monthly nocturnal (19:00-07:00) UHI_{raw} for all stations and meteorological conditions (2008-2011):

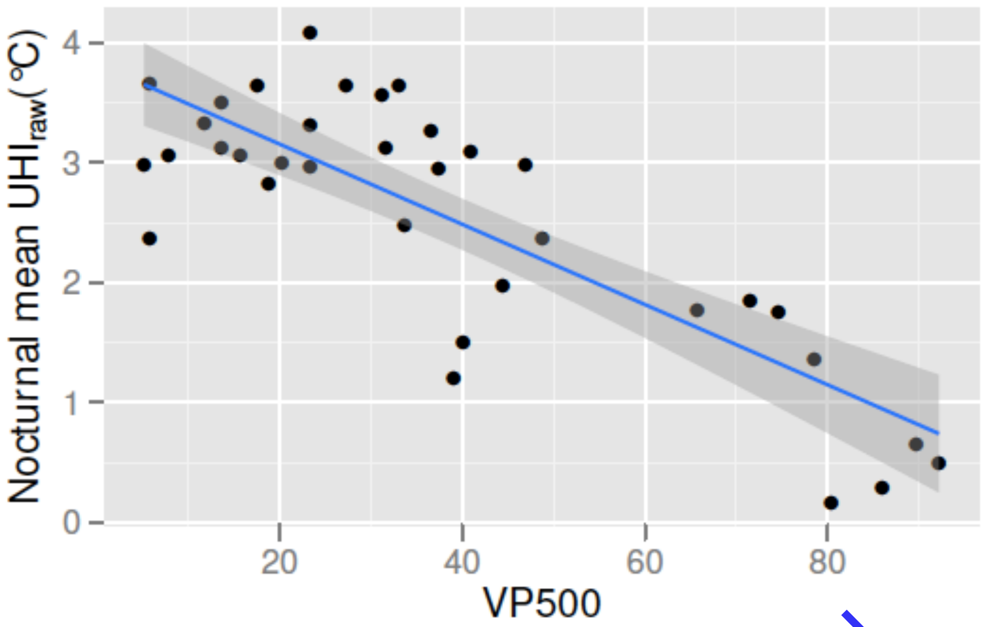


(Li 2013)

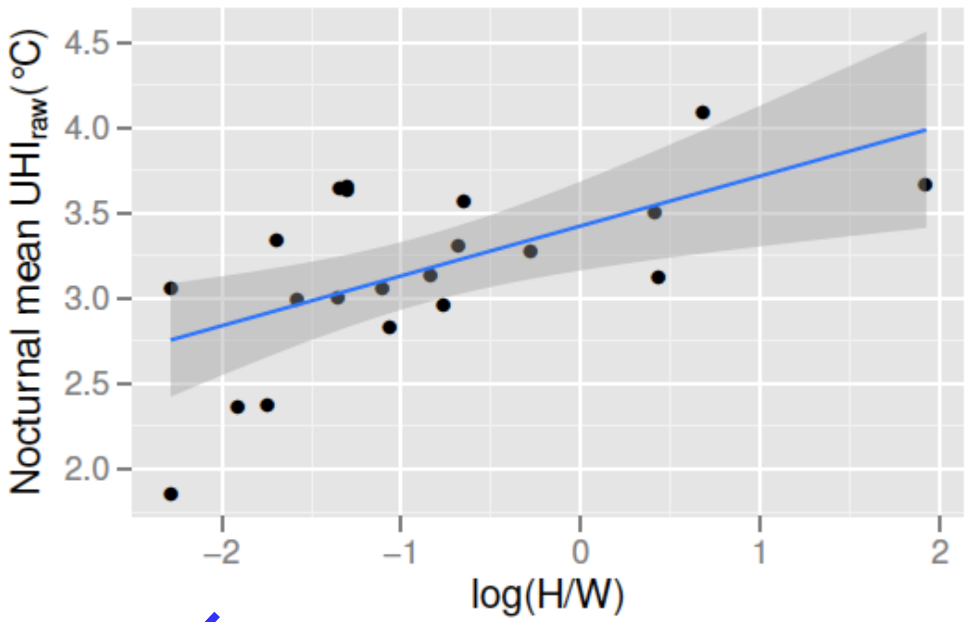
Statistical model to predict canopy layer UHI, Singapore

Regression curves for nocturnal mean UHI_{raw} against % vegetation and log of height-width (H/W) ratio for 500 m radius:

Land cover (from Google Earth and RS)

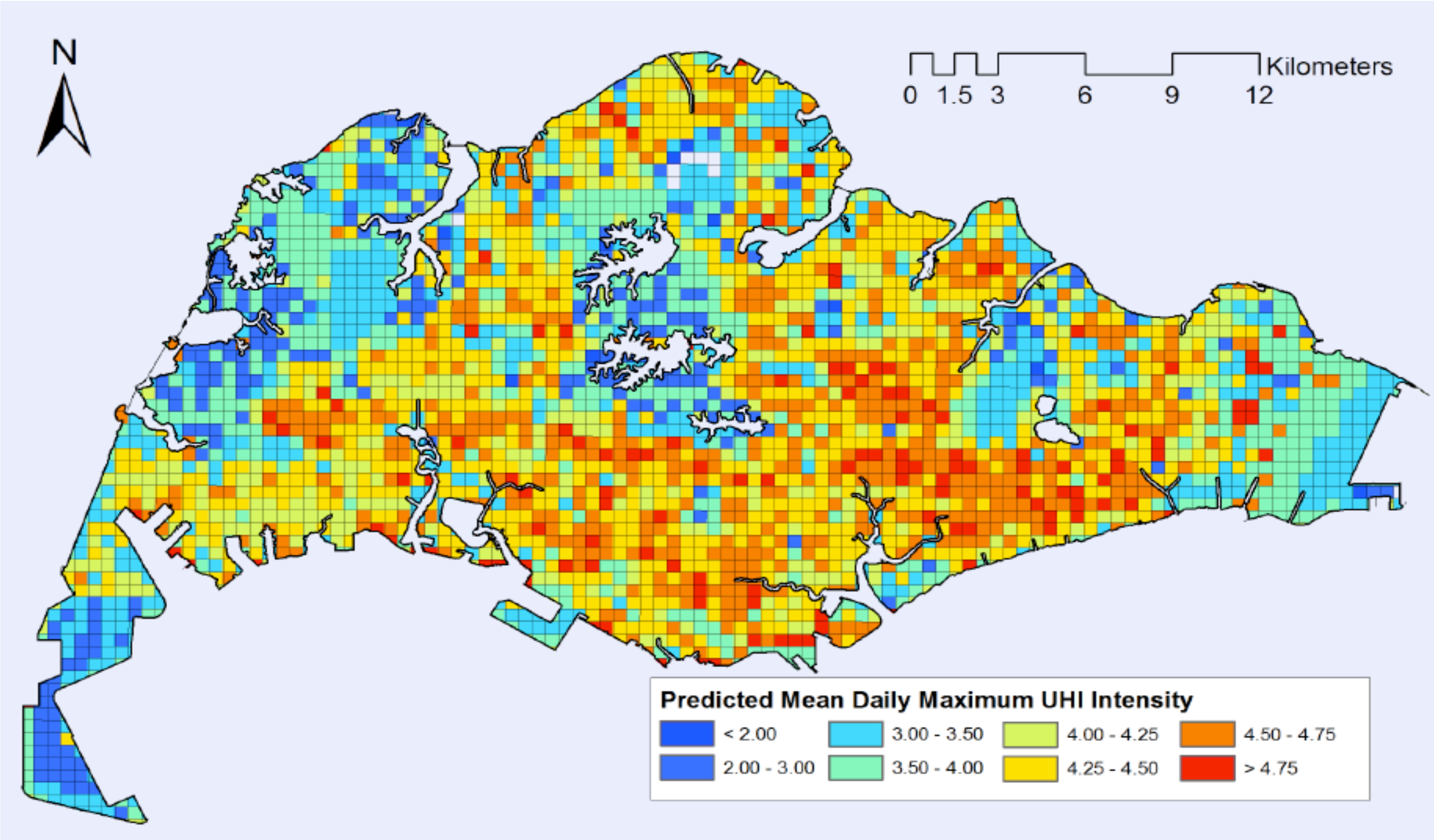


Geometry (Building plans, field visits)



