Digital Urban Environment – Urban Heat Island, Air Quality and Urban Environmental Quality

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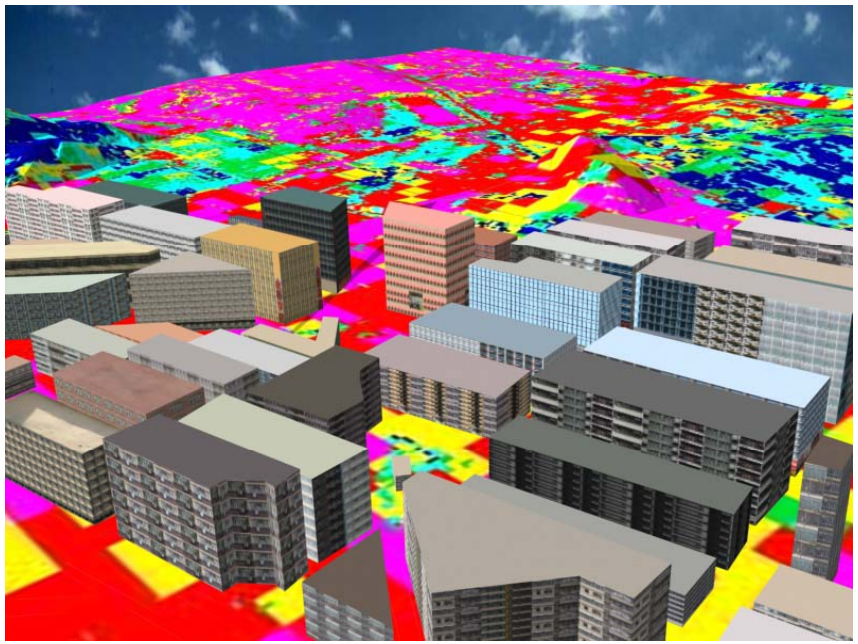
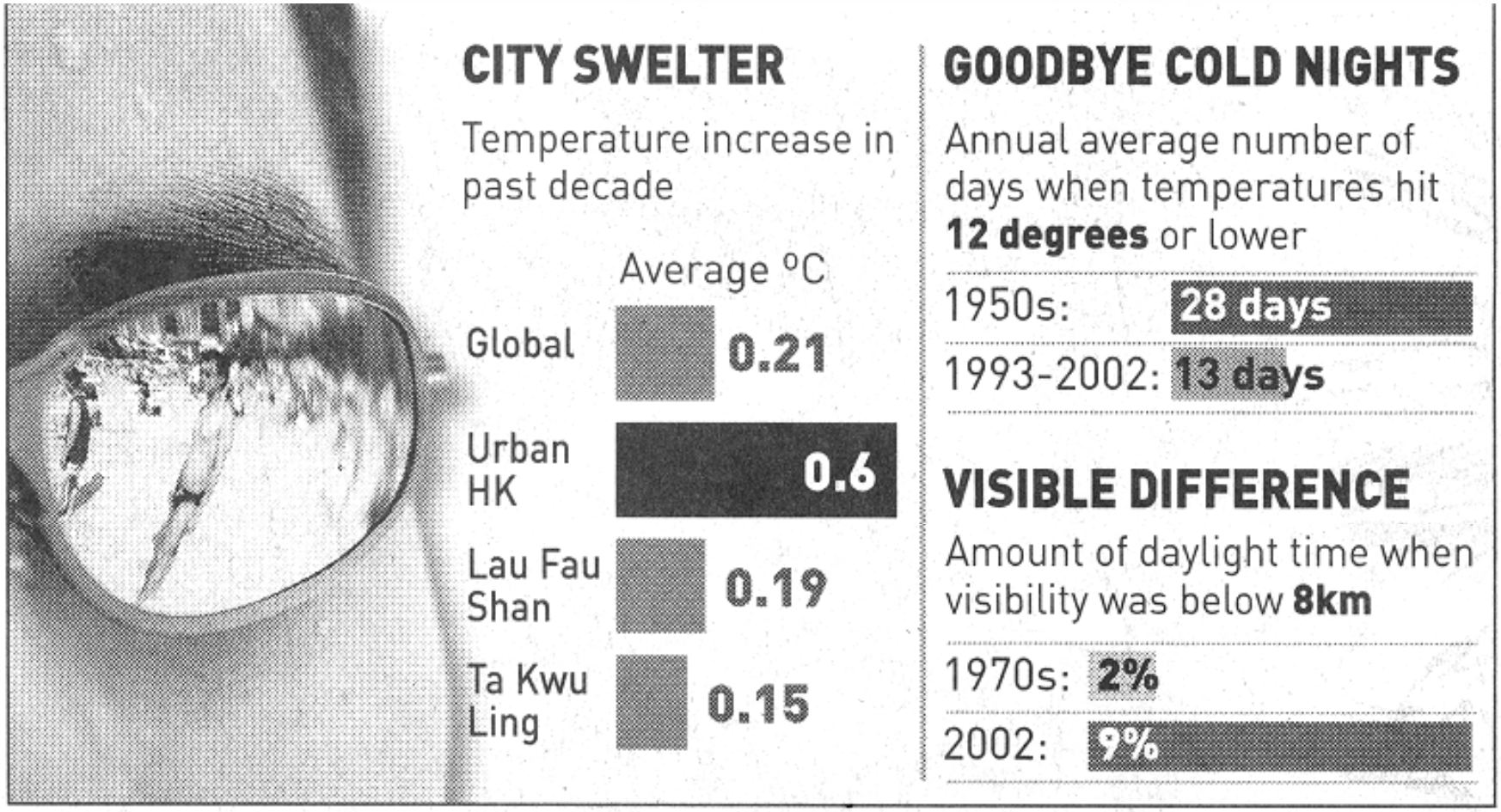
Digital Urban Environment

- Urban Heat Island,
- Air Quality,
- Urban Environmental Quality



Why do we want to understand the Urban Heat Island in Hong Kong?



Source: SCMP

Urban Heat Island: Definition

"Difference between background rural and highest urban temperature $\Delta T(u\text{-}r)$"

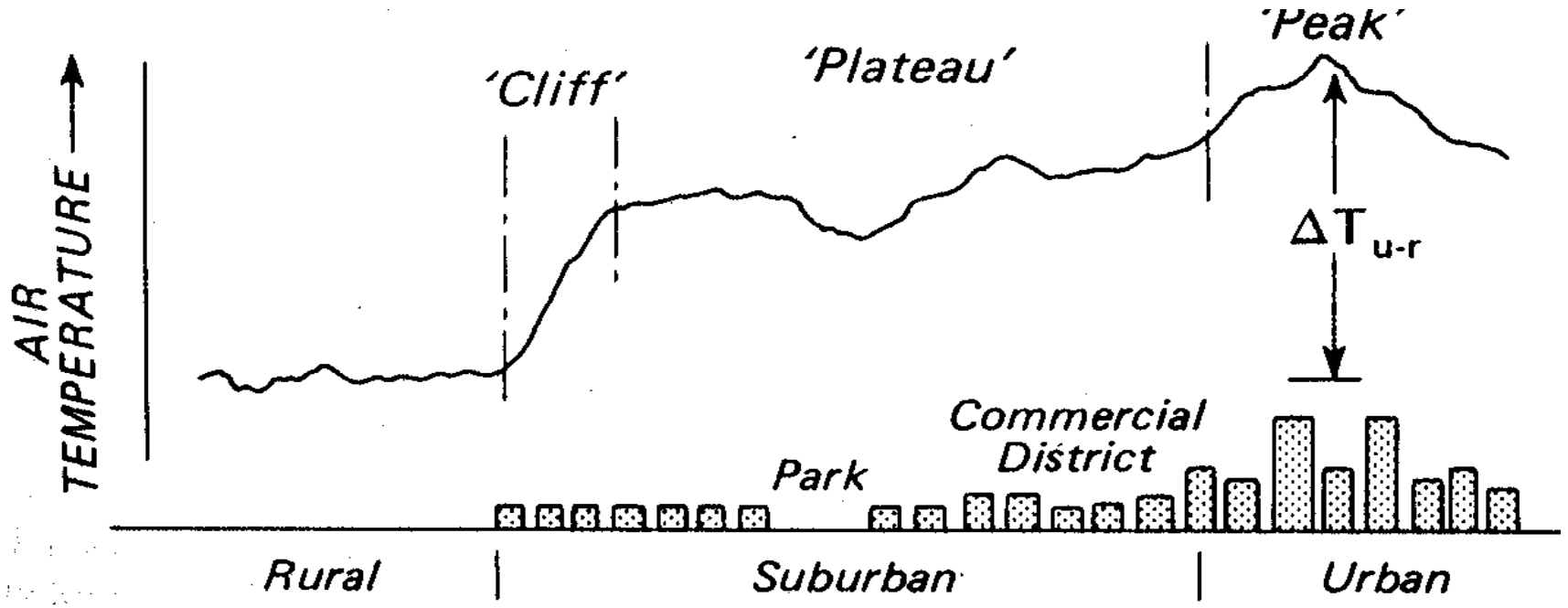
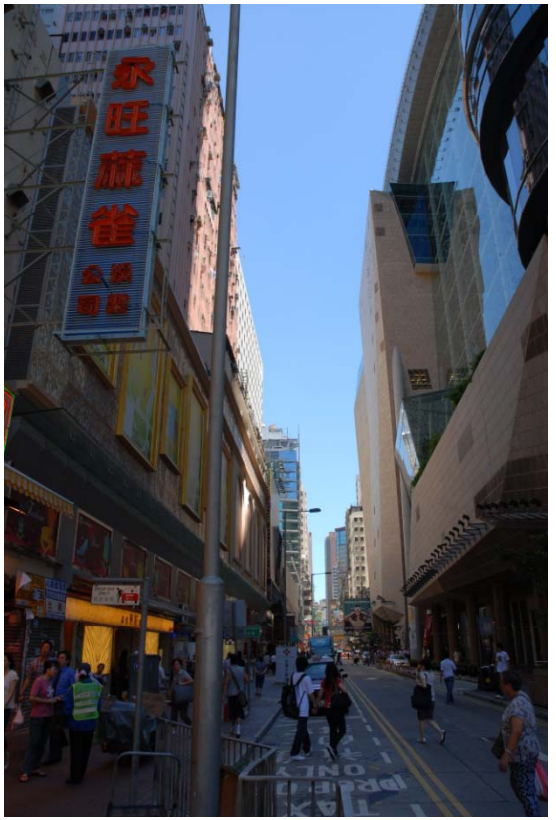


Figure 8.13 Generalized cross-section of a typical urban heat island (after Oke, 1976b).

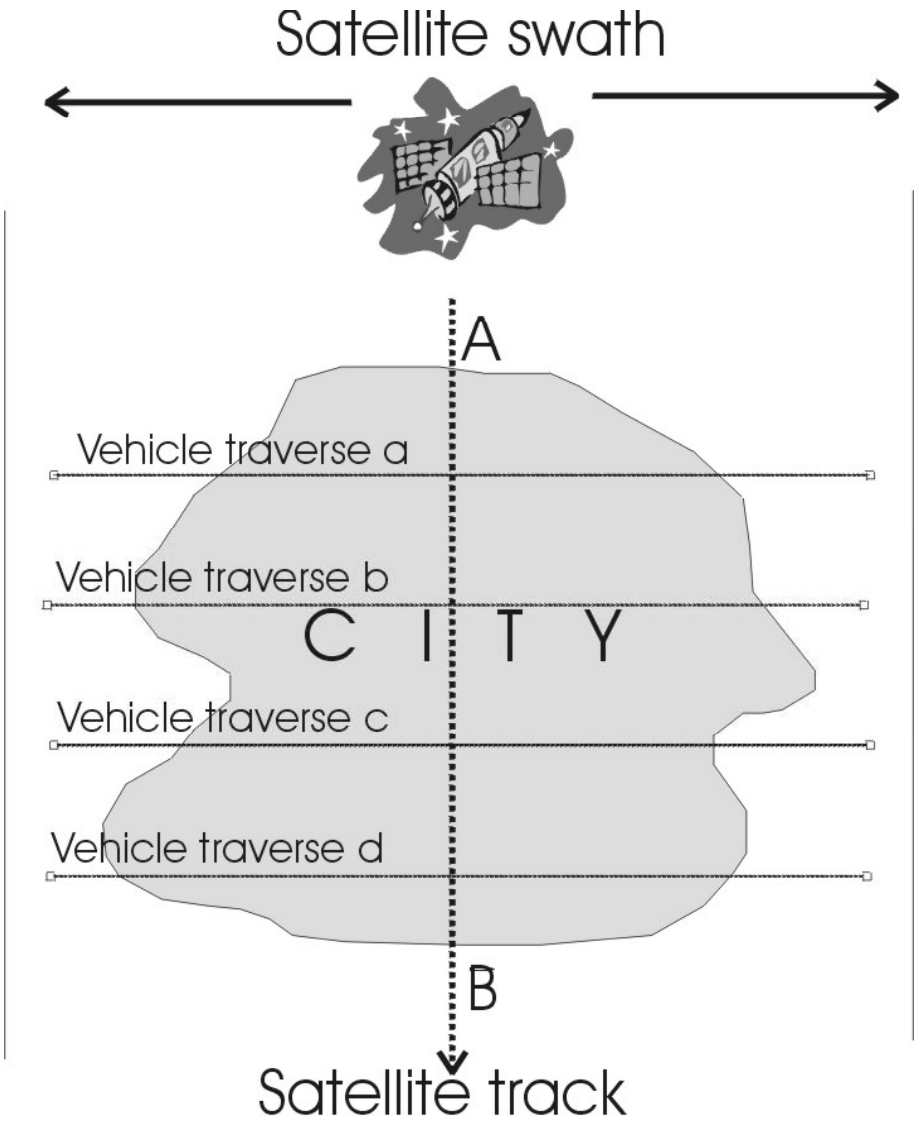
Environmental factors of urban heat island

- Building materials
- Sky view factor
- Wind
- Green space
- Pollution
- Anthropogenic heat inputs

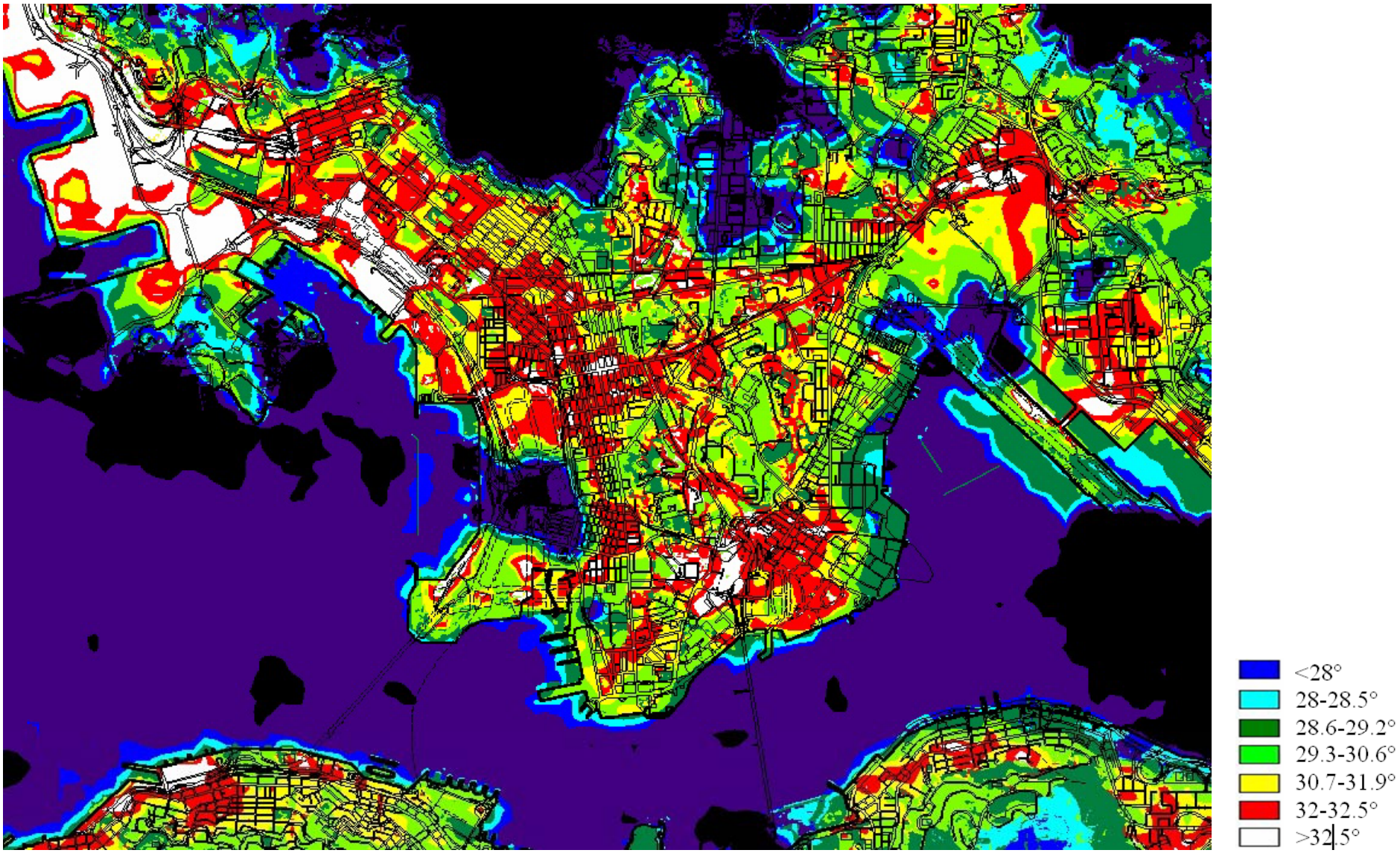


Advantage of remote sensing for Urban Heat Island

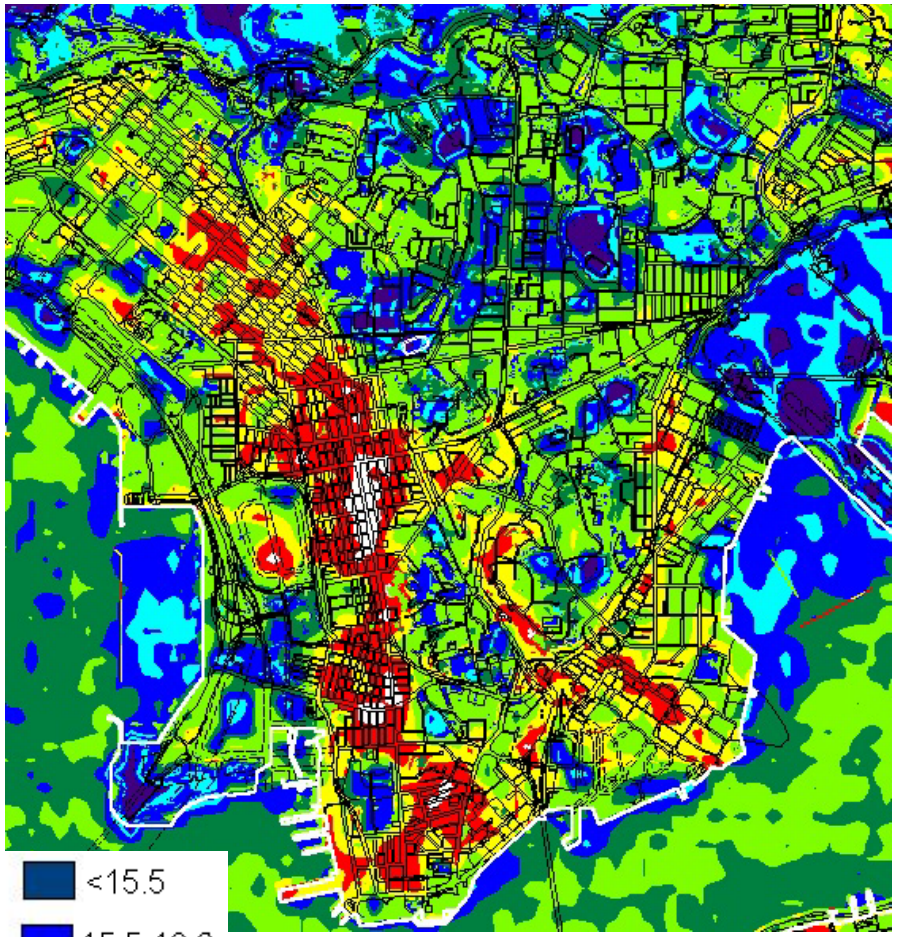
Ability to provide a time-synchronised dense grid of temperature data over a whole city



