Modeling the anthropogenic heat flux using remote sensing data
- A preliminary study in Hong Kong

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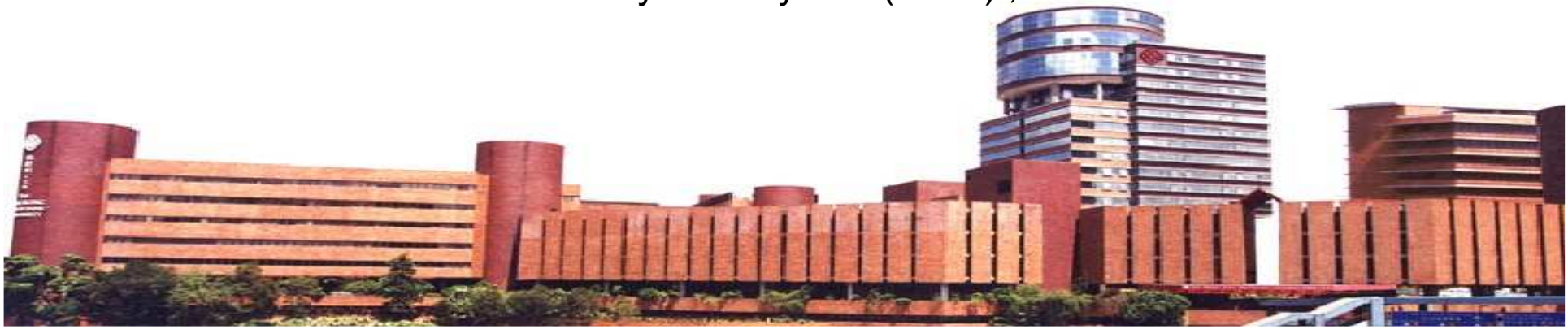


What is anthropogenic heat?

- Anthropogenic heat mainly from

1. electricity inputs to buildings
   - household heating eg. cooling and heating devices, household light
2. fuel combustion by traffic
3. fuel combustion during industrial activities

- Examples:

  Tokyo: central Tokyo exceed 400 Wm^{-2} in daytime, maximum value 1590 Wm^{-2} in winter, residential area reached about 30 Wm^{-2} in summer

  Beijing: 104.3 Wm^{-2} in city center, 8.6 Wm^{-2} in countryside, average 19 Wm^{-2}

Anthropogenic heat

Estimation methods:

- In-situ measurements
  - Accurate determination of heat fluxes in urban environments at the roof-level (Arnfield, 2003; Oke et al., 1999; Taha,1997)
- GIS estimations
  - Number of electricity and gas consumers by class, number of people, vehicle numbers by road type, length of road in the contributing area (Grimmond, 1992; Sailor and Lu, 2004)
- Remote sensing measurements
  - Couple with local meteorological observations (Chrysoulakis, 2003; Kato & Yamaguchi, 2005; Schmugge et al.,1998)

Energy balance model

- Net radiation (R_n) is the sum of latent heat (phase change of water), sensible heat (changing the temperature of the air) and ground heat (subsurface)

- Sensible heat (H) is heat energy transferred between the surface and air when there is a difference in temperature between them
  - Heat is transferred into the air by conduction as air molecules collide with those of the surface

- Latent heat (LE) is the heat energy of evaporation
  - Heat is transferred from liquid phase to gas

- Ground heat (G) is the radiant energy warming/cooling the subsurface of the Earth
  - Heat is transferred from the surface to subsurface

- Anthropogenic heat (A) is the heat energy due to human activities

In rural:
$R_n = G + LE + H$

In urban:
$R_n + A = G + LE + H$

Image preprocessing

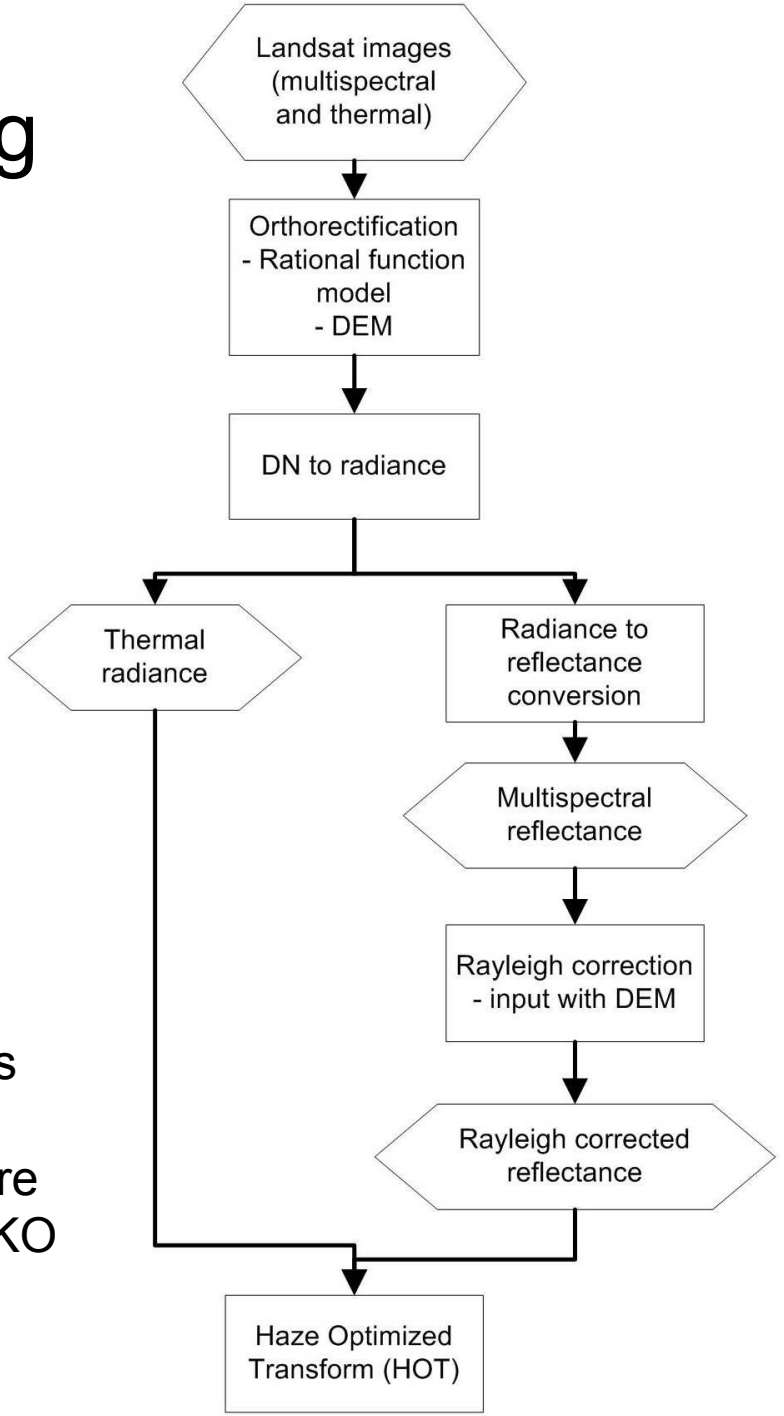
- Landsat TM/ETM images
  10-Dec-1988 (10:22am)
  30-Dec-1995 (9:54 am),
  03-Mar-1996 (9:58 am),
  14-Sep-2000 (10:36 am),
  28-Dec-2006 (10:46am)