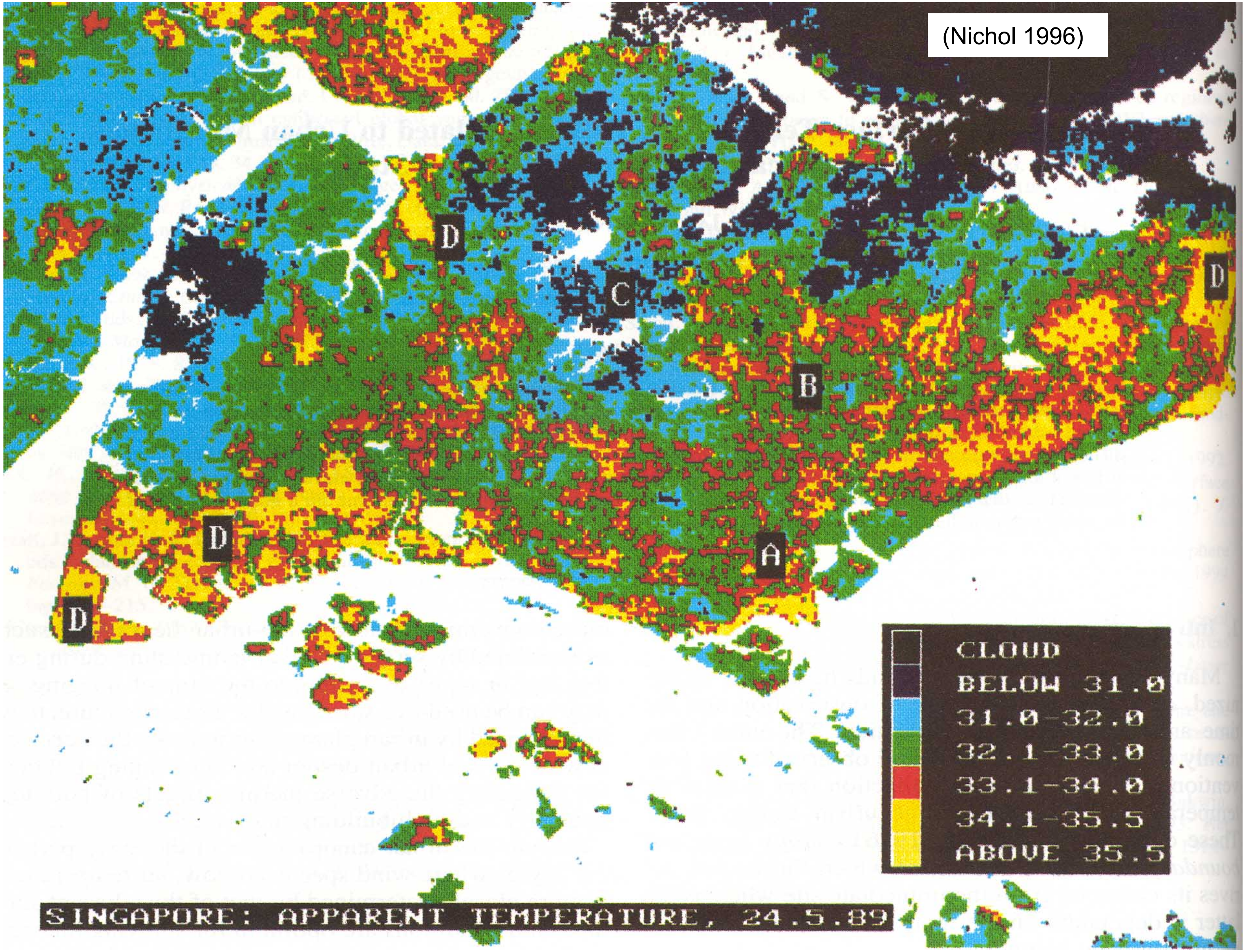
(Li and Roth 2009, Li 2013)

Canopy layer UHI map, Singapore (05/2008, 02:50 hrs)

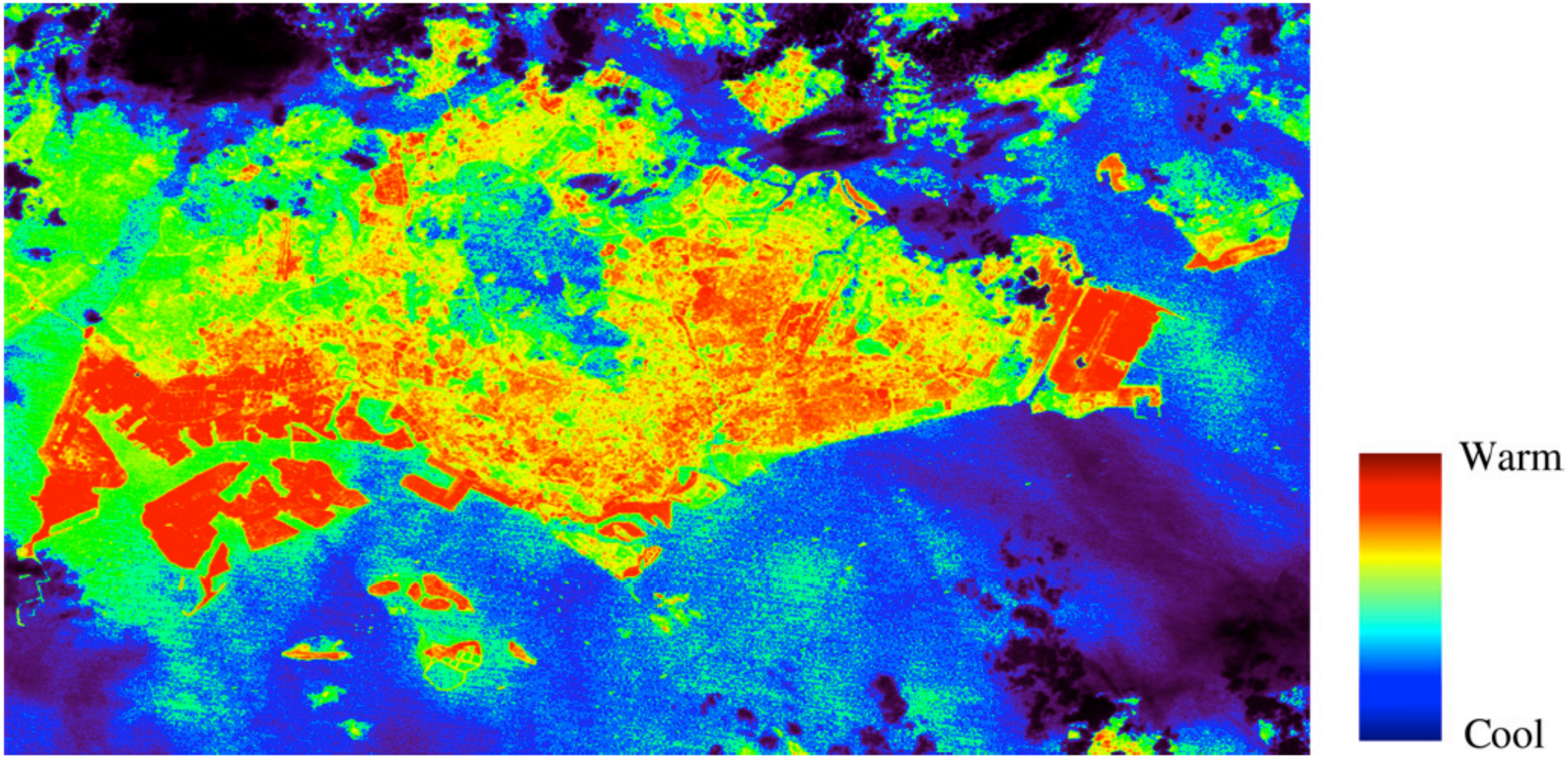


(Li and Roth 2007, unpublished)

