Workshop on Earth Observation for Urban planning and Management
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Relationship between surface and air temperatures over Hong Kong on a winter night

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Outline

Part I – Teresa

- Devise a method computing the air temperature from a thermal image (surface temperature)
- Apply this methodology over Hong Kong on a winter night

Part II – Janet

- Discuss Factors of Heat Island Distribution over Hong Kong

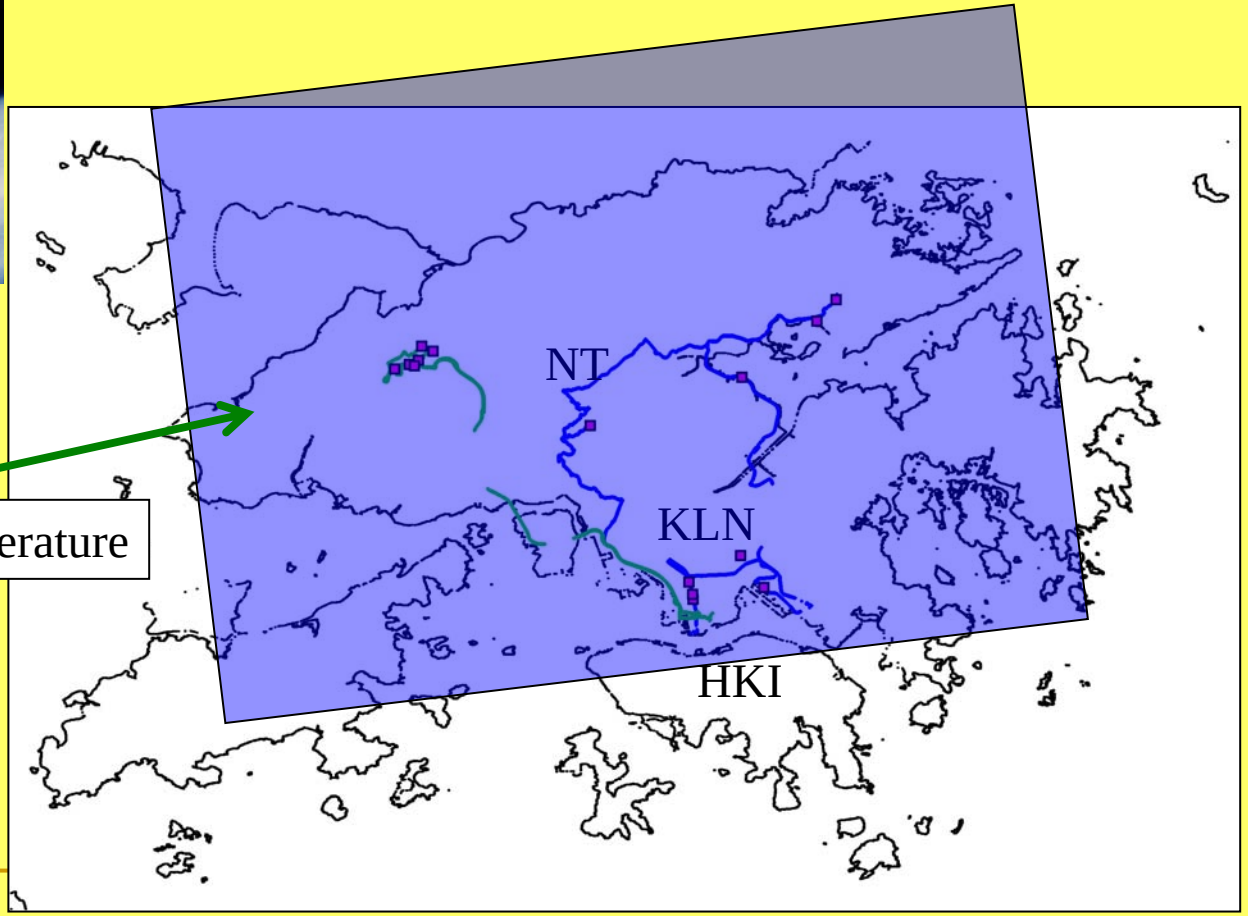
Introduction

- Remote sensing becomes a widely use method to study SUHI, but not for atmospheric UHI
- Theoretically, air temperature depends on surface temperature (conversion, conduction) and wind (advection)

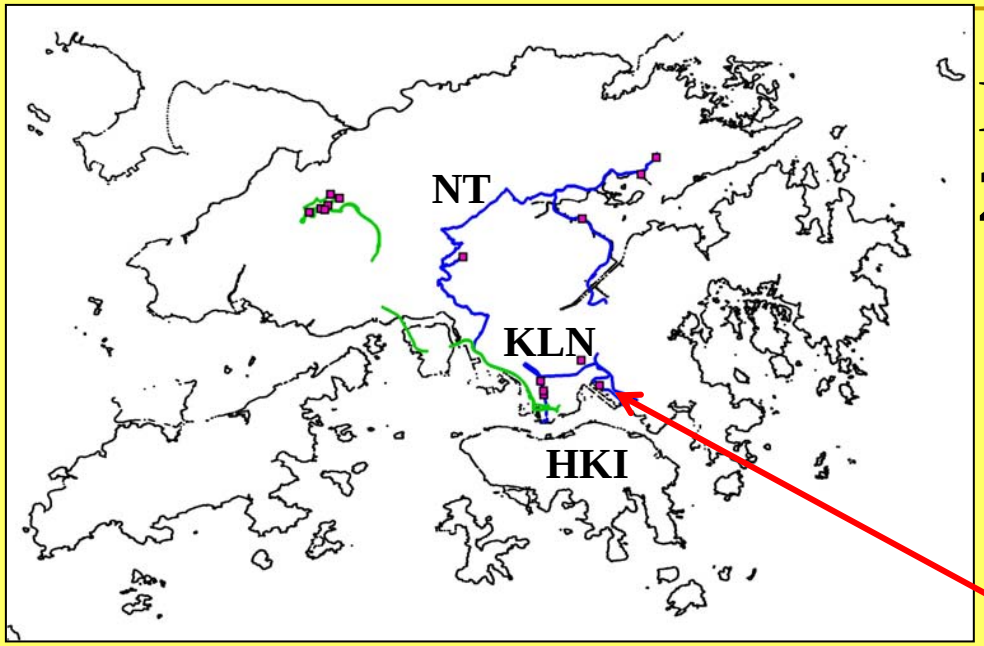
Methodology

Methodology (1)

January 31st, 2007
22:42pm LST



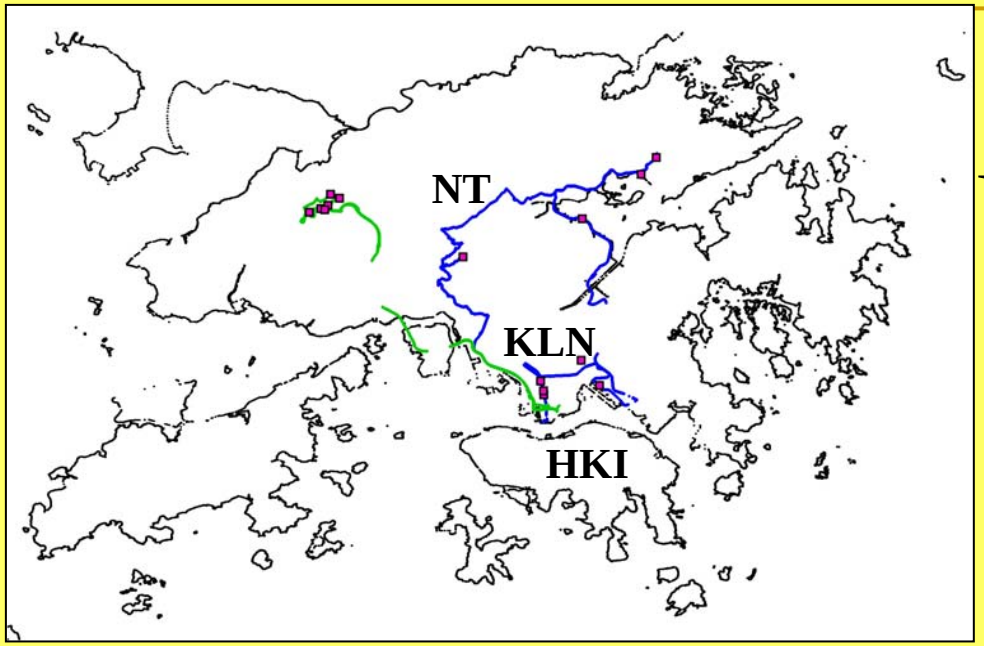
Satellite derived surface temperature



In-situ measurement
25 paired temperature readings

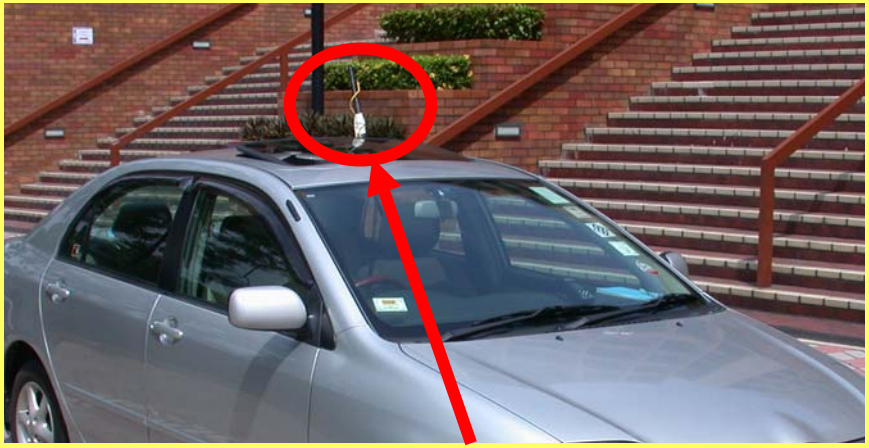

In-situ surface temperature


In-situ air temperature



Vehicle Transverse equipments

Mobile Air Temperature

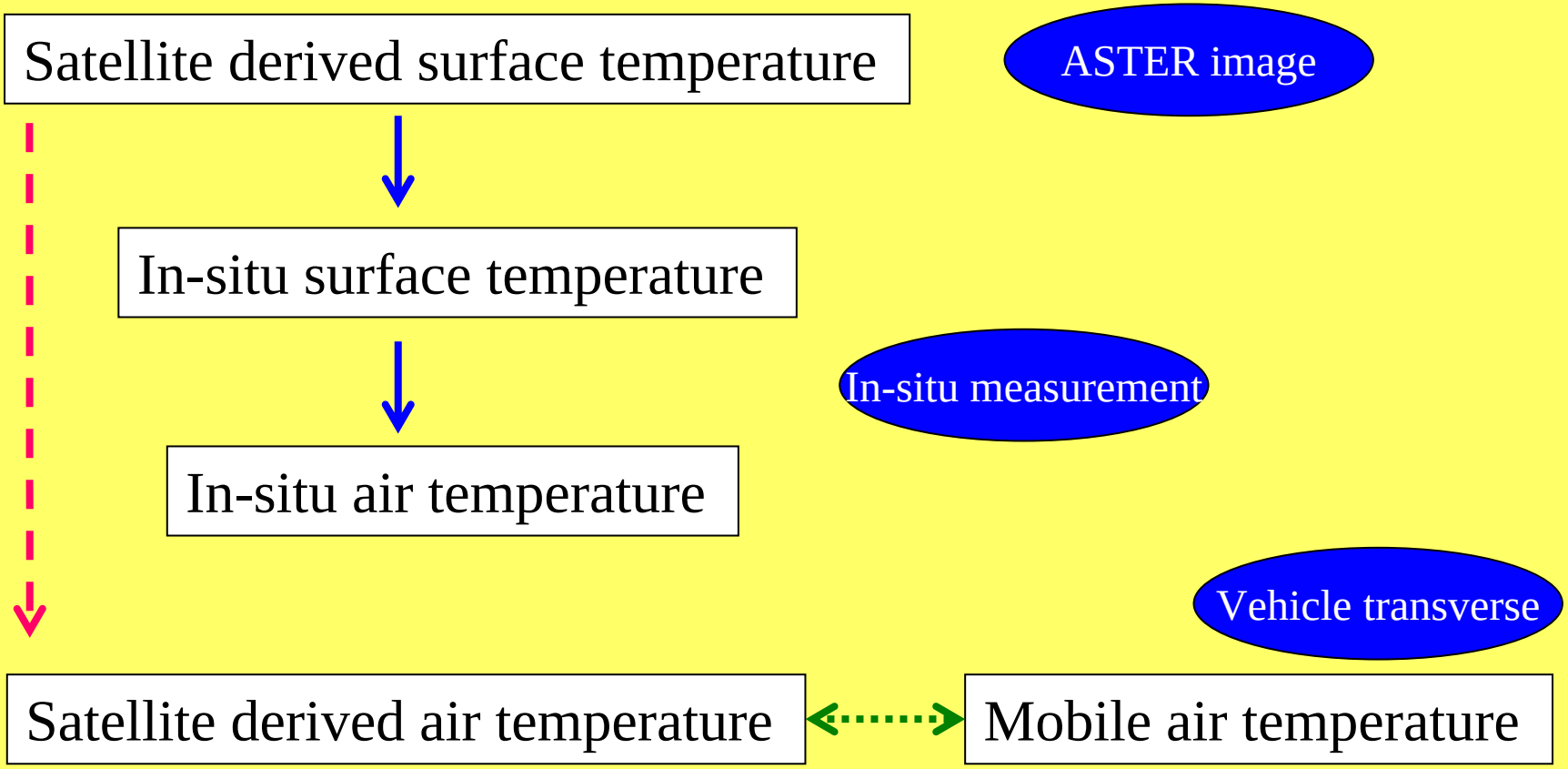


GPS receiver

IAQ Calc
thermistor

Thermocouple

Methodology (2)