  - Resolution: 30m

- DEM
  10m resolution

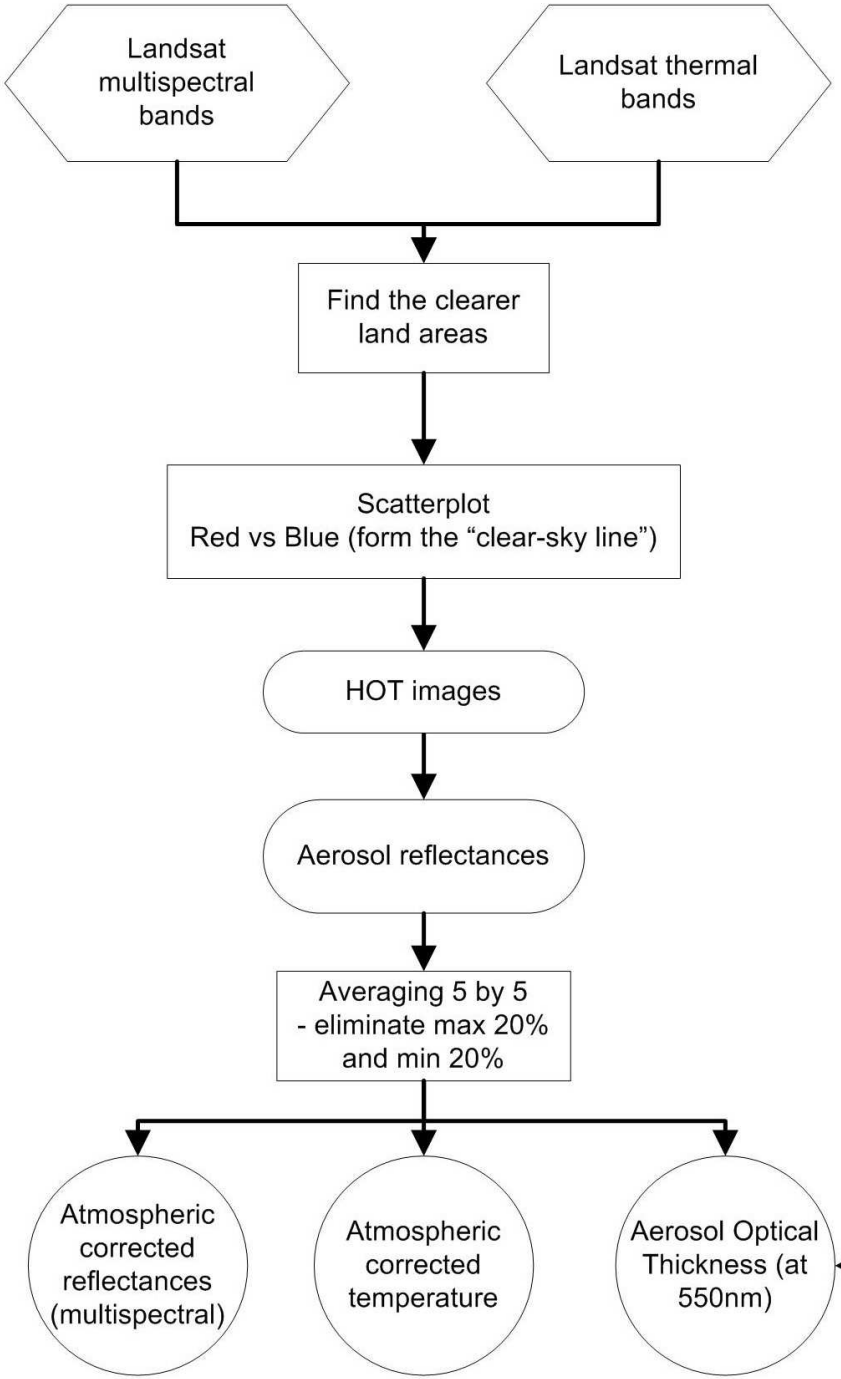
- Meteorology data
  O3 – from TOMS satellite images

  RH, surface wind and temperature – from NOAA NCEP data and HKO meteorology stations

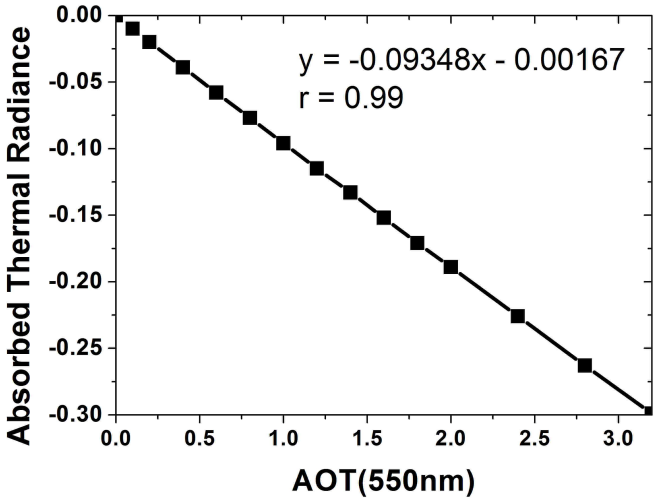


Haze Optimized Transform (HOT)

- For atmospheric correction



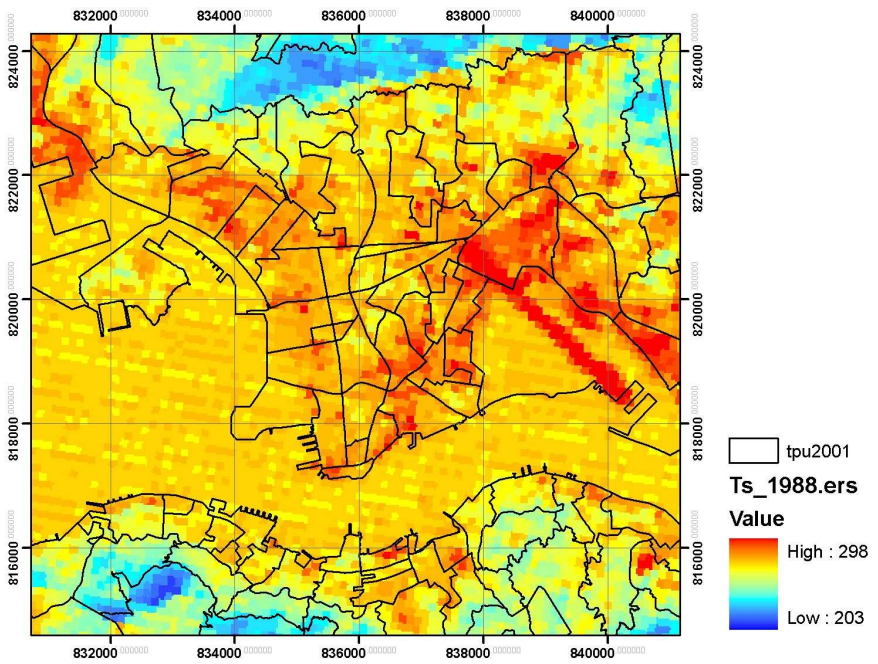
LUT simulated using SBDART



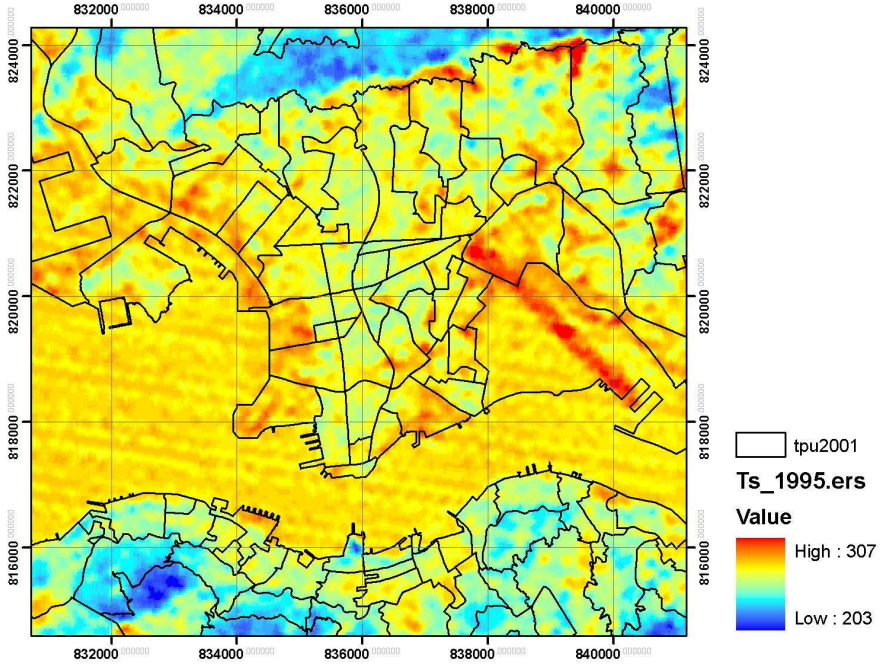
Zhang et al., 2002, RSE

- Atmospheric corrected spectral bands
- Used for land cover classification
  - Maximum likelihood classification in four broad land classes:
    - water, urban, vegetation, bare ground

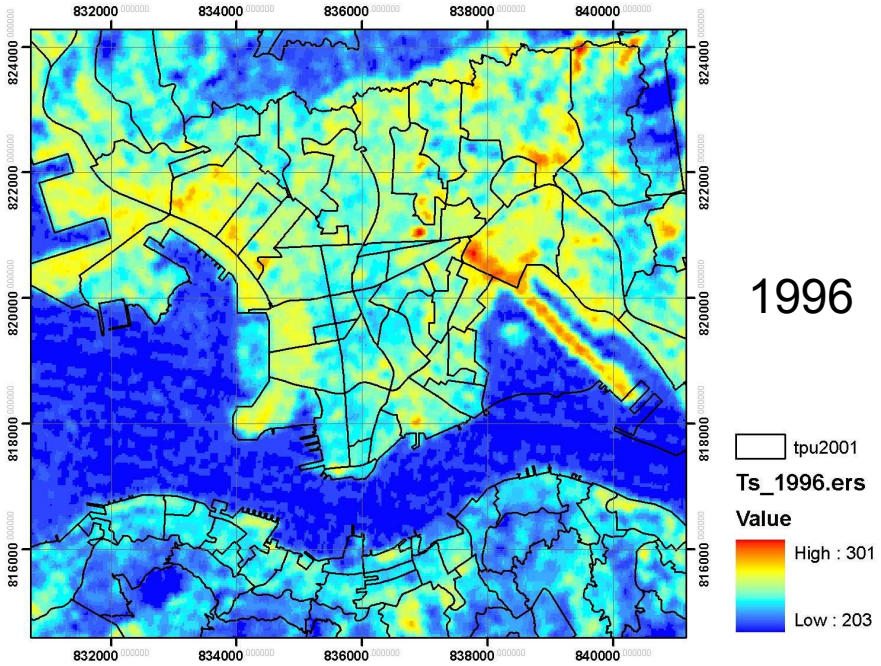
- Atmospheric corrected thermal bands



1988



1995



1996

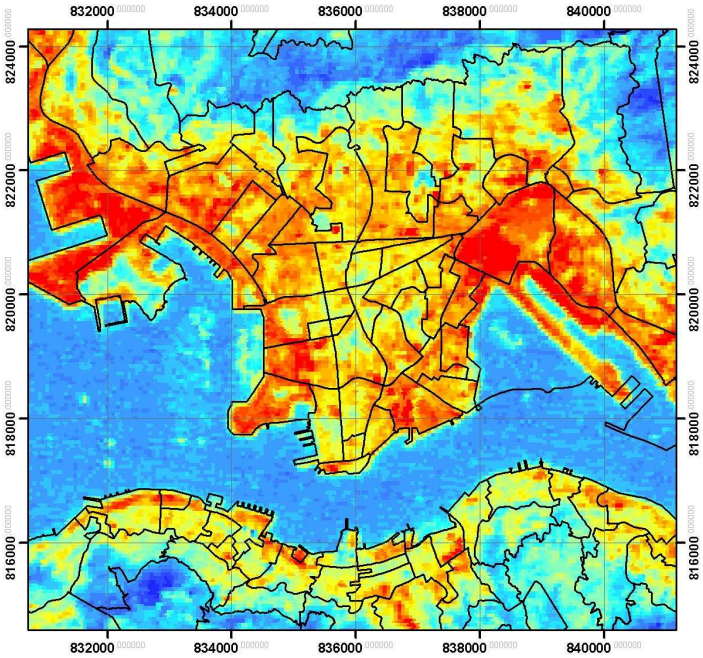
tpu2001

Ts_1996.ers

Value

High : 301

Low : 203



2000

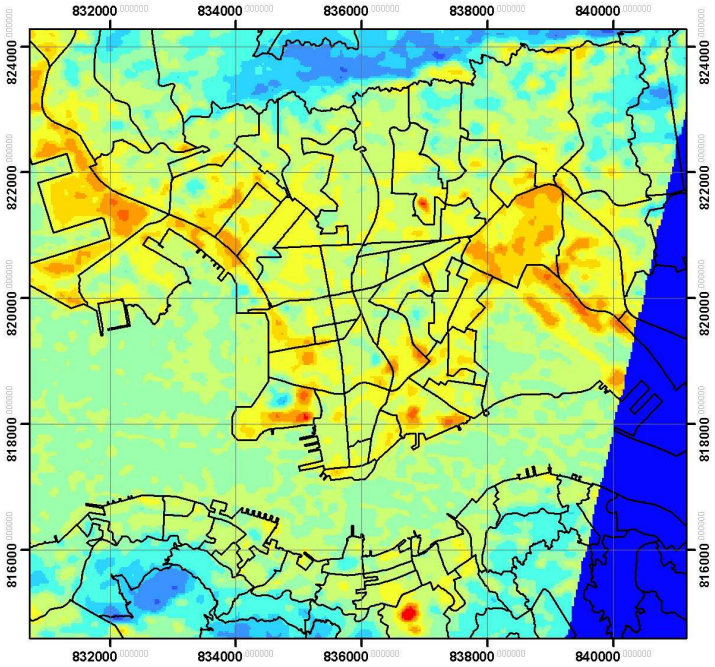
tpu2001

Ts_2000.ers

Value

High : 311

Low : 293



2006

tpu2001

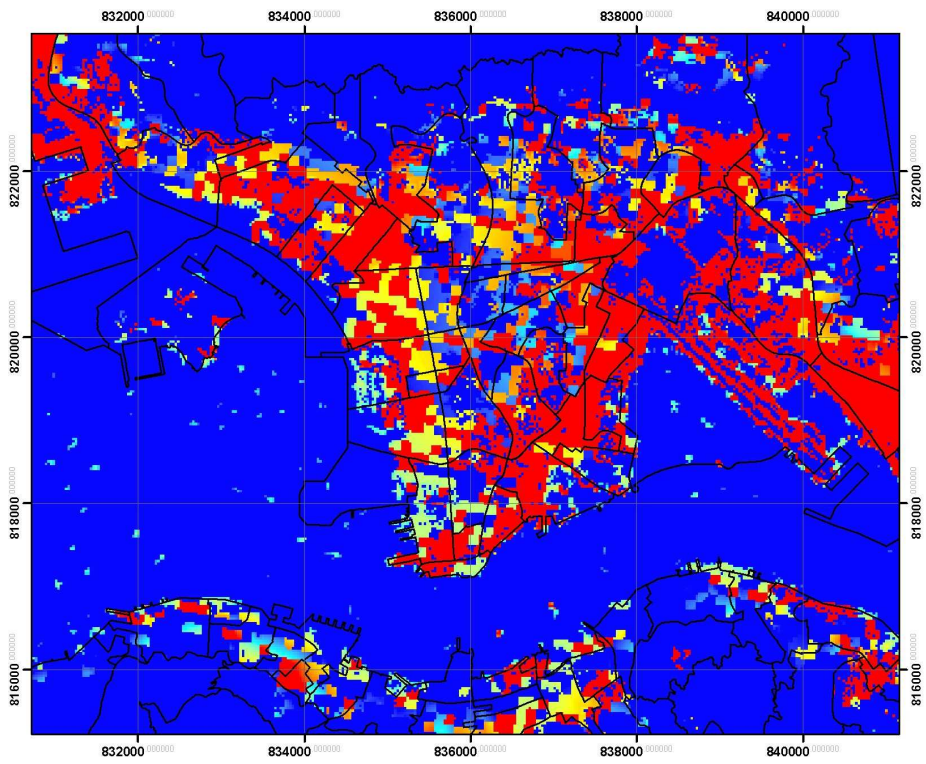
Ts_2006.ers

Value

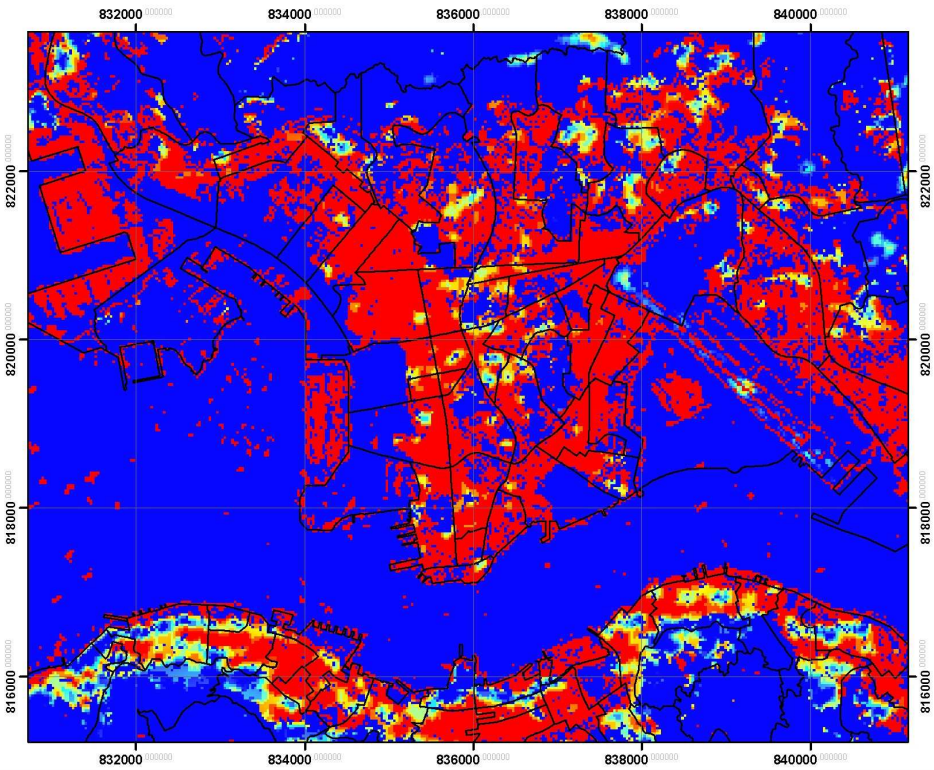
High : 300

Low : 293

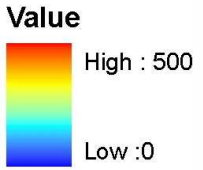