Form of surface temperature UHI, Singapore (24/05/1989, 09:40 hrs)

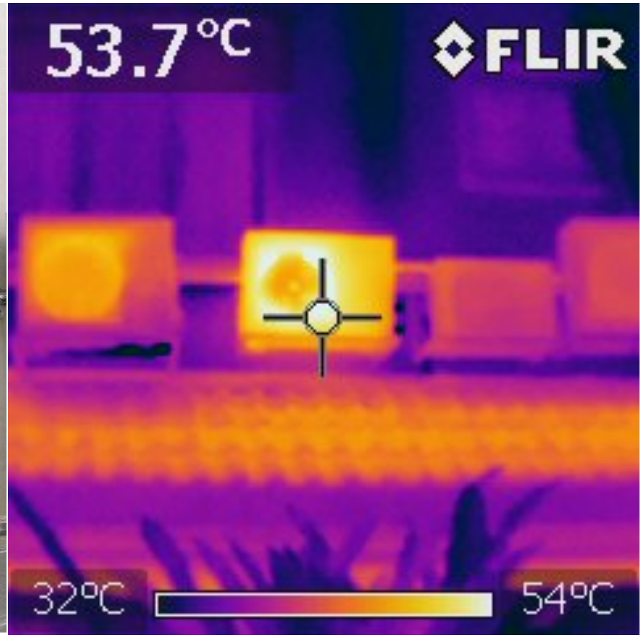


Form of surface temperature UHI, Singapore (11/10/2002, 10:09 hrs)

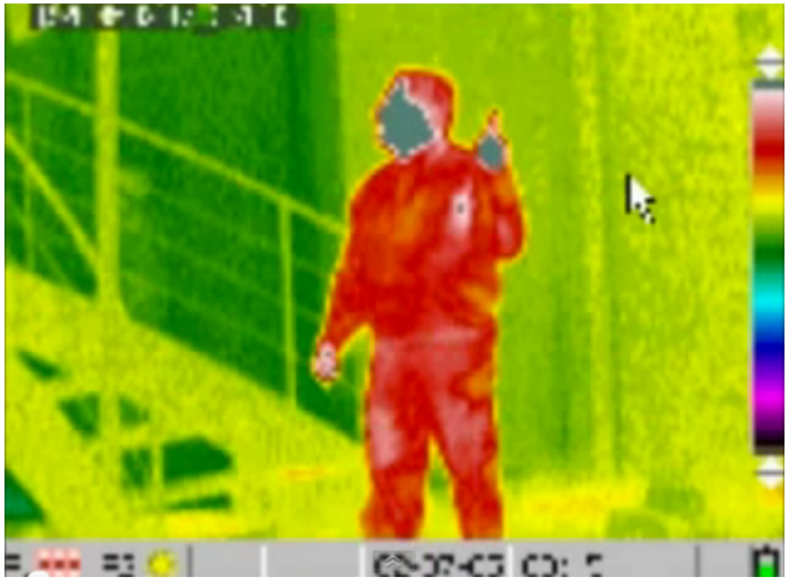


(Priyadarsini *et al.* 2008)