ASTER nighttime thermal image 04-08-2007

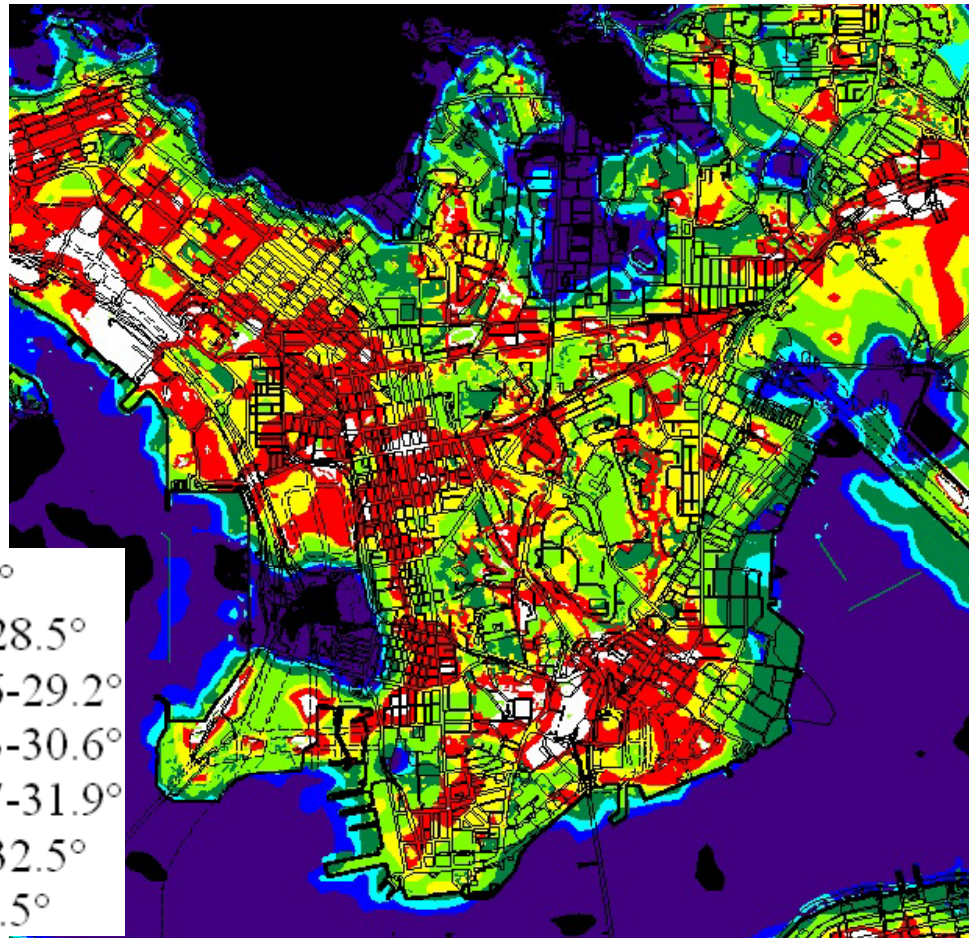


January/August night comparison

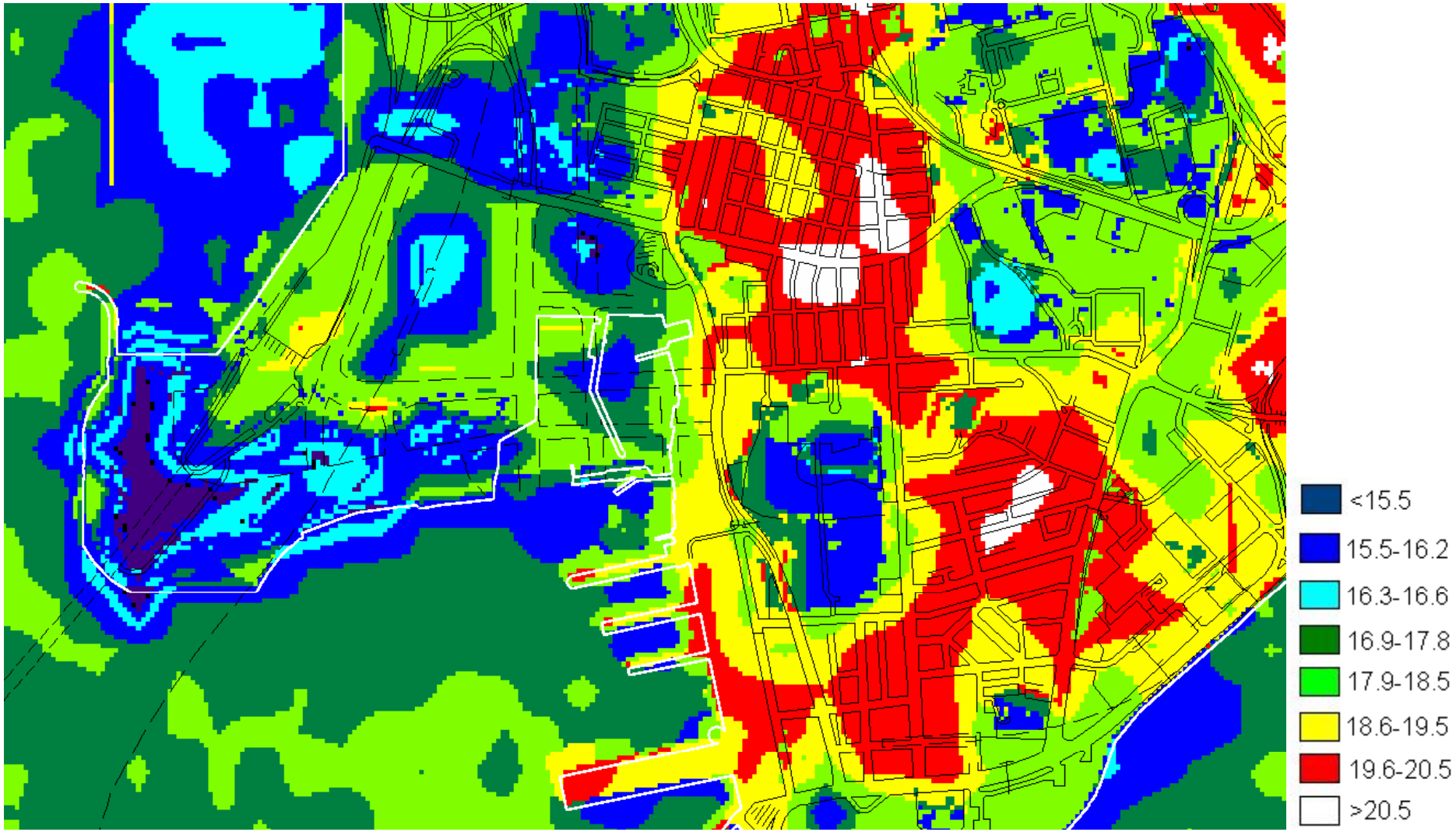


Night-time images

Black=cloud

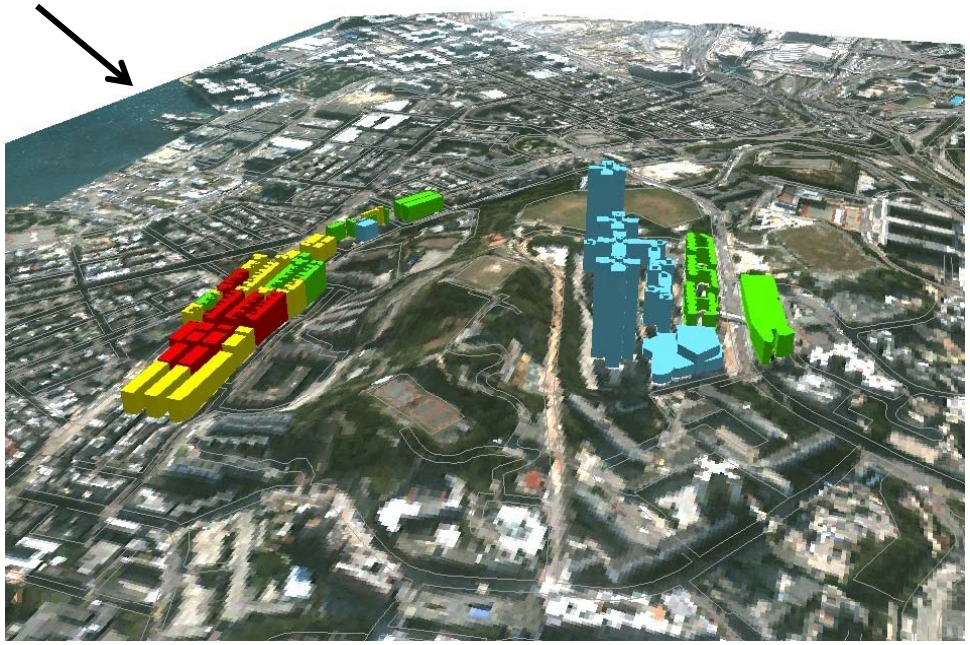


Heat Island of Tsim Sha Tsiu on 31-01-2007 at 10:41pm

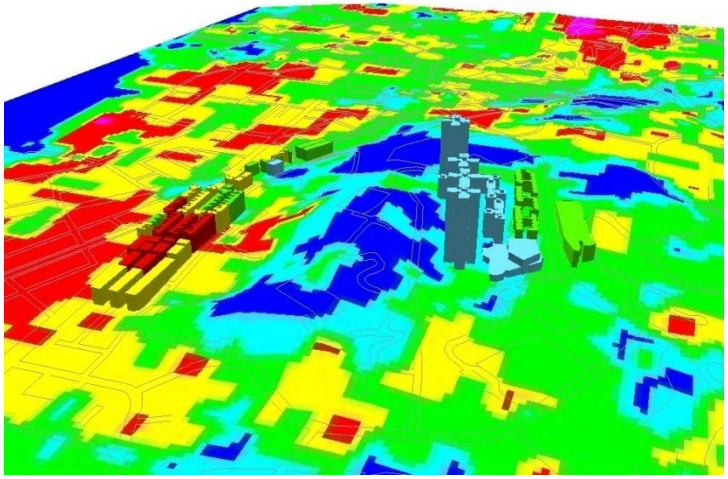


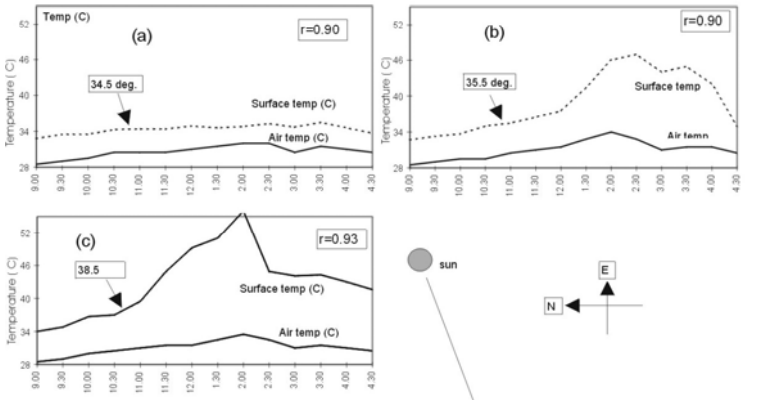
Thermal satellite sensors 'see' only horizontal surfaces: ground data required for extrapolation to vertical surfaces at image time

Solar azimuth
at image time

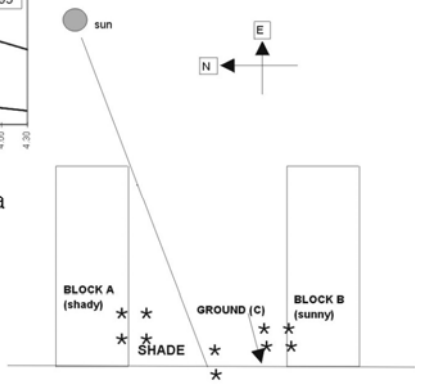


Looking southward over Kowloon:
Ho Man Tin Plaza



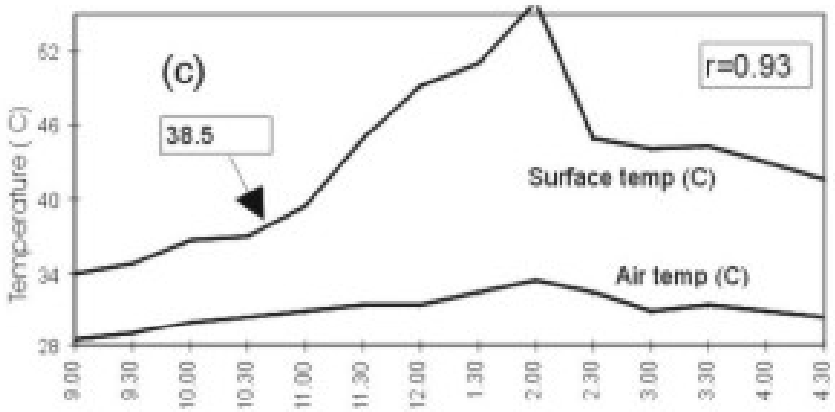


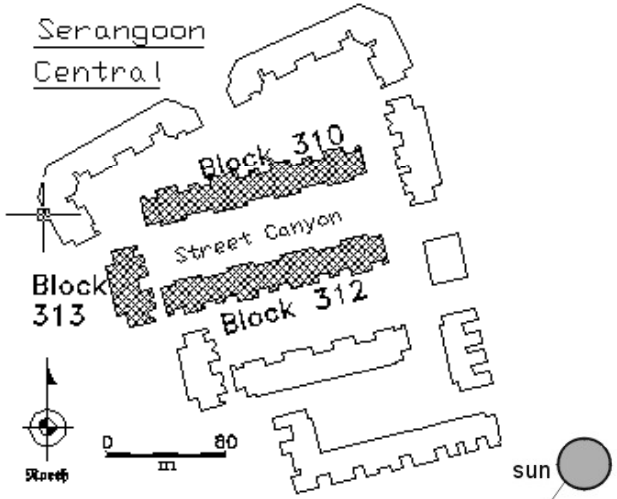
Surface and air temperatures for a street canyon on a sunny day.
(a)=shady walls:
(b)=sunny walls:
(c)=ground, mid-canyon

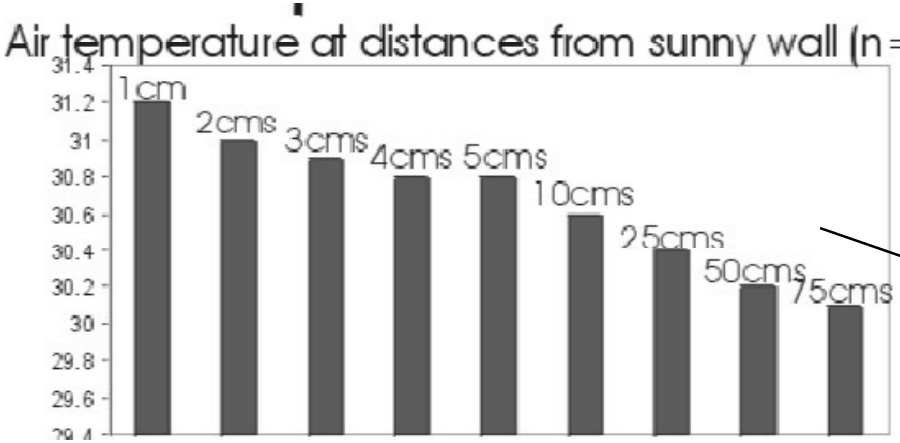


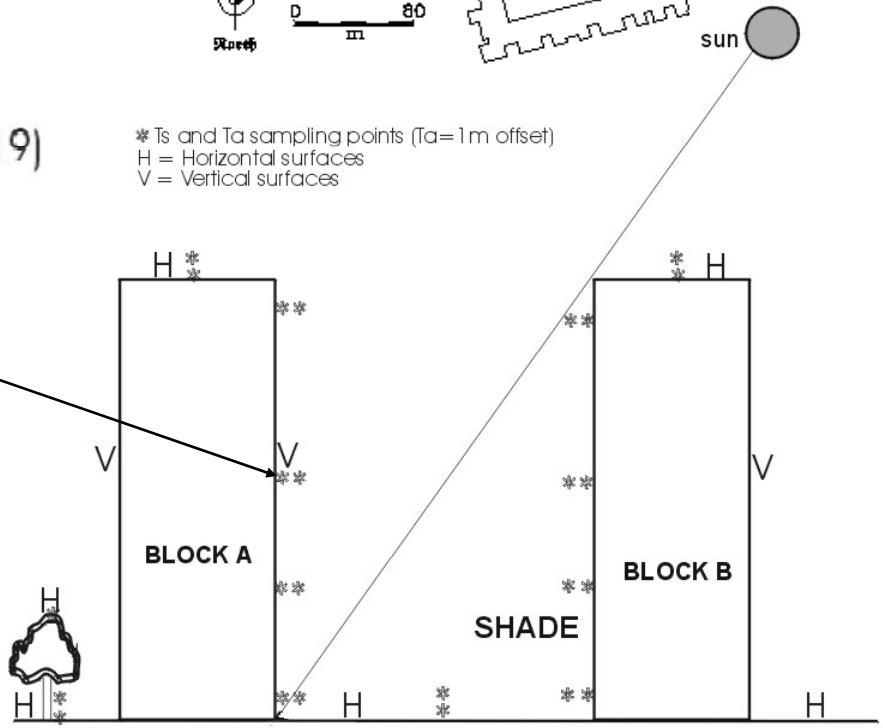
Arrow indicates Ts at time of satellite pass

Thermal satellite sensors 'see' only horizontal surfaces: ground data required for extrapolation to vertical surfaces at image time

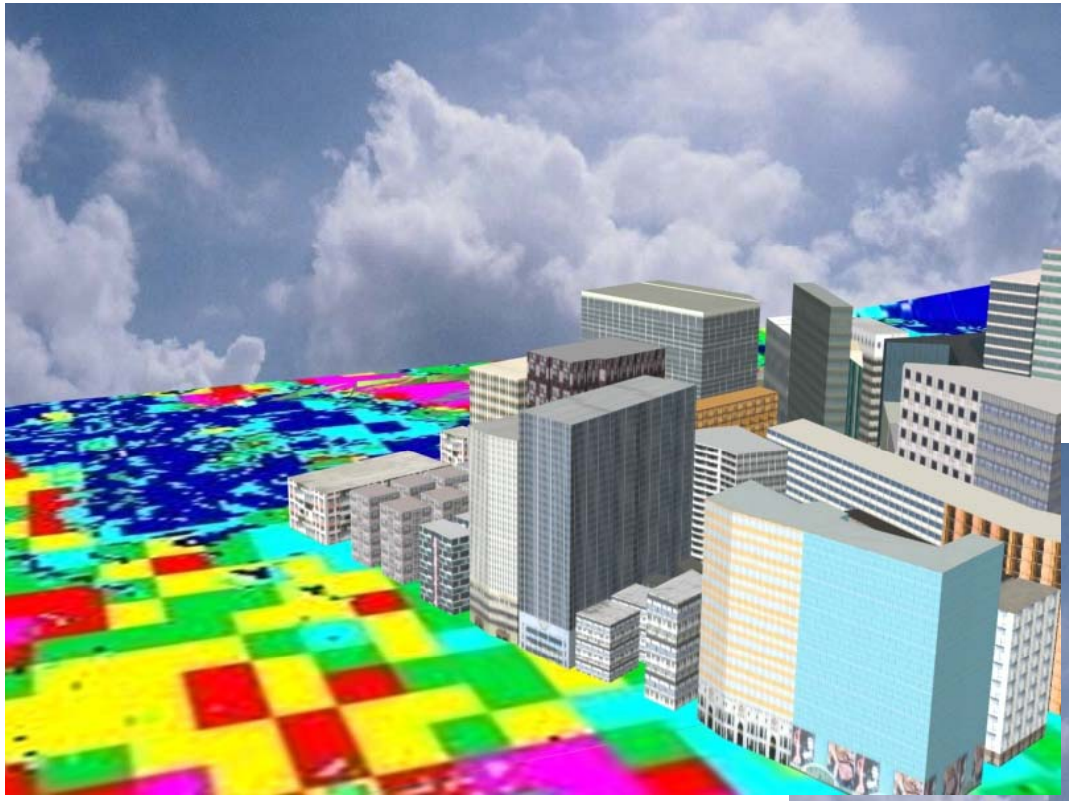




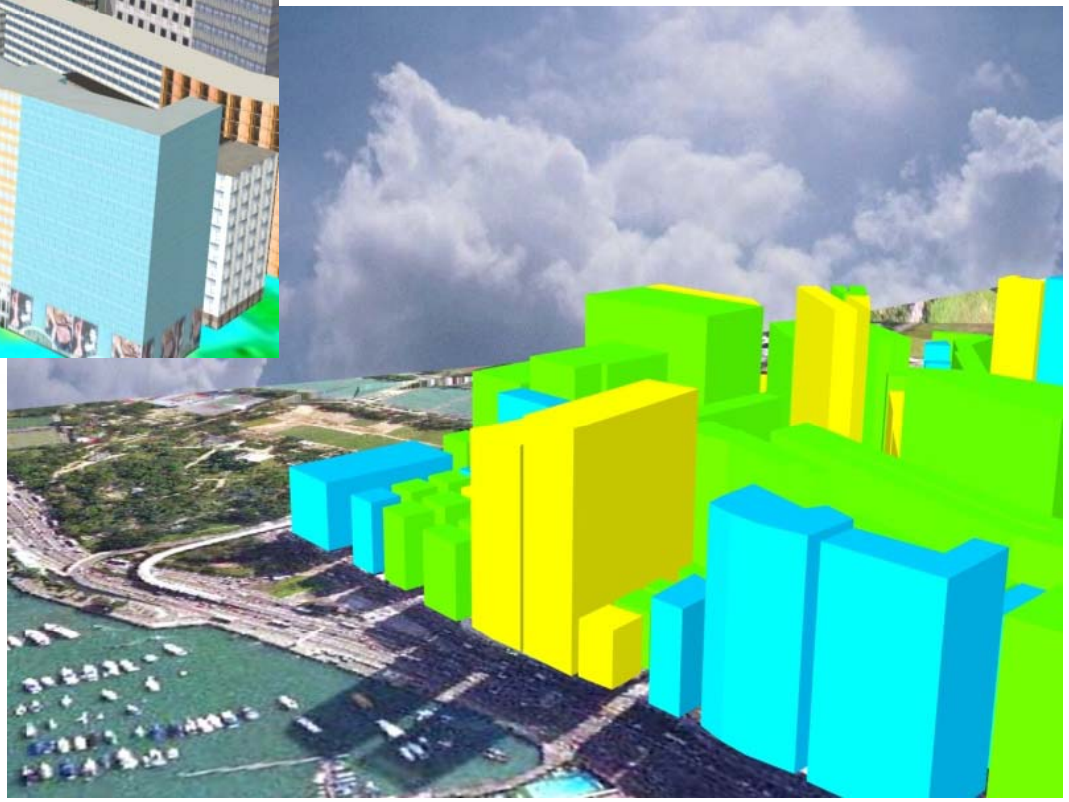




3D Visualisation of the Urban Heat Island



In Causeway Bay the building surfaces are mainly tile and reflective glass and remain relatively cool



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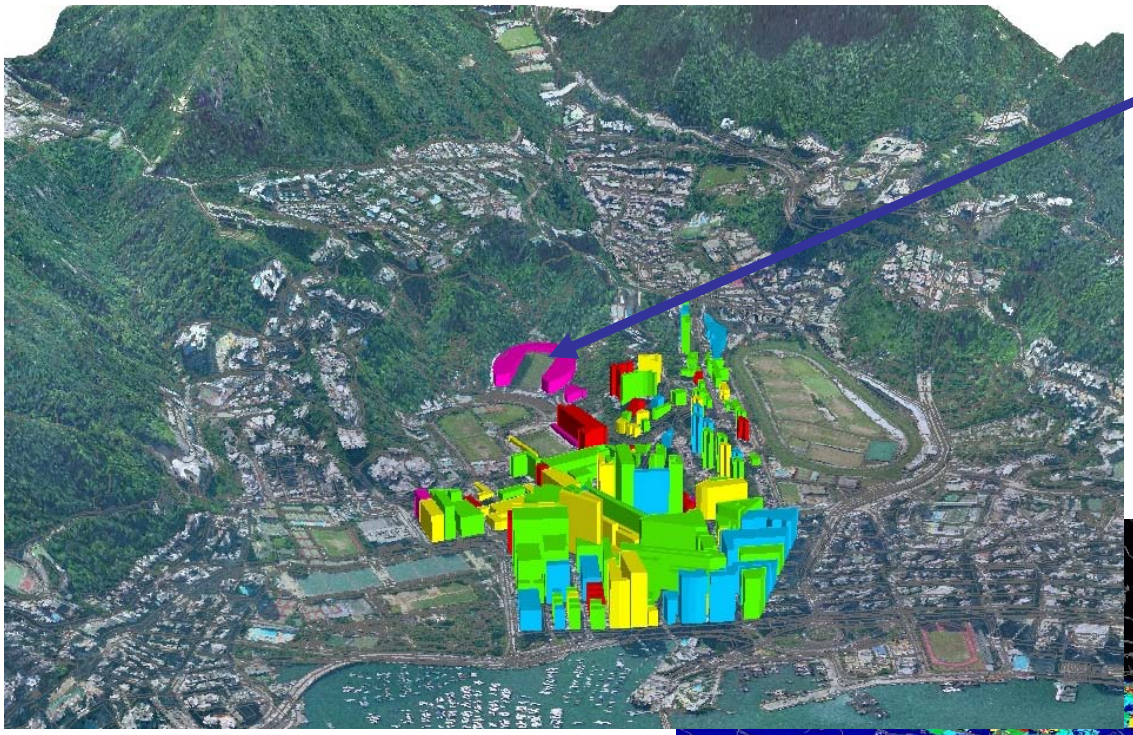
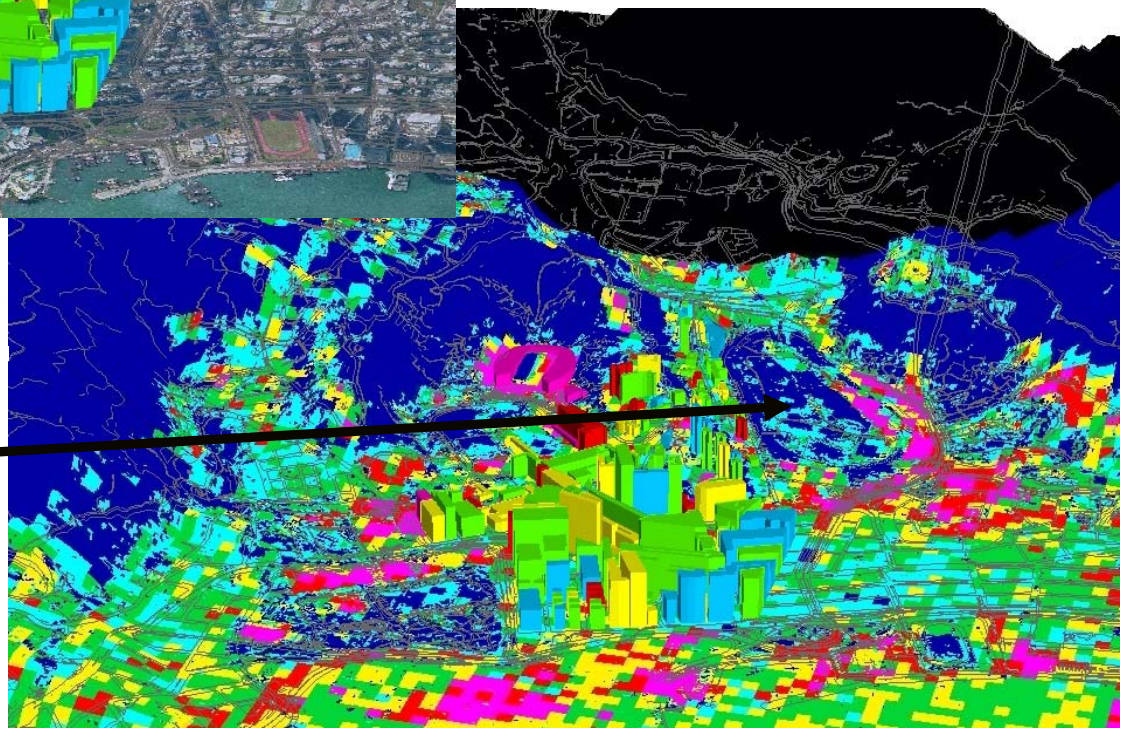