Temperature calculation

$$T_u = T_m + T_a$$

where T_u is the modified air temperature

T_m is the measured air temperature

T_a is the adjusted temperature

$$T_a = T_c + T_d$$

where T_c is the adjusted temperature due to calibration

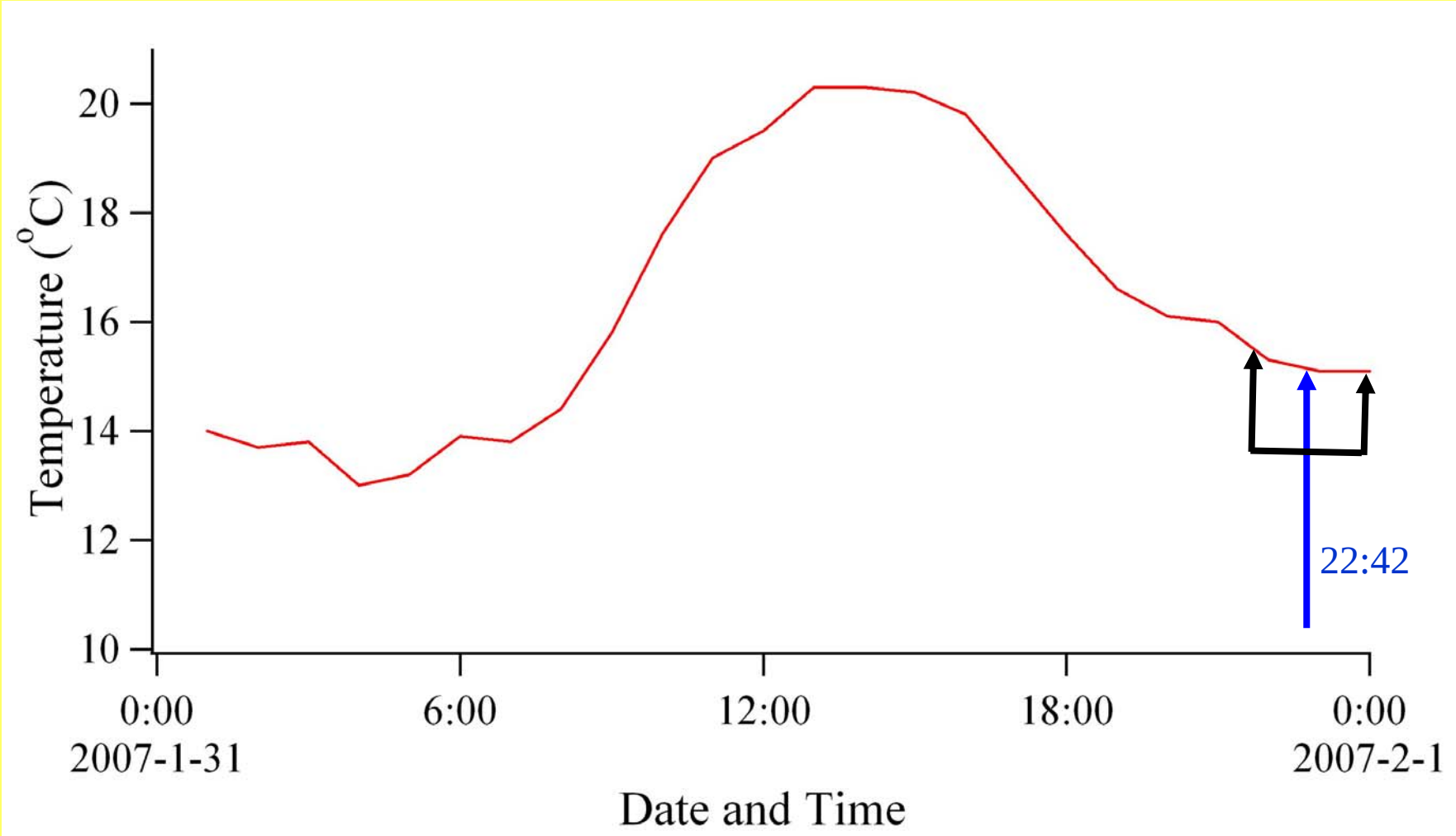
T_d is the adjusted temperature due to diurnal change in specific time

Temperature calibration

QA/QC – Temperature records

1. OMEGA CL750A calibrator, Ice Bath
2. Standard thermometer (NIST SRM 934)

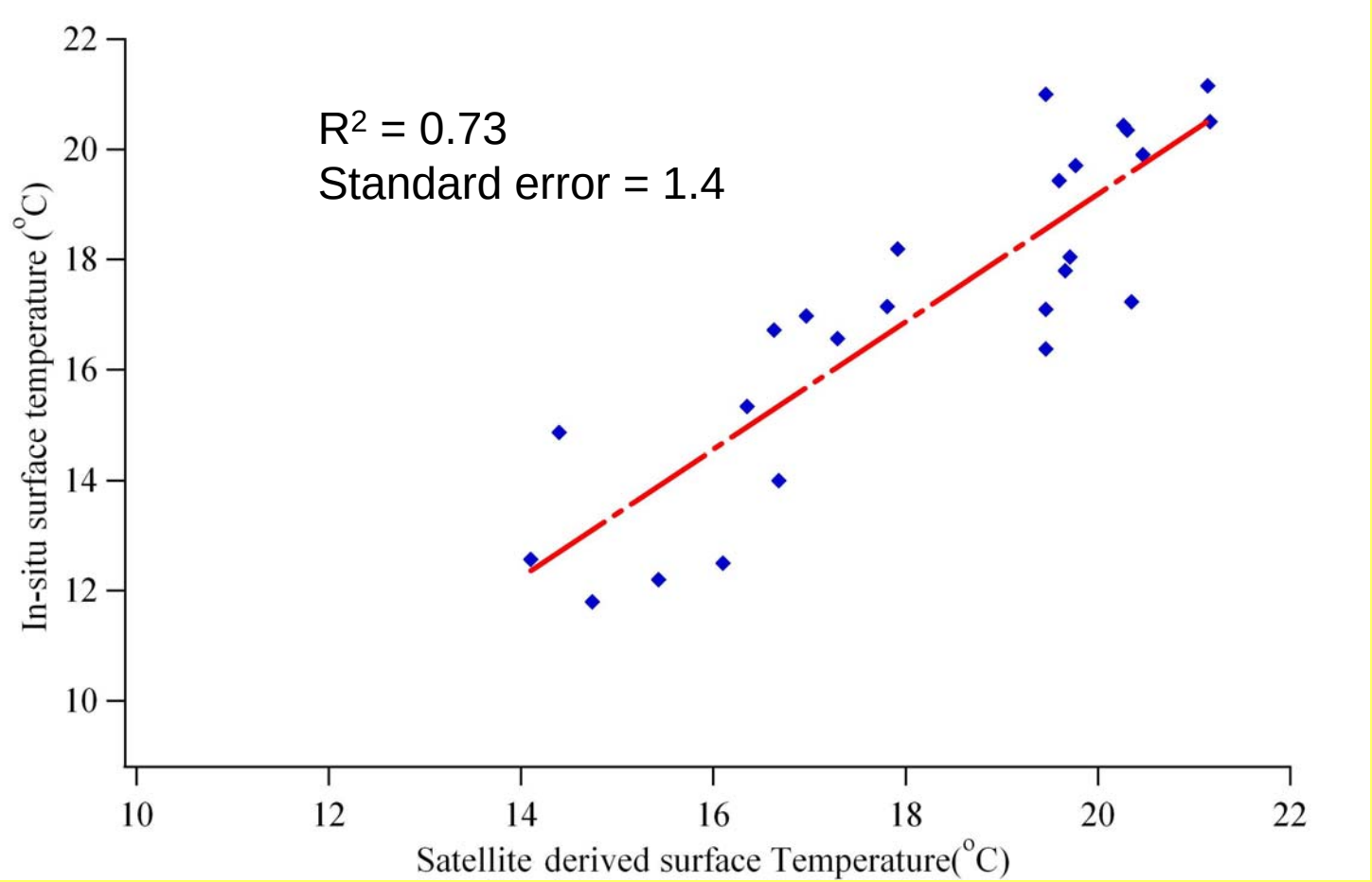
Diurnal Adjustment



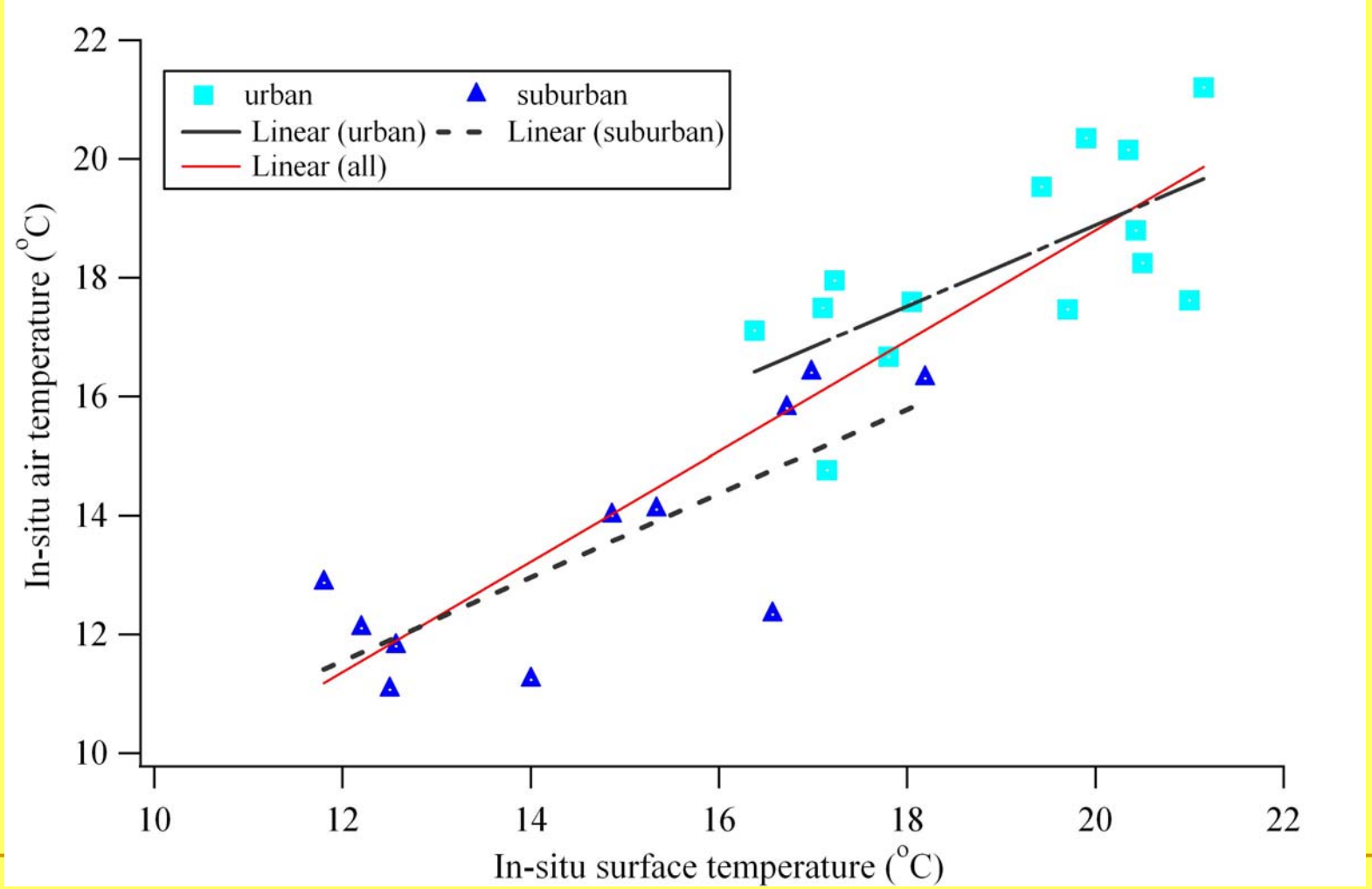
Source: King's Park, Hong Kong Observatory

Results

Correlation between Satellite Derived Surface temperature to In-situ surface temperature