Anthropogenic heat

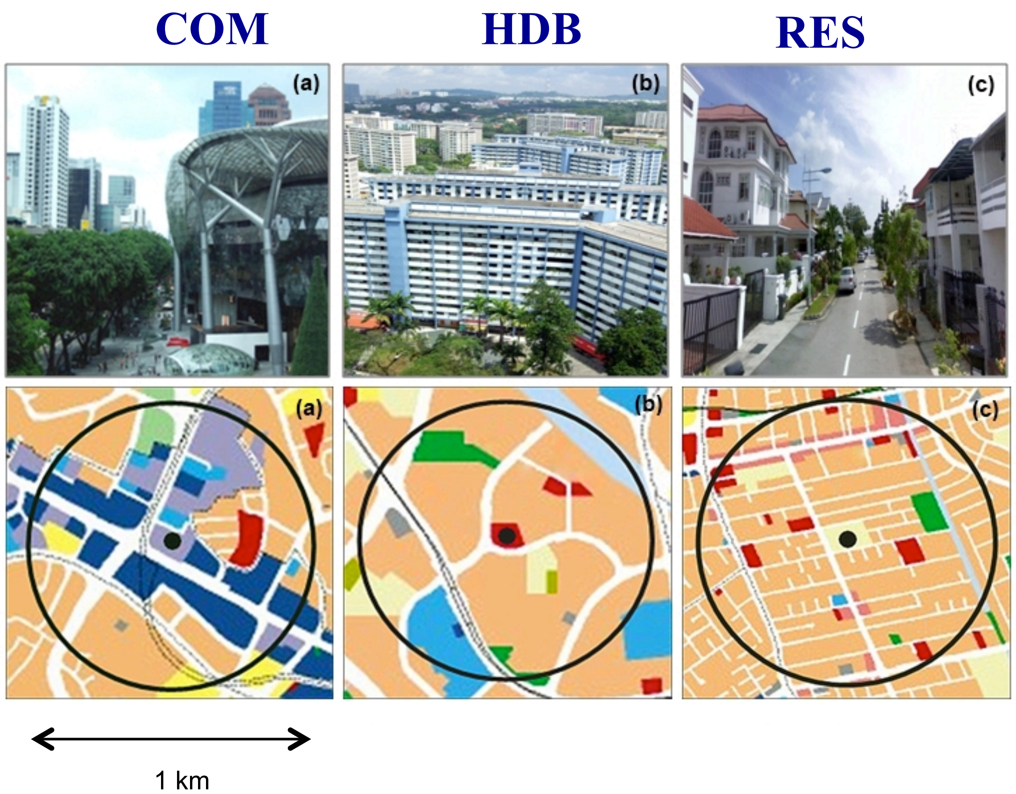


$$Q_F = Q_B + Q_V + Q_M$$

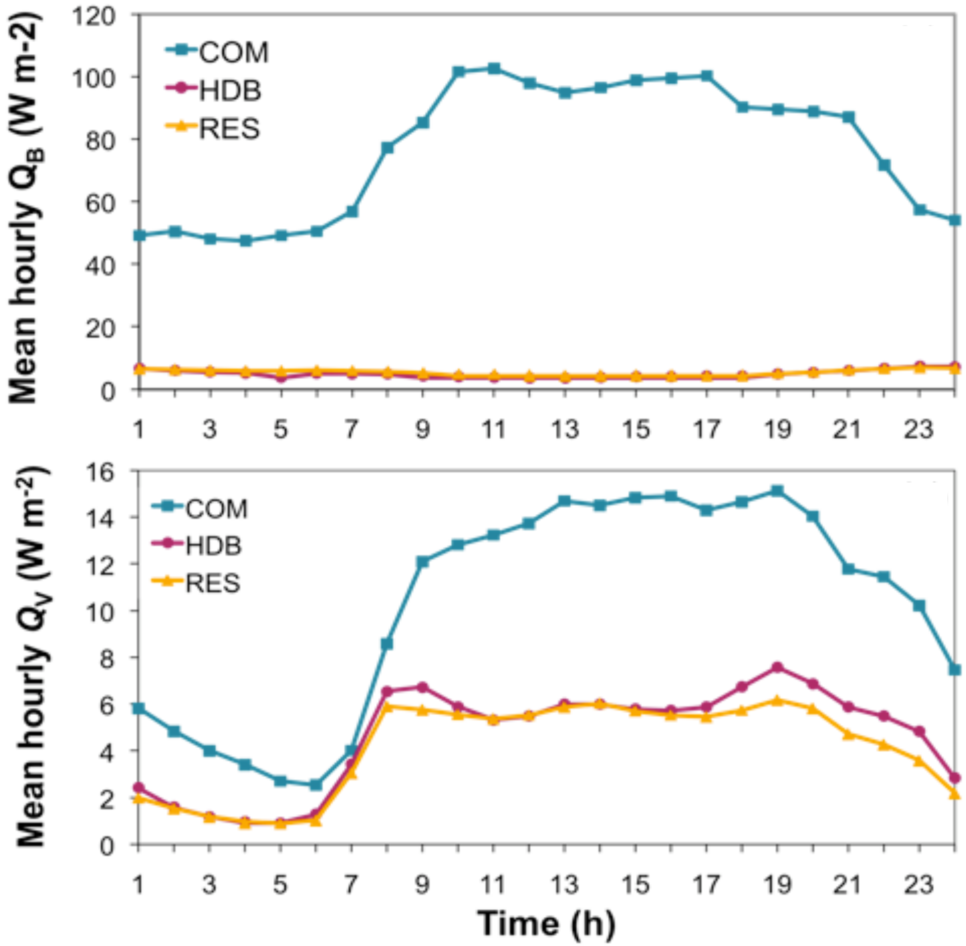


Diurnal variability of Q_F, Singapore (annual)

Three distinct urban land uses:

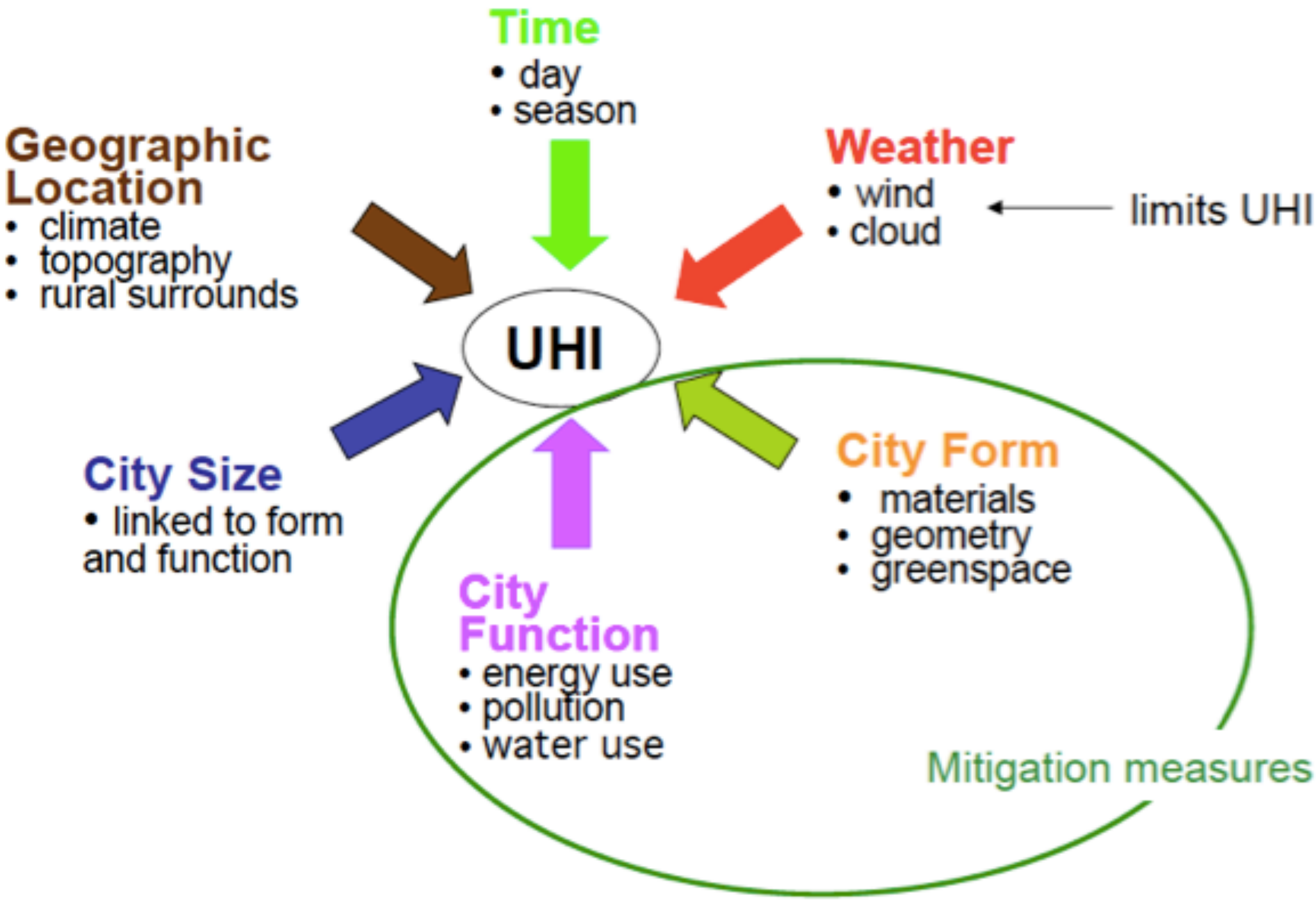


Excluding Q_M which is < 10% of total:



(Quah and Roth 2012)

Cities as solutions: Climate-sensitive urban design



(Oke, pers communication)

Cities as solutions: Climate-sensitive urban design


Fukuoka City Hall (Japan)

Hong Kong


Arcadia Garden (Singapore)


SOTA (Singapore)

Cities as solutions: Climate-sensitive urban design

Before (1968-2003)

After (>2005)

Restoration of a Cheong-gye stream in Seoul, Korea: 8.4 km long recreation space

(Kim 2005)

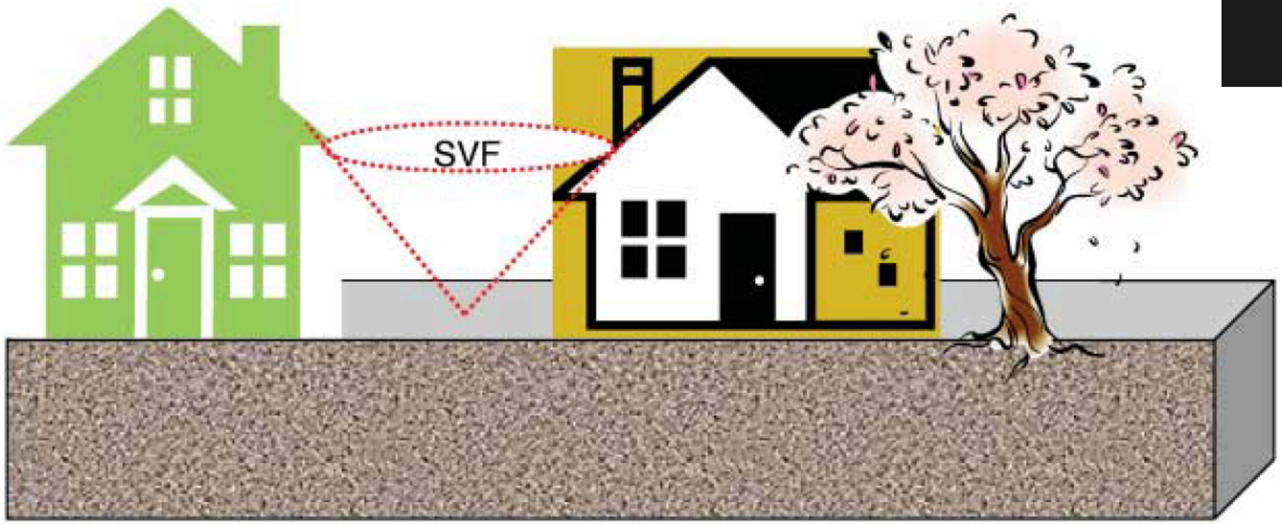
Mitigation

Basis of most mitigation measures informed by cause of UHI:

- ❑Provide shade and shelter (trees, overhangs, narrow spaces)
- ❑Ensure high reflection or emission of radiation (light surfaces increase albedo, wide spaces promote emission of heat radiation)
- ❑Good or poor heat storage (thick walls, roof insulation)
- ❑Surface moisture (water, vegetation, permeable covers) for evaporative cooling. Co-benefits:
  - Green roofs – also cool rooftop surface through shading and improve building energy performance by adding an additional layer of insulation
  - Trees – also provide shade
  - Porous pavements – also reduce runoff

Role of urban geometry on UHI

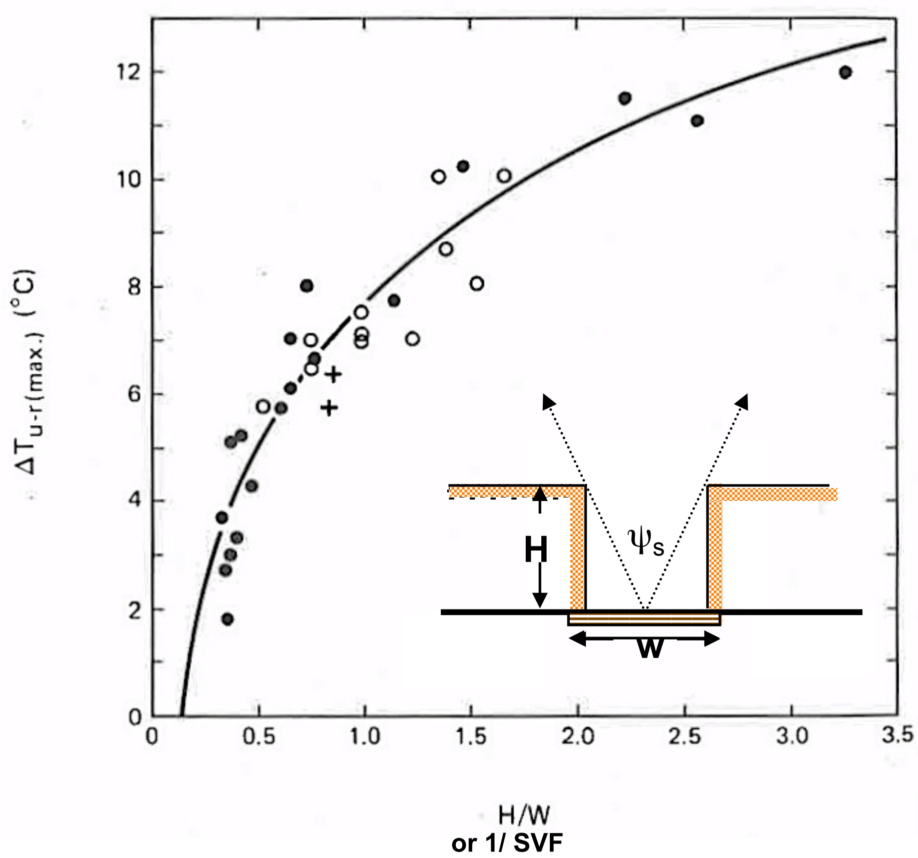
The sky view factor (SVF) – a commonly used measure to quantify the openness of a site has important implications for incoming and outgoing radiation and thus heating and cooling patterns.



(Grimmond 2007)

Role of urban geometry on UHI

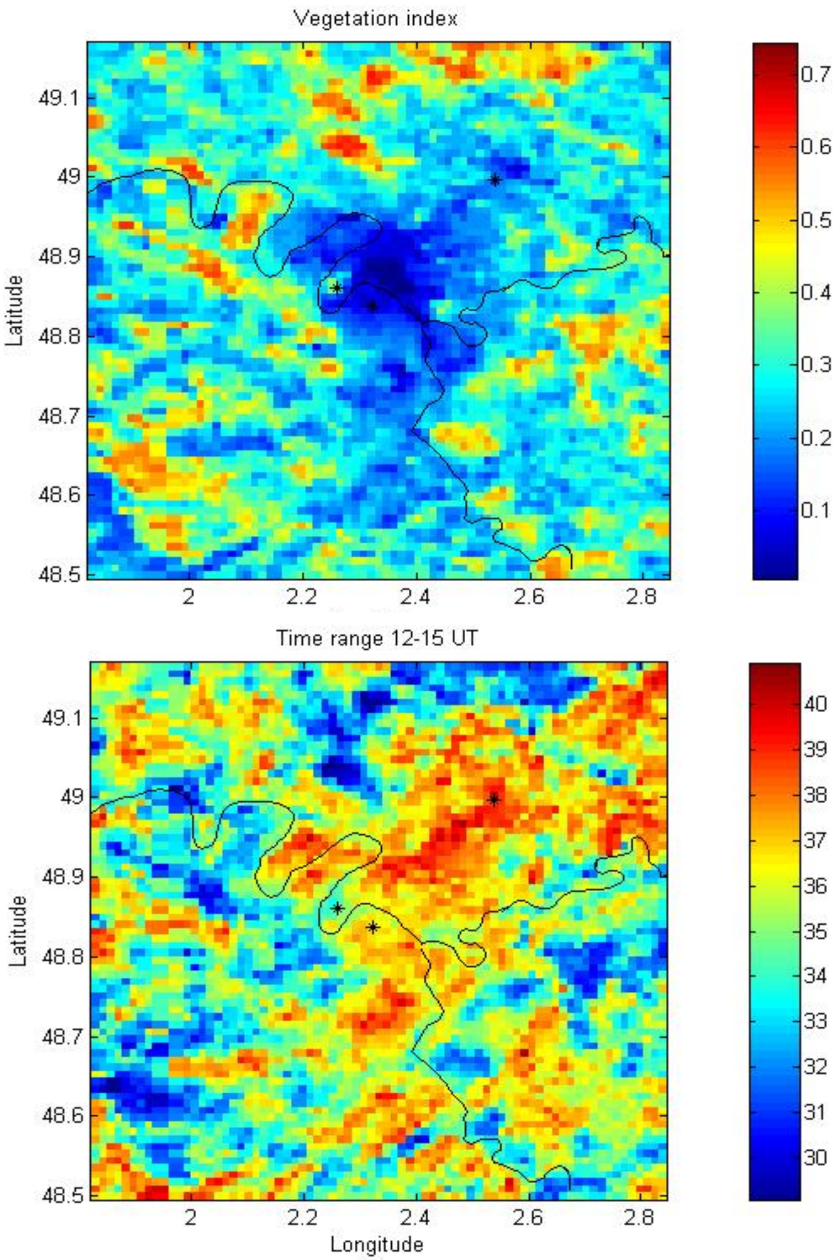
Influence of increasing density (expressed through H/W ratio or SVF) on UHI:



- Influences trapping of incoming solar and outgoing thermal radiation (UHI)
- Reduces wind speed; wind shelter (turbulent transport)
- Is associated with decreasing greenspace and more massive buildings (thermal properties of materials)

(Oke 1981, 1987)