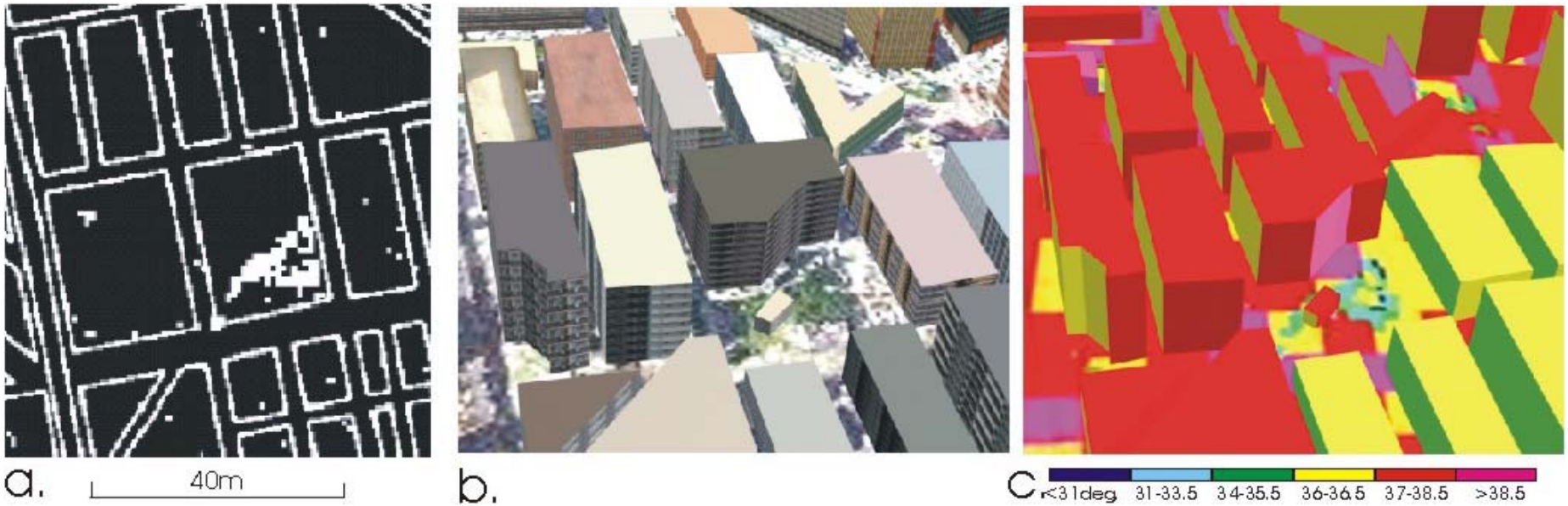
National Stadium is a low rise building so has no shadow: also it has artificial turf so it heats rapidly and is the hottest building in the image



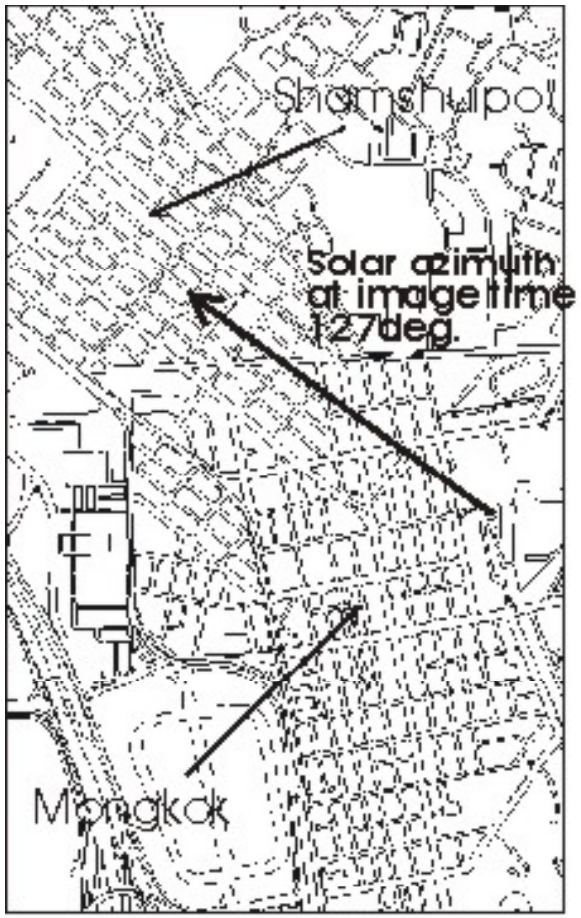
The racecourse is real grass and remains cool due to evapotranspiration

Benefits of 3D visualisation of satellite data

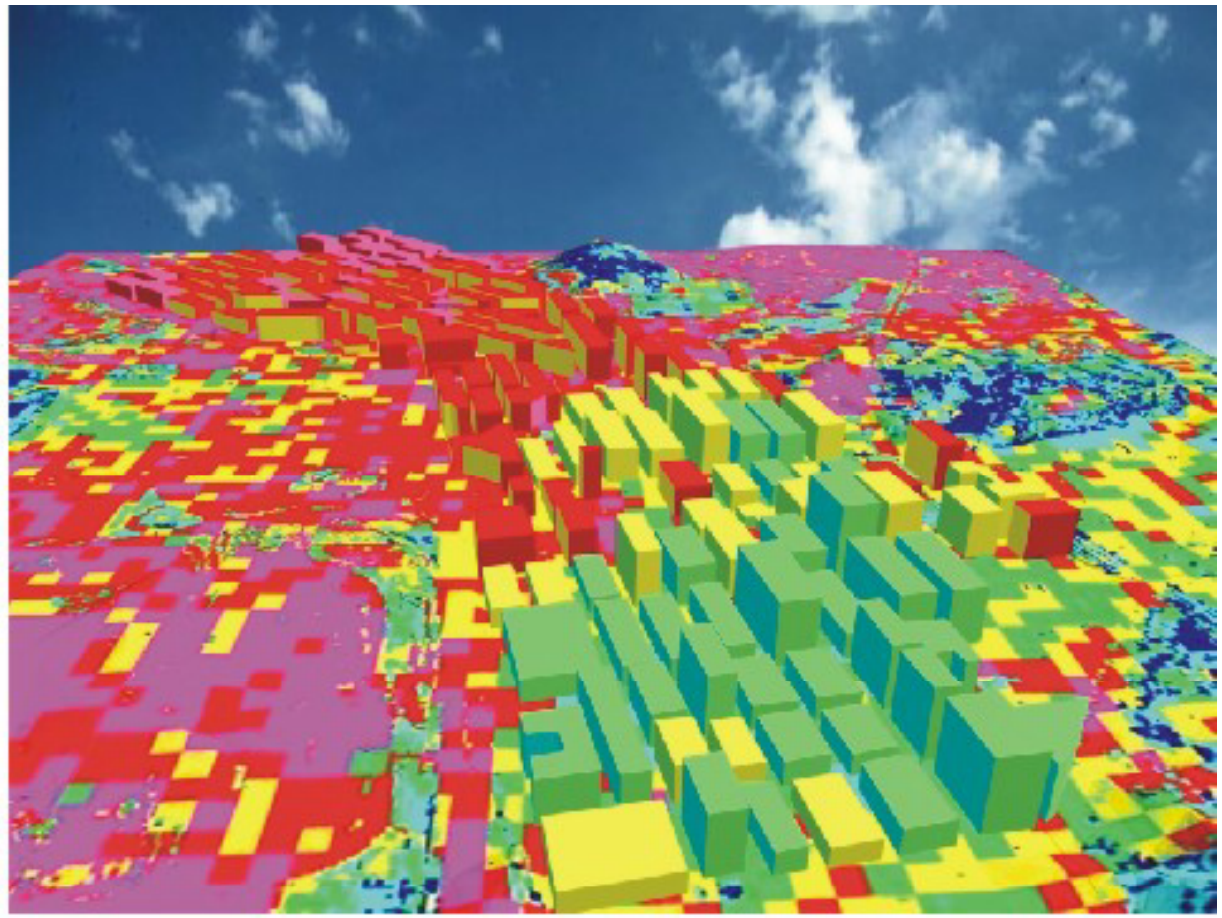
The dominant cooling effect is not shadow but vegetation, as the surface temperature of the park is 6-7^{o}C cooler than surrounding areas which include shady street canyons



3D model shows Mongkok is still in shade at image time (importance of geometry)

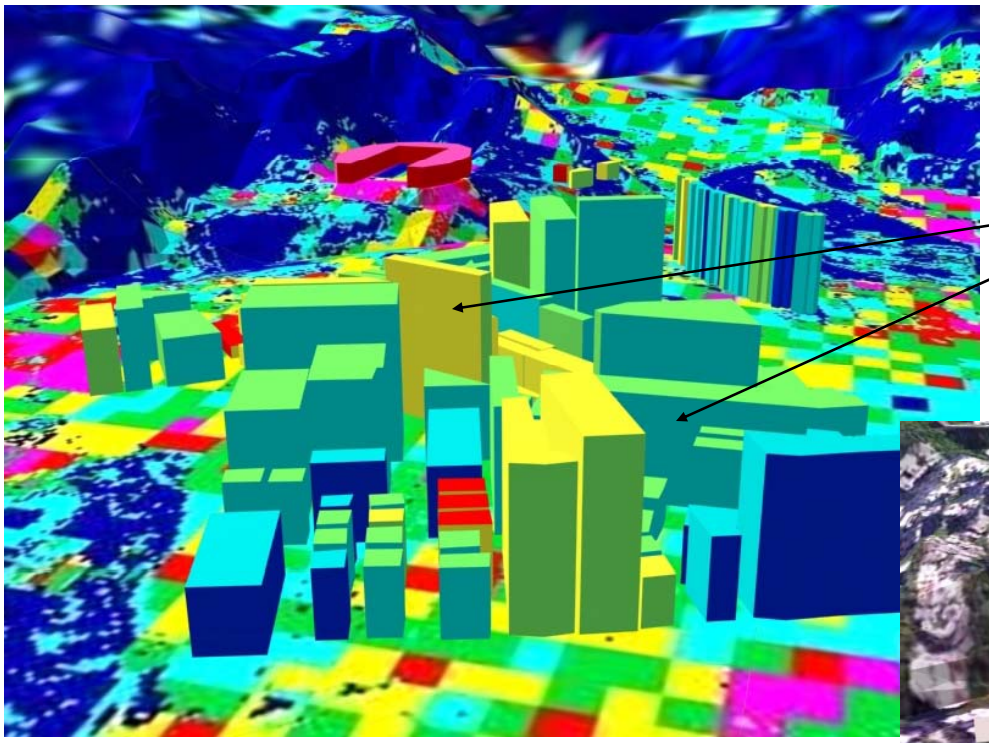


a. 600m



b. <31deg. 31-33.5 34-35.5 36-36.5 37-38.5 >38.5

3D model shows two buildings in Causeway Bay block the monsoon wind



Blocking the monsoon wind

Causeway Bay

Scenario analysis

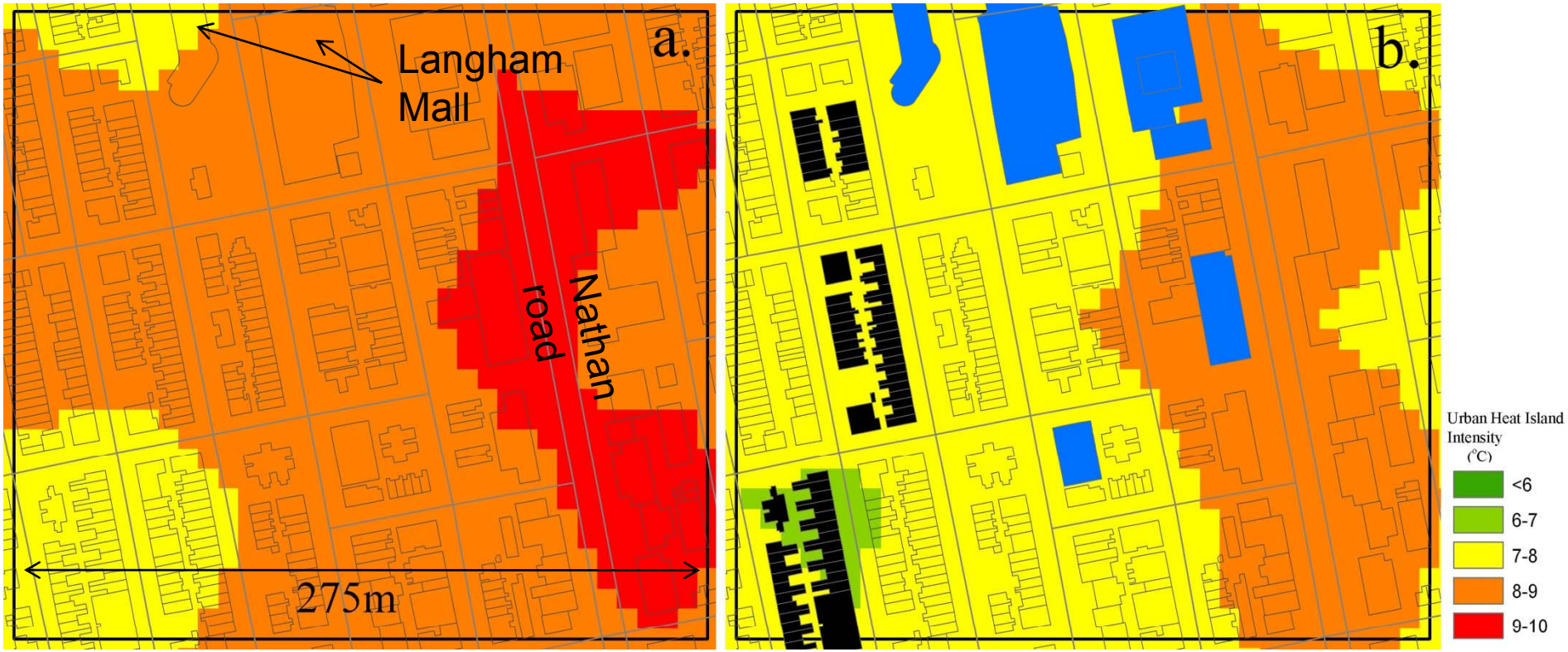
- The application of the derived **mathematical models can be related to planning situations**, and results can be tabulated

With AOT						
	AOT	**NDVI**	**BD**	**BH**		**HII**
Case 1	-1%	+1%	-1%	-1%	➔	-5%
Case 2	-5%	+5%	-5%	-5%	➔	-23%
Case 3	-10%	+10%	-10%	-10%	➔	-46%
……						
Without AOT						
		NDVI	**BD**	**BH**		**HII**
Case 1		+1%	-1%	-1%	➔	-16%
Case 2		+5%	-5%	-5%	➔	-83%
Case 3		+10%	-10%	-10%	➔	-166%
……						

ie. the AOT, BD and BH are reduced by 1% and NDVI increased by 1%, then estimated Heat Island Intensity will reduce by 5%

Scenario analysis of planning situations for planning and decision-making

Scenario analysis (case 1: MongKok)



- AOT and NDVI (no change), BD and BH decrease 10%
- = UHII decrease 10%
- Polygons with blue colour are reduced the heights by 60%
- Polygons with black colour are removed

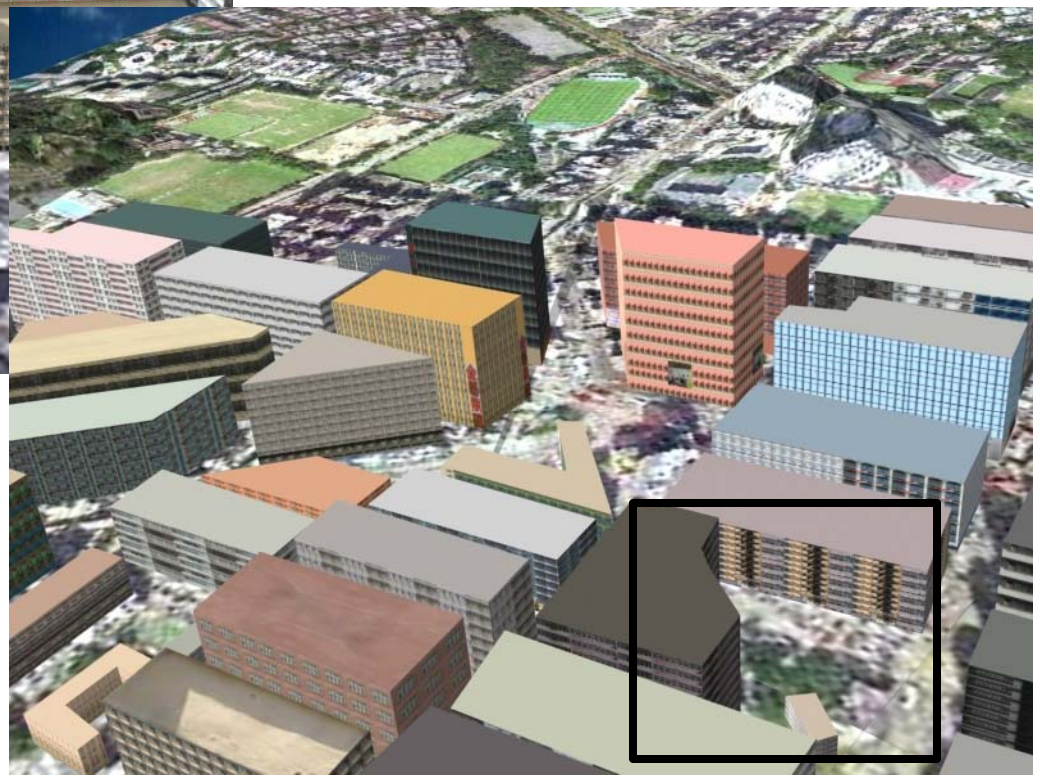
Scenario analysis of planning situations for planning and decision-making
Scenario analysis (case 2: To Kwa Wan)

- AOT and NDVI (no change), BD and BH decrease 10%
- = UHII decrease 10%
- Polygons with blue colour are reduced the heights by 60%
- Polygons with black colour are removed

Scenario analysis of planning situations for planning and decision-making

Site 1

BEFORE



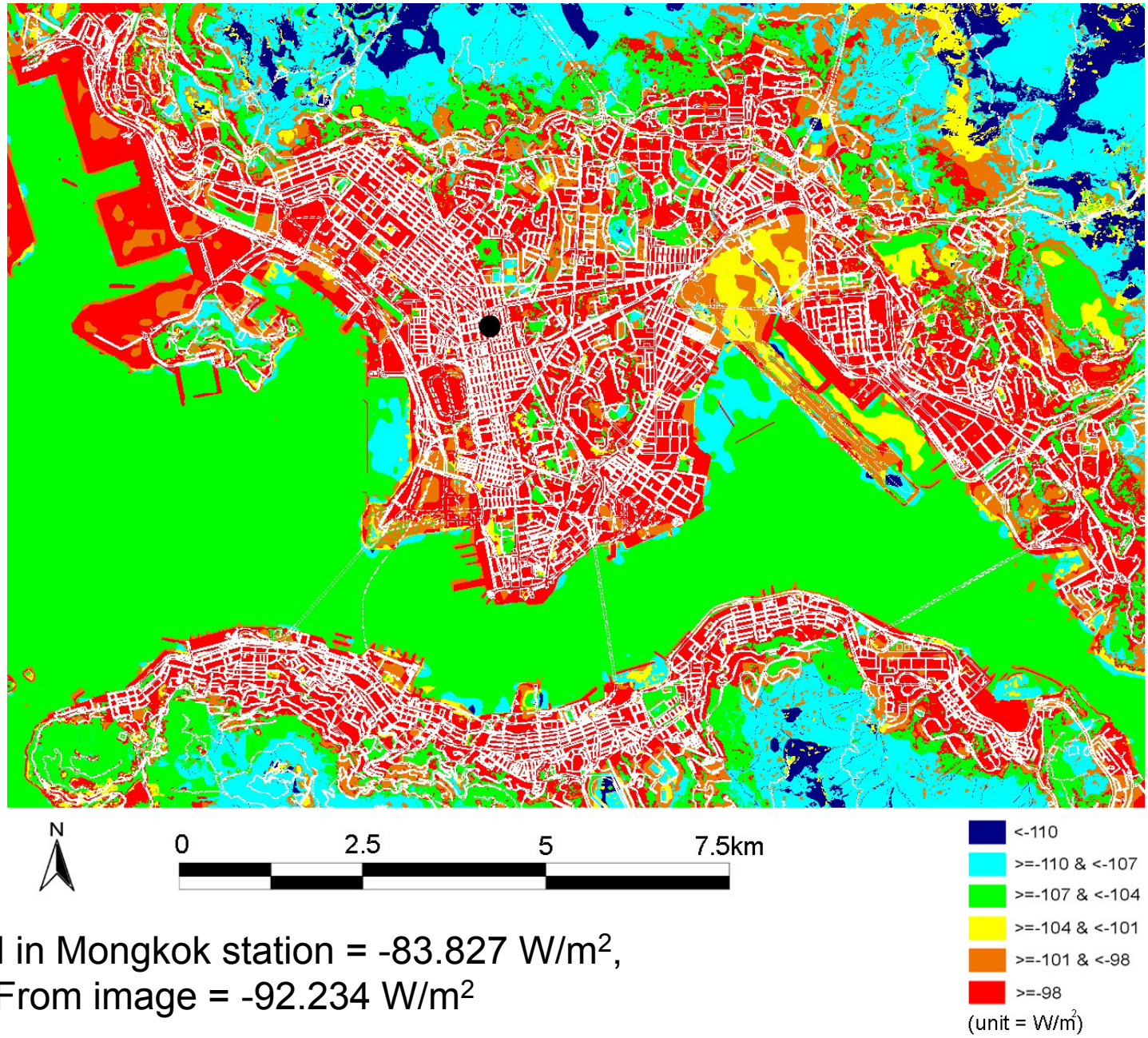
Site 2

Scenario analysis of planning situations for planning and decision-making

AFTER

Maps of anthropogenic heat inputs

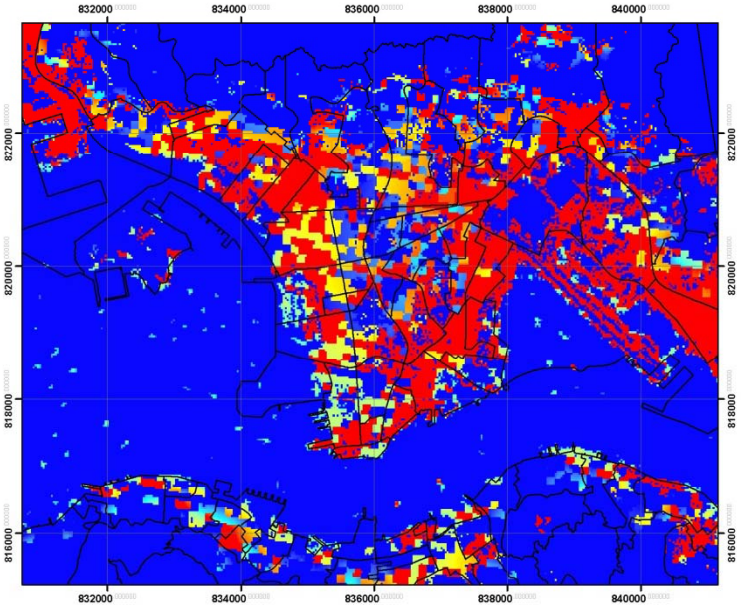
Image converted to Net Radiation (W/m^2)