Conversion of In-situ surface temperature to In-situ air temperature



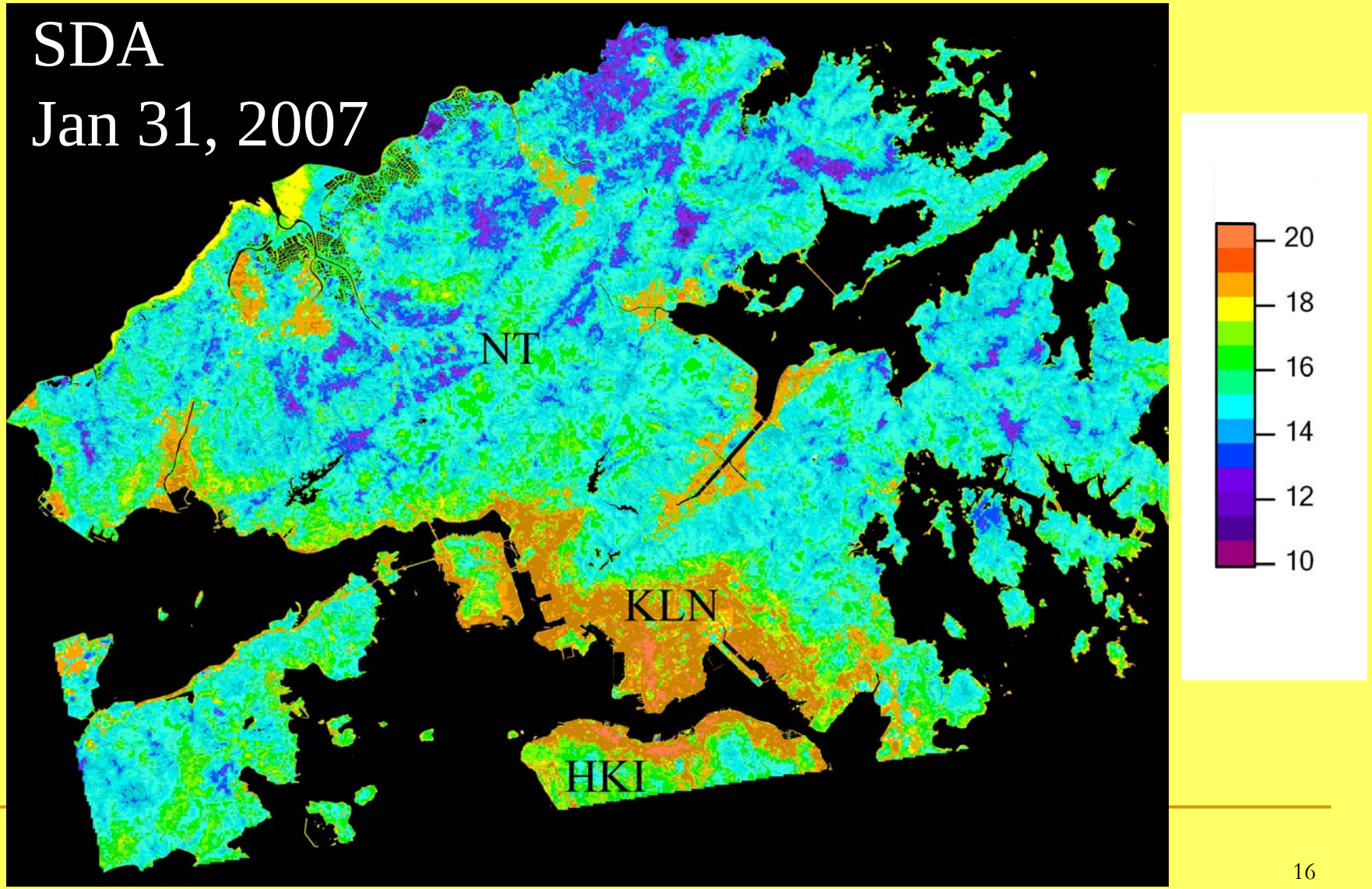
Combining two conversions into one equation

- For all data (n = 25):
- SDA = 1.07* SDS – 3.5 ---- Eqt (1)

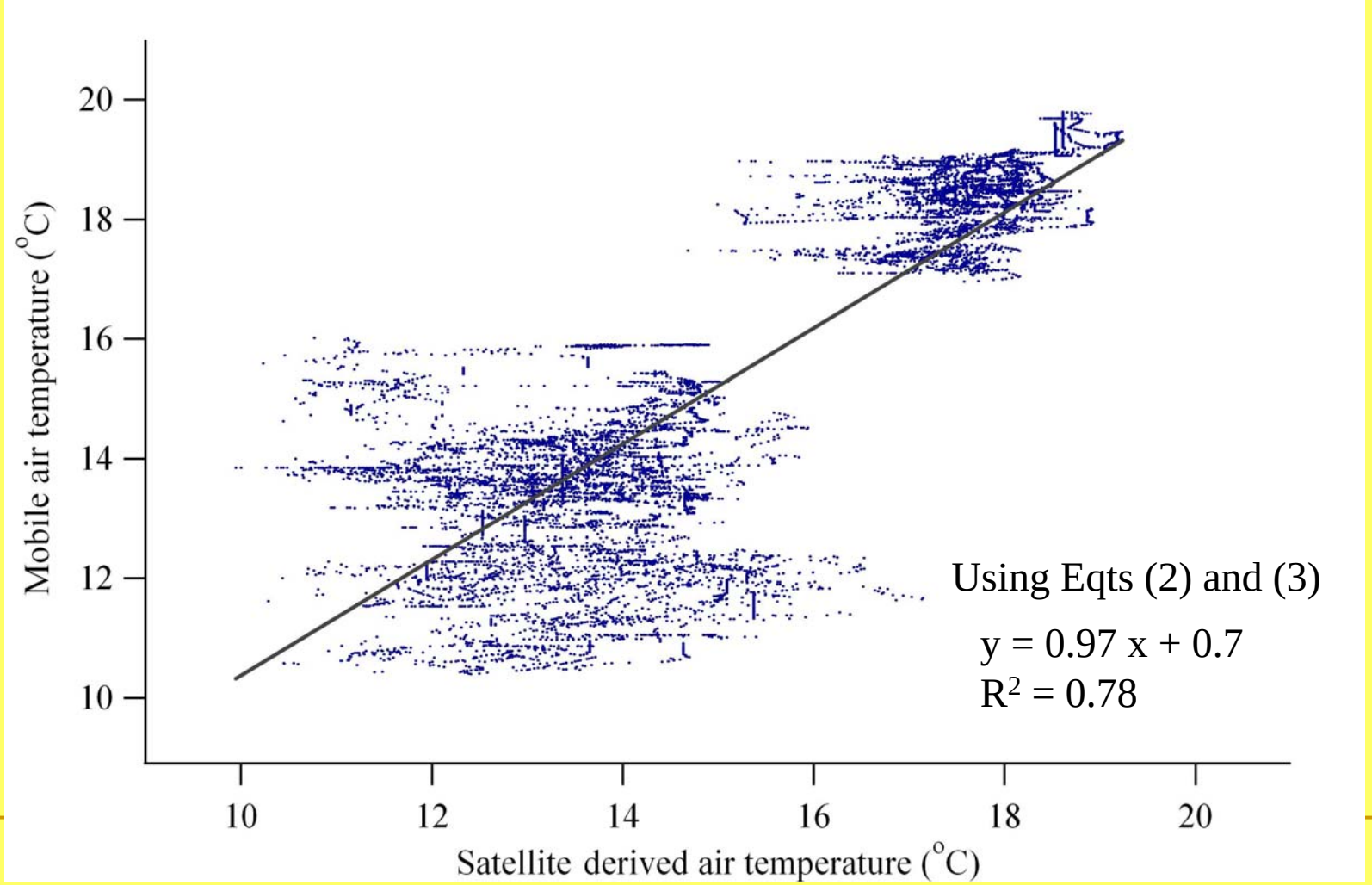
- For urban locations (n = 14):
- SDA = 0.79* SDS + 2.6 ---- Eqt (2)

- For suburban locations (n = 11):
- SDA = 0.82* SDS + 0.3 ---- Eqt (3)

Application of UHI on winter night



Correlation between Mobile air temperature and Satellite derived air temperature



Conclusion

- The first study in converting surface temperature to air temperature over Hong Kong on a winter night

- The relationship between air and Surface temperatures in different land covers are required to improve the satellite derived air temperature

End of Part I

Spatial Enhancement

1. Radiance (**L**) to Brightness Temperature (**Tb**) using the Planck function with gain and offset coefficients from image header

$$T = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)} \qquad (3)$$

where

T	= Effective at-satellite temperatures in Kelvin, K
K2	= Calibration constant 2 in K from Table 5
K1	= Calibration constant 1 in $mW \cdot cm^{-2} \cdot ster^{-1} \cdot \mu m^{-1}$ from Table 5
L_λ	= Spectral radiance in $mW \cdot cm^{-2} \cdot ster^{-1} \cdot \mu m^{-1}$ from Eq. 1

2. Emissivity Modulation for **Tb** to Surface Temperature (**Ts**) using Stefan Bolzmann Law (emitted radiation from a Black Body (W.m2) is proportional to 4th power of absolute temperature)

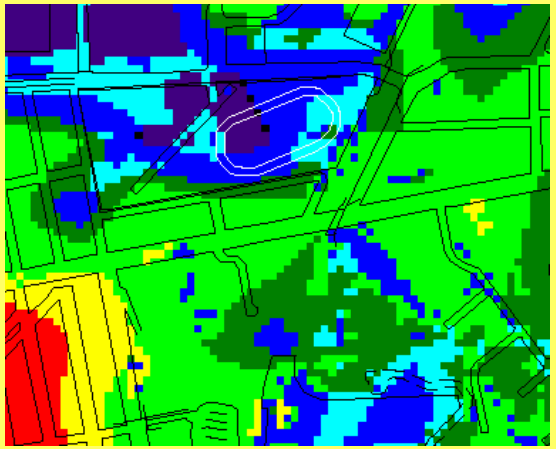
Ts = Tb/ ε 1/4 (Sabins, 1997)

Atmospheric correction

- low atmospheric column water vapour amount of 2.3cm
- low aerosol optical thickness (AOT) (<0.3 at 0.65µm)
- limited range of surface temperatures between 287K and 294K
- Within this range, surface kinetic temperature is a linear function of brightness temperature

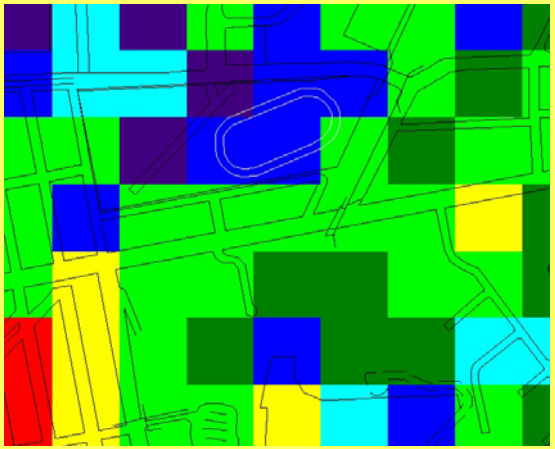
- Therefore, used in situ Sea Surface Temperature

Retrieval of Surface Temperatures: 10m indicates source areas and more accurate

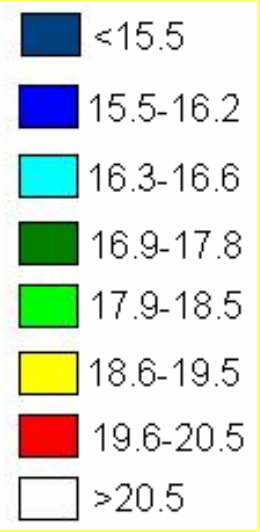


a.

b.



c.



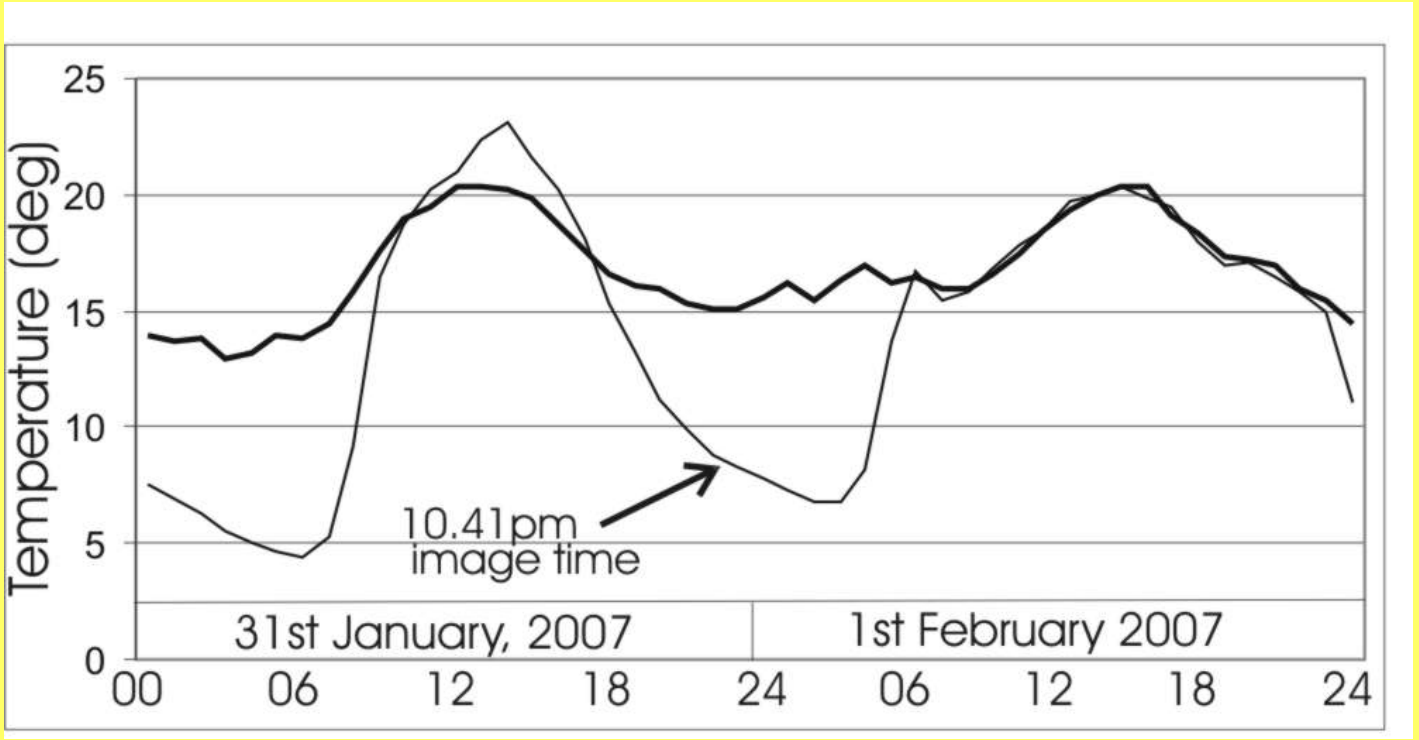
Comparison with 18 'in situ' data points
a. 10m Ts image, R^2=0.71, MAD=1degC
b. air photo,
c. 90m Ts image R^2=0.56, MAD=1.4 degC

