GLOBAL HEAT HEALTH
INFORMATION NETWORK

Part 5.1
Essential elements of urban climatology for understanding the urban heat island effect

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- Different types of urban heat islands and their spatio-temporal characteristics
- Most common observation approaches

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Different types of urban heat islands and their spatio-temporal characteristics

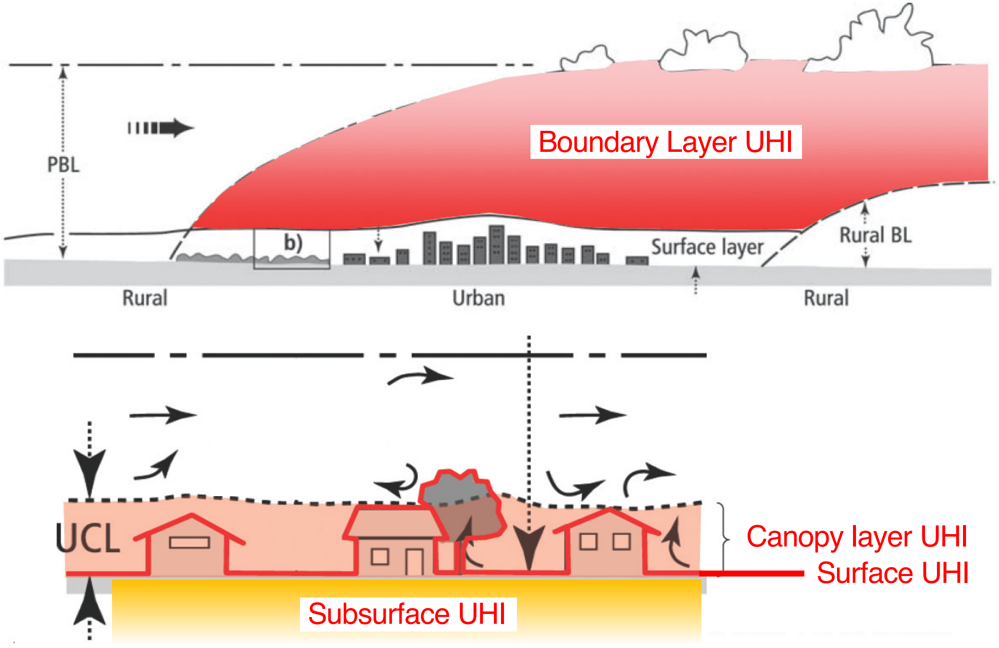
There is more than one UHI type!

- Subsurface UHI (SS-UHI)
  Local scale
- Surface UHI (S-UHI)
  Microscale
- Canopy layer UHI (CL-UHI)
  Local scale
- Boundary layer UHI (BL-UHI)
  Local and mesoscale

Term “heat island” derives from similarities between the spatial patterns of nighttime isotherms of T_a in UCL and height contours on topographic map.

Analogy works for SS, S and BL heat islands during day and night, but for CL heat island usually only for nighttime.

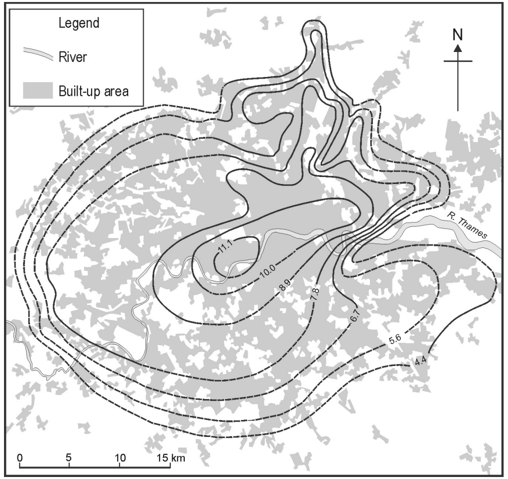
Source: after Oke *et al* (2017)