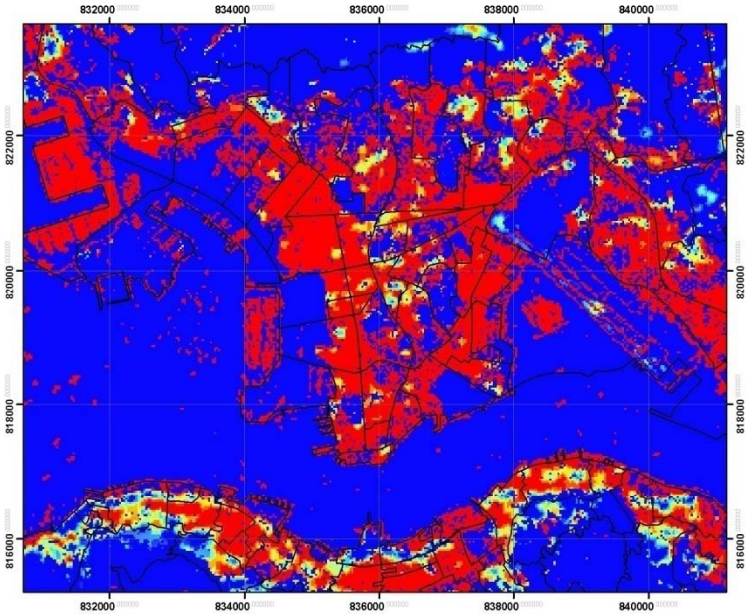
Measured in Mongkok station = -83.827 W/m^2,
From image = -92.234 W/m^2

Maps of anthropogenic heat

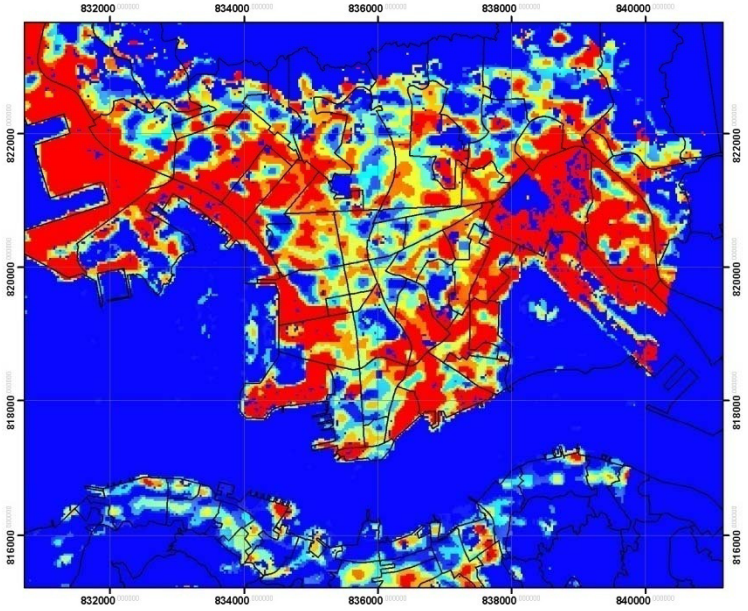
Net radiation (R_n) + Anthropogenic heat (A) = Ground heat (G) + Latent heat (LE) + Sensible heat (H)



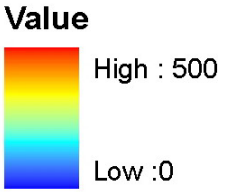
10-Dec-1988



30-Dec-1995



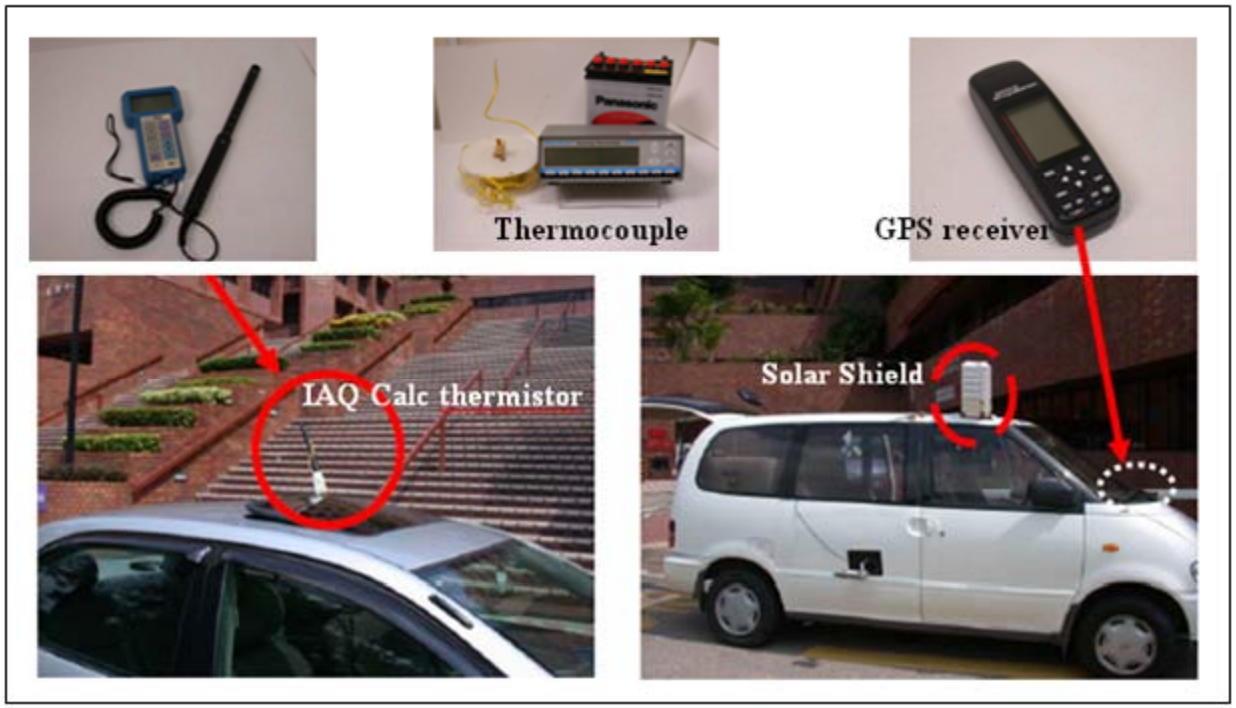
28-Dec-2006



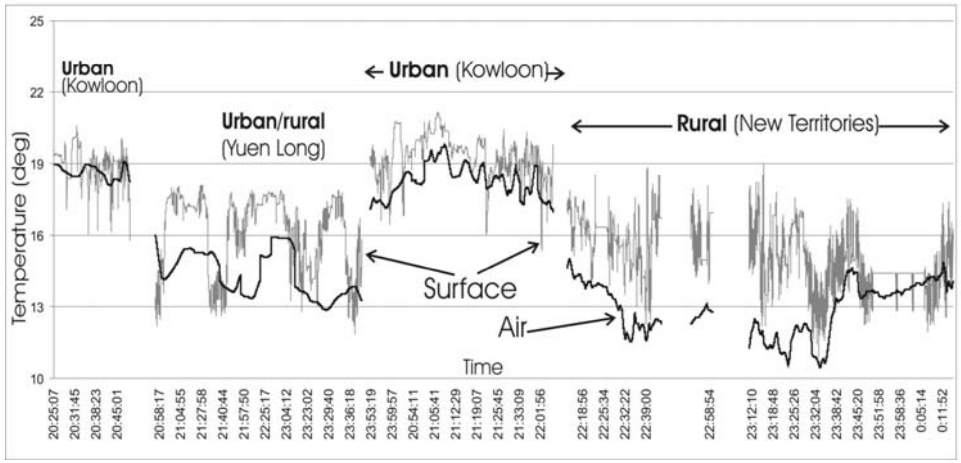
Unit = Wm^{-2}

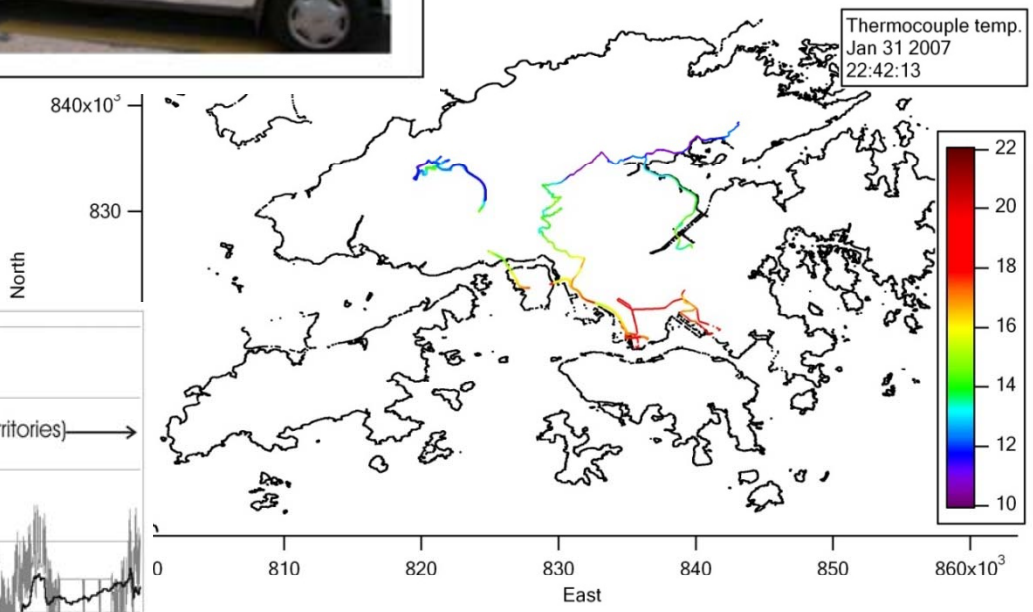
	1988	1995	2006
Kowloon West	13.3	35.3	72.2
Cheung Sha Wan	11.9	35.9	78.8
Hung Hom Bay	10.8	51.4	68.8

Field validation

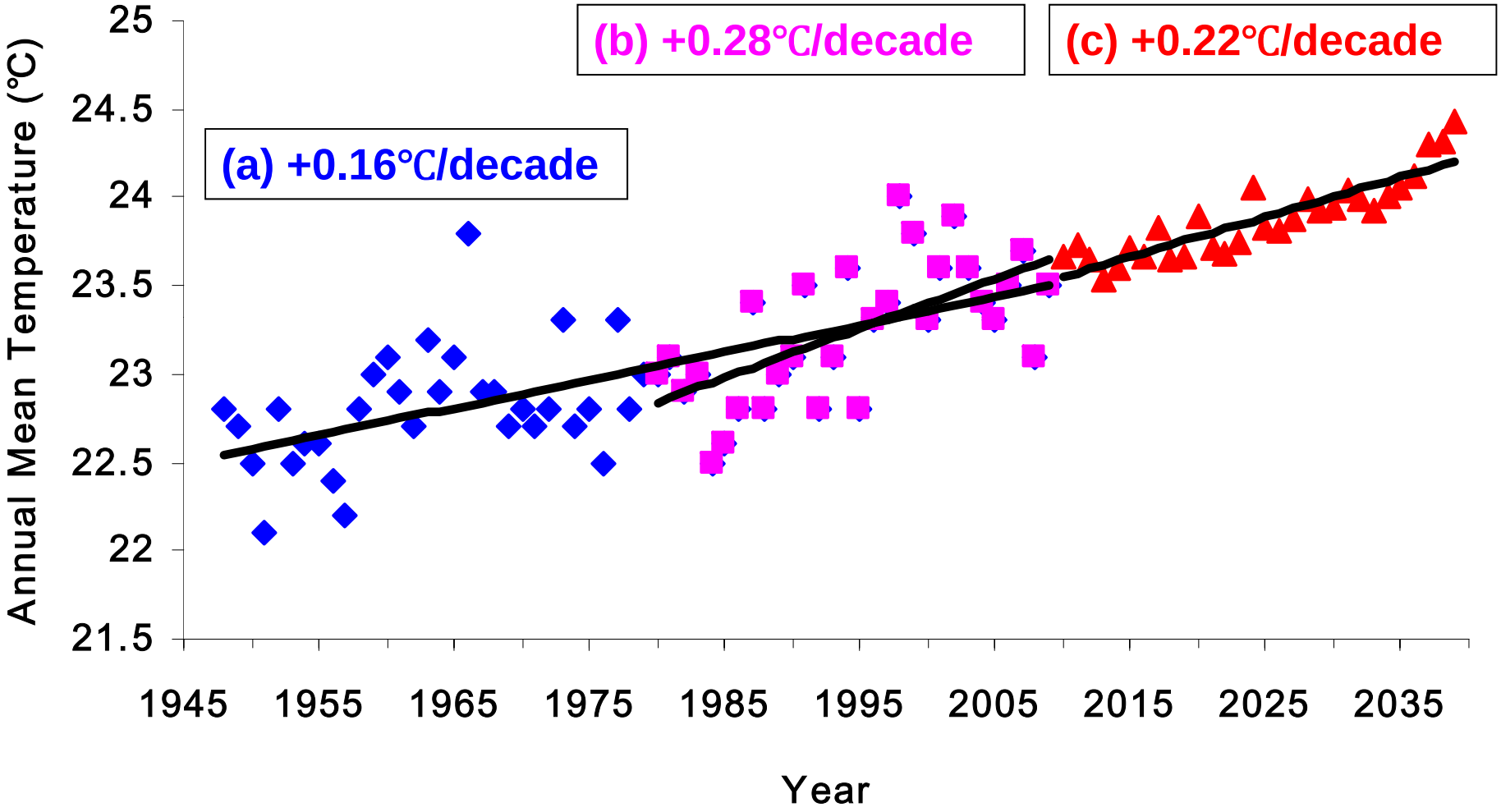


Equipment setting in two cars: two temperature sensors, a GPS receiver and a solar shield





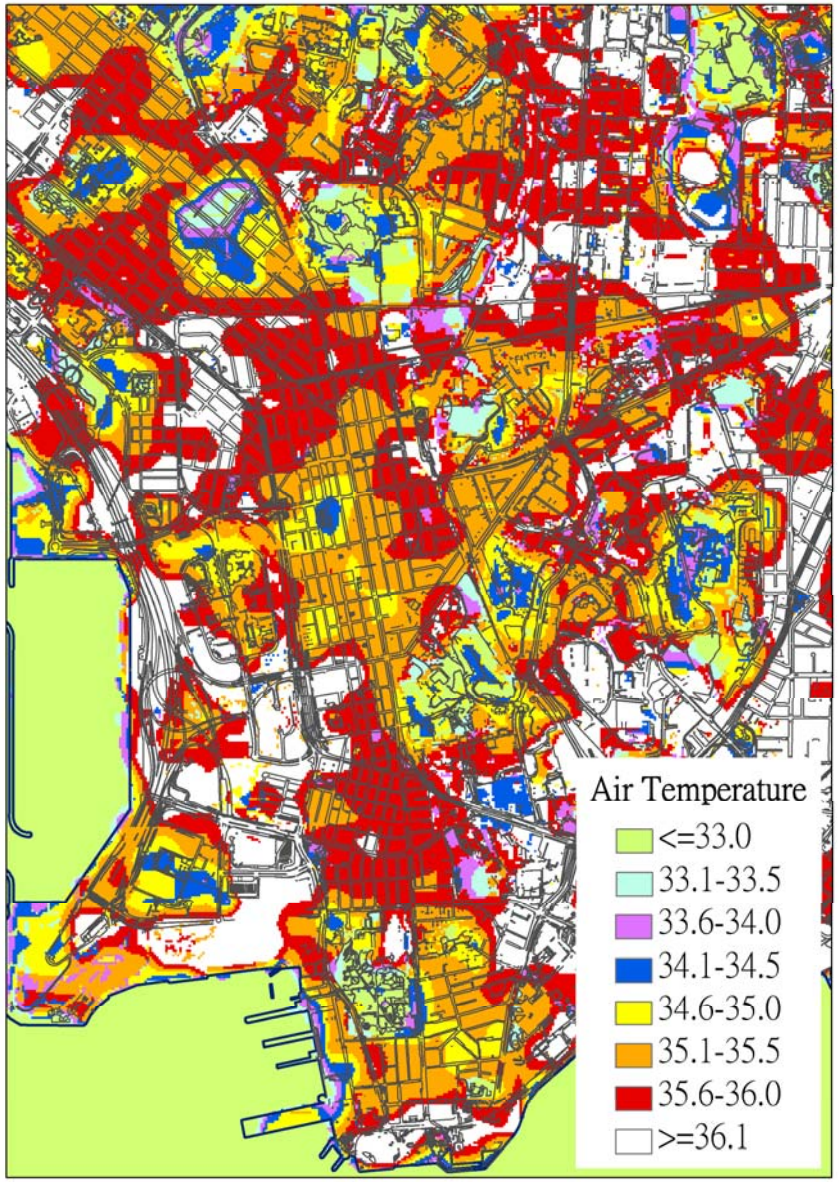
Predictions for high density living under urbanisation trends and climate change scenarios



A comparison between past and projected annual mean temperature at HKO Headquarter (a) 1948 to 2009; (b) 1980 to 2009 and (c) 2010 – 2039 (our projection: assume no further urbanisation)

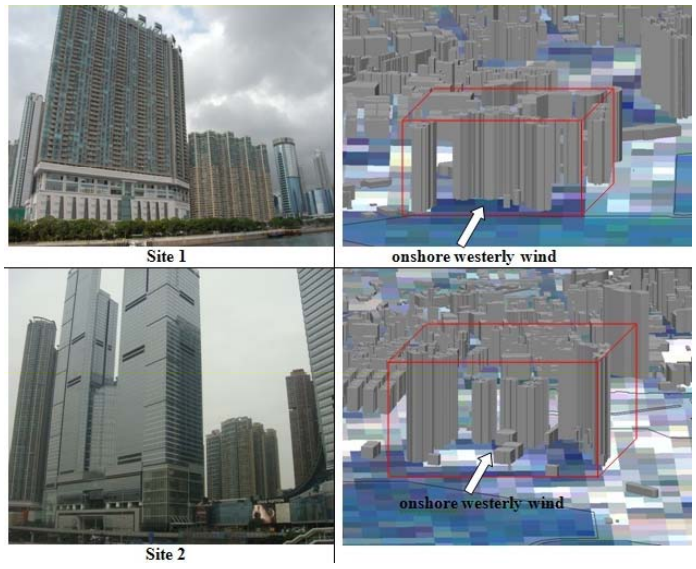
In 2030

- Daytime air temperature remains high
  - >35˚C at most of the urban areas
- Public health
  - In HK 7 more people die per 1˚C increase in temperature in hot days (temperature >29.8˚C)
  - Heat exhaustion and heat stroke
- Thermal comfort
  - 35˚C needs the wind speed of > 5 m/s to mitigate
  - Average wind speed in summer is only 2.44 m/s



Mitigating factors in city design

- Sky view factor
  - Increase this to promote radiation loss
- Roof gardens and street trees
- More irrigation on roadsides
- Increase ventilation flow from upland areas (and sea breezes?)
- Use reflective building materials and natural ventilation features



Our work

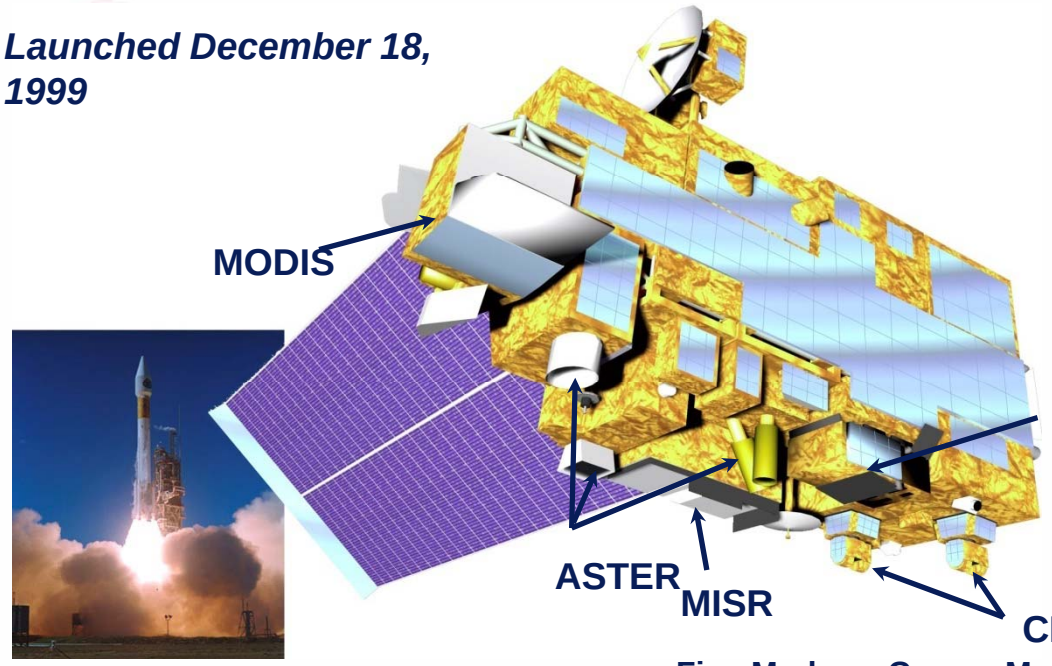
- Wong M. S., Nichol J. E., To P. H. and Wang J. Z. (2010). A simple method for designation of urban ventilation corridors and its application to urban heat island analysis, *Building and Environment*, 45(8), 1880-1889.
- Wong M. S., Nichol J. E. and Lee K. H. (2010), A satellite view of urban heat island: causative factors and scenario analysis, *Korean Journal of Remote Sensing*, 26(6), 617-627.
- Wong M. S., Shaker A. and Lee K. H. (2010), Integrating biophysical and socioeconomic data to support land surface temperature analysis: An example in Hong Kong, *International Journal of Geoinformatics*, 6(1), 1-10.
- Nichol J. E., Fung W. Y., Lam K. S. and Wong M. S. (2009), Urban heat island diagnosis using ASTER satellite images and 'in situ' air temperature, *Atmospheric Research*, 94(2), 276-284.
- Fung W. Y., Lam, K. S., Nichol J. E. and Wong M. S. (2009), Heat Island Study - Satellite Derived Air Temperature, *Journal of Applied Meteorology and Climatology*, 48(4), 863-872.
- Nichol J. E. and Wong M. S. (2008), Spatial variability of air temperature over a city in a winter night, *International Journal of Remote Sensing*, 29(24), 7213-7223.
- Nichol J. E., Wong M. S., C. Fung and K. K. M. Leung (2006), Assessment of urban environmental quality in a sub-tropical city using multispectral satellite images, *Environment and Planning B: Planning and Design*, 33, 39-58.
- Nichol J. E. and Wong M. S. (2005), Modeling urban environmental quality in a tropical city, *Landscape and Urban Planning*, 7, 49-58.
- Nichol, J.E., (2005), Remote sensing of urban heat islands by day and night, *Photogrammetric Engineering and Remote Sensing,* 71(5), 613-621

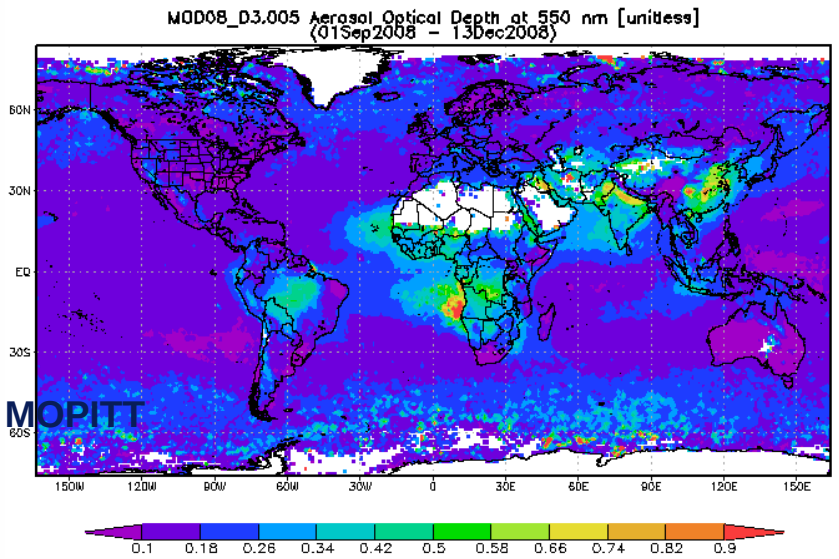
Captured by Dale Quattrochi, 2007

Bad day?