Image used for study

- night-time ASTER scene of Hong Kong at 10.42pm on 31.01.07

- ΔT(u-r) had reached 80% of its full development

Temporal development of the UHI at image time 31.01.07



Thick line, Kings park, Thin line Ta Kwu Ling

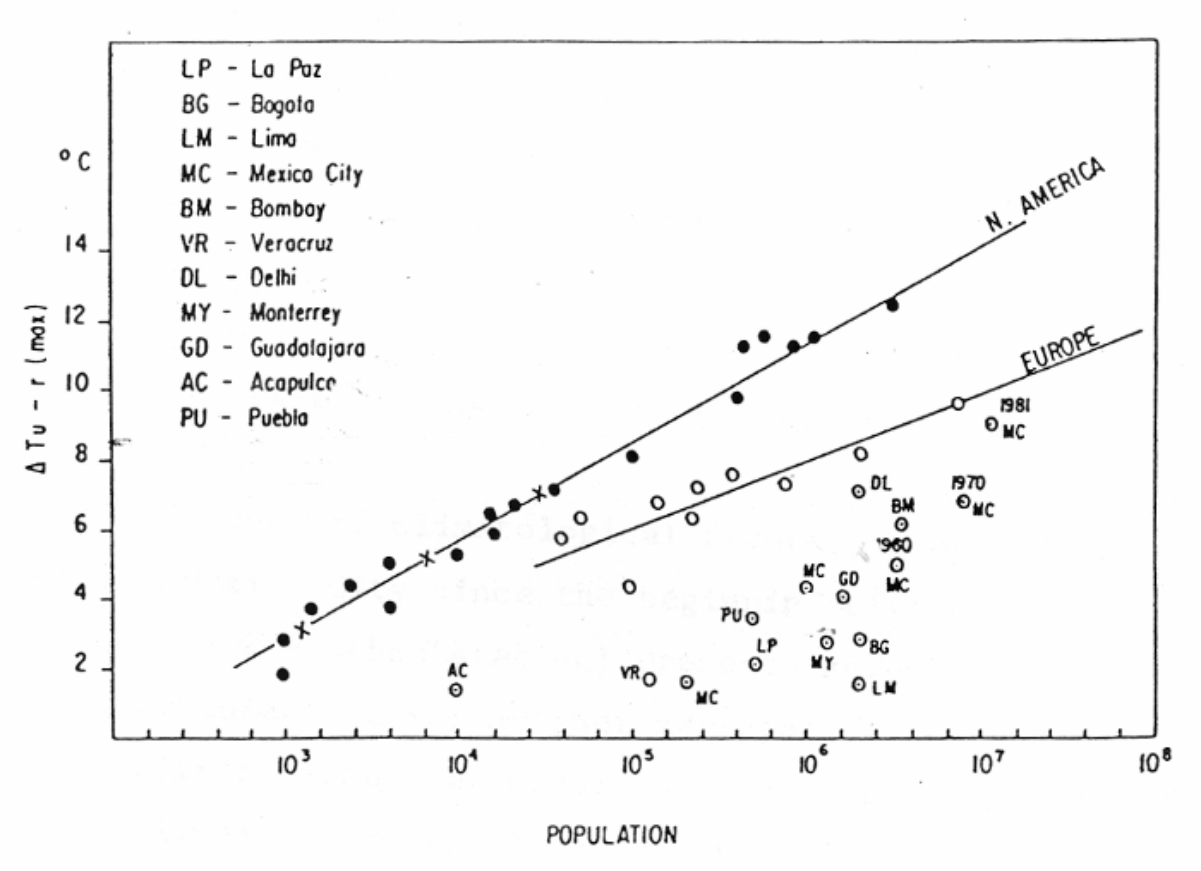
Wind speed at image time: 1m.sec

Temperature inversion at ca. 600m elevation

Objective

- Examine the usefulness of thermal satellite images for urban heat island (UHI) analysis
- Evaluate existing models of UHI formation
  - **Population/physical structure/city size model (Oke, 1976)**
  - **Advection/city size model (Oke, 1976; Summers 1964)**
- To what extent is UHI intensity (ΔT(u-r)) a function of physical structure, and to what extent is it dependent on distance from the rural boundary ie. urban areal extent?

Heat Island intensity: population/city size model (Oke)

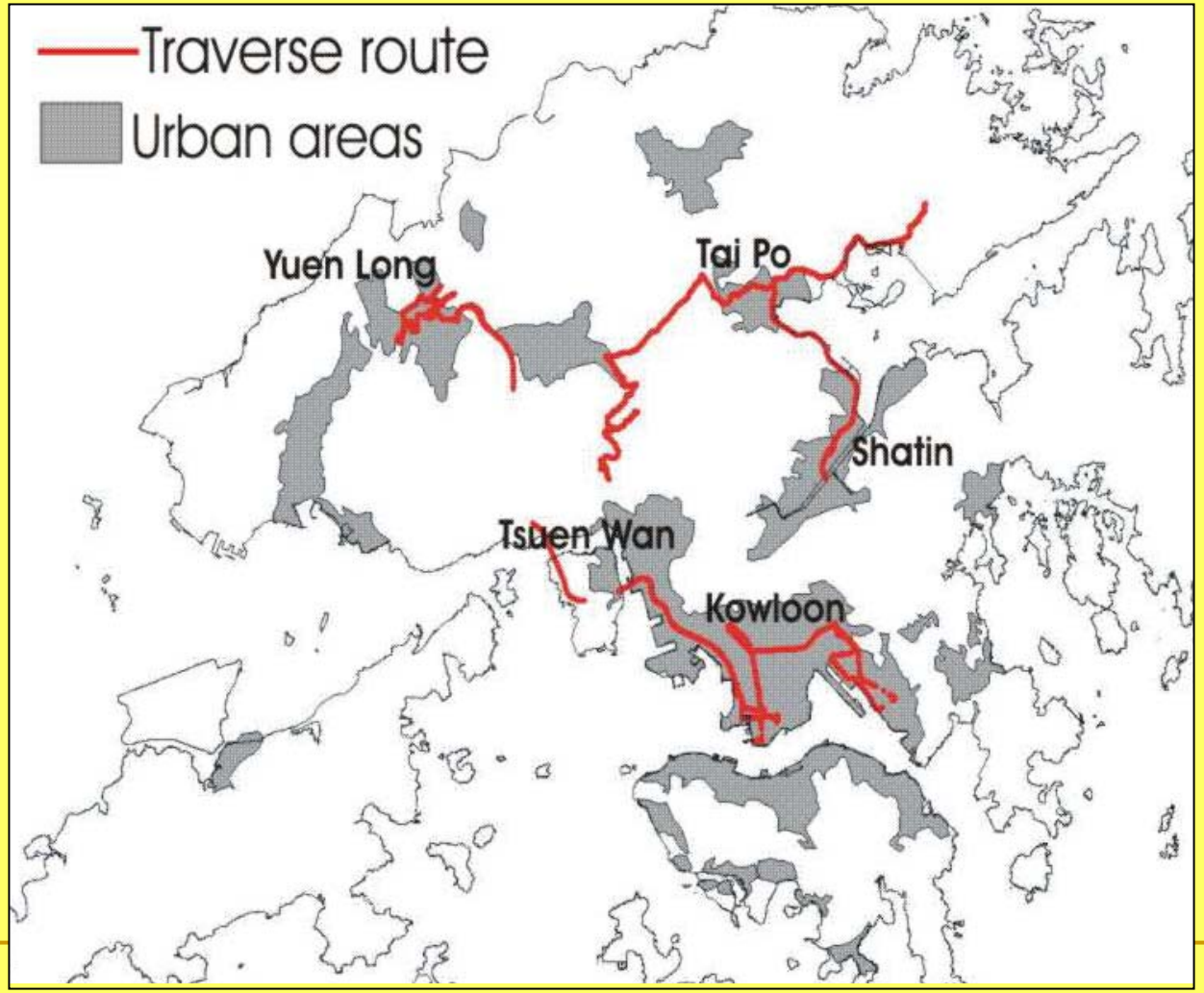


Maximum heat island intensity versus population for tropical and temperate cities

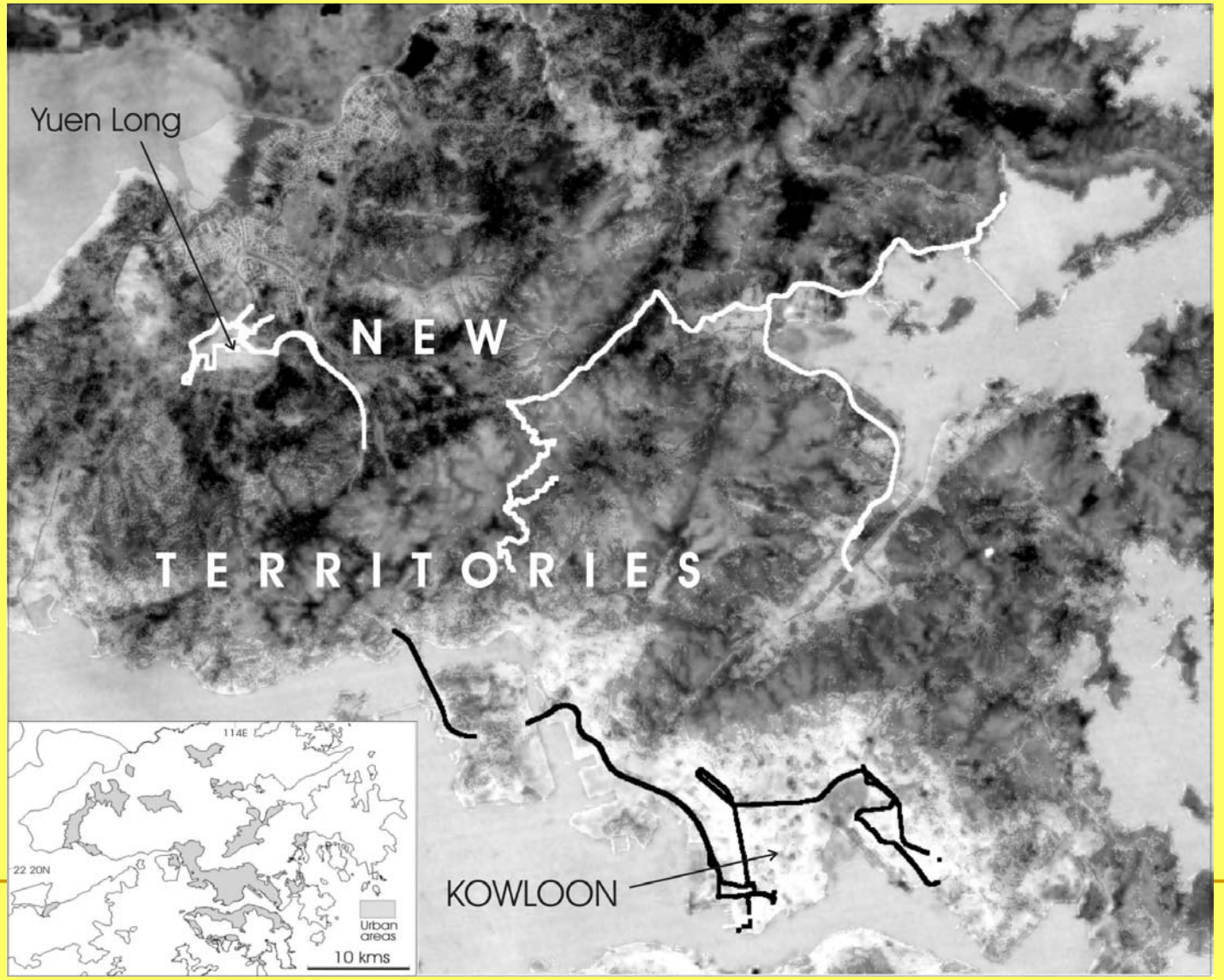
Extreme signs of urbanisation in core areas

- Sky view factor decreases
- Heat capacity of construction materials increases
- Thermal inertia of structures increases
- Density of anthropogenic heat emissions increases
- Amount of vegetation decreases etc