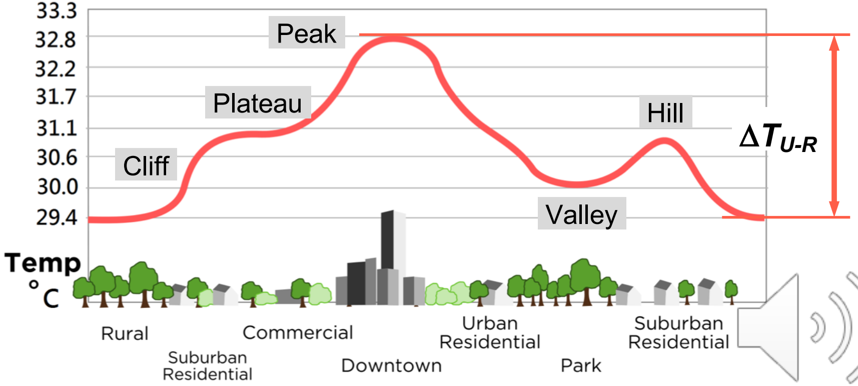
Four types of UHI. Source: after Voogt, US EPA. UCL – urban canopy
PBL – planetary boundary layer, BL – boundary layer

CL-UHI: spatial morphology under ideal conditions

- Most commonly studied type
- Every settlement has an UHI
- Close relationship between urban development and thermal pattern – unique pattern for every city
- All have cliff, plateau, hill, valley and peak features
- For any type, heat island magnitude is defined as the sustained maximum urban temperature, minus a representative temperature of the rural surroundings: $\Delta T_{U\text{-}R} = T_U - T_R$



Minimum temperature in London, UK, 14 May 1959 based on a network of stations. Source: re-drawn from Chandler (1965).



Schematic of a typical nighttime CL-UHI, with isotherms illustrating typical UHI features corresponding to degree of urban development. Source: Wikimedia Commons (2021)

CL-UHI: genesis and controls

- Heat island magnitude is driven by differential rates in urban warming and cooling

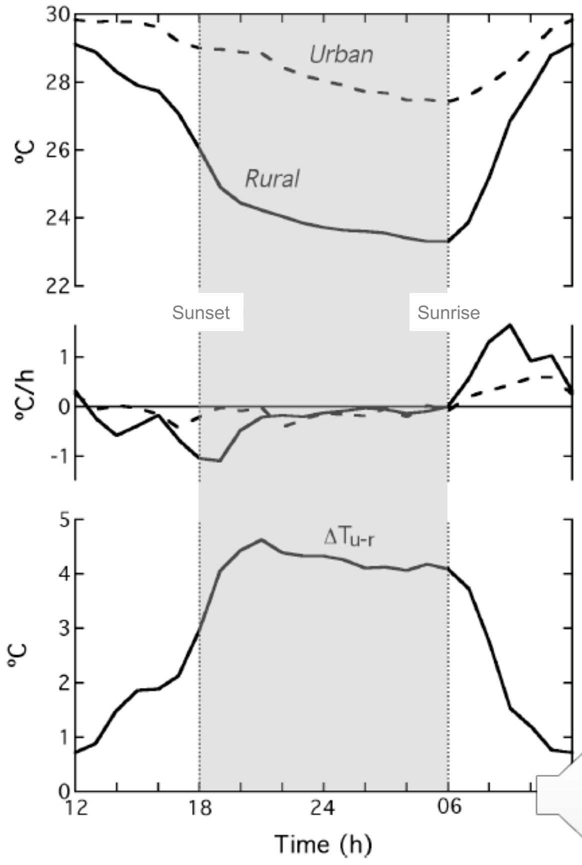
- Magnitude is controlled by season (daylength and antecedent moisture conditions), time of the day (day *vs* night) and weather (winds and clouds)

  - high windspeed reduces horizontal T_a gradients and increases turbulent transport of heat away from the surface