Captured by Dale Quattrochi, 2007

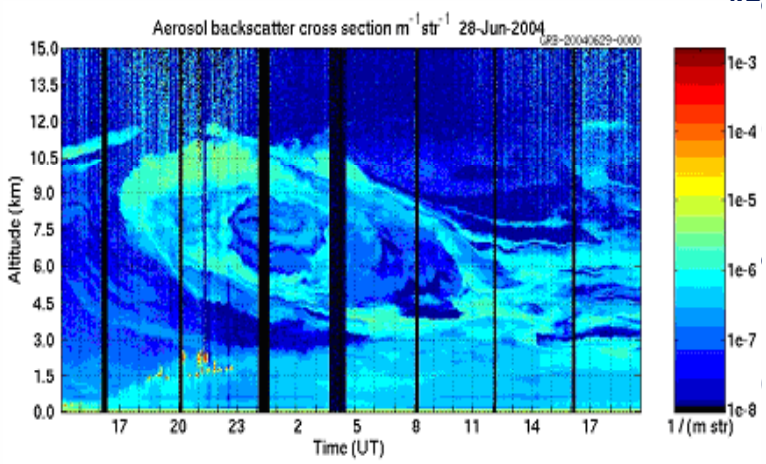
Launched December 18, 1999

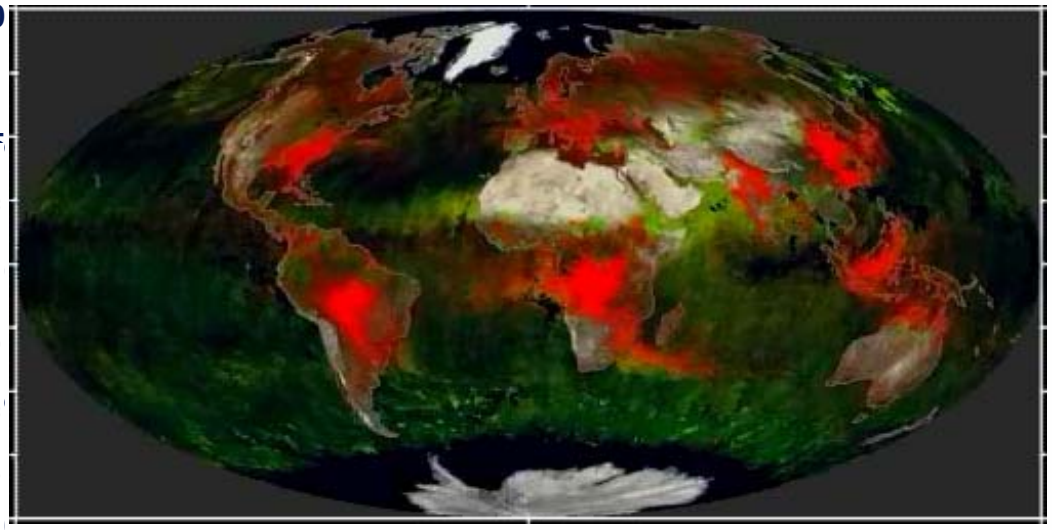




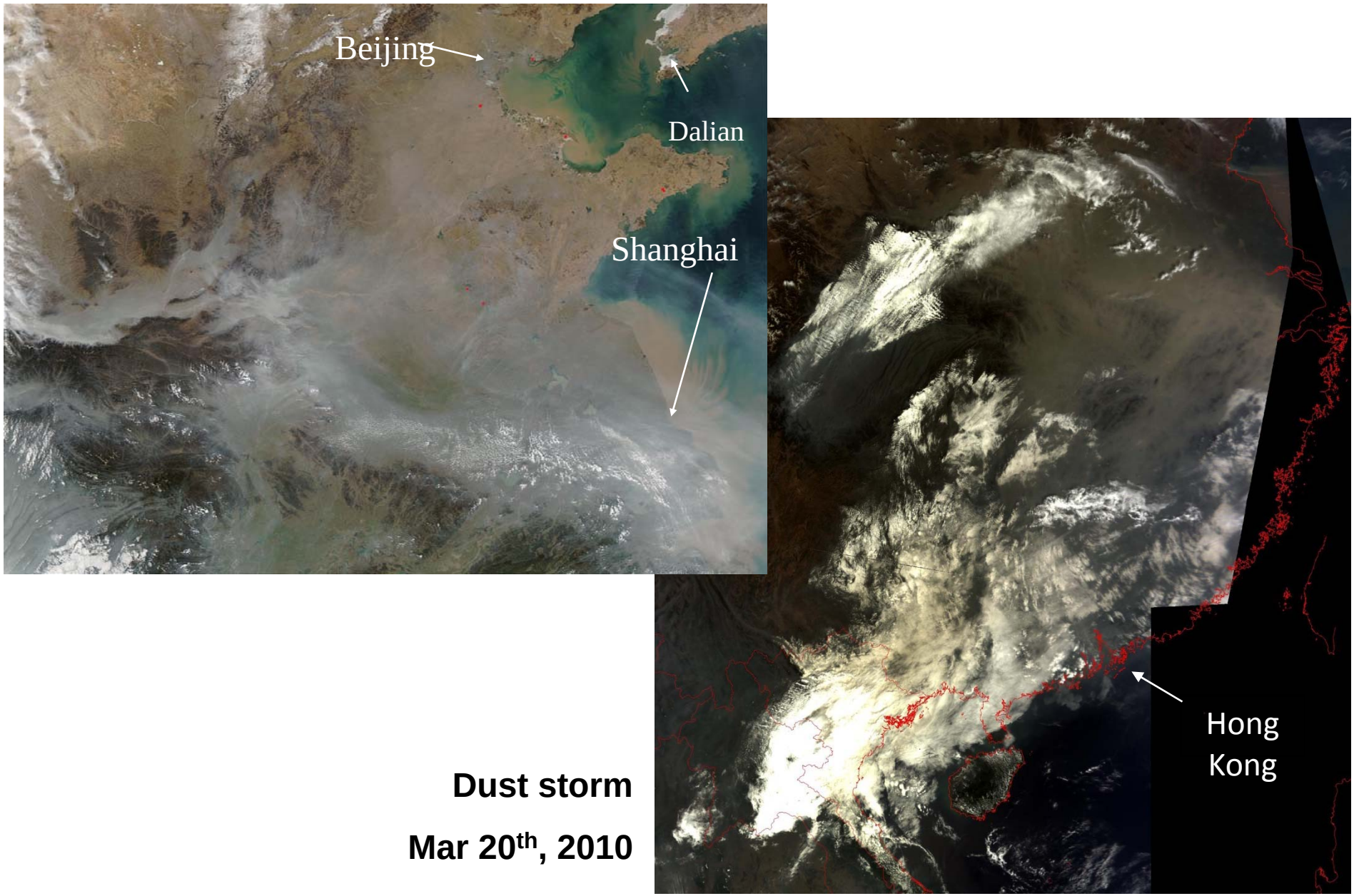
Fine Mode vs Coarse Mode Aerosol

August 30, 2001





Air pollution - MODIS image (China and Hong Kong)



Dust storm

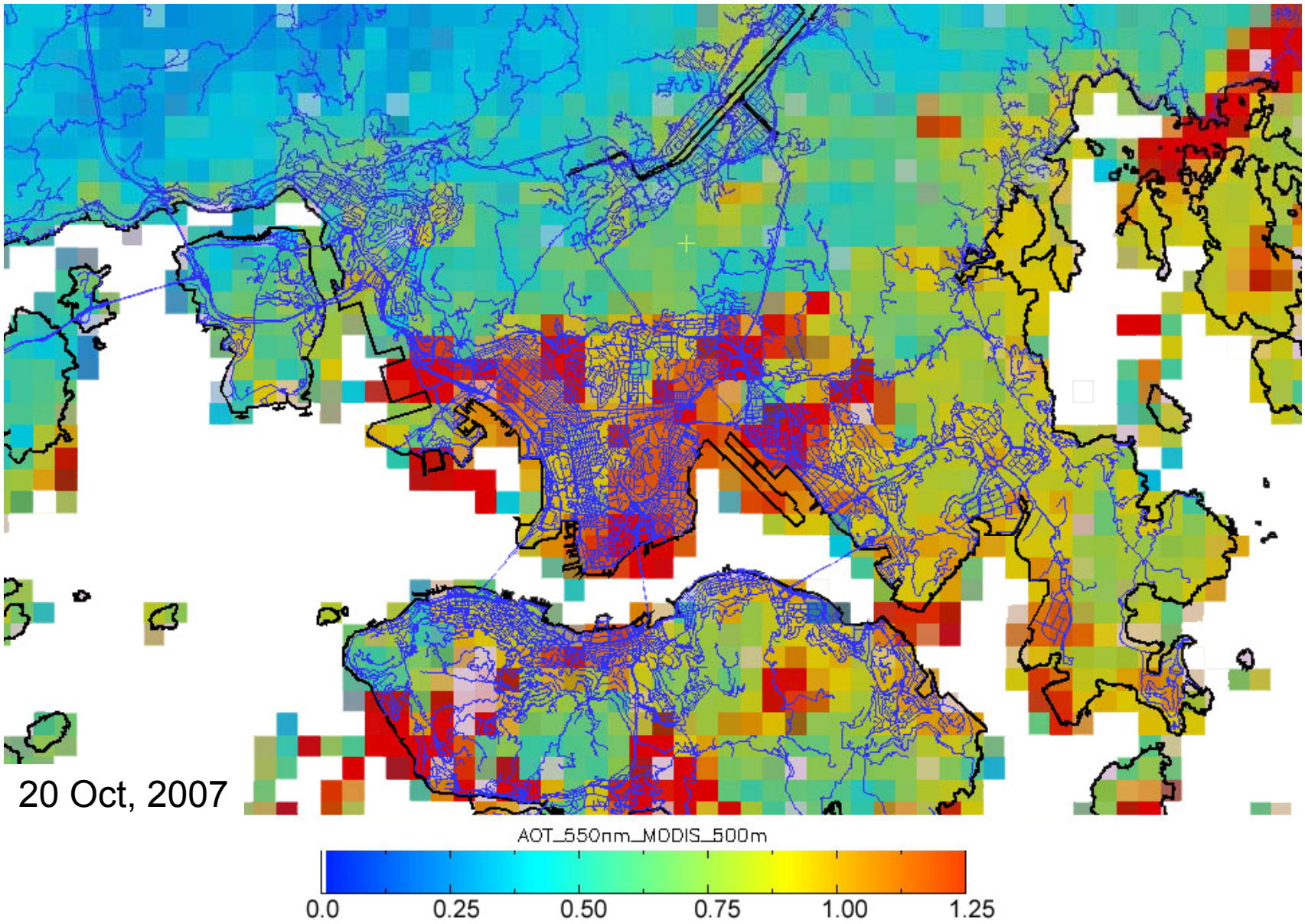
Mar 20th, 2010

Hong Kong AERONET stations – PolyU under 10-year agreements with NASA

PolyU Campus

Hok Tsui

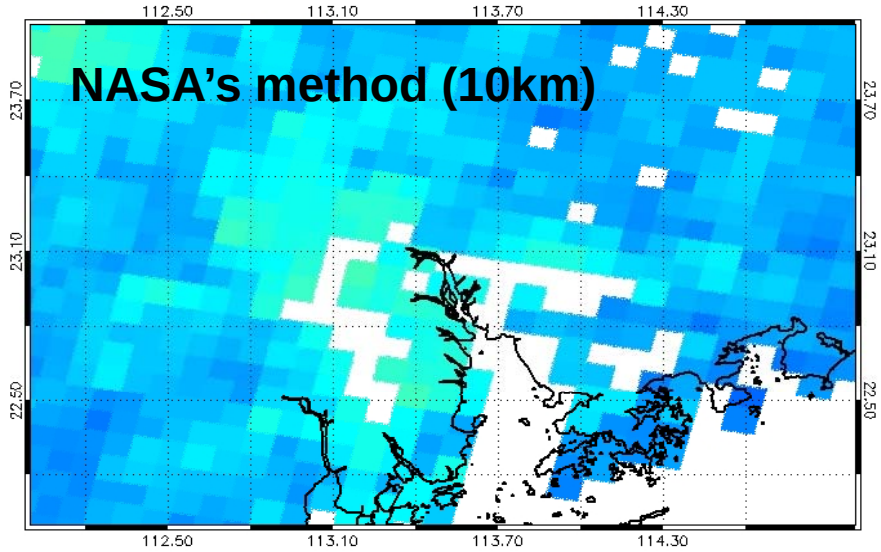
Mapping of urban pollution concentrations

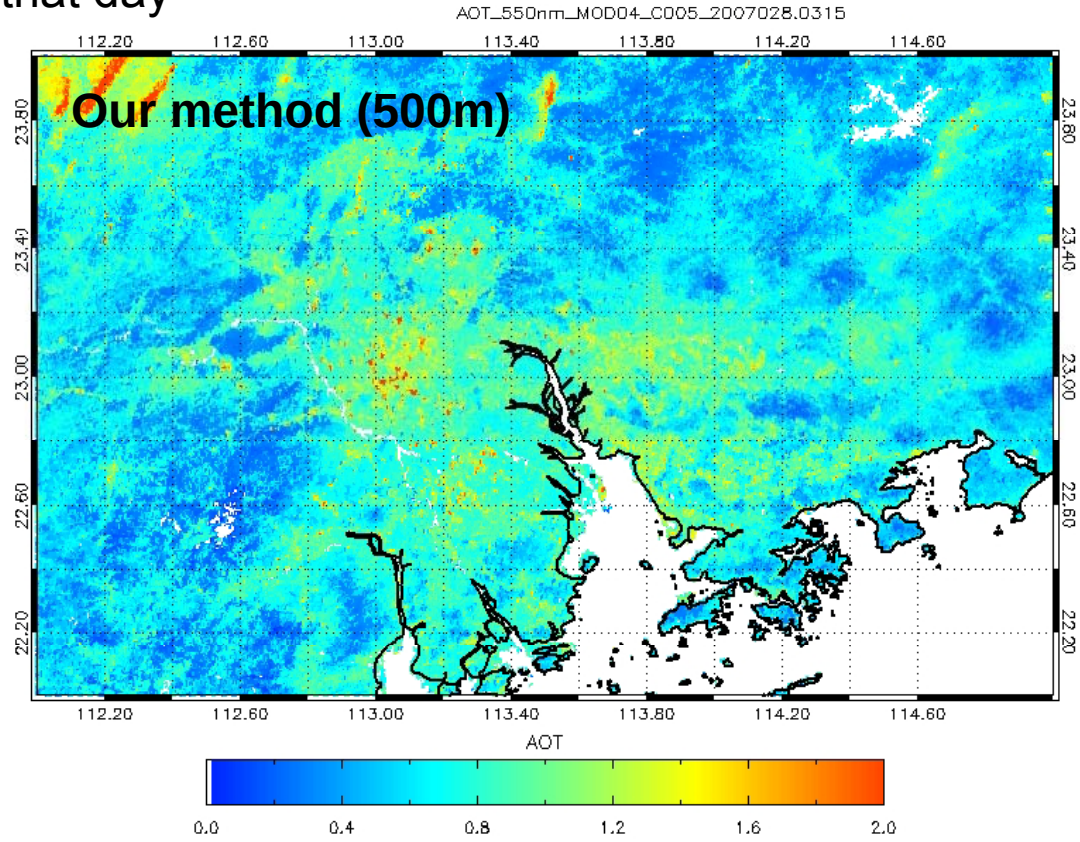


Correlations of 0.69, 0.40 and 0.31 for NO_2, NO_x and SO_2 were obtained

Monitoring of regional aerosols

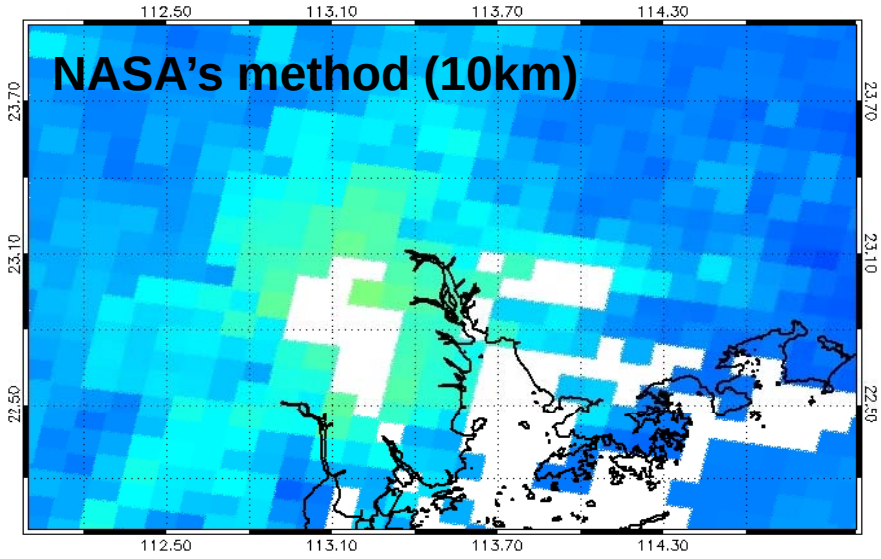
- AOT image on 28 Jan, 2007
  - Relative low AOT values over the PRD
  - High wind speeds (~4ms^{-1}) on that day

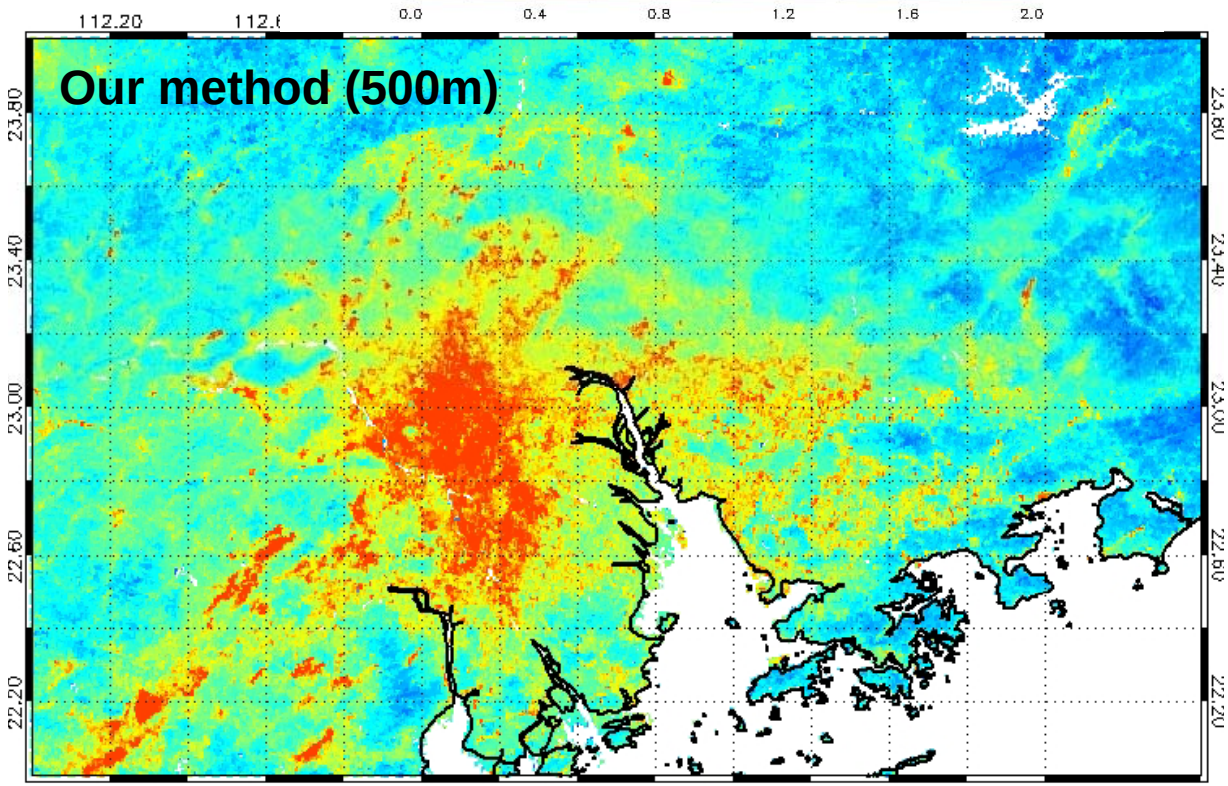




•AOT image on 30 Jan, 2007

- A rapid increase of AOT occurred two days later
- Extremely high AOT
- Low wind speeds (~1ms^{-1}) on that day
- The northern part of H.K. also suffered from cross-boundary pollutants

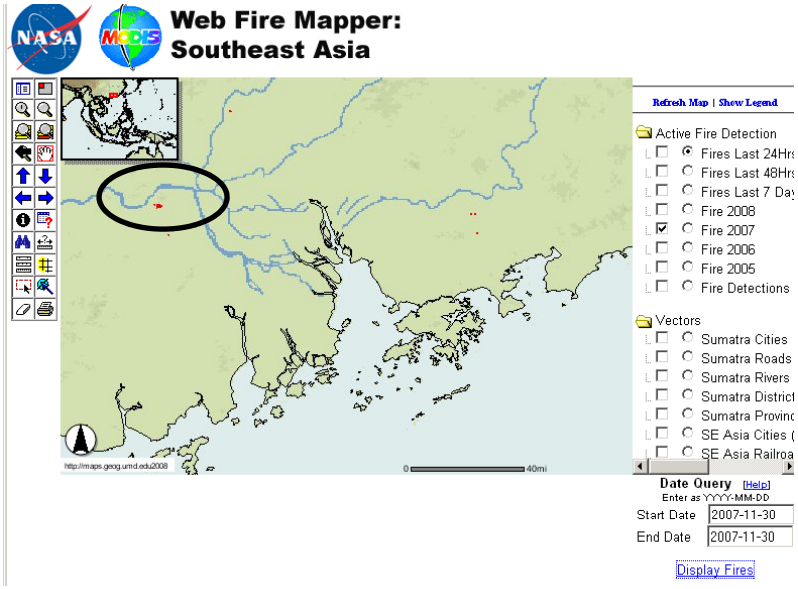




Mapping of aerosols from biomass burning

- Biomass burning is clearly evident on 30 Nov, 2007
- Located in the dense forest area of Zhaoqing county
- Same fire spot also located from the Web Fire Mapper developed by the Geographic Department of the University of Maryland

