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SPATIAL VARIATION OF THE CHARACTERISTICS OF URBAN HEAT ISLAND EFFECT IN HONG KONG

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ABSTRACT

Recent studies by the Hong Kong Observatory show that the urban centre of Hong Kong has considerable Urban Heat Island (UHI) effect that arises from the different thermal properties between urban and the surrounding rural areas. The studies have also shown that the urban-rural temperature difference or UHI intensity in the urban centre of Hong Kong can be greater than 10 oC. However, the characteristics of UHI in Hong Kong would not be unique were it not for its complex topography and the significant spatial variation in the degree of urbanization within the territory. Making use of the extensive spatial coverage of the automatic weather stations operated by the Observatory, this study attempts to document the spatial variation of the characteristics of UHI effect in Hong Kong in summer and winter through cases studies. Cases in summer and winter with meteorological conditions typical for high UHI effect (that is, clear sky, light wind and stable atmospheric condition) are selected for the study. The characteristics of UHI effect in terms of the daytime warming rates, nocturnal cooling rates and diurnal temperature ranges at the selected automatic weather stations are analysed. The territory of Hong Kong is then classified into different categories according to the identified characteristics with a view to portraying the spatial morphology of UHI effect in Hong Kong..

KEYWORDS

Hong Kong, Urban Heat Island, heating rates, cooling rates, diurnal temperature ranges.

INTRODUCTION

The higher temperature in urban areas than the surrounding rural areas is