  - Cloud cover disproportionally affects rural cooling given the larger sky view

  - Rural moisture increase thermal admittance which reduces nighttime cooling

- Largest magnitudes likely occur on calm clear nights during the dry season



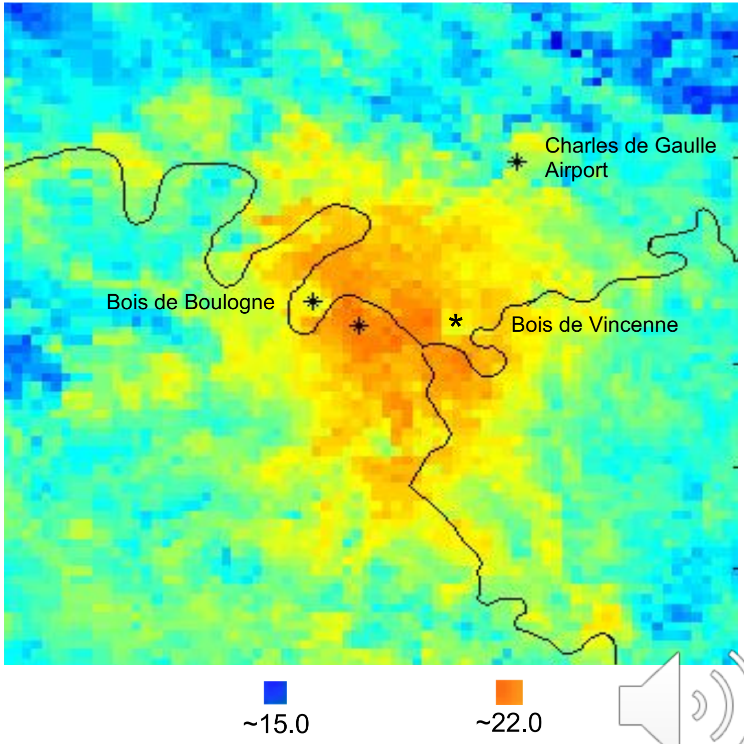
Measurements of diurnal variation of CL-UHI for (top) urban and rural air temperatures, (middle) urban and rural heating/cooling rates, and (bottom) derived UHI magnitudes for ~11 months during ideal weather (clear skies, light winds) in Singapore. Source: modified from Roth (2013).

S-UHI: spatial morphology under ideal conditions

Urban areas stand out from the surrounding landscape, both by day and night. Main characteristics include:

- consistently positive correlations between T_0 and impervious surface fraction, and strongly negative relations between T_0 and vegetated surface fraction
- daytime: hottest areas are light industrial, warehouses, transport infrastructure; heavily vegetated areas (especially with tree canopies) have lower daytime T_0; coolest are water bodies and well-watered vegetation
- nighttime: commercial and city center districts are warmest, roads remain warm; vegetated open parks with grass and well-watered vegetated surfaces are coolest

Paris, France



Thermal image of surface brightness temperature for Paris, France, at 03:27 UTC. Data from NOAA-AVHRR thermal IR scanner. Source: Dousset 2007 (pers communication); see also Dousset and Gourmelon (2003).

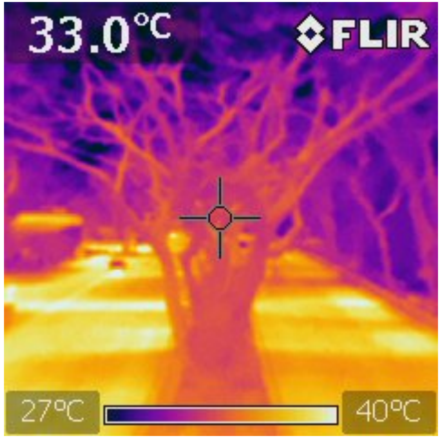
S-UHI: surface temperature controls

Depends of the following surface properties:

- geometric – orientation of facet, openness to sky and Sun
- radiative – albedo and emissivity
- thermal – thermal conductivity and heat capacity
- moisture – heat loss via latent heat flux
- aerodynamic - roughness

Endless mix of these properties in the urban context, hence spatial variability of surface temperature (T_0) is much higher than that of air temperature (T_a).

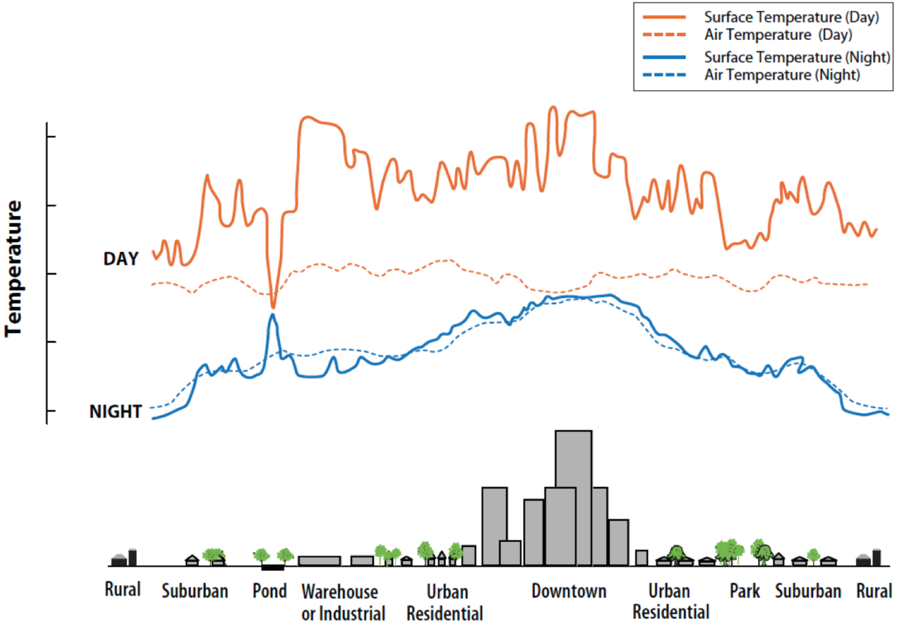
S-UHI is a microscale phenomenon, unlike the CL-UHI which represents the local scale.