Mobile traverse covered urban areas of different size



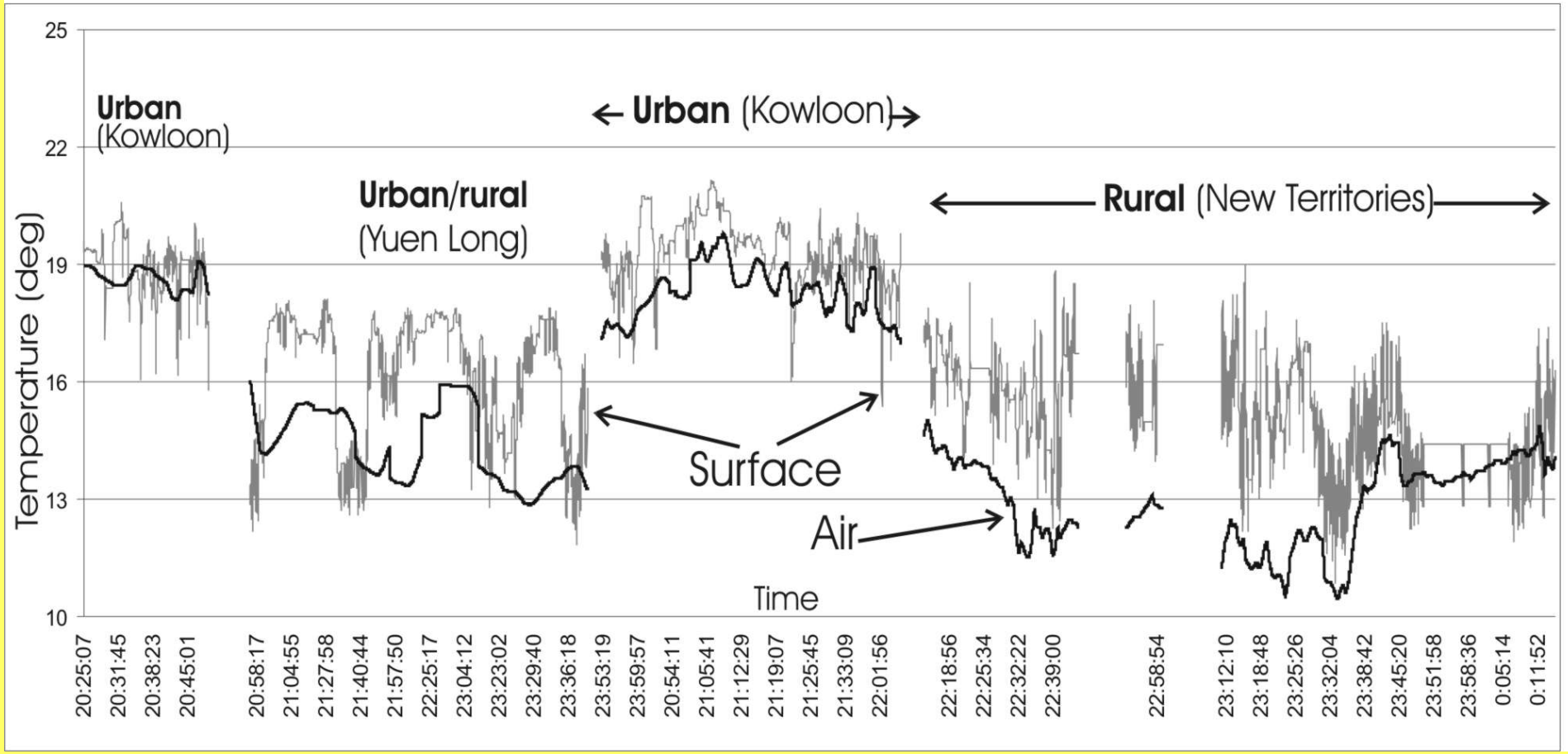
Compared mobile air temperature directly with corresponding image pixels by overlay



Results: temperature range

- Mobile **Ta** range of 11-20^{o}C whole of Hong Kong (UHI of 9^{o}C)
- Kowloon urban area, only a 2^{o}C range of **Ta**
- Kowloon urban area **Ts** 7-8^{o}C range

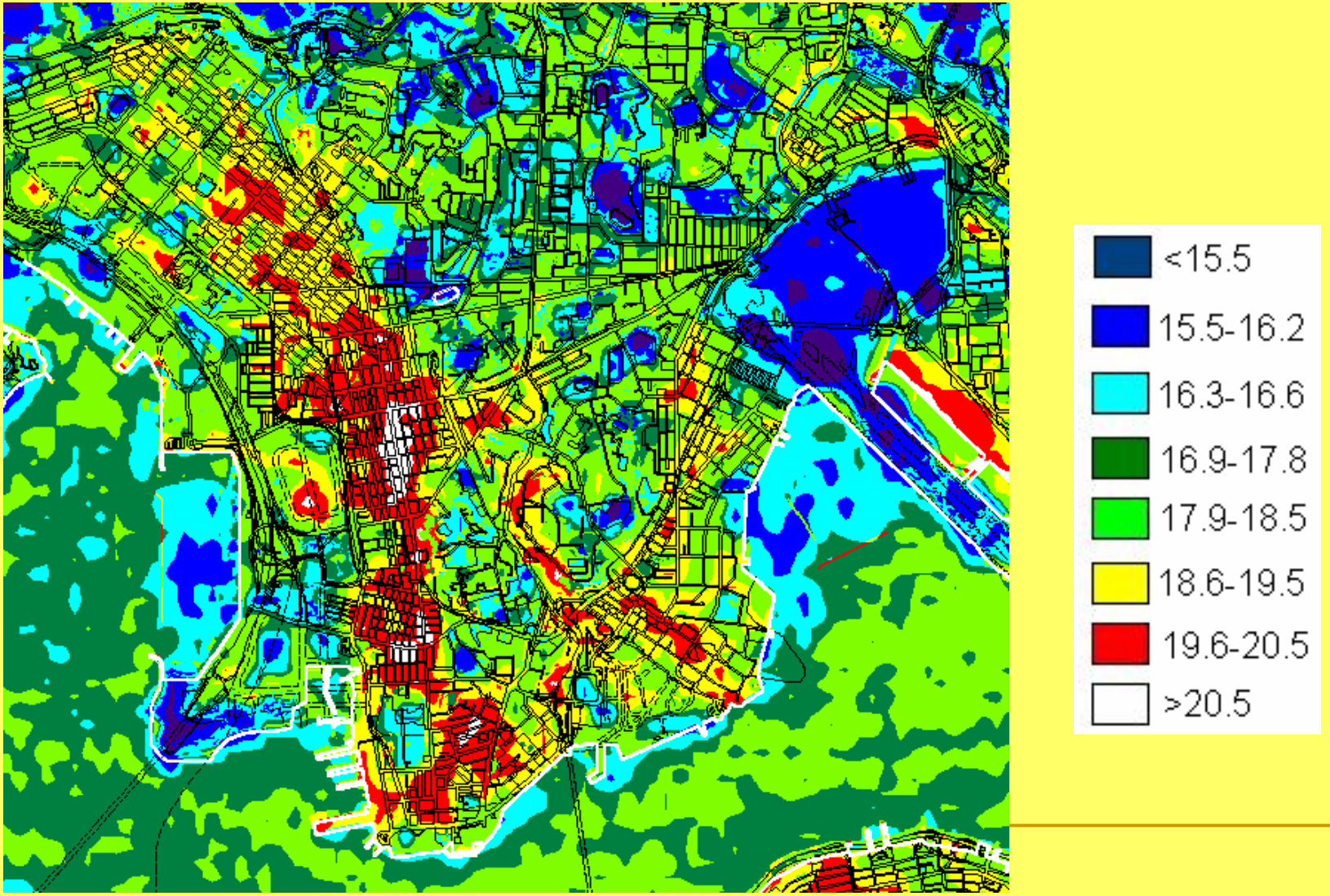
Mobile traverse versus Ts



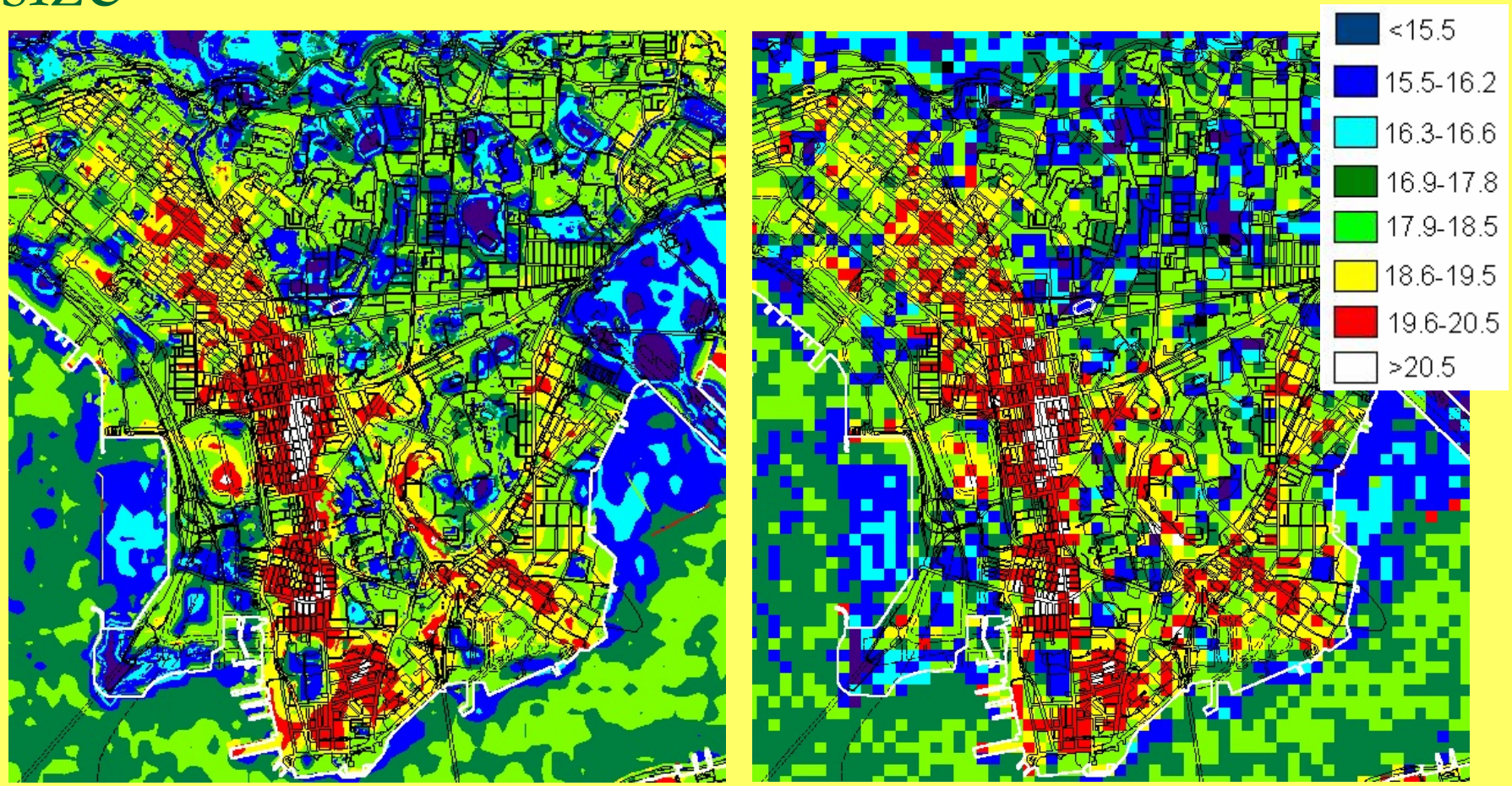
Results:spatial scales of SUHI

- Core of SUHI aligned N-S (medium-rise commercial districts)
- Regional scale transition clearly seen (similar to isothermal map)
- Micro-scale: steep temperature gradients correspond to surface land cover

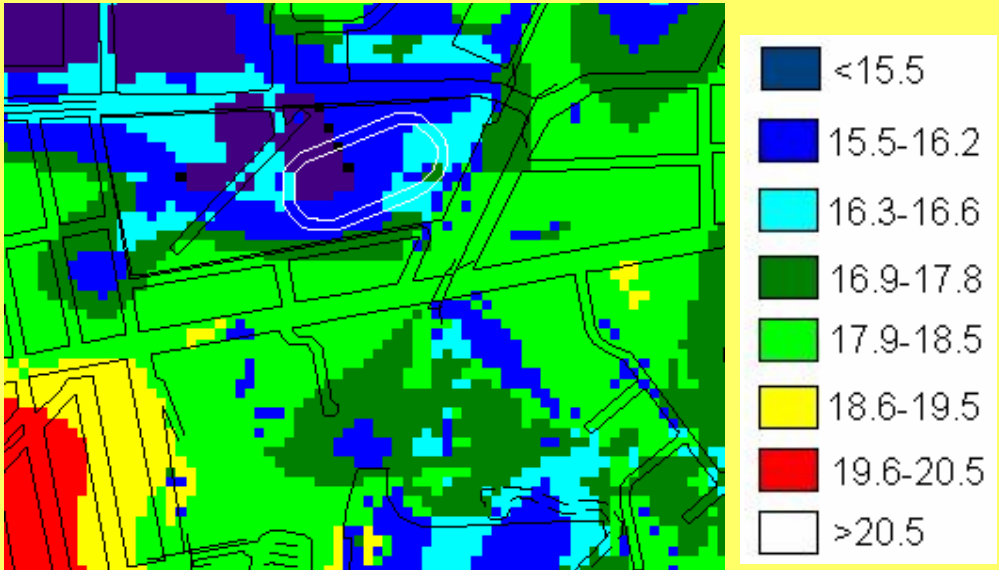
SUHI over Kowloon showing north-south alignment of heat island core along Nathan Rd