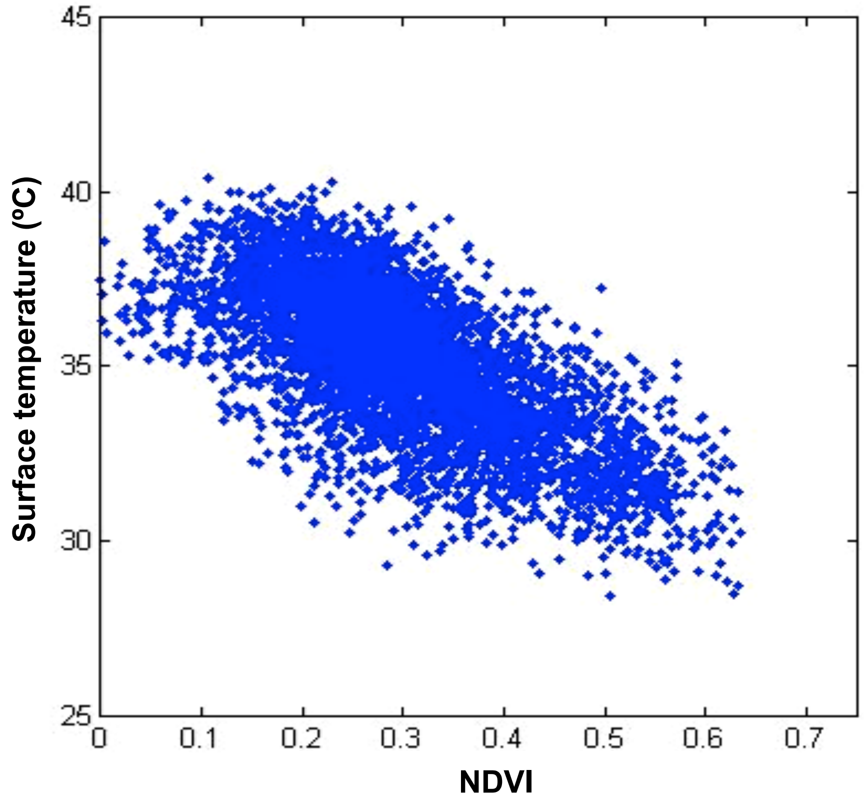
Role of vegetation on UHI



Vegetation Index

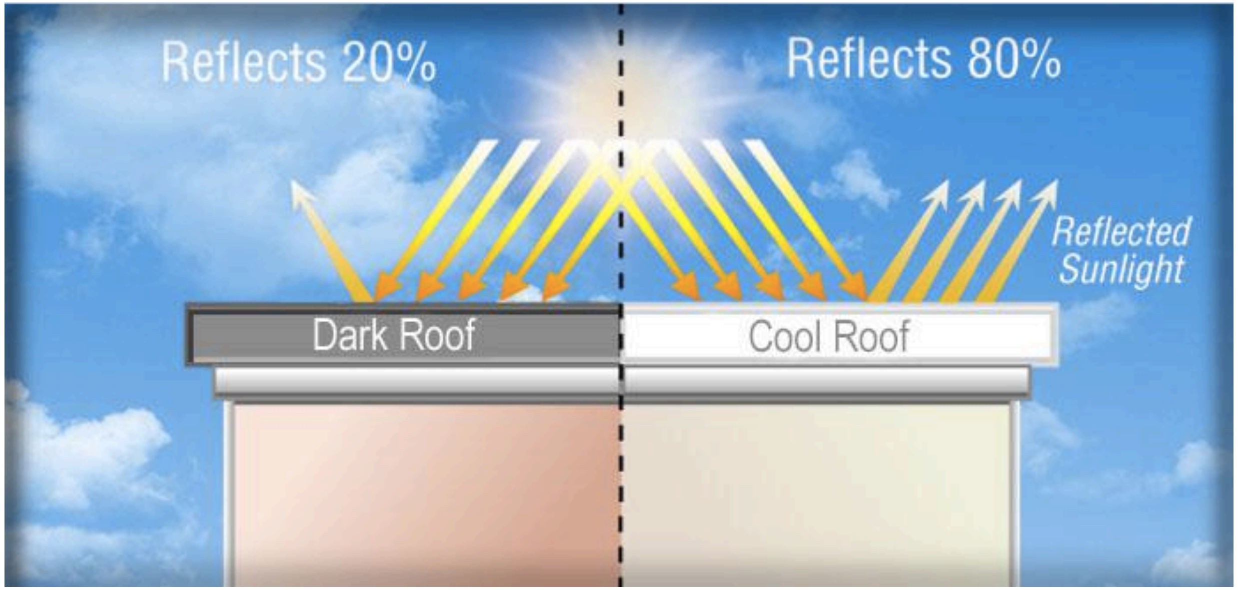
Surface temperature

Afternoon surface temperature *vs* greenspace for Paris:

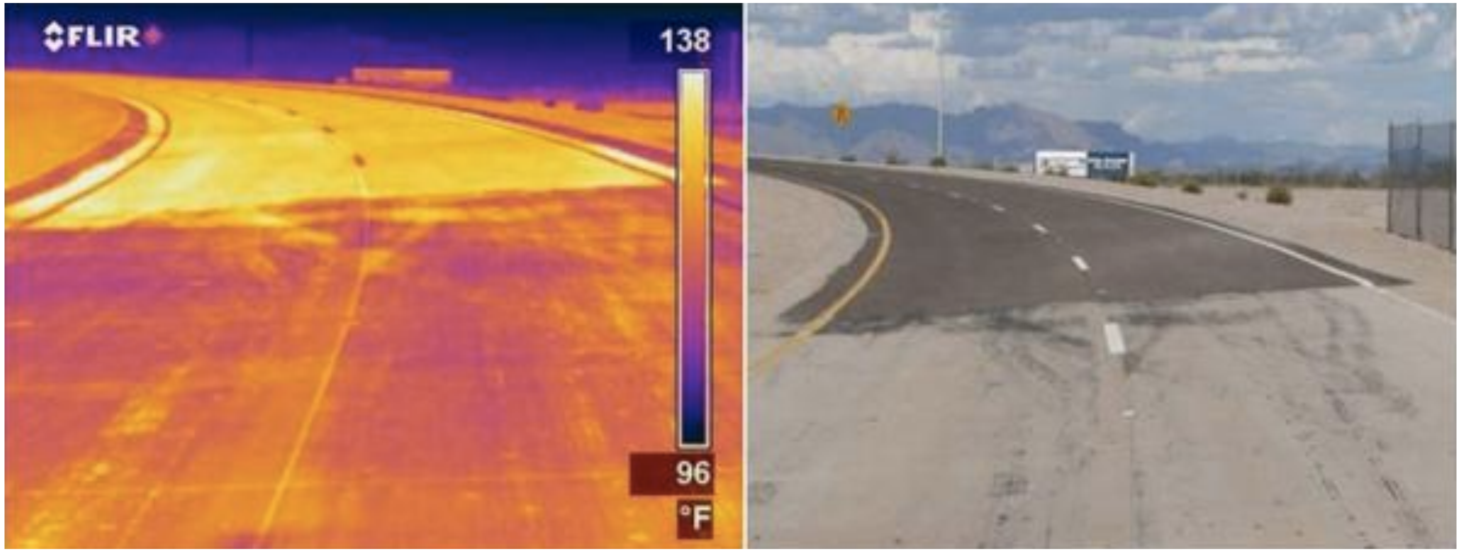


(Dousset 2007)

Cools roofs and pavements



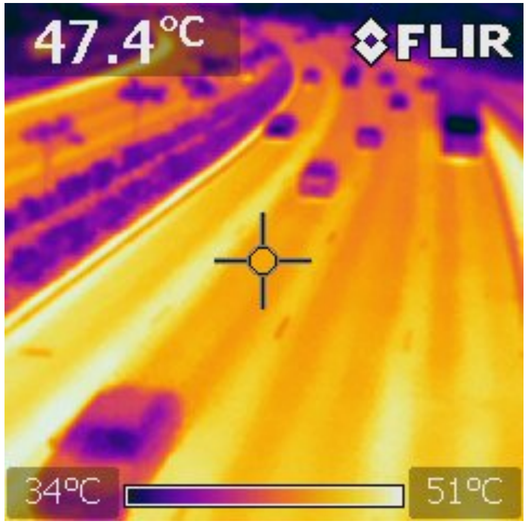
White roof reflecting 80% of sunlight will stay ~30 ºC cooler than grey roof reflecting only 20%.