(Top) photograph tree-lined street in Singapore, and (bottom) thermal image of same street on a cloudy afternoon (M Roth).

Difference between CL-UHI and S-UHI!

- Greater variability in surface temperature (T_0) compared to air temperature (T_a) in response to large variability in surface properties (especially during daytime).
- During daytime T_0 of all surface facets > T_a in UCL, except water bodies or wet surfaces; at night T_0 of roofs < T_a in UCL (e.g. industrial area).
- S-UHI represents an immediate temperature response at the scale of facets to inputs and outputs of energy.
- CL-UHI response is slower blending contributions of nearby surfaces + anthropogenic heat within the UCL + advected contributions from the neighbourhood.
- Satellite-derived S-UHI is often confused with the CL-UHI, but they measure different thermal responses at different scales!



2D cross-section of surface and air temperature along a rural-urban-rural transect for day- and nighttime, respectively. Source: US EPA (2008) adapted from Voogt (2002).

Observational approaches

Approach depends on UHI type; most work has been done on the S- and CL-UHIs heat islands:

- S-UHI: Two types: ’true’ 3D T_0 or ‘bird’s eye’ 2D T_0 (sensors on *eg* airplane, helicopter, satellite)

  - provides spatially continues measurements of T_0 across the city and hence is able to sample the vast range of urban facets and materials

  - depends on the timing of the satellite overpass, which may not coincide with the time of maximum heat island development or the time of desired application

  - sensors with near-nadir angles are biased to horizontal surfaces since they neglect *eg* ‘unseen’ surfaces underneath trees and/or vertical walls (2D)

  - complete (3D) surface temperature is key variable in modelling the urban energy exchange, building heat demand and thermal comfort

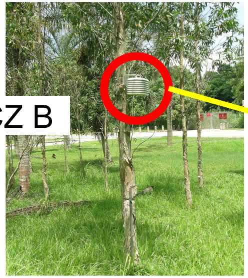
- CL-UHI: Fixed stations (at screen level): simplest way to measure CL-UHI over time on a routine basis; T_a can be measured in a weather screen or ventilated radiation shield, at one or more sites considered to be representative of urban and rural local climate zones (LCZs) (Stewart and Oke 2012).

  Traverse: Spatial surveys to monitor CL-UHI using a sensor mounted on a vehicle (car, train, bicycle); provides insight into small scale spatial variations.