Difference between 10m and 90m pixel size



SUHI at 10m shows both micro- and meso-scale temperature patterns



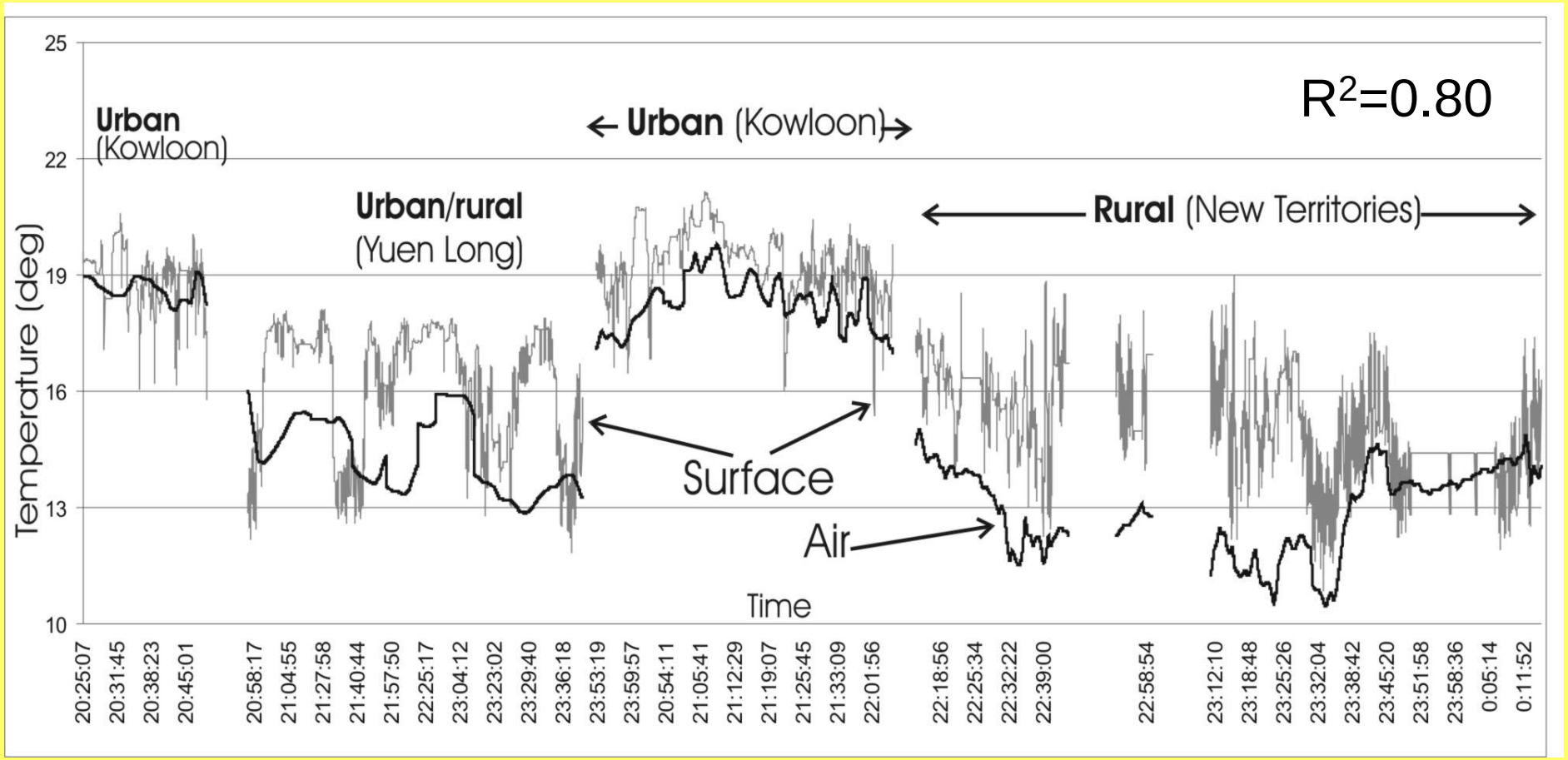
10m Surface temperature image

air photo

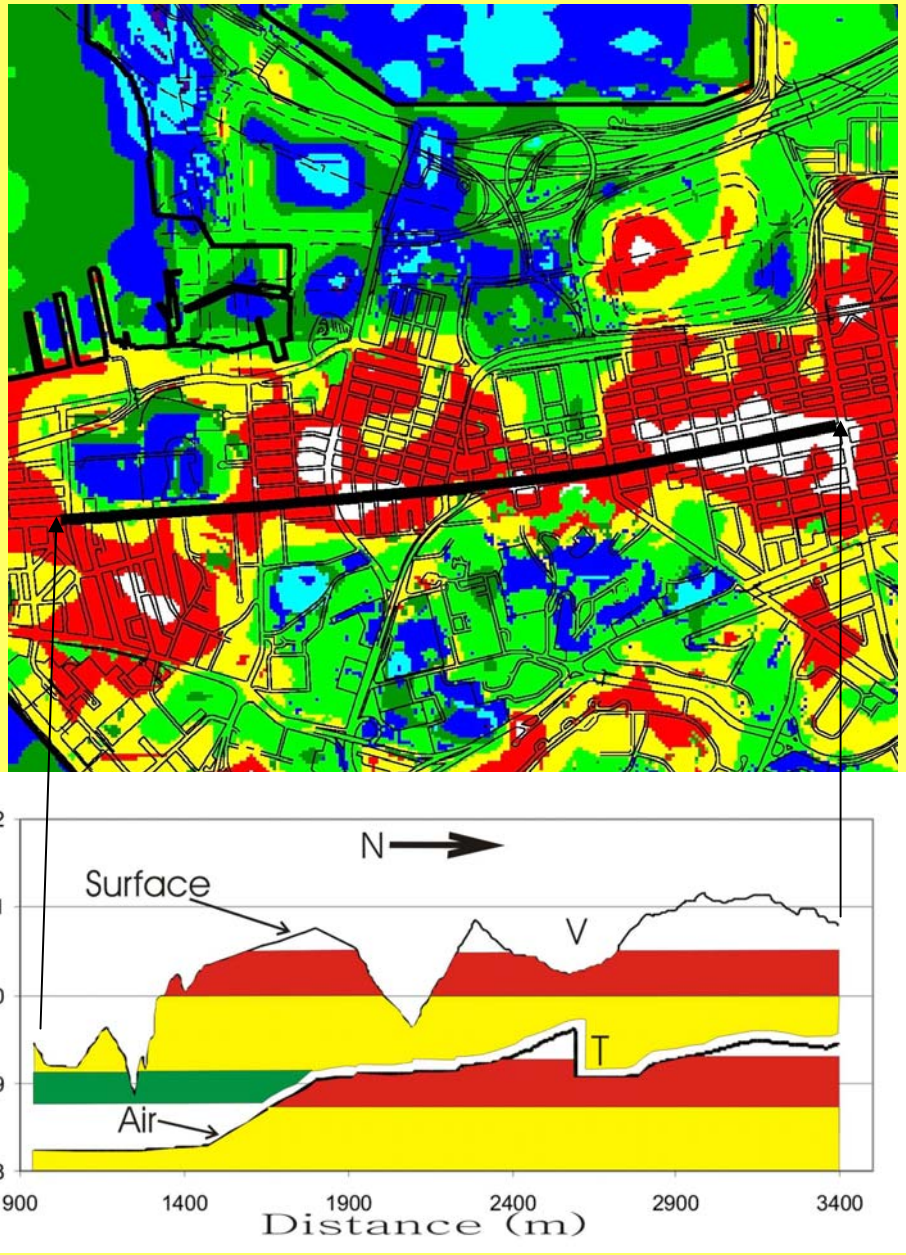
Results:relationship between Ts and Ta

- High correlation (R^2=0.81) between **Ts - Ta** at 18 points and also for whole mobile route (R^2=0.80)
- High frequency **Ts** variation on mobile route correspond to image **Ts** details
- Lower frequency **Ts** variation on mobile route correspond to general (isothermal) image patterns and to patterns of **Ta**

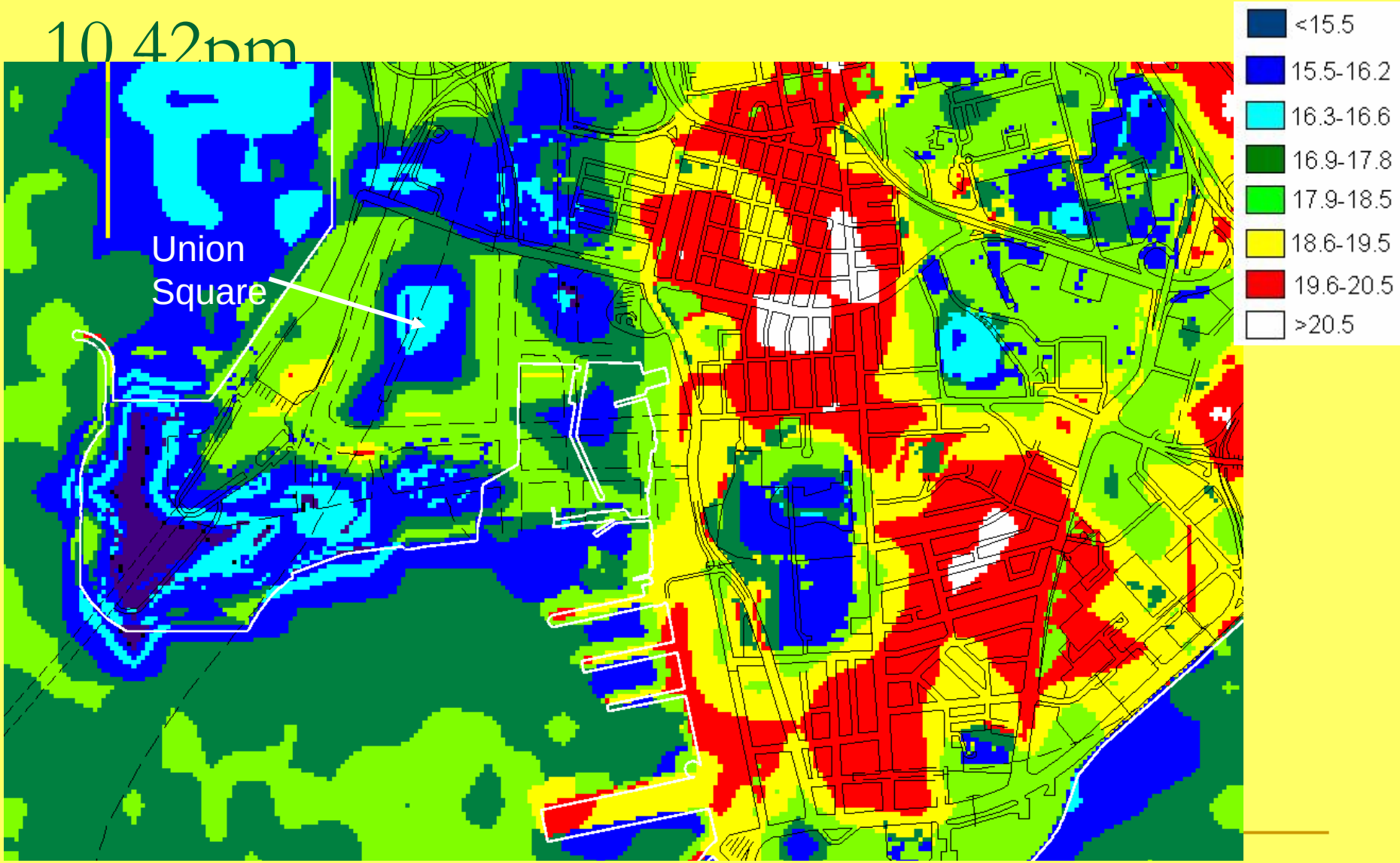
Mobile traverse versus Ts



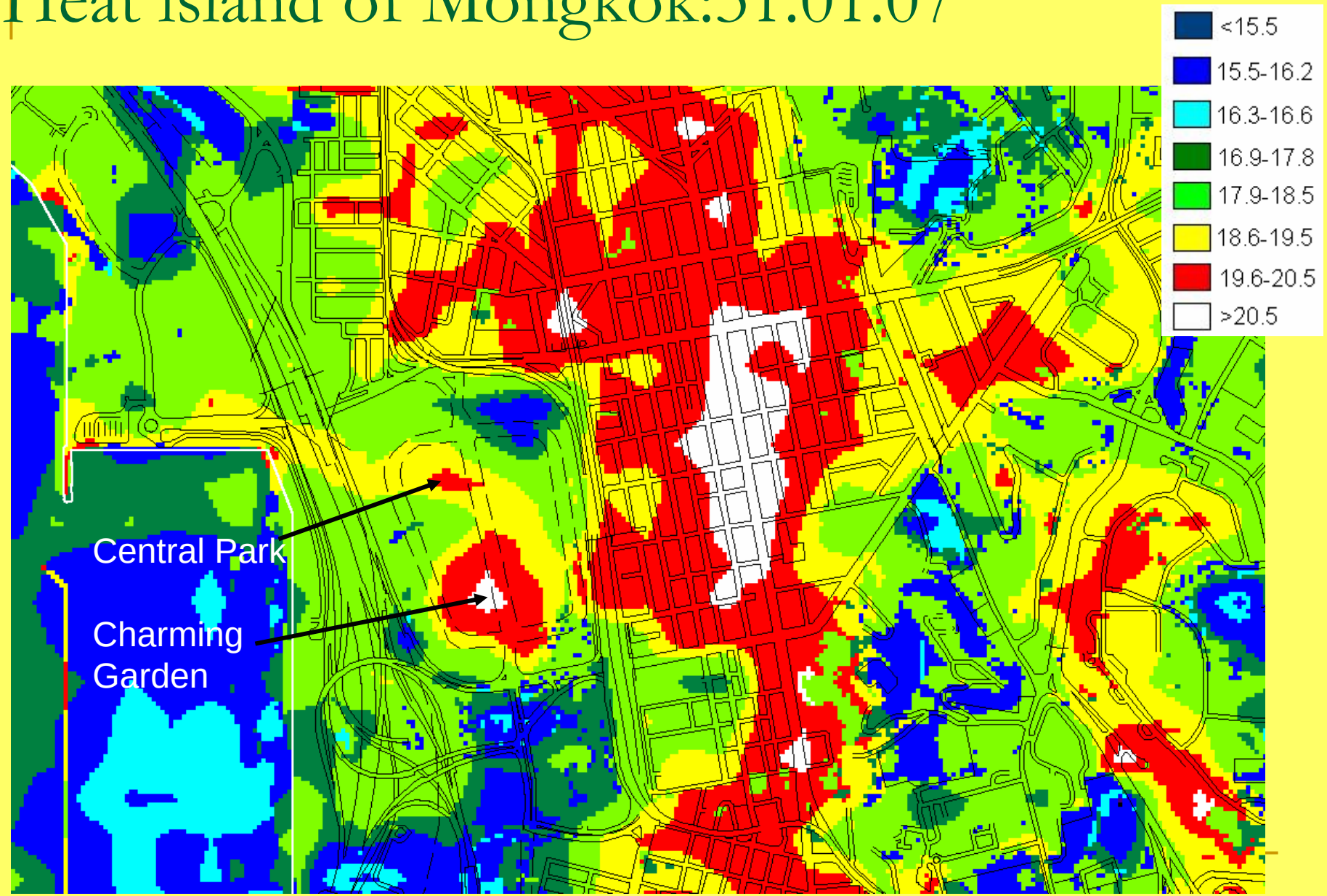
Mobile traverse (thick black line) showing lower temperatures alongside Kowloon Park and higher toward Mongkok. Graph has 4 colour classes of **Ts** which can be related to the image