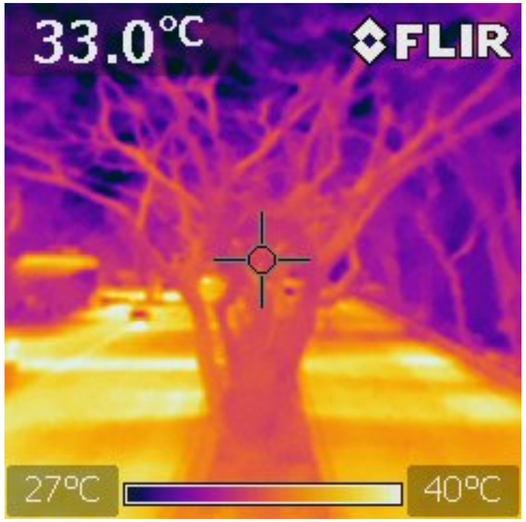


Light segment (bottom) is about 17°C cooler than dark segment (top)

(http://heatisland.lbl.gov/)

20-40% of urban surfaces are used as roads, parking lots, etc





Climate-sensitive building design in humid tropics

Which residents have a lower energy bill?

“New” is not always better!

Climate-sensitive building design in humid tropics

(i) Reduce direct solar insolation through e.g. window recess, eaves, proper building orientation, shading by trees

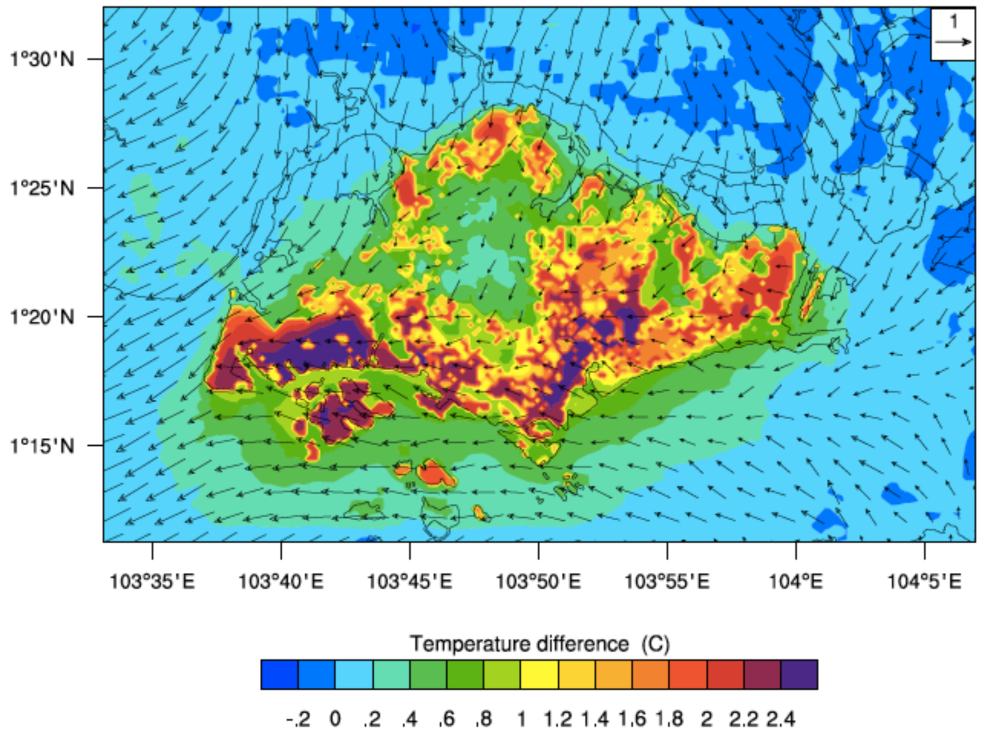
(ii) Maximize ventilation through e.g. taking advantage of prevailing winds /breezes, plenty of openings/windows, minimize blockage from nearby buildings, allow for ground level ventilation (e.g. void decks of HDBs)

(iii) Use ight building materials and reflective roofs

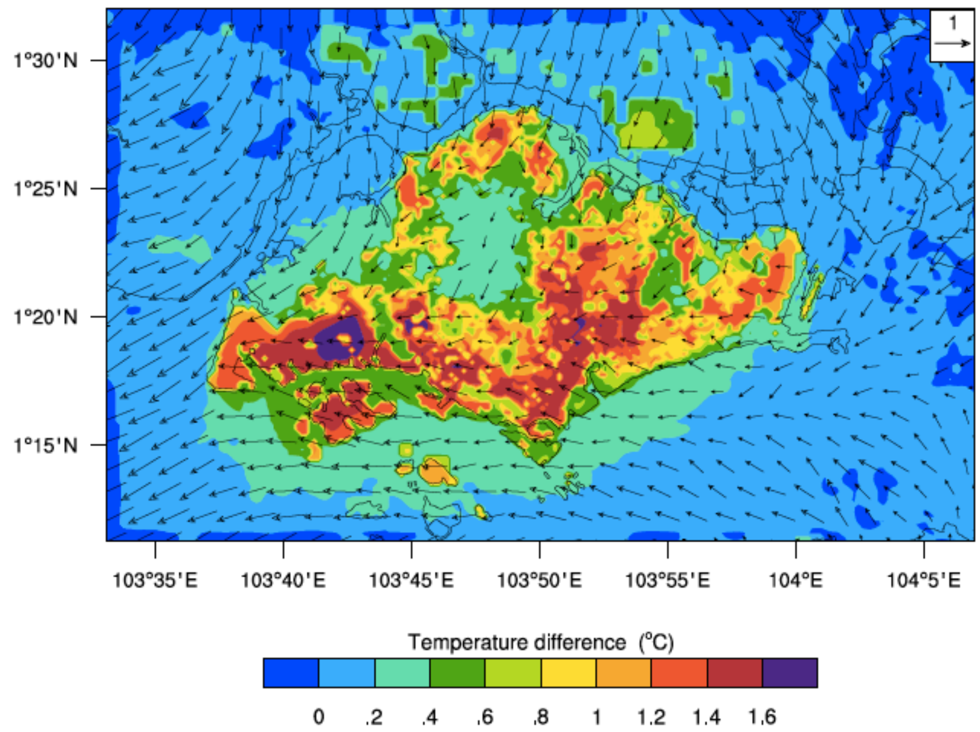
Challenge: How to upscale from individual building to dwellings for the masses