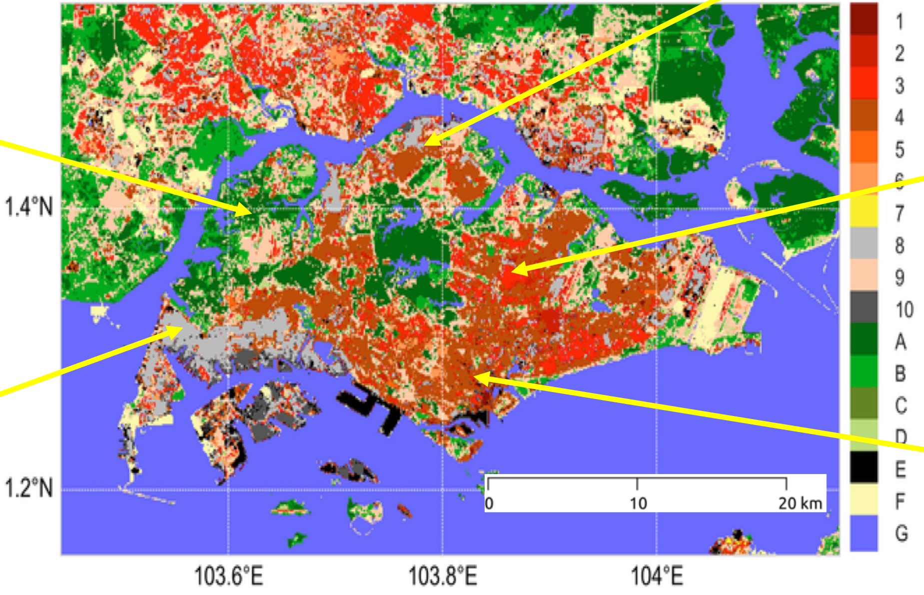
Observational approaches: CL-UHI

Fixed station approach using simple air temperature/relative humidity sensors housed in a naturally ventilated radiation shield deployed in representative urban and rural local climate zones (LCZs) in Singapore:

LCZ B



LCZ 8



LCZ 2

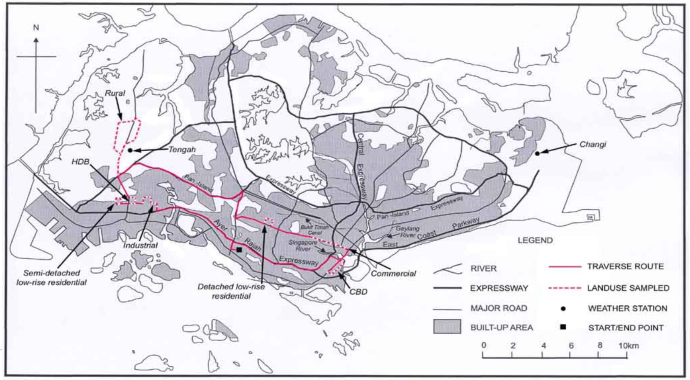
LCZ 3

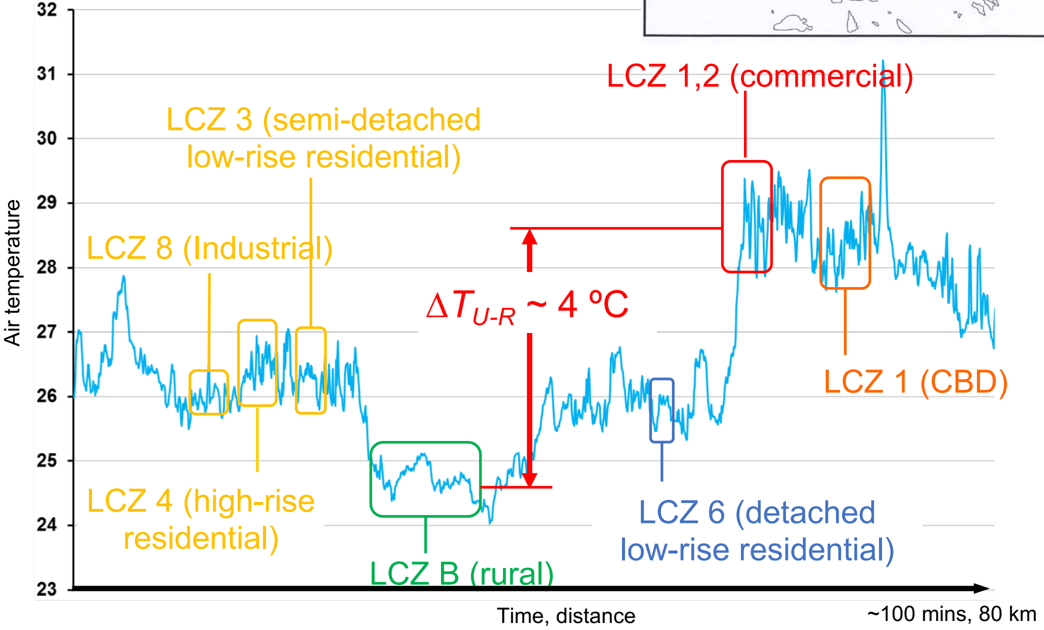
LCZ 1

Singapore local climate zone map. Source: Middle *et al* (2018, proofs); photographs by M Roth (unpublished)

Observational approaches: CL-UHI

Nighttime spatial variation of T_A on 14 March 2002 (21:00-23:00) from a car traverse in Singapore (M Roth, unpublished):





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Thank you for your attention!

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