RGB image on 30 Nov, 2007

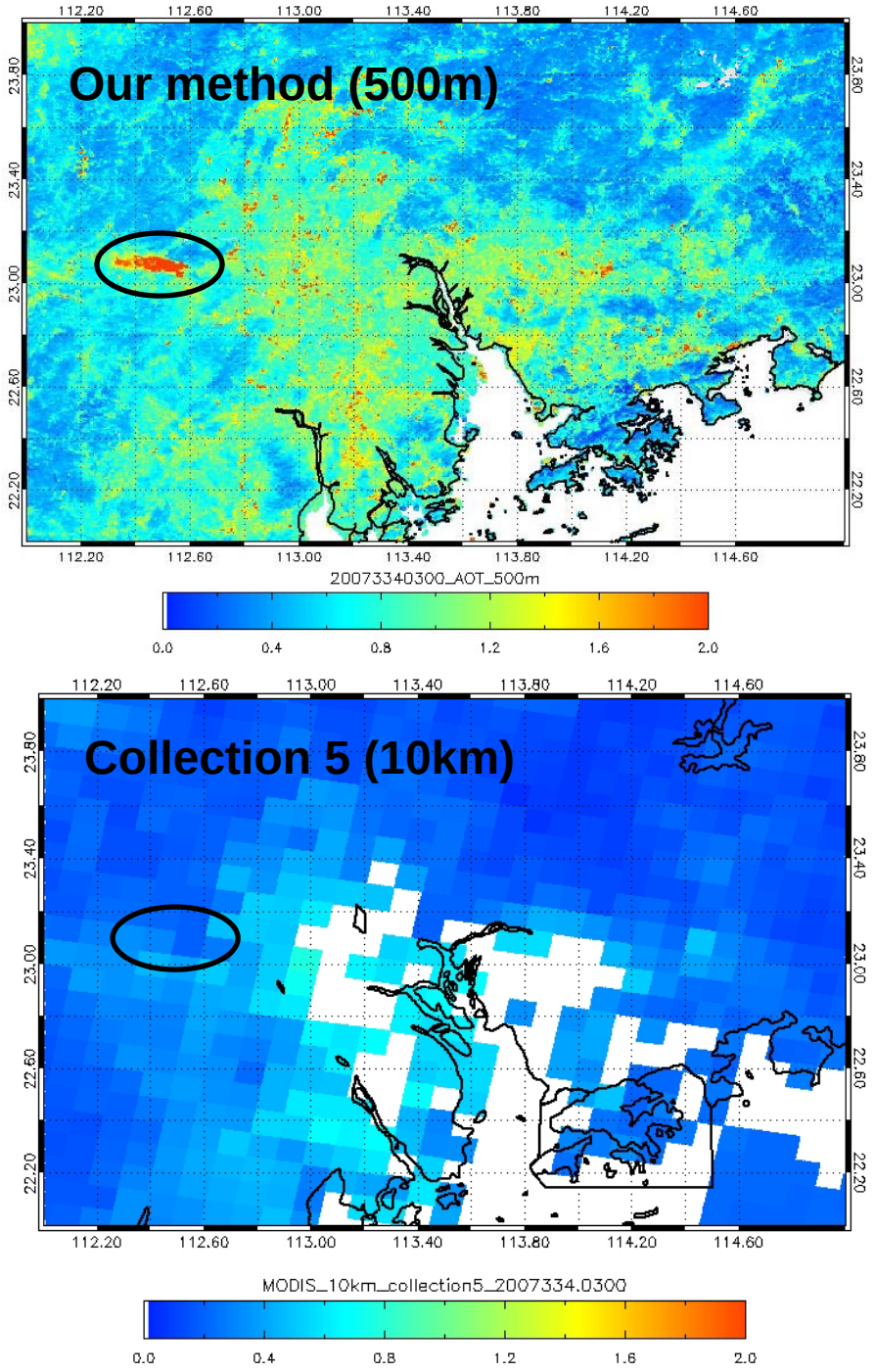


Web fire mapper

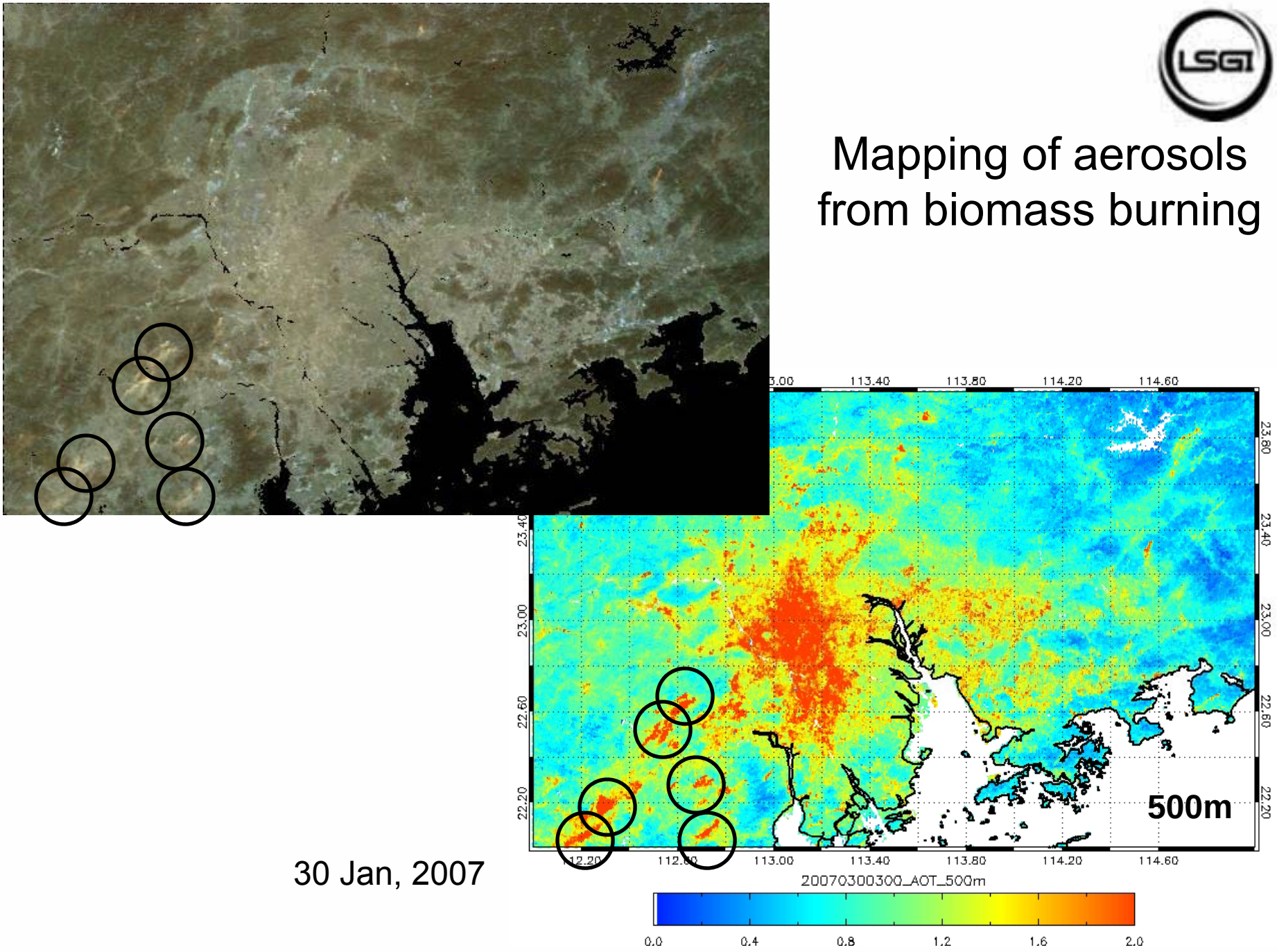
Mapping of aerosols from biomass burning

- Aerosols from biomass burning can be observed from MODIS 500m AOT image
- High AOT values (>1.8)
- The smoke plumes and the source of burning can be easily identified

- For MOD04 image
- Cannot identify the burning
- Urban areas are masked out with no AOT data values



Mapping of aerosols from biomass burning



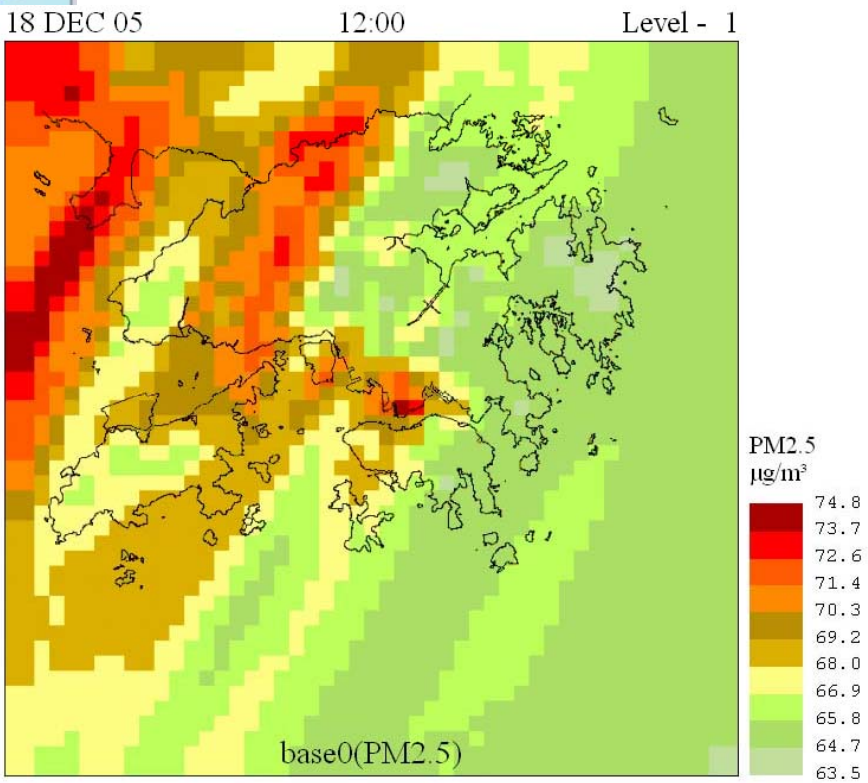
30 Jan, 2007

Monitoring/Modeling Fine Particulate Matter (PM2.5)

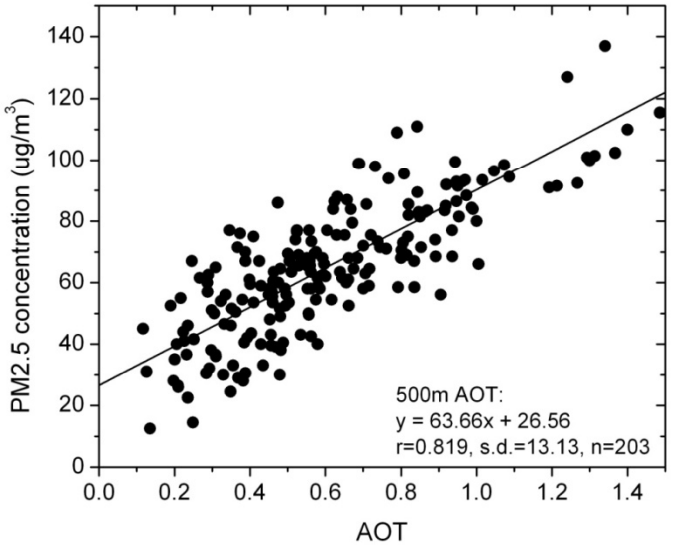
EPD has 3 roadside and 11 general air quality monitoring stations

5 stations for PM2.5

EPD PATH model:
Outputs a range of pollutants at a range of resolutions from 1km To 10kms



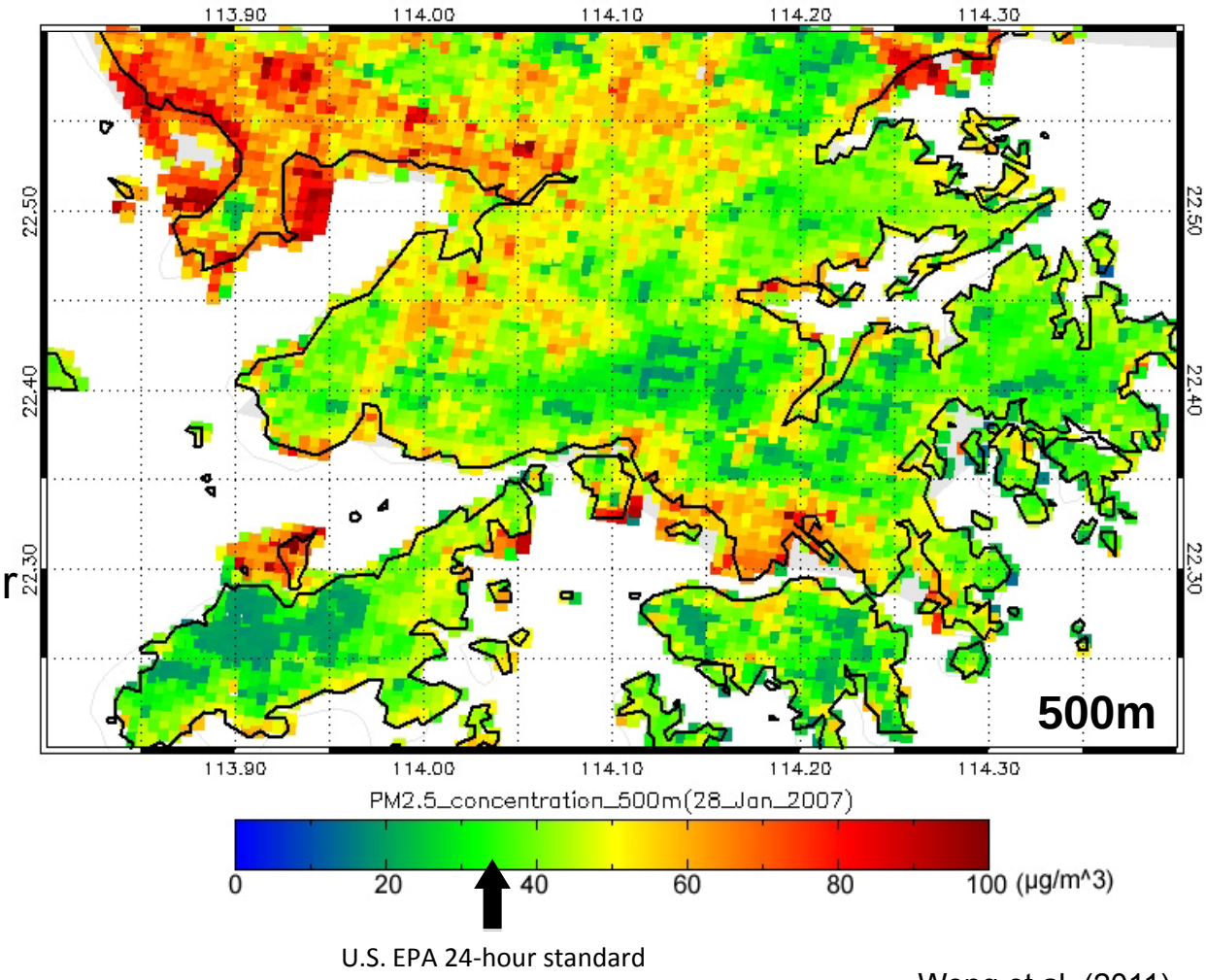
Monitoring/Modeling Fine Particulate Matter (PM2.5)



PM2.5 = (63.66 *AOT) + 26.56

MODIS 500m AOT:
Correlation coefficient is higher
r = 0.819

Satellite derived PM2.5

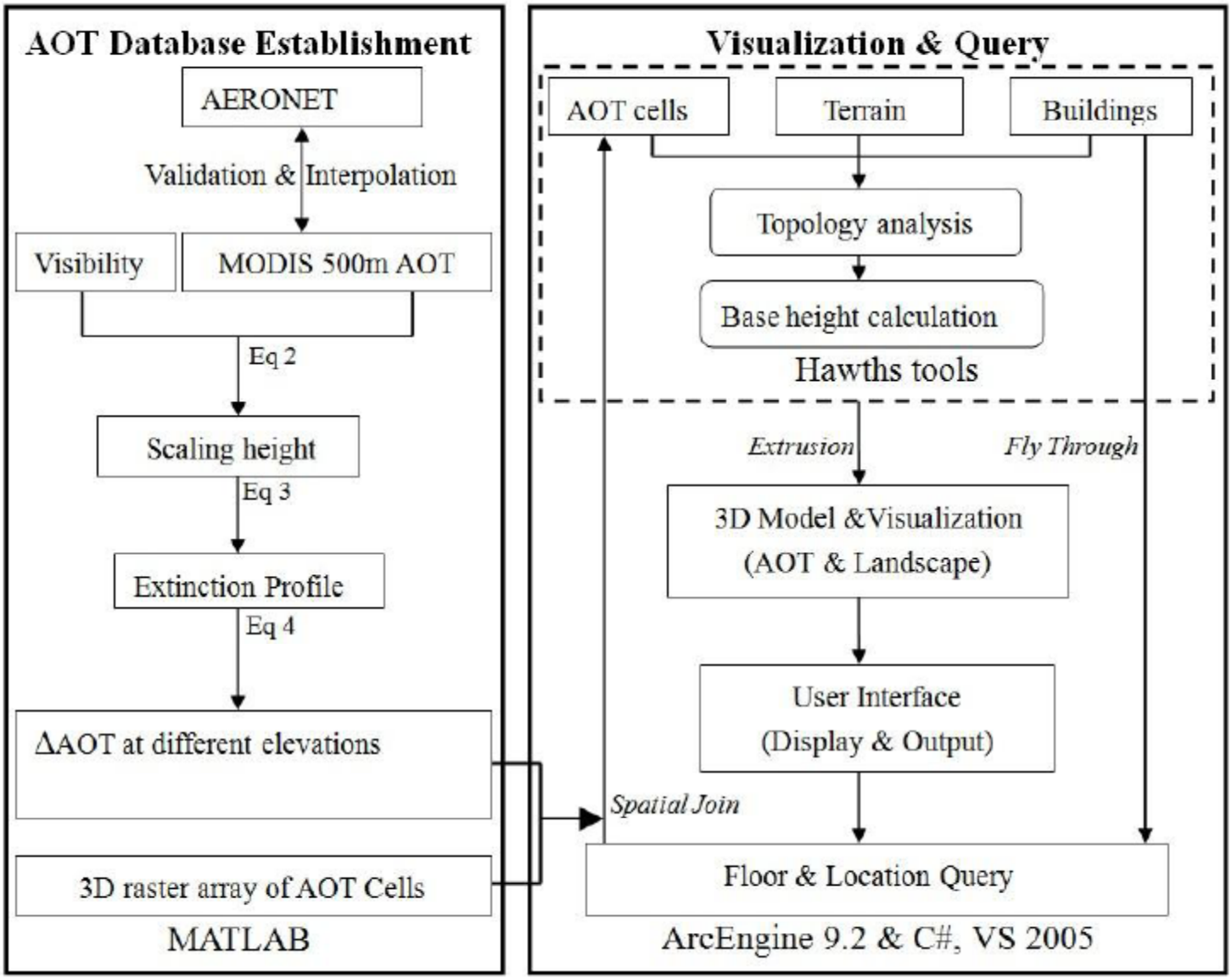


Wong et al. (2011)

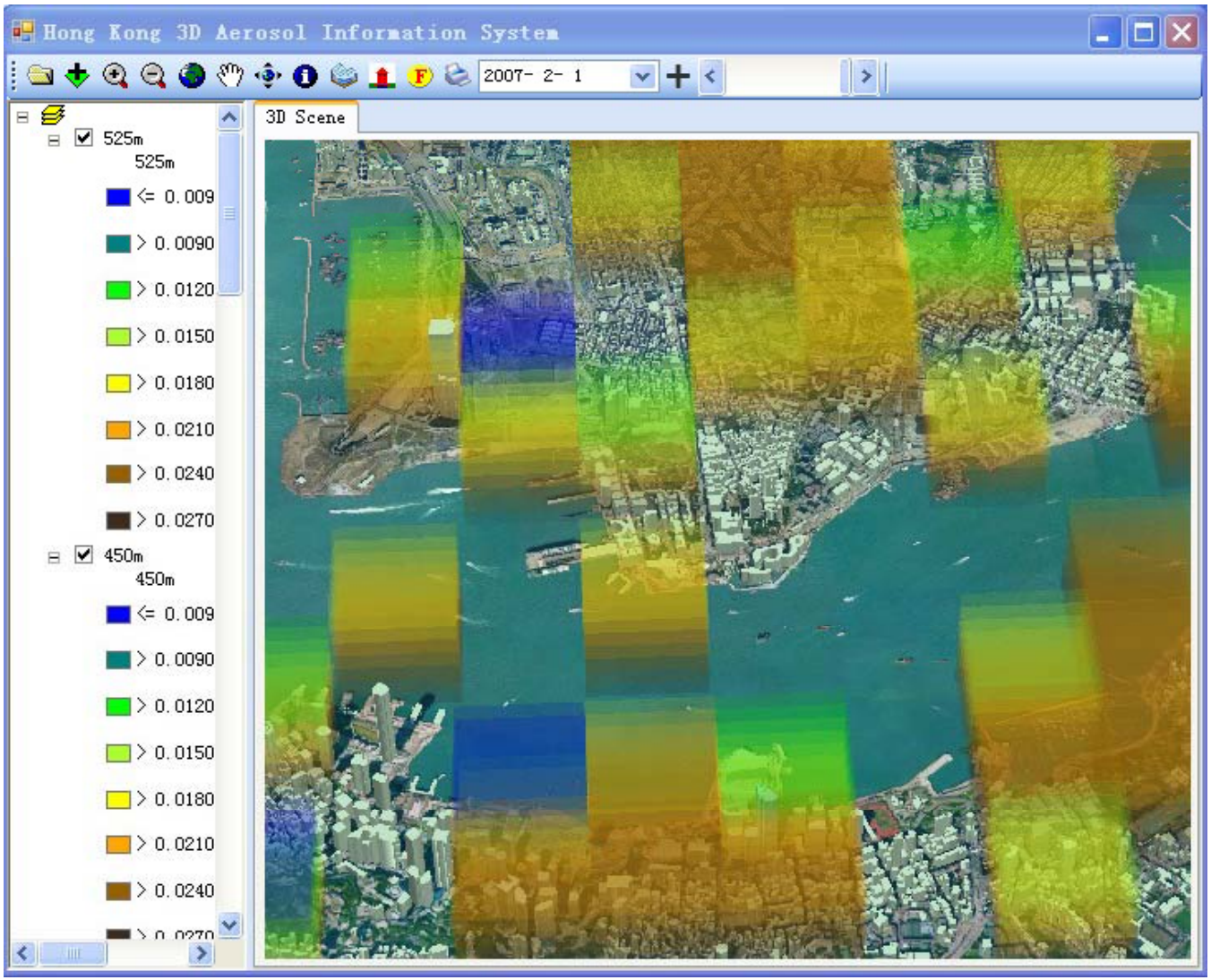
Aerosol vertical profiles using GIS and Remote Sensing