Predictive regional scale urban climate modeling: WRF with UCM

UHI difference (2 m) due to urban land use and Q_F at 4:00 AM



UHI difference (2 m) due to Q_F only at 4:00 AM



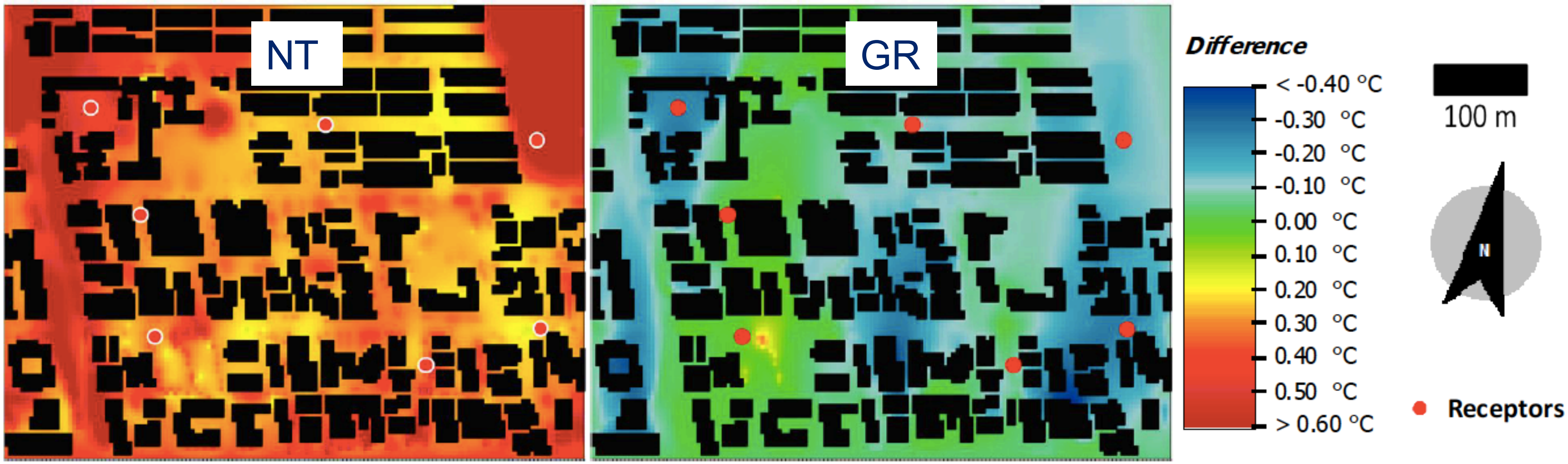
(Li *et al*, 2013)

Predictive neigborhood scale urban climate modeling: ENVImet

Influence on 2 m air temperature at 14:00 LT in residential area of Singapore:

NT = removing all trees (-8%)

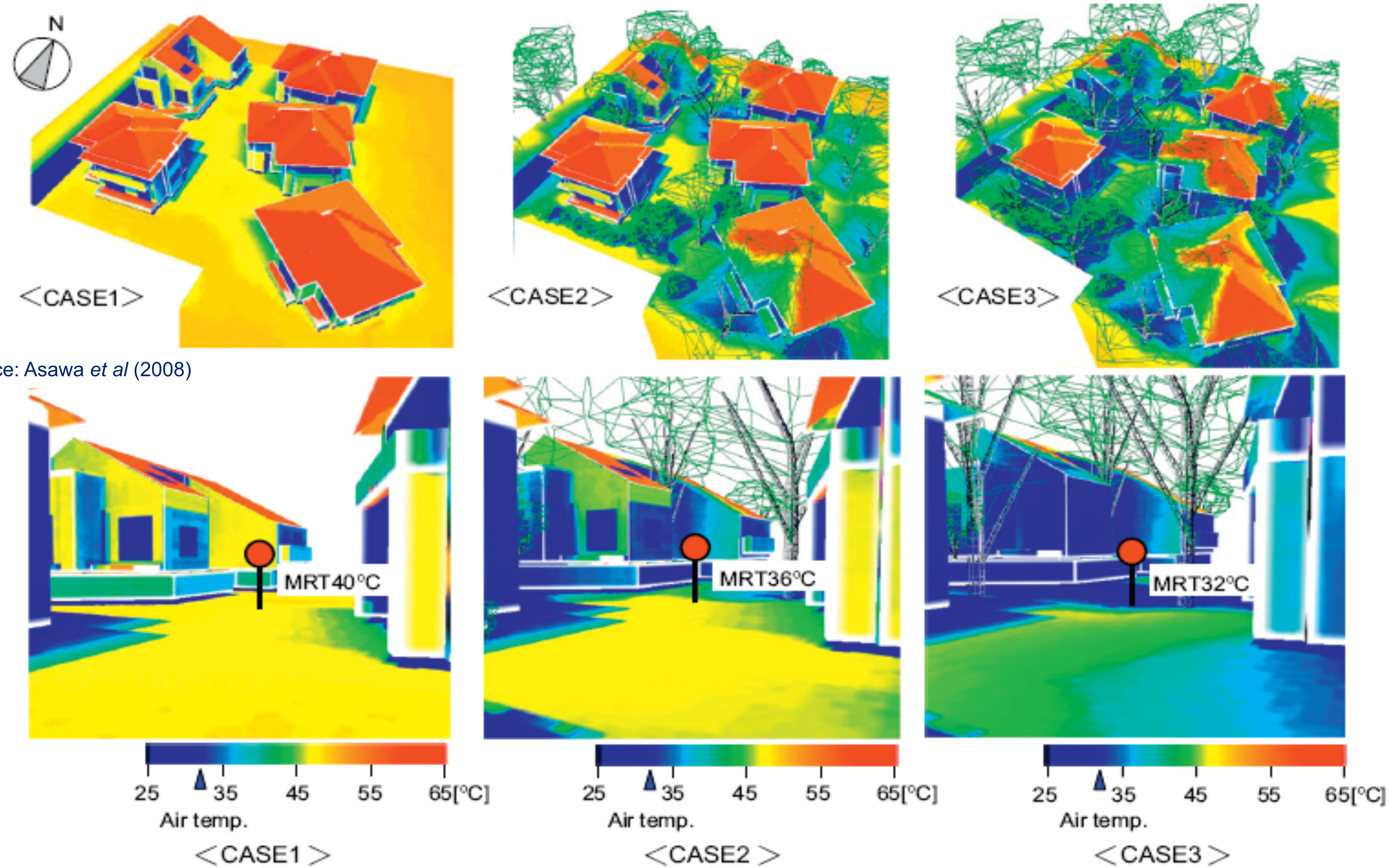
GR = implementing green roofs (+47%)



(Lim and Roth, in progress)

Predictive microscale urban climate modeling

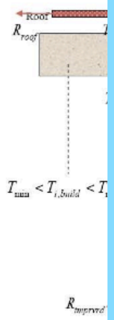
Surface temperature and human comfort (noon, clear summer day)



Source: Asawa *et al* (2008)

Challenges

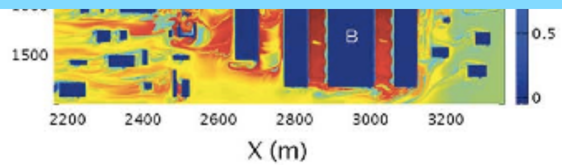
How to get from here……………..……… to…………………..………… there

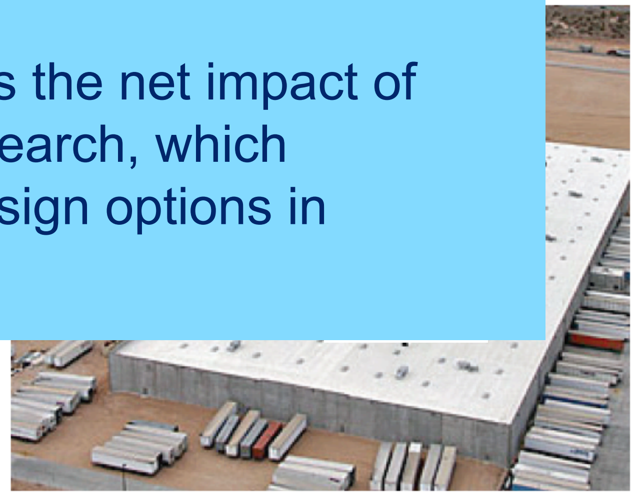


- Where there has been intervention, it would be especially valuable to have 'before' and 'after' data to illustrate the benefit of intervention. Unfortunately, such data are rarely available.

- Communication: Too little climate knowledge is accessible. There is a need to codify knowledge of urban climates. This would provide clear guidelines for interventions that are compatible with achieving climate goals (at whatever scale). These guidelines need to be accessible and supported by relevant case studies.

- This requires urban climate knowledge that identifies the net impact of planning interventions. Traditionally, this type of research, which compares the effectiveness of different planning/design options in achieving a given outcome, has not been done.





Questions?