Anthropogenic heat



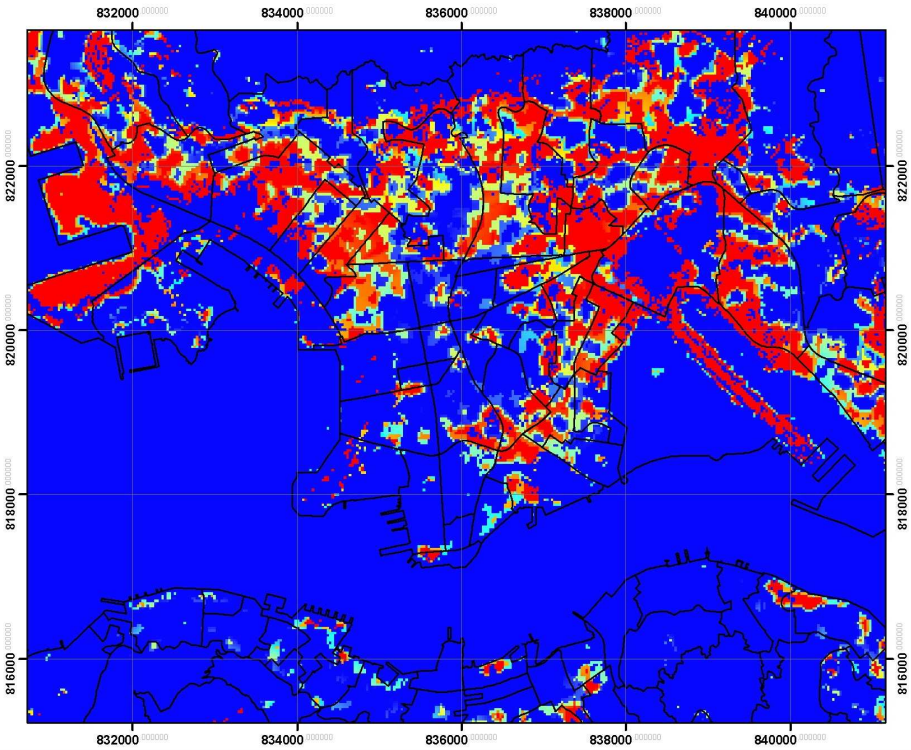
10-Dec-1988



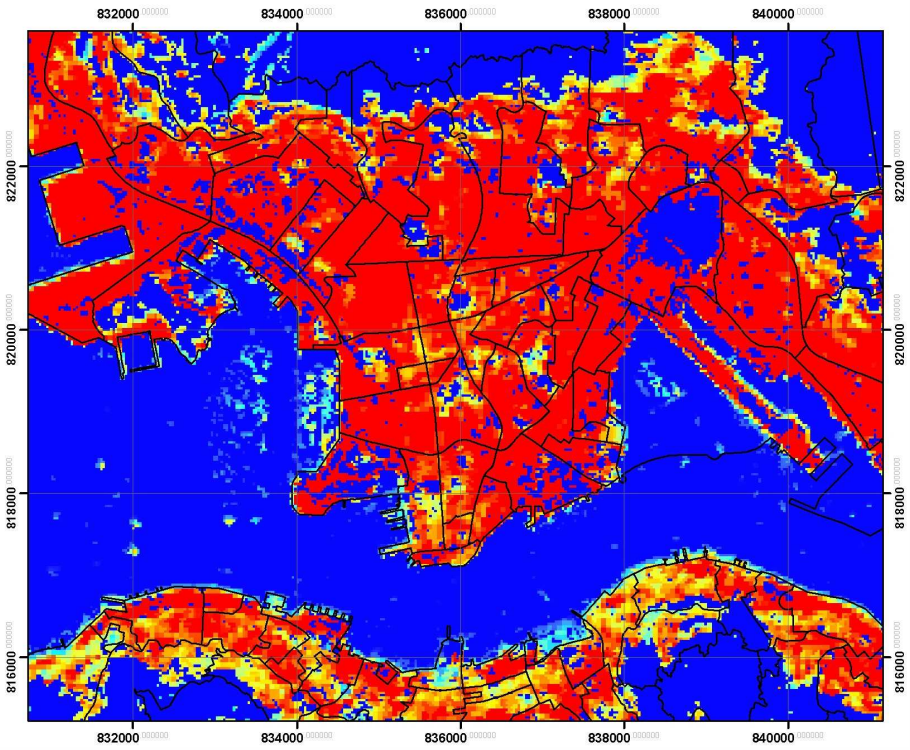
30-Dec-1995



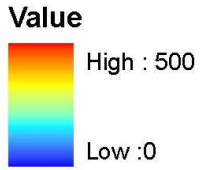
Anthropogenic heat

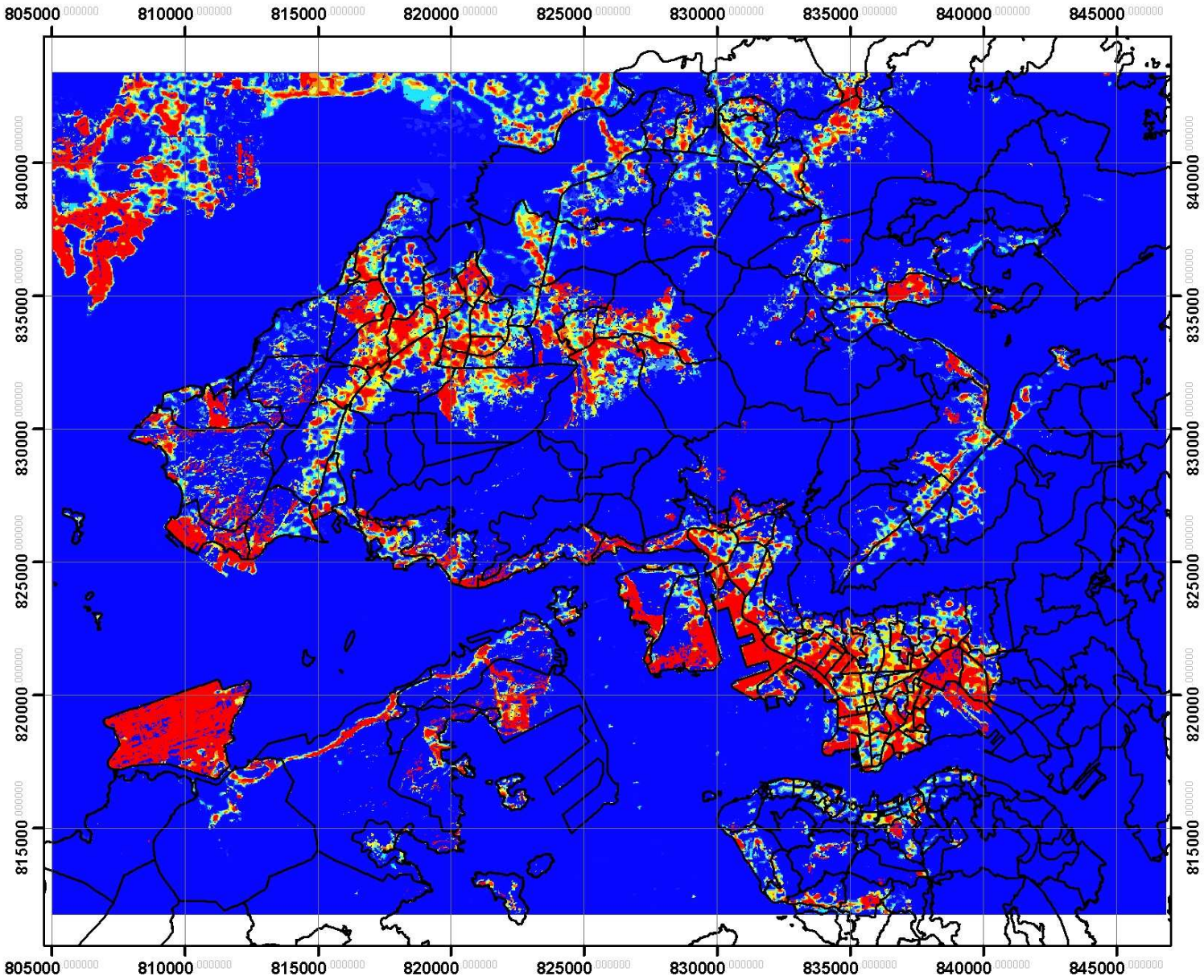


03-Mar-1996



14-Sep-2000





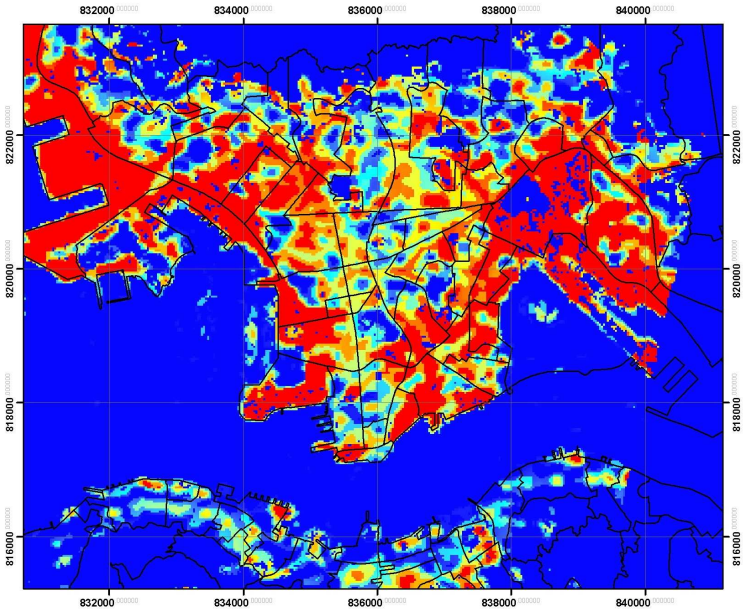
Anthropogenic heat

28-Dec-2006

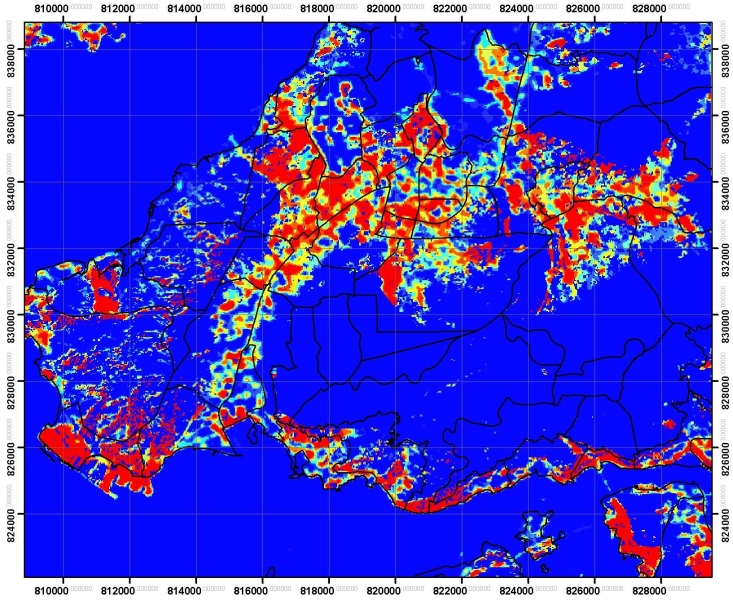
Value

High : 500

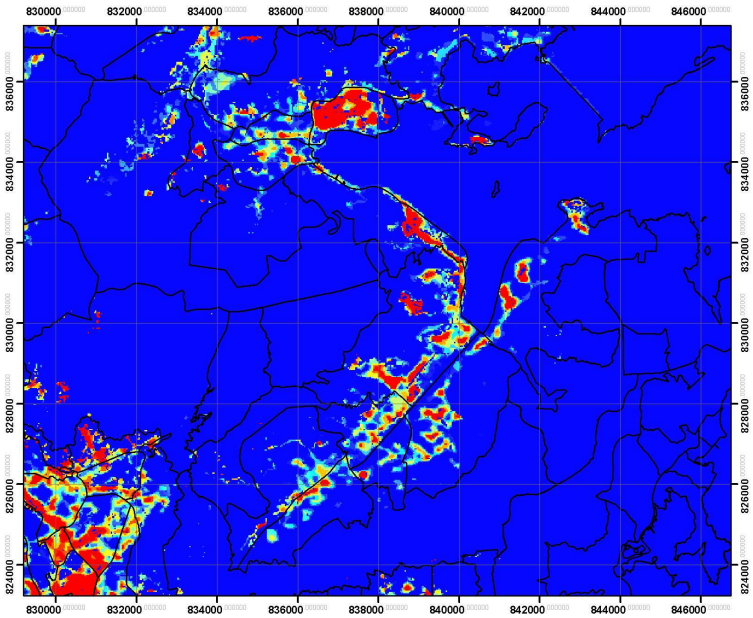