View of atmosphere over Hong Kong on 22 Nov, 2009

Flowchart for modeling aerosol vertical profiles on a GIS platform



Tailor-made GIS system (Hong Kong 3D aerosol information system)

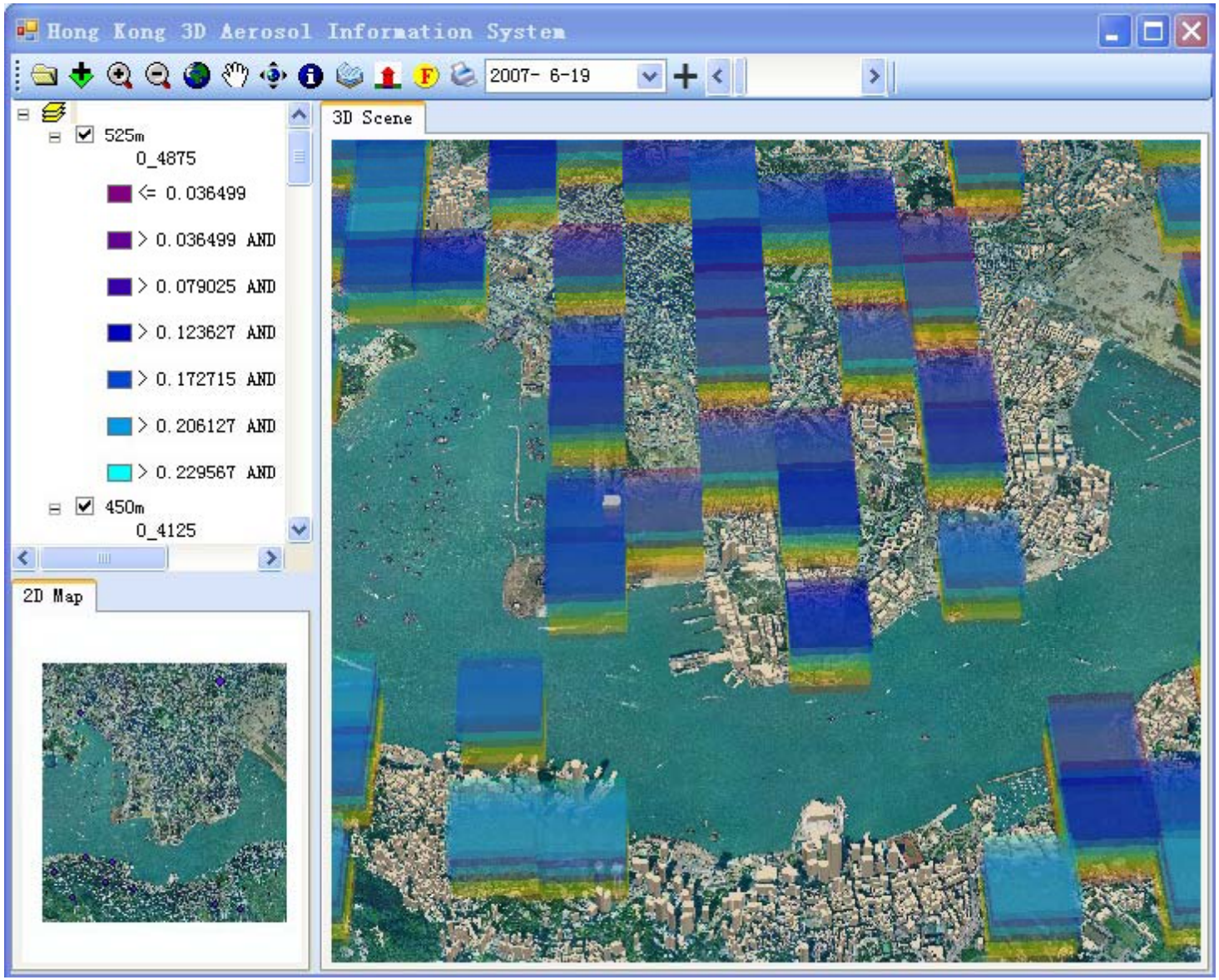


Provide:

- 3D visualisation
- GIS query of ΔAOT
  - by elevation
  - by building
  - by date
  - by time
- Automatic update

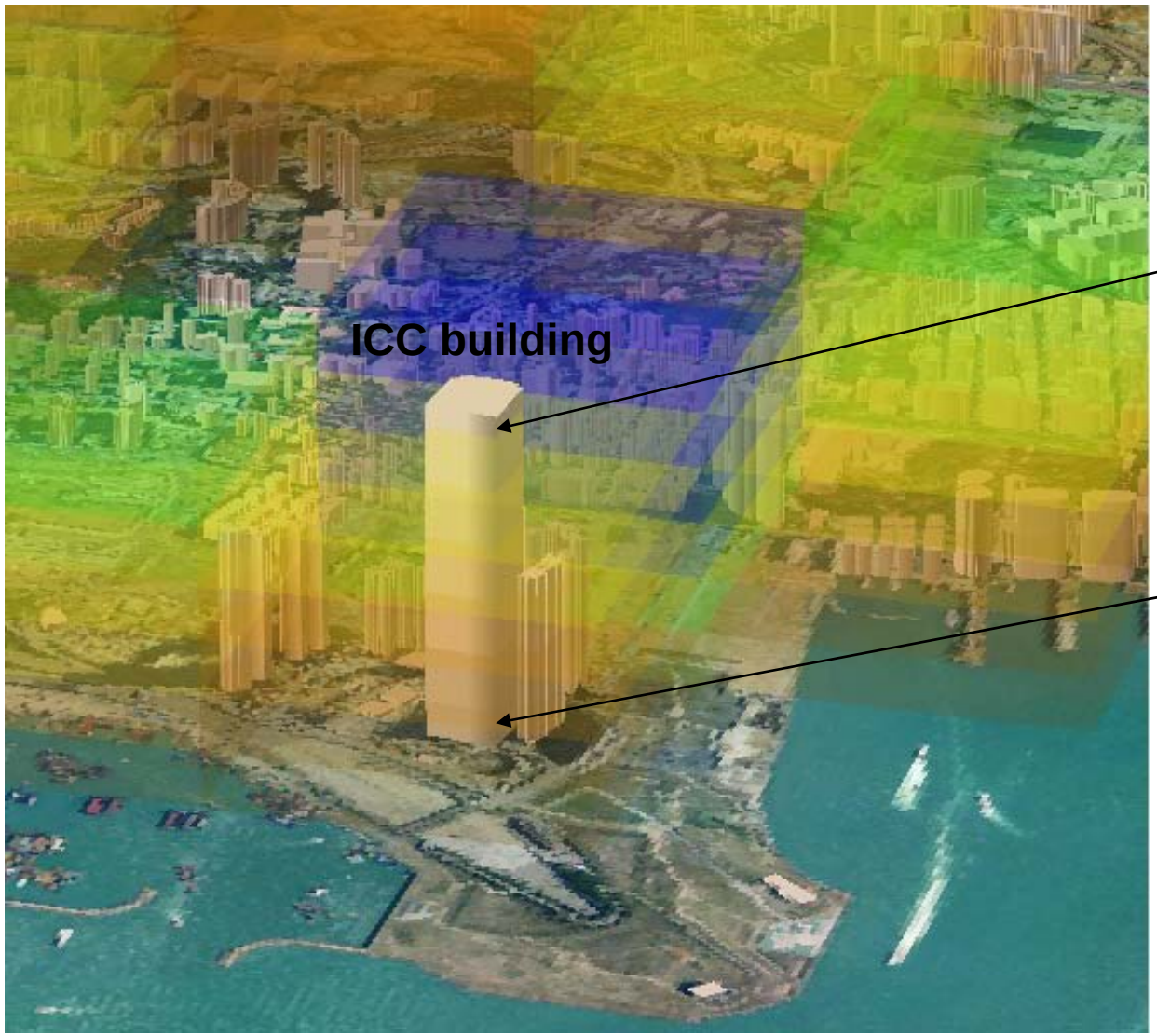
Data on Feb 1st, 2007

Tailor-made GIS system (Hong Kong 3D aerosol information system)



Data on Jun 19th, 2007

Derived AOT for different atmospheric layers



1st Feb, 2007, 10.50am

Elevation: 460m

Floor: 115

AOT: 0.018

Visibility: 15.9km

1st Feb, 2007, 10.50am

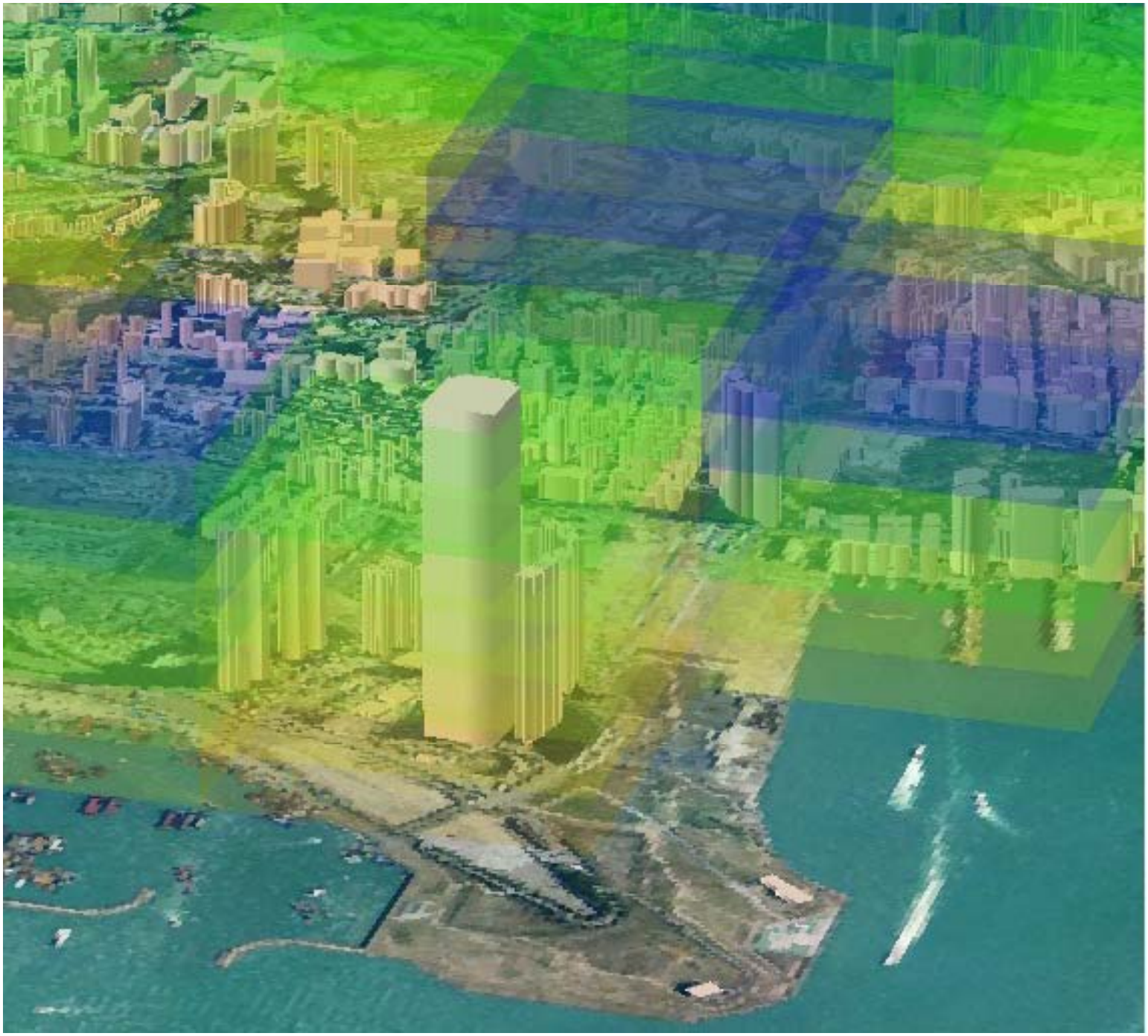
Elevation: 60m

Floor: 15

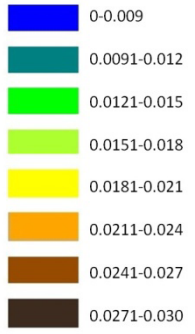
AOT: 0.022

Visibility: 13.1km

Data on Feb 1st, 2007



Data on
Feb 4th, 2007



Our work

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- Wong M. S. and Nichol J. E. (2011), Remote sensing of aerosols from space: a review of aerosol retrieval using MODIS, Chapter in Advances in Environmental Remote Sensing: Sensors, Algorithms, and Applications, edited by Weng, Q. and Quattrochi, CRC Express, Taylor & Francis Group, pp. 423-438. ISBN: 978-1-4200-9175-5.
- Wong M. S., Lee K. H., Nichol J. E. and Li Z. Q. (2010), Retrieval of Aerosol Optical Thickness using MODIS 500 x 500m2, a study in Hong Kong and Pearl River Delta region, IEEE Transaction of Geoscience and Remote Sensing, 48(8), 3318-3327. DOI: 10.1109/TGRS.2010.2045124.
- Wong M. S., Nichol J. E. and Holben B. (2010), Desert dust observed in a humid tropical city: Hong Kong, International Journal of Remote Sensing, 31(4), 1043-1051.
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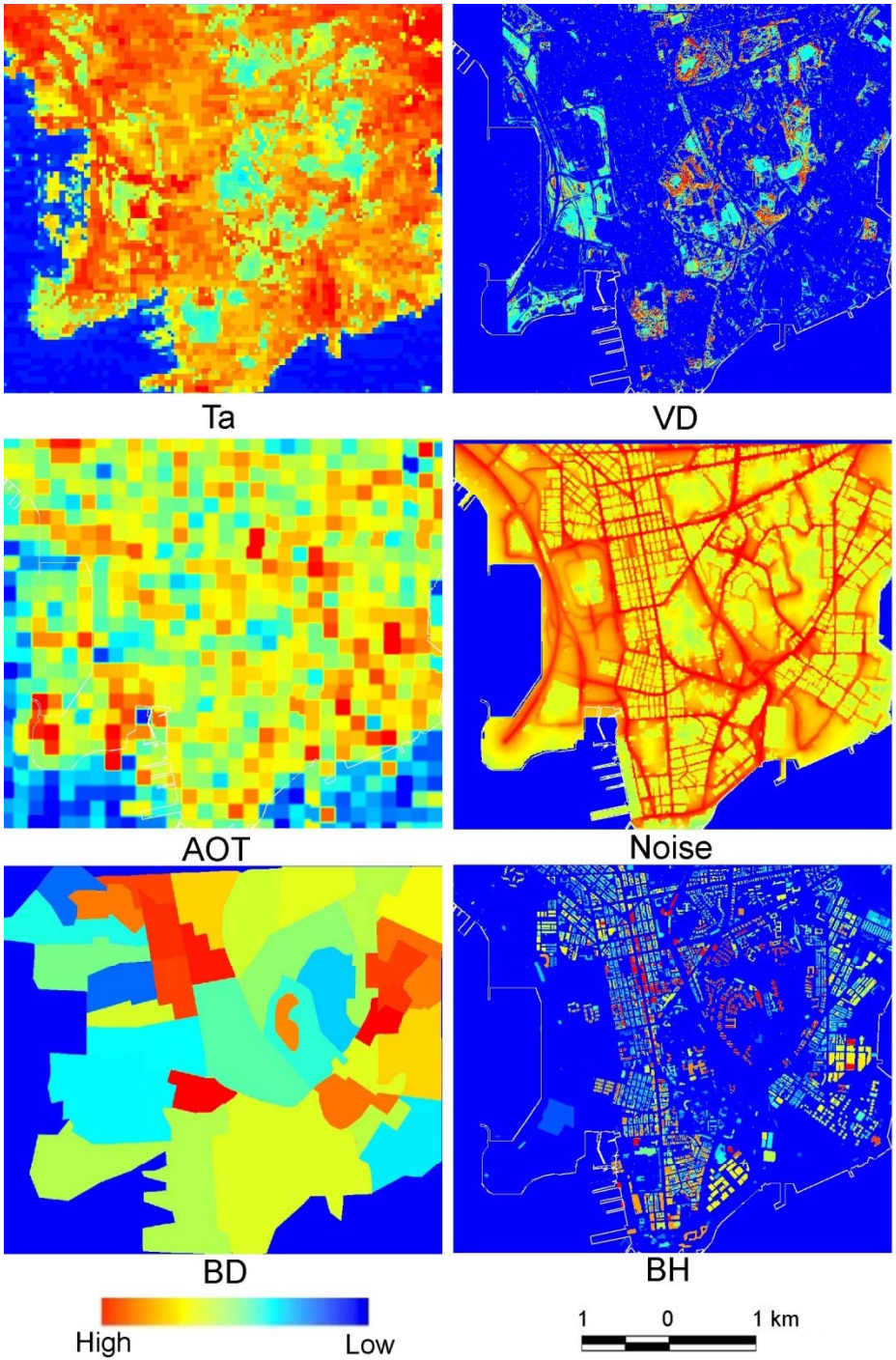
- Nichol J. E., Wong M. S. and Chan Y. Y. (2008), Fine resolution air quality monitoring from a small satellite, CHRIS/PROBA, Sensors, 8(12), 7581-7595, DOI: 10.3390/s8127581.
- Lee K. H., Li Z. Q., Wong M. S., Xin J. Y., Wang Y. Hao W. M. and Zhao F. S. (2007), Aerosol single scattering albedo retrieval using ground-based and satellite observation data. Special Issue on East Asian Study of Tropospheric Aerosol: an International Regional Experiment (EAST-AIRE), Journal of Geophysical Research – Atmosphere, 112, D22S15, 1-17.
- ……

Urban Environmental Quality: Definitions and facts

- Urban Environmental Quality (UEQ) is an abstract, dynamic and multi-facetted concept
- Varies spatially and temporally
- Rarely measured as a single index
- People experience UEQ holistically
- Parameters involved measured in different units and at different scales

Objective

- To map UEQ as it varies spatially over an urban area



UEQ parameters

Ta – Air temperature

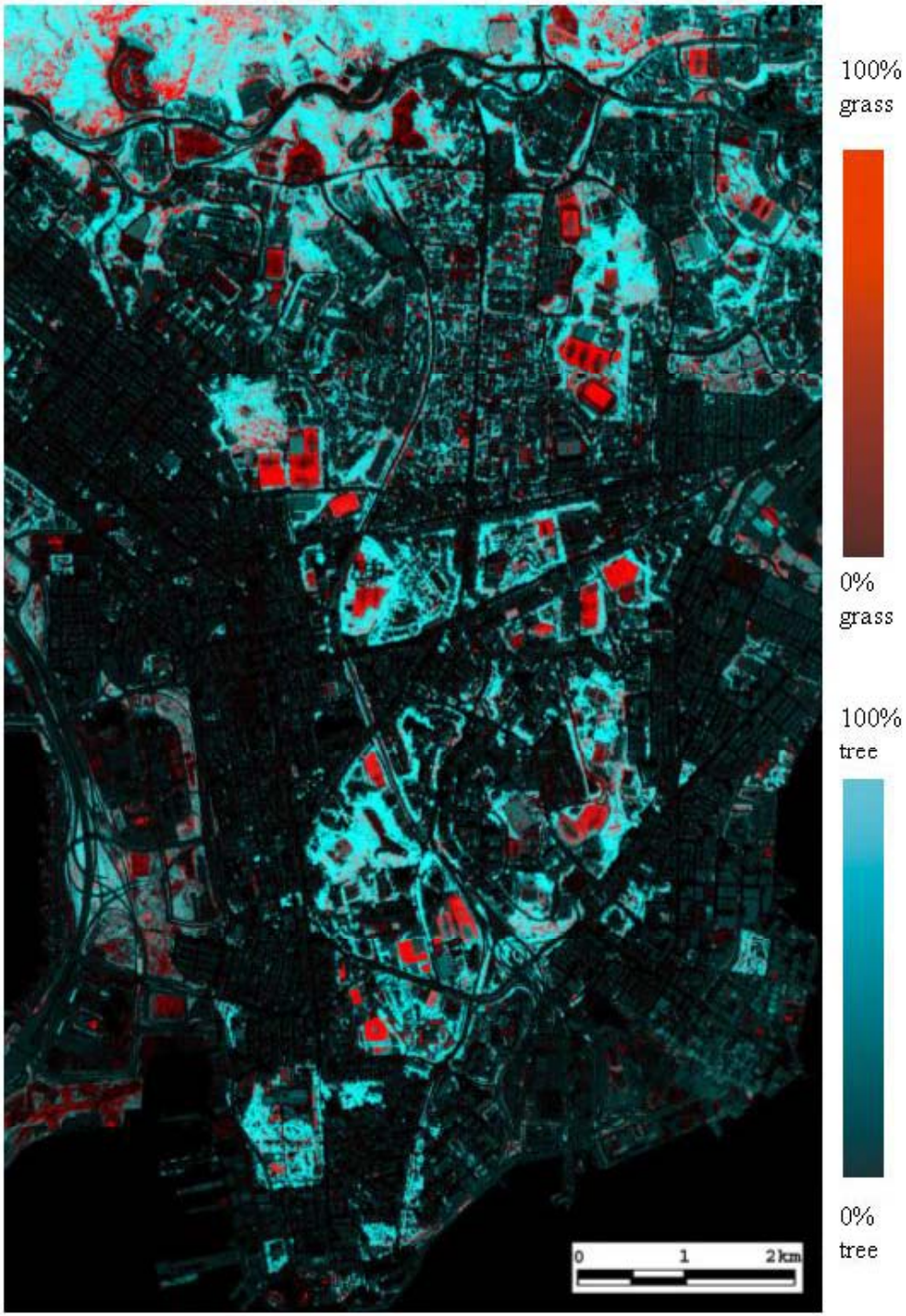
VD – Vegetation density

AOT – Aerosol Optical Thickness

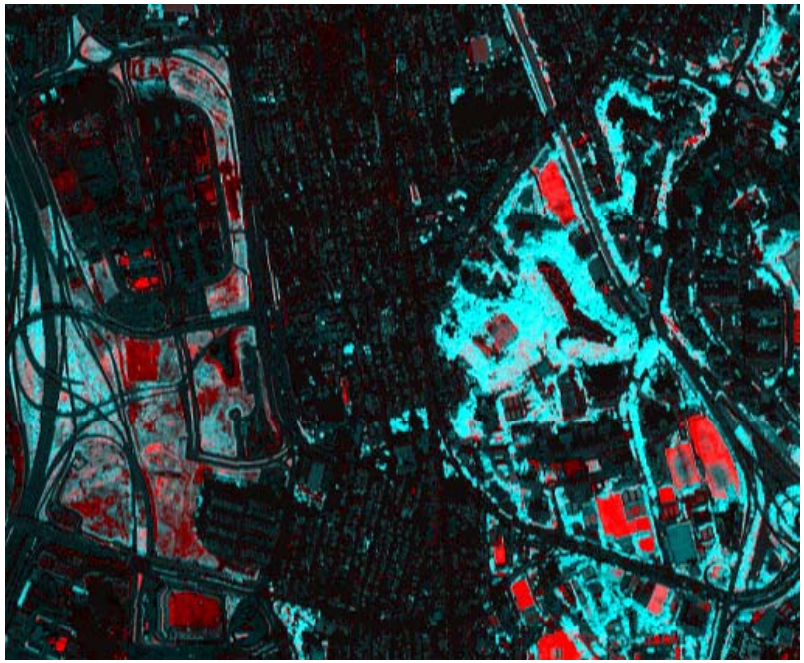
Noise – Noise modeling

BD – Building density

BH – Building height



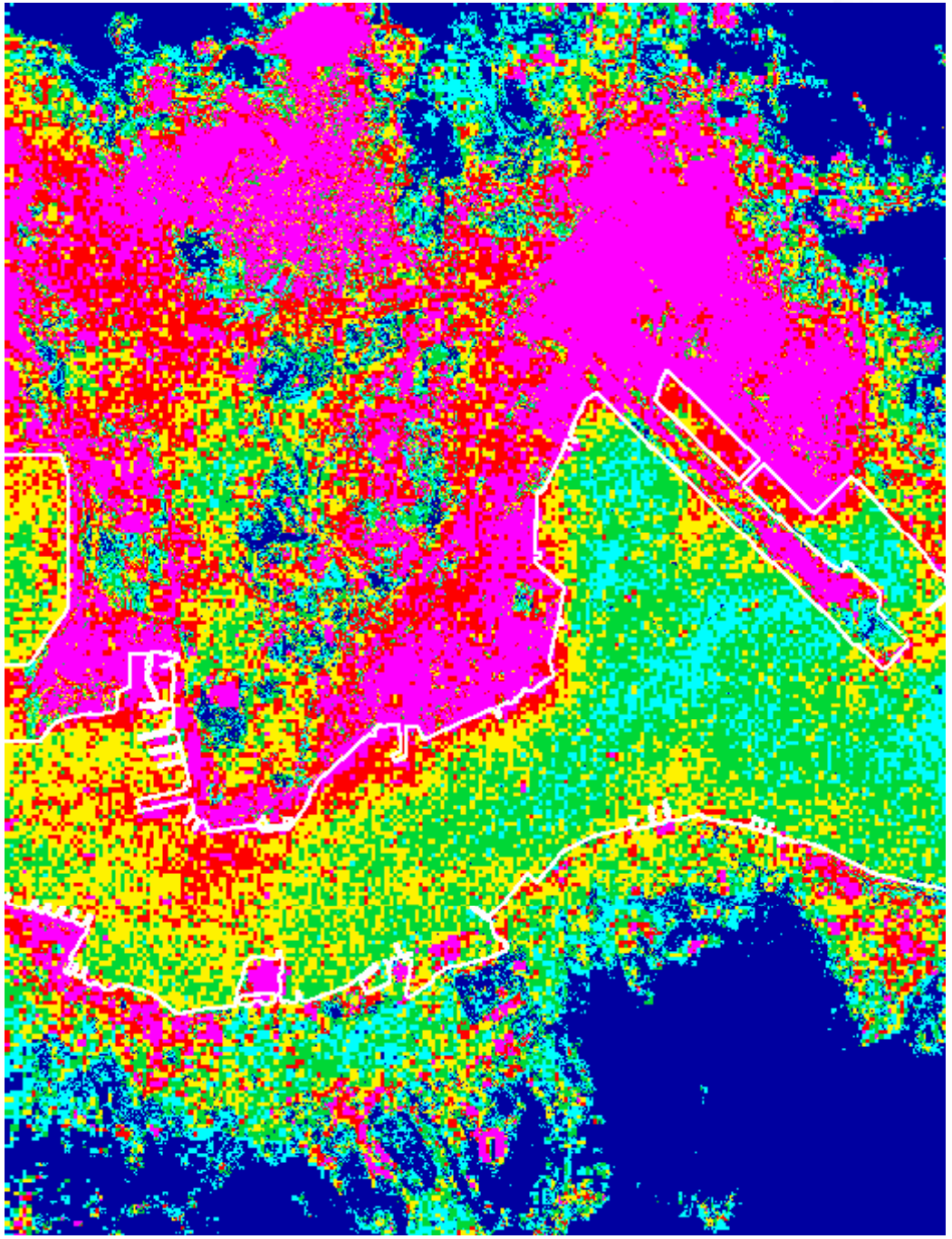
Vegetation life form from spectral unmixing of IKONOS 4m pixels



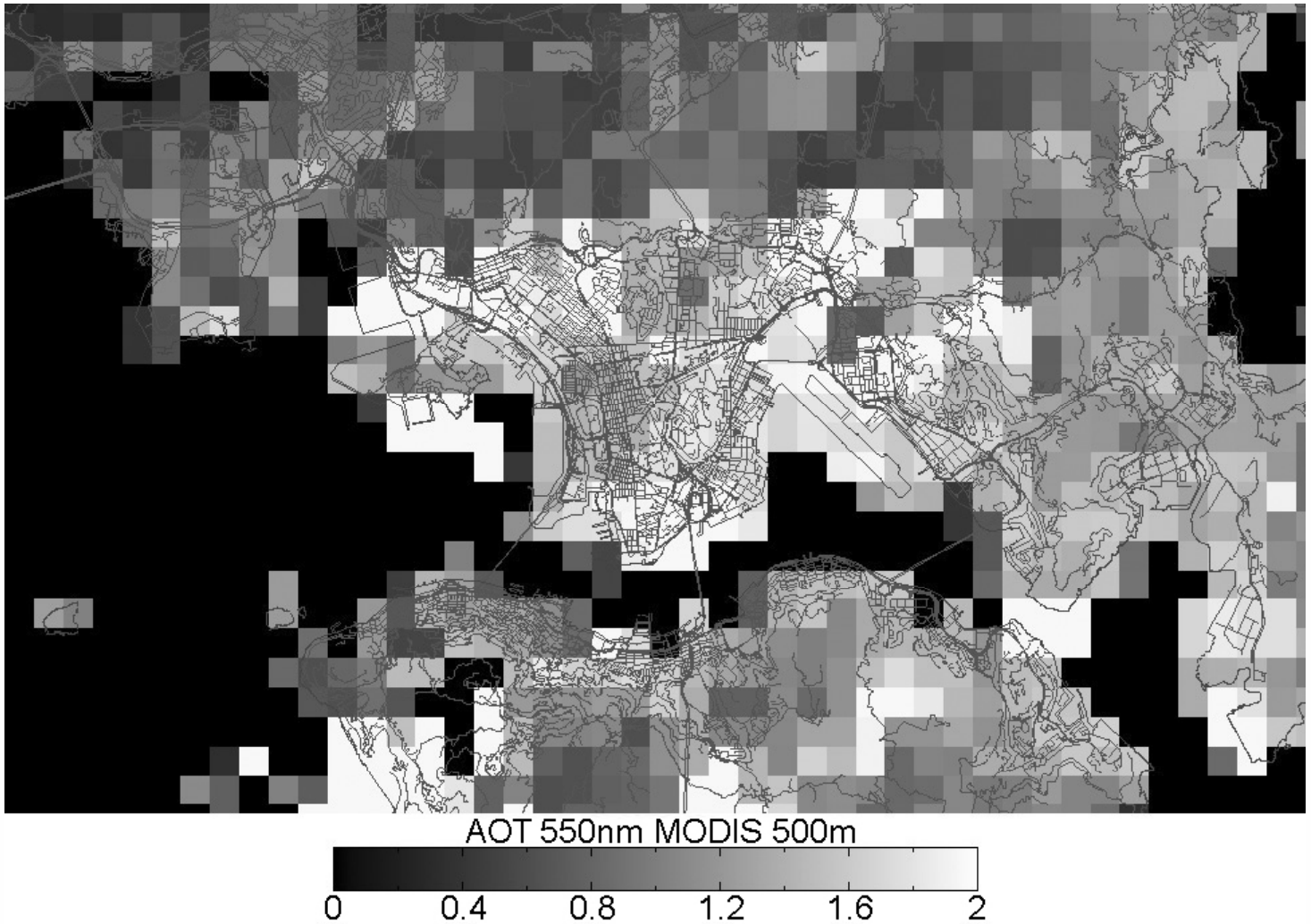
Kowloon West

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Heat Island Intensity from Landsat ETM+ corrected for emissivity using IKONOS at 4m



Aerosol Optical Thickness (Air pollution)



Building height

Building Density

within 37 electoral districts

Kowloon Tong

Noise modeled from ‘Predictor’ at 10m resolution-raster format

Noise Level in dB(A)

Building

Ground region

Road

< 50.0

50.0 - 55.0

55.0 - 60.0

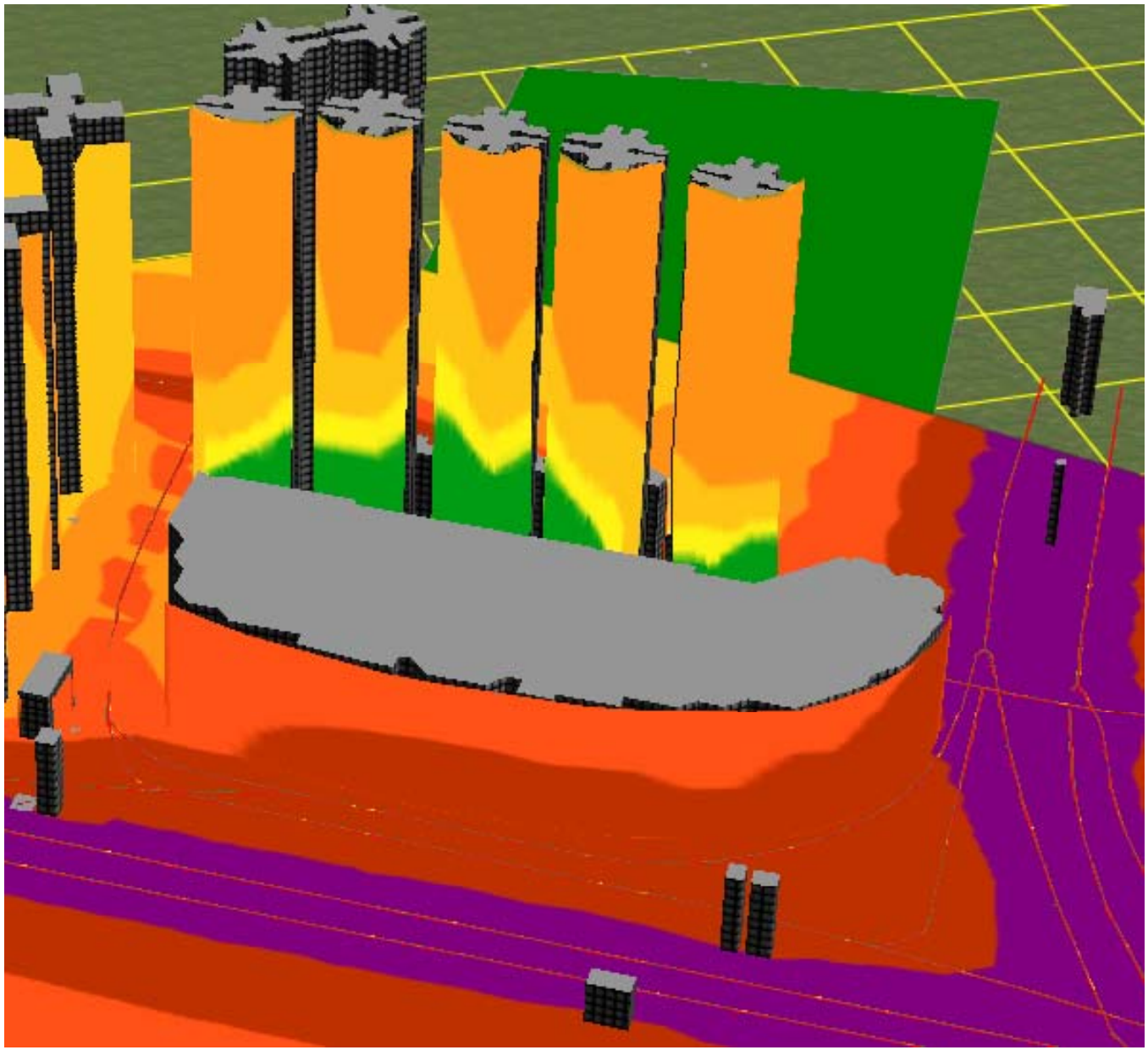
60.0 - 65.0

65.0 - 70.0

70.0 - 75.0

> 75.0

3D noise model of Plaza Hollywood



Integrated Urban Environmental Quality Index

- To obtain a single relative index of UEQ that permits comparison of the highest and lowest UEQ over the whole urban area

- How to combine the parameters?

- What spatial units should be chosen?

- Is it possible to obtain an absolute index permitting comparison between different cities eg. Hong Kong and New York?

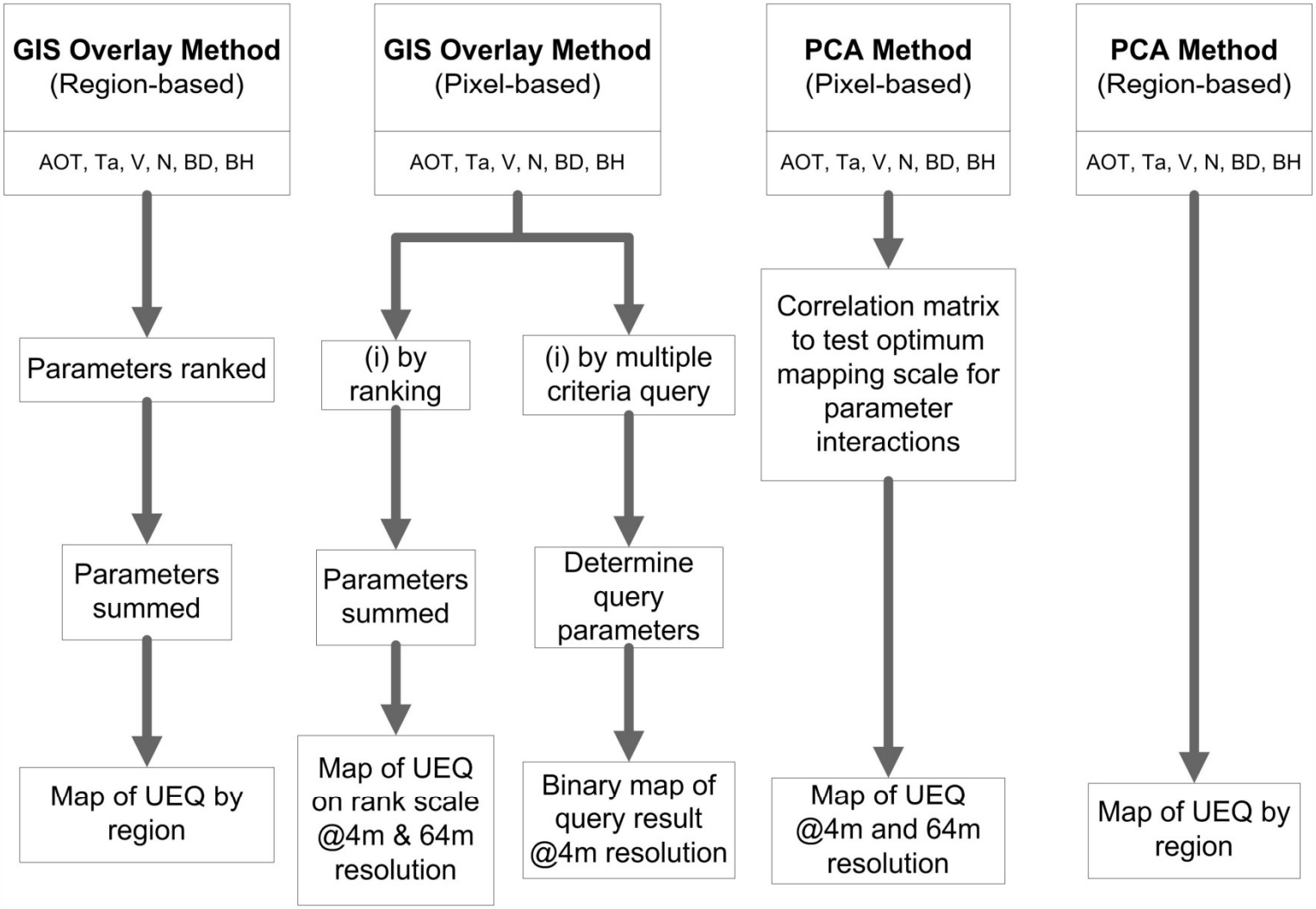
Email questionnaire to 200 HK residents - example

Part III: Case study

Q9. The following are nine cases, please considers its "local suffering", (5 – most suffering, 4 – more suffering, 3 – suffering, 2 – less suffering, 1 – least suffering, 0 – no comment)

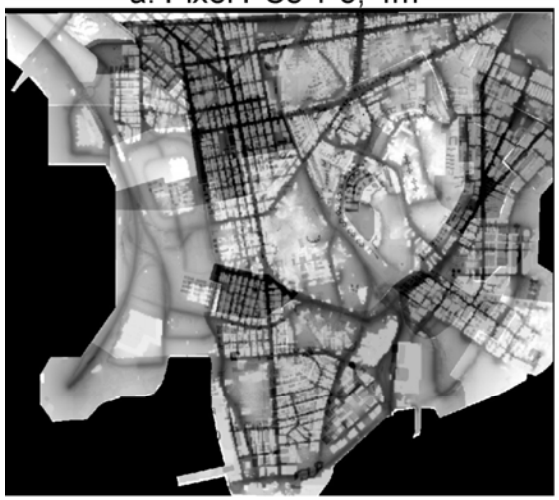
		High air temperature	Lack of green space	Noise pollution	Air pollution	Compact building density	High-rise building
a	Mongkok	4	5	4	5	1	0
b	Jordan	4	5	4	5	1	0
c	Sham Shui Po	4	5	0	5	1	0
d	Prince Edward	0	0	0	0	0	0
e.	Tsim Sha Tsui	4	5	4	5	1	0
f.	Tsim Sha Tsui East	4	5	4	5	1	0
g.	Hung Hom	4	5	4	5	1	0
h.	Kowloon Tong	4	2	2	4	1	0
h.	Ho Man Tin	4	2	2	4	1	0

Methodology for UEQ modeling



Results

a. Pixel PCs 1-3, 4m

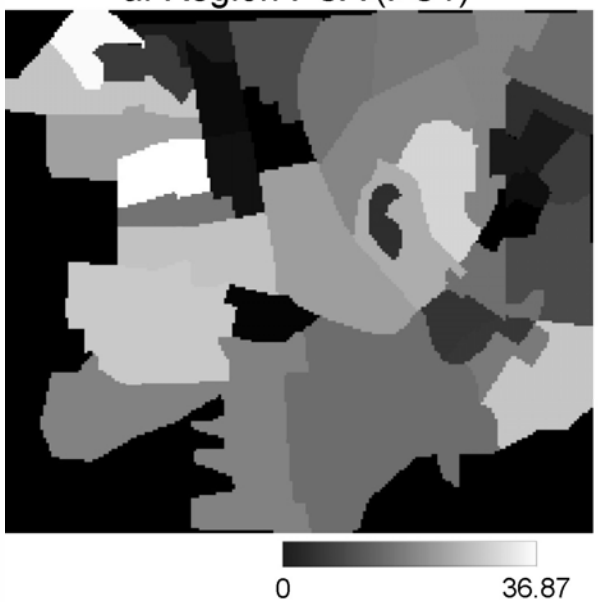


b. Pixel PCs 1-3, 64m

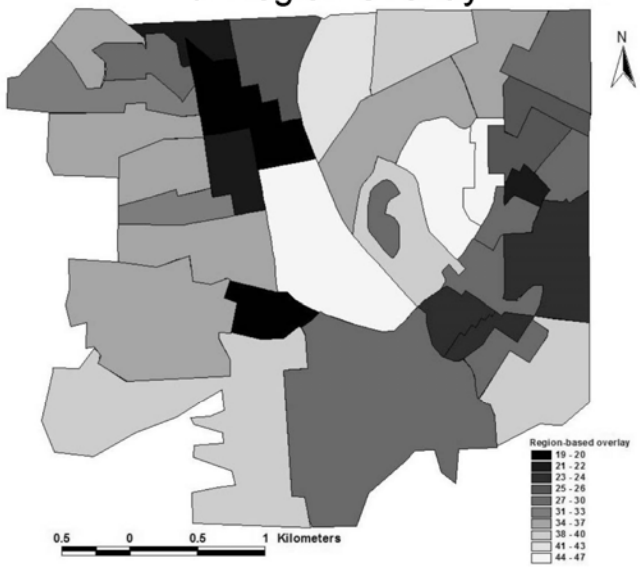
Result from Pixel PCA method

Result from Region PCA and Region Overlay method

a. Region PCA (PC1)



b. Region Overlay



Validation: Field questionnaires to 608 HK residents in 80 locations

KOWLOON ENVIRONMENT QUESTIONNAIRE

Date: (eg. 11/07) (1108)
Time: (eg. 15.40) (13.45)

Site Number: KA 4

1. Some places in Hong Kong suffer from very serious **air pollution** problems but others do not. How polluted is this place (0-100)? 10
2. Some places in Hong Kong are very **hot and uncomfortable** but others are not. How hot and uncomfortable is this place (0-100)? 65
3. Some places in Hong Kong are very **noisy and disturbing** but others are not. How noisy is this place (0-100)? 10
4. Some places in Hong Kong are fresh and **green with lots of vegetation** but others are not. How would you rank this place (0-100)? 60
5. Some places in Hong Kong are full of **high rise buildings** but others are not. How would you rank this place (0-100)? 0
6. Some places in Hong Kong are **densely built-up and congested** but others are not. How would you rank this place (0-100)? 50
7. How do you rank the **overall environmental quality** in this place? (0-100) 95

High rise 100% - High rise 0%

80 Field questionnaire locations

How do you rank the overall environmental quality in this place? (0-100)

Comparison of data integration methods with reference field questionnaires

Mapping method	R (n=76)
Region PCA (PC1)	0.49
Region PCA (PCs 1-3)	0.59
Pixel PCA 4m (PC 1)	0.01*
Pixel PCA 4m (PCs 1-3)	0.46
Pixel PCA 64m (PC 1)	0.07*
Pixel PCA 64m (PCs 1-3)	0.24*
Region overlay	0.53
Region overlay with weighting	0.51
Pixel overlay 4m (V+BD+BH)	**0.62**
Pixel overlay 64m	0.55
Pixel overlay with weighting 4m	0.61
Pixel overlay with weighting 64m	0.54

Equal weighting

Weighting from email questionnaires

* significant at 1% level

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Assessment of urban environmental quality in a subtropical city using multispectral satellite images

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Abstract. Urban environmental quality (UEQ) is a complex and spatially variable parameter of increasing concern, especially in densely populated cities of the tropics and subtropics where climate, air quality, and the urban infrastructure may interact to produce uncomfortable and hazardous effects. The study investigates the application of multispectral remote sensing from the Landsat ETM+ and IKONOS satellite sensors for the mapping of UEQ in urban Hong Kong at a detailed level, using the measurable, image-based parameters of temperature and biomass, and examines the relationship between these and air quality in selected study districts. Multiple-criteria queries on these two parameters show that spatial variations in UEQ are closely related to natural topographic factors and urban morphology. The amount of biomass, as opposed to total area of vegetation, is also shown to be an important factor in the spatial variation of UEQ. The data permit visualisation of the relationship between the human and natural factors involved in UEQ and generate recommendations for future planning and urban-renewal projects.

12 Assessing Urban Environmental Quality with Multiple Parameters

Janet Elizabeth Nichol and Man Sing Wong

CONTENTS

ABSTRACT

This chapter investigates the integration of environmental datasets derived from remotely sensed images with other environmental variables, for the assessment of Urban Environmental Quality (UEQ) using a variety of resolutions and mapping units. The example of the Kowloon Peninsula in Hong Kong is given, due to the availability of high quality datasets of vegetation, air temperature, building height, building density,

Nichol J. E. and Wong M. S. (2006), Remote sensing of urban environmental quality, Invited chapter in *Remote Sensing of Urban Areas,* edited by Weng, Q. and Quattrochi, CRC Express, Taylor & Francis Group, 253-268. ISBN: 0-8493-9199-7

Nichol J. E. and Wong M. S. (2009), Mapping Urban Environmental Quality using multiple parameters, *Environment and Planning B: Planning and Design,* 36, 170-185.

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Thank you

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