Heat Island of Tsim Sha Tsiu on 31.01.07 at 10.42pm



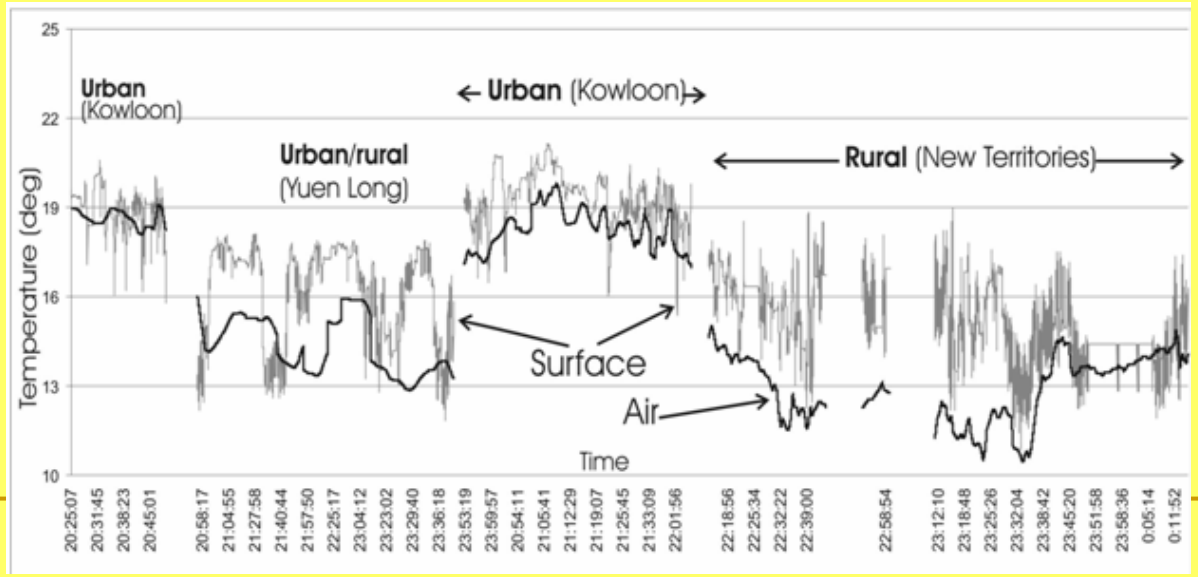
Heat island of Mongkok:31.01.07



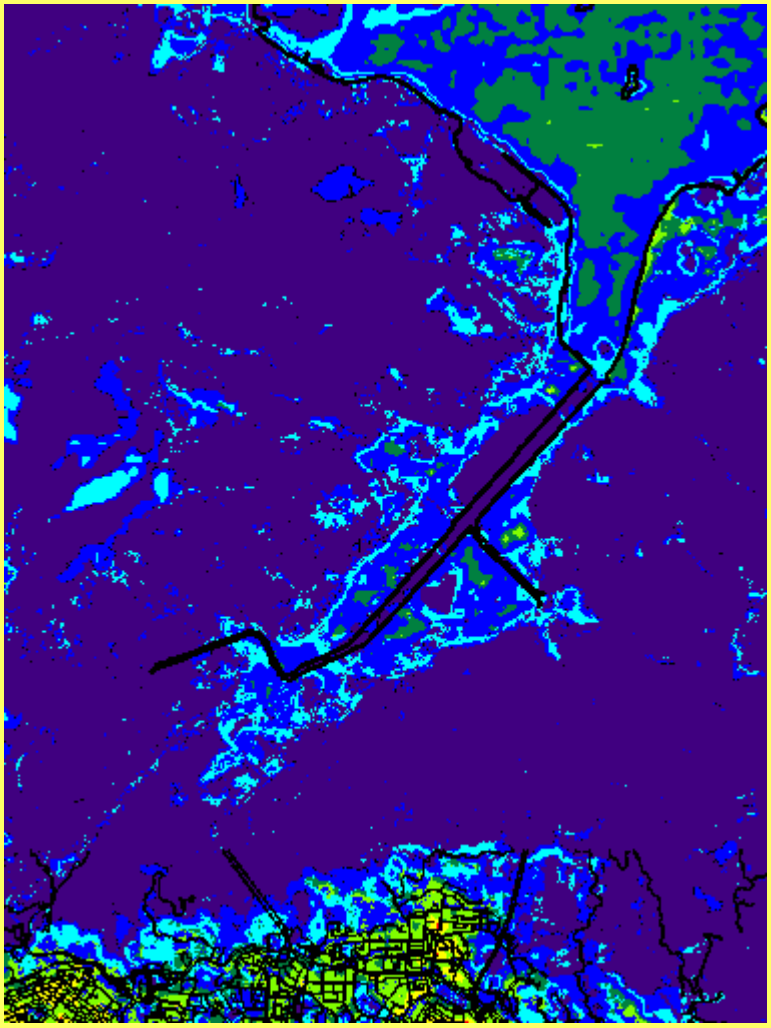
Sky view factor: Langham Place at Portland St, Mongkok

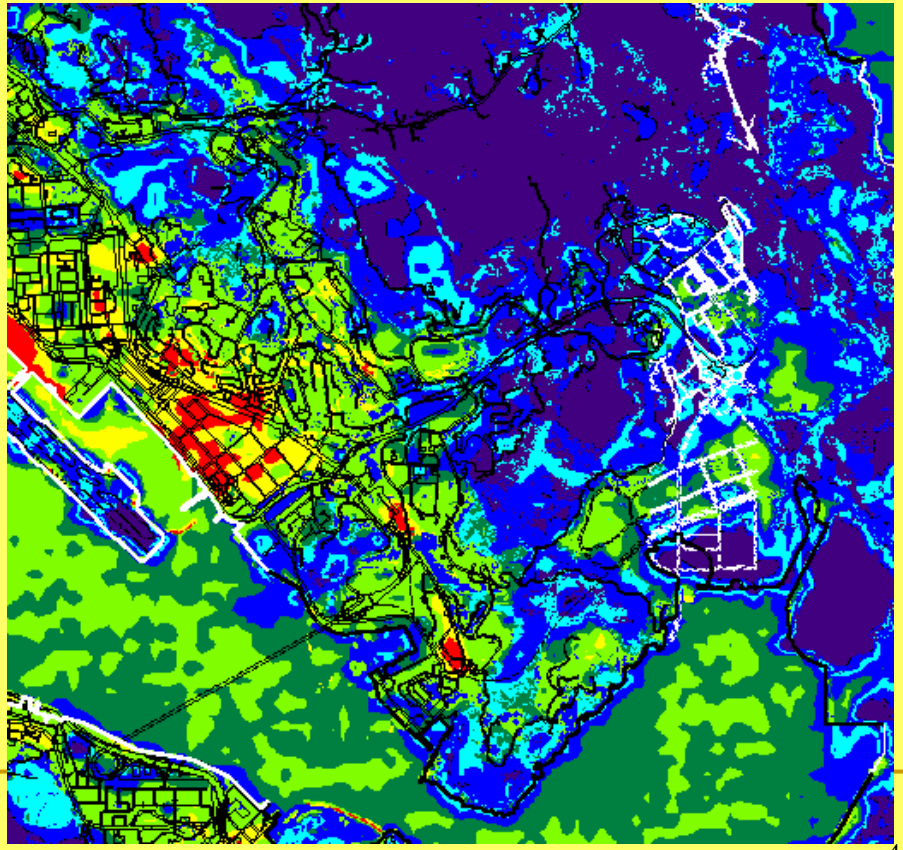
Results

- Both **Ts** and **Ta** in Kowloon 4°C warmer than in Yuen Long, Shatin, Tai Po
- eg. lowest **Ta** in Kowloon 17.5°C, highest in Yuen Long, Shatin, Tai Po 16.3°C



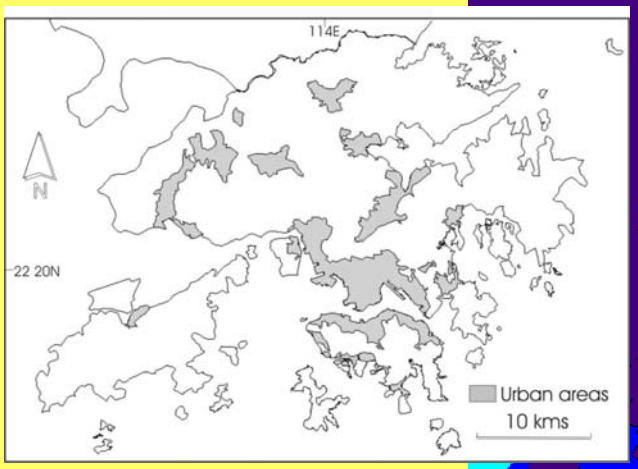
Shatin/Tseung Kwan O

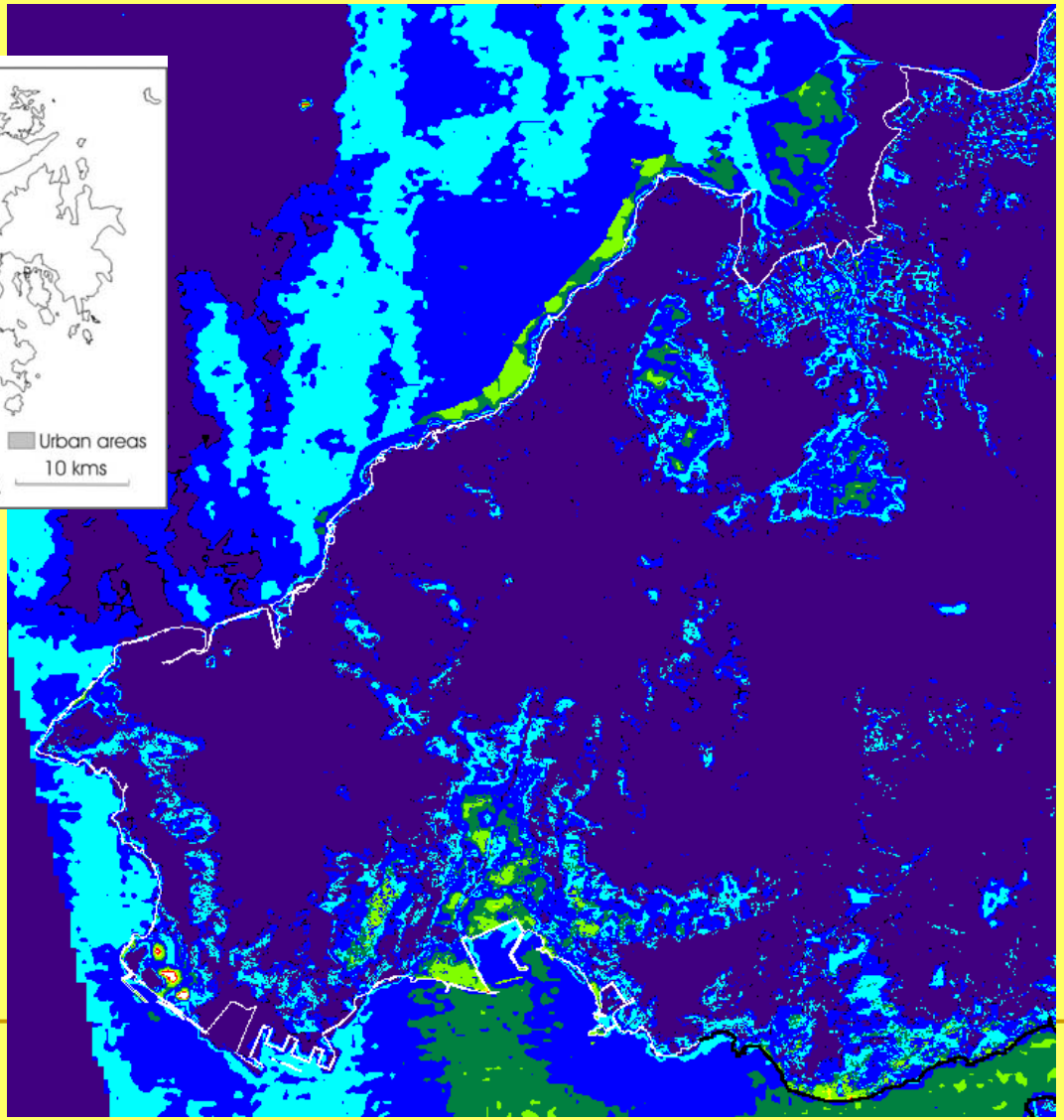


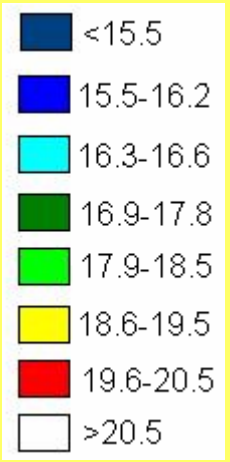


(January Night-time)