Low :0



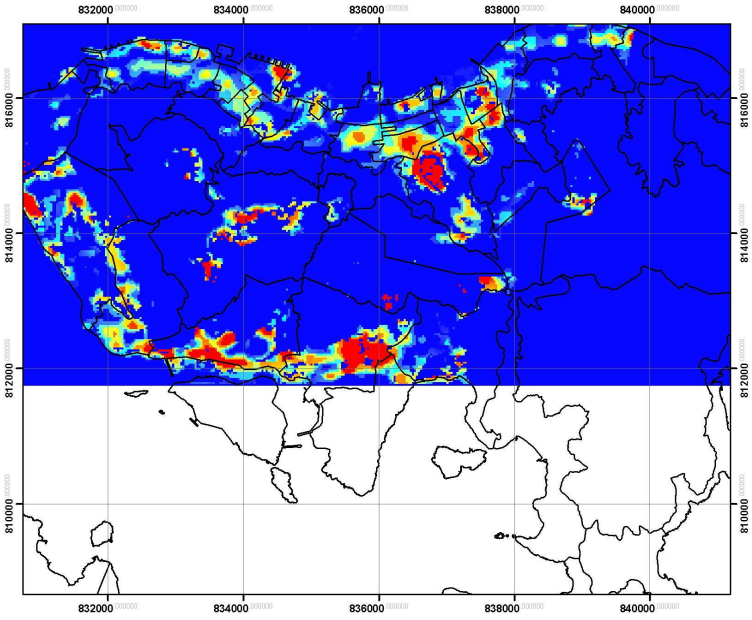
Kowloon peninsula



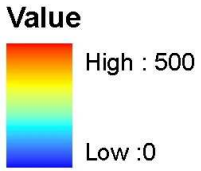
New Territories west



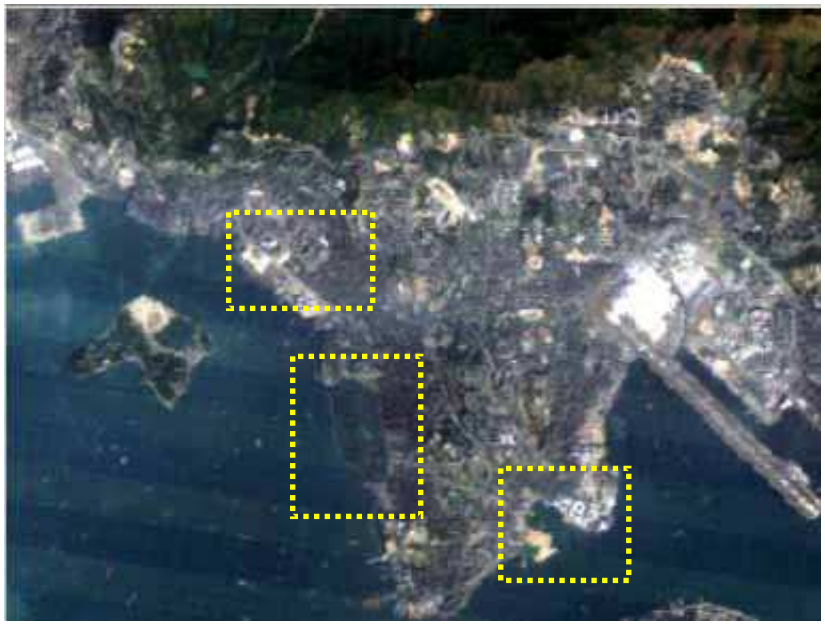
Shatin and Tai Po



Hong Kong island



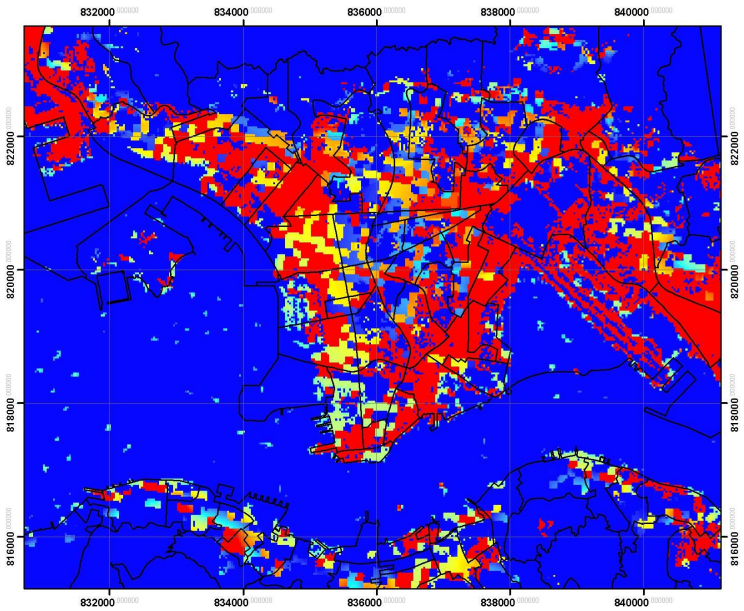
Urban development and land reclamation



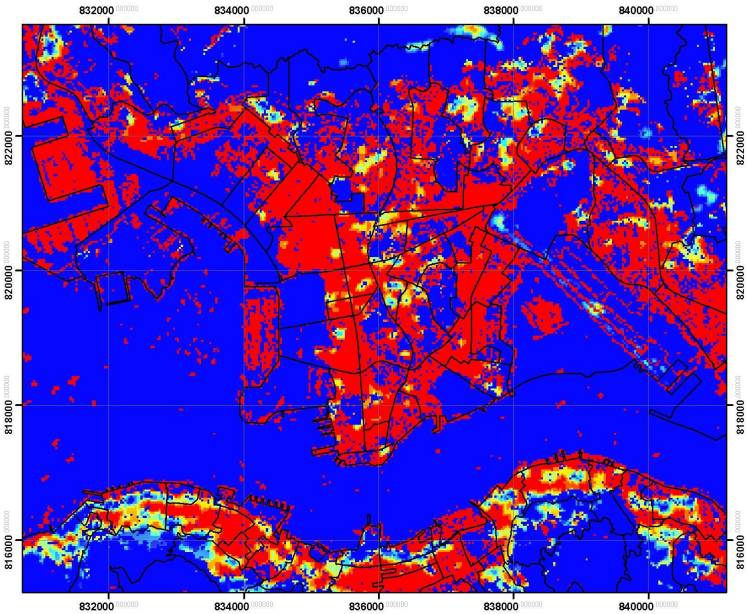
10-Dec-1988

30-Dec-1995

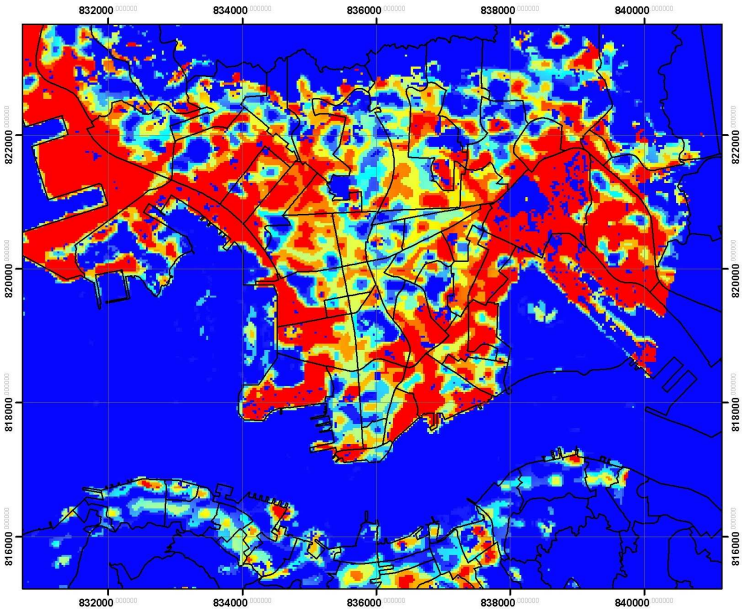
28-Dec-2006



10-Dec-1988



30-Dec-1995



28-Dec-2006

	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

Unit = Wm^{-2}

Value

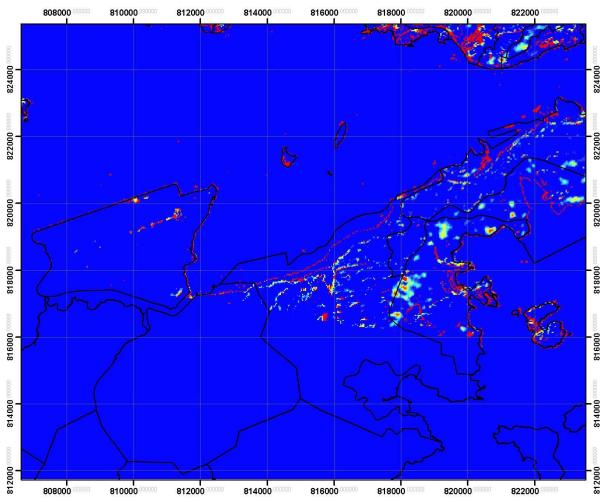
High : 500

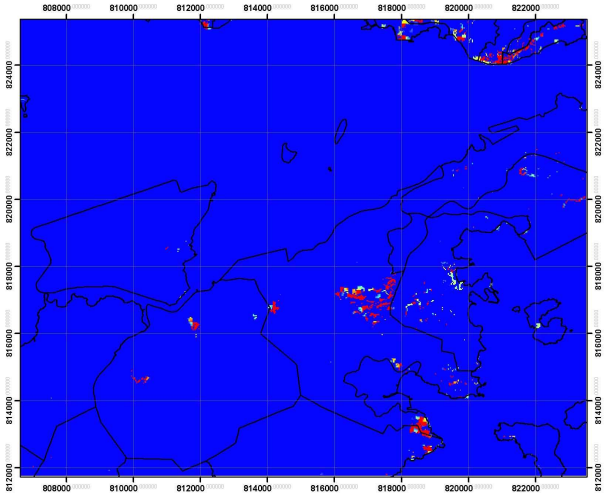
Low :0

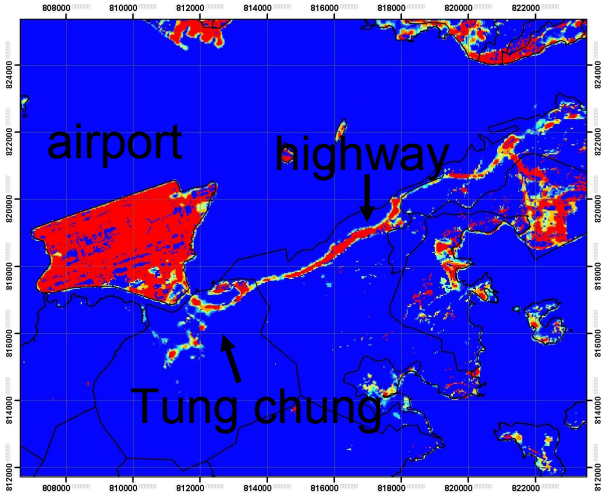
10-Dec-1988

30-Dec-1995

28-Dec-2006



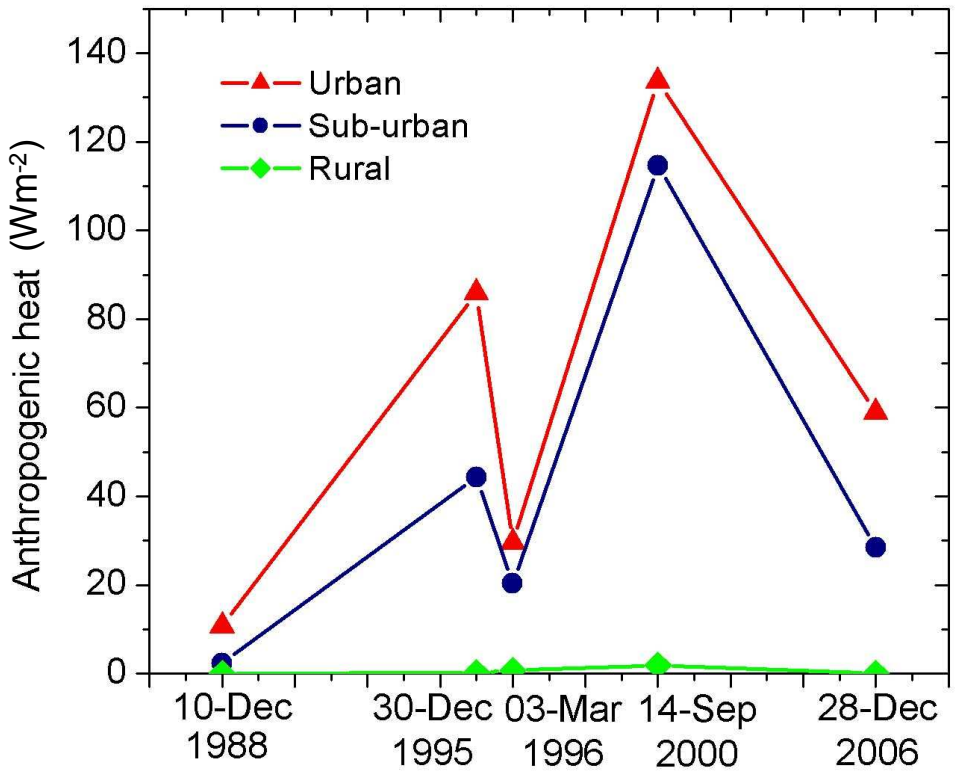




The Hong Kong international airport is started using in year 1997

Average anthropogenic heat observed in 28-Dec-2006,
on airport = 128.4 Wm^{-2}, on highway and airport express = 59.5 Wm^{-2}

Urban vs Sub-urban vs Rural



Urban: Kowloon and Central
Sub-urban: Tai Po and Shatin
Rural: Tai Mo Shan

- Due to the large heat capacity of dense tall buildings and heavy traffic, heat fluxes discharged into city downtown areas are larger than in sub-urban towns

<u>In winter of 2006</u>
Urban = 2 times of sub-urban

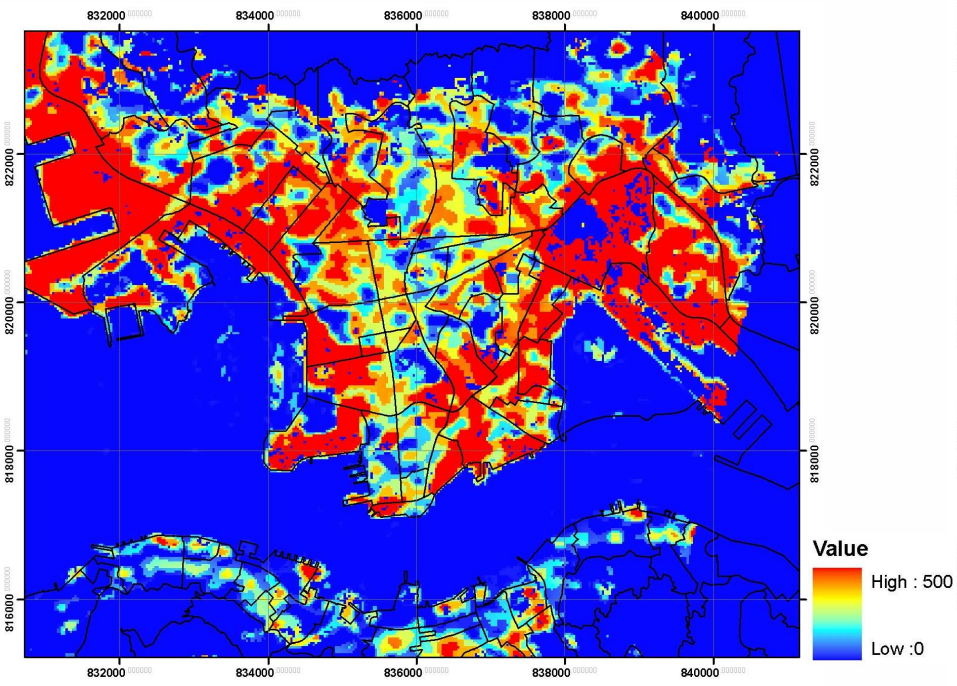
<u>In fall of 2000</u>
Urban = 1.16 times of sub-urban

<u>In spring of 1996</u>
Urban = 1.45 times of sub-urban

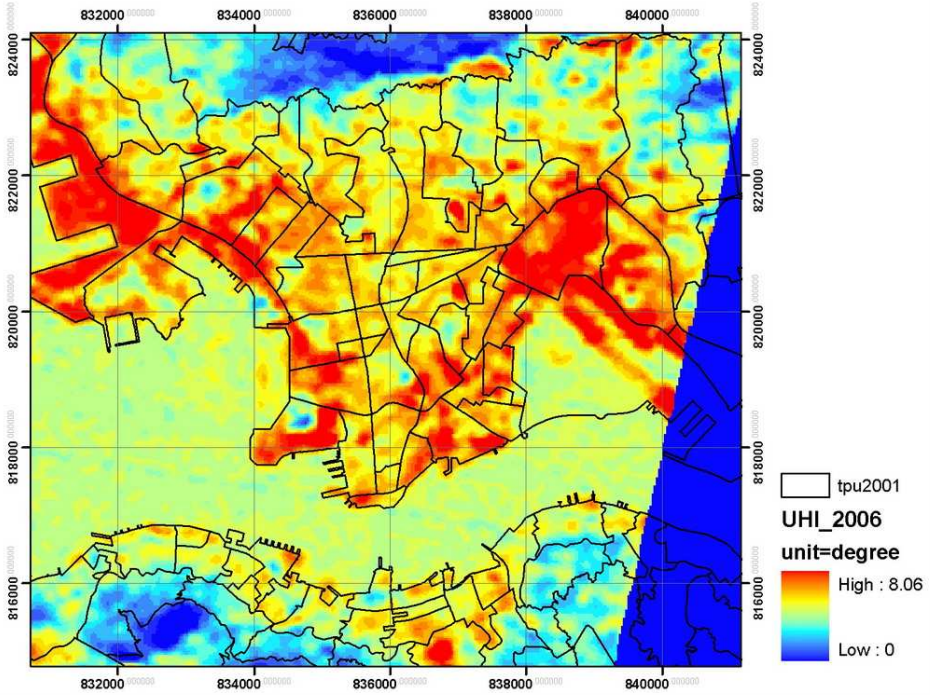
- Due to the influence of seasonal variation → a conclusive trend cannot be inferred

Correlation between Anthropogenic heat and UHI

Anthropogenic heat



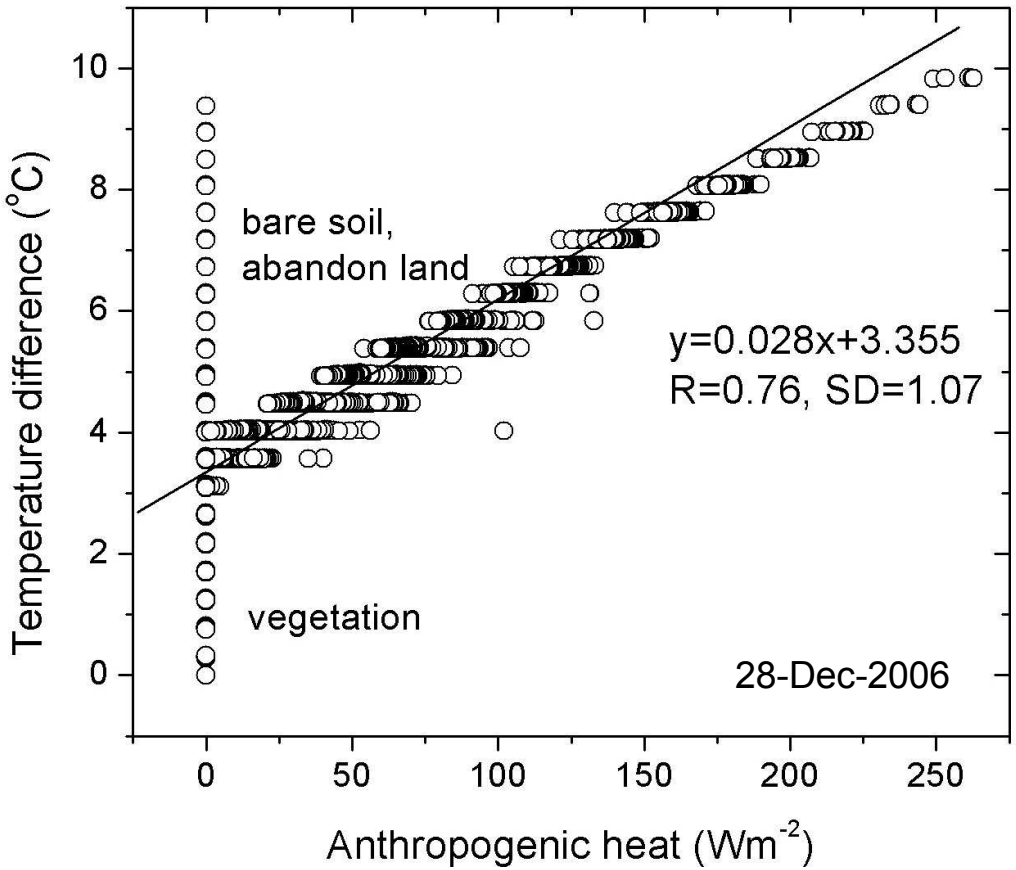
UHI – temperature differences



28-Dec-2006 (10:46am)

Urban heat island refers to the difference of surface temperature between urban and rural areas

Correlation between Anthropogenic heat and UHI



year	R
10-Dec-1988	0.676
30-Dec-1995	0.686
03-Mar-1996	0.572
14-Sep-2000	0.615
28-Dec-2006	0.760

Anthropogenic heat plays an important role of the formation of UHI in winter (average R=0.707), than those in spring (R=0.572) and autumn (R=0.615)

Moderate correlations are observed during daytime (image time), but it would be expected to be more significant during nighttime and early morning

Discussion and Conclusion

- High resolution anthropogenic heat maps can be retrieved using Landsat images
- Land reclamation and urban development appear to have raised the anthropogenic discharges. Examples shown on Kowloon West, Hung Hom Bay, Cheung Sha Wan and Hong Kong International airport
- Due to the large heat capacity of dense tall buildings and heavy traffic, anthropogenic heat fluxes in city downtown are about 2, 1.16, 1.45 times as large as those in the sub-urban towns in winter 2006, fall 2000 and spring 1996
- Anthropogenic heat has a more significant impact on winter time urban heat islands formation (R=0.707), than those in spring (R=0.572) and autumn (R=0.615). It depends on time of day and climatic conditions
- Energy consumption and heat discharge in city downtown are comparatively high in autumn. Since there are few images in summertime, definitive conclusion cannot be drawn

Future improvements

- Validation will be done using (i) GIS method (e.g. no. of vehicle, no. of buildings) and (ii) in-situ measurements
- T_a estimation based on Nichol and Wong's method (in press, IJRS) will be involved in the program code
- Calculate the H_{as} (sensible heat flux due to anthropogenic heat), and H_n (sensible heat flux due to radiant heat balance)
- Use of a detailed land use map instead of land cover map may improve the anthropogenic heat estimation
- Test the feasibility of the model on night-time ASTER images
- Examine the model results of anthropogenic heat flux combined with air-quality modeling
- Test the feasibility of the model applied to MODIS images which can provide daily retrieval

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