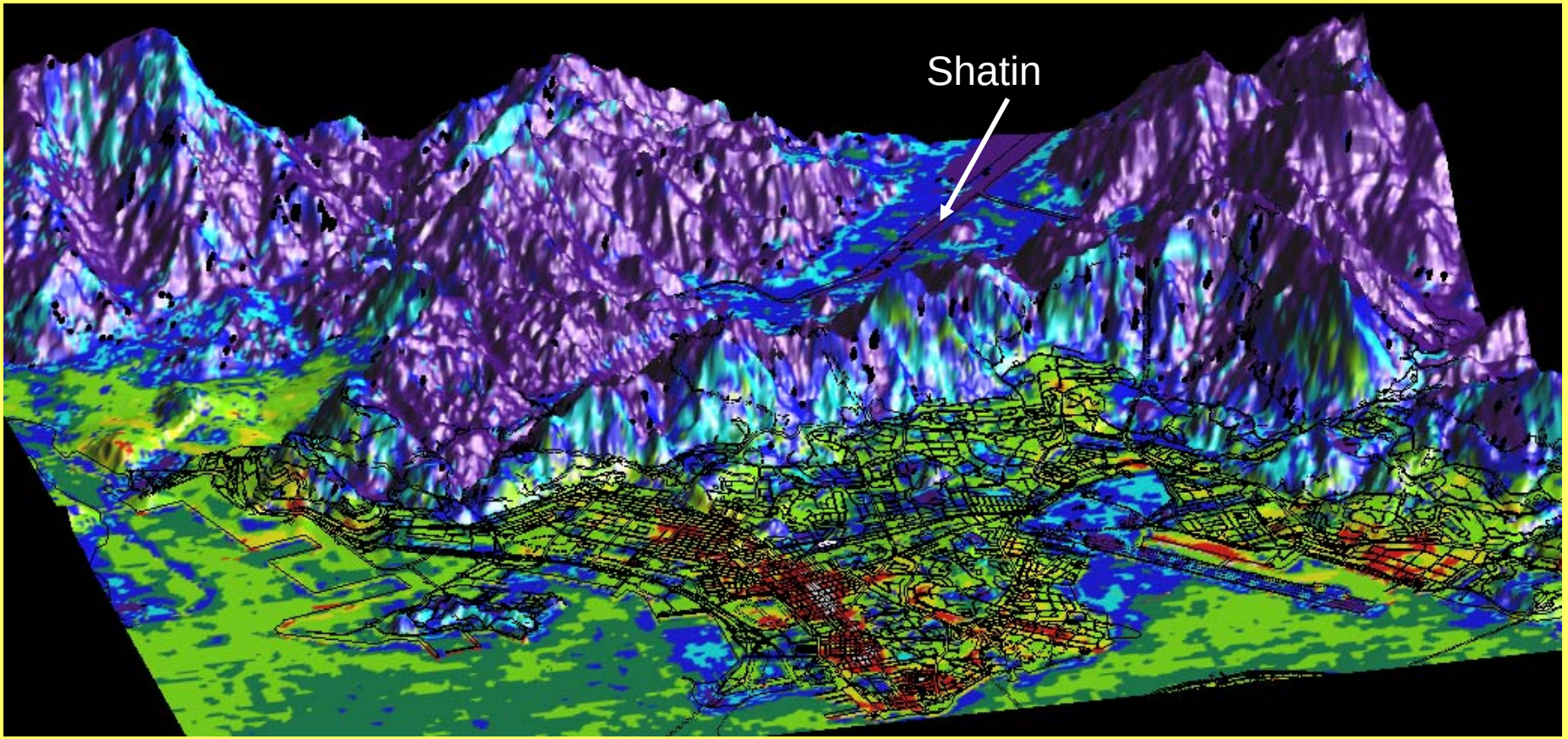
Yuen Long and Tuen Mun New Towns





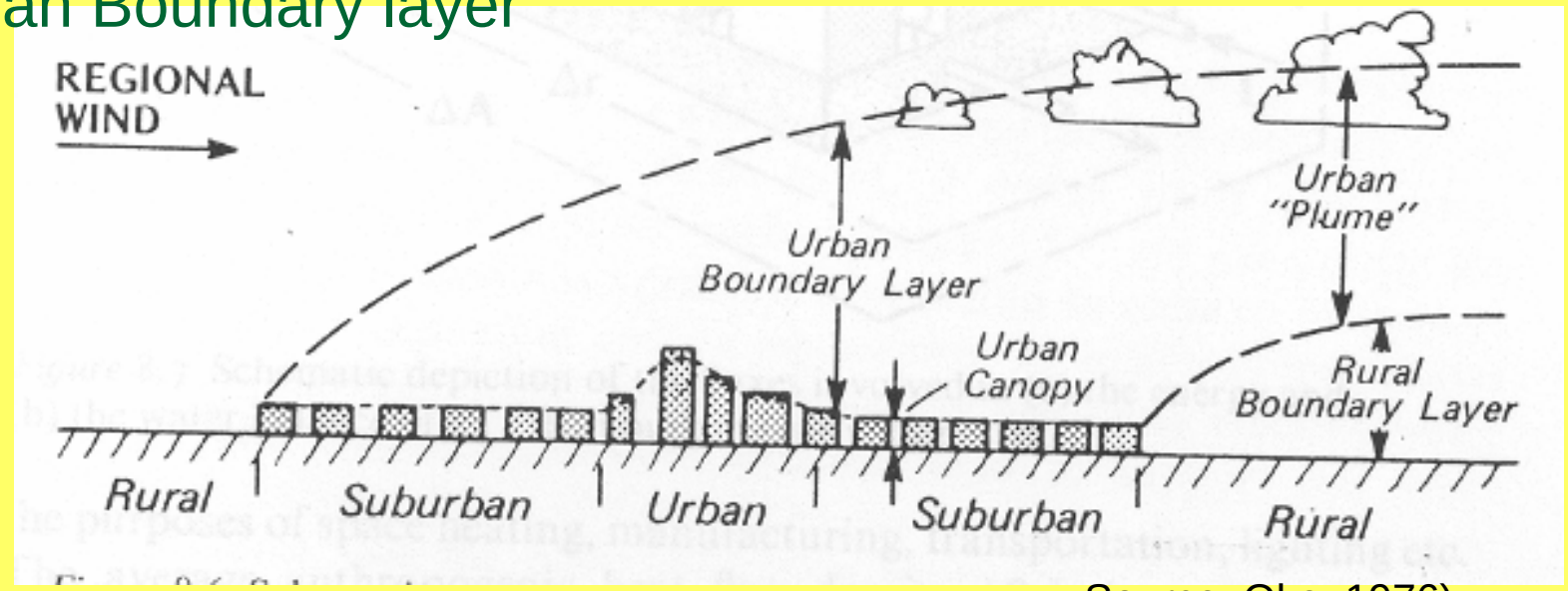


Mountain range separates Kowloon from New territories



Presence of two layers over cities

- Urban Canopy layer
- Urban Boundary layer



Source: Oke, 1976)

Due to

- Mountain range of 500m
- Inversion @600m
- Low wind speeds
- Warm air trapped south of mountain range
- UCL reinforced from both above and below

Conclusions

- Both **Ts** and **Ta** correspond to classic UHI situation (cliff and gradient)
- Different scales of variation between **Ts** and **Ta** eg. small green space lowers **Ts** but not **Ta**- is 10m too fine for UHI?
- 10m resolution indicates radiative entities within UCL, and is more accurate

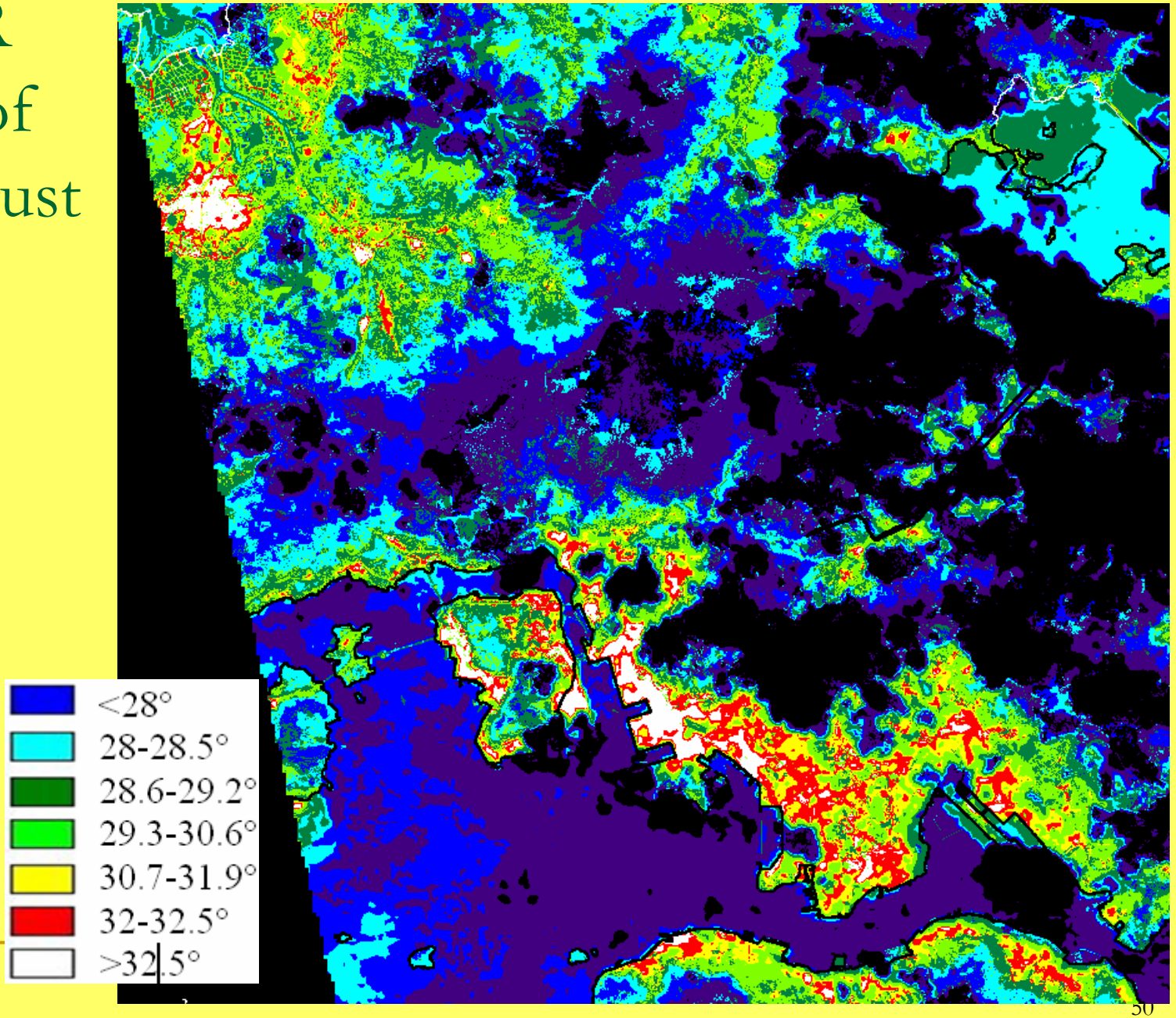
Conclusions

- Temperature gradients in both **Ts** and **Ta** can be related to land cover transitions- little evidence of large scale advection (except ventilation corridors) (supports physical structure model)
- However, much higher **Ts** and **Ta** in Kowloon appears to support advection/city size model
- More attention to boundary layer conditions

References

- Nichol, J.E., (in press), An Emissivity Modulation method for spatial enhancement of thermal satellite images in urban heat island analysis. **Photogrammetric Engineering and Remote Sensing.**
- Oke, T.R. (1976), The distinction between canopy and boundary-layer heat islands. **Atmosphere**, 14, 268-277.
- Oke, T.R., (1982), The energetic basis of the urban heat island. **Quarterly Journal of the Royal Meteorological Society**, 108, 1-24.
- Oke, T.R., (1987), **Boundary layer climates**, New York, Methuen, 435p.

ASTER image of 4th August 2007



Recommendations

- Increasing the urban extent may somewhat increase the overall $\Delta T(u\text{-}r)$ but not by a simple increase of distance from periphery to centre
- Building at lower density to increase ventilation and SVF, even at expense of higher rise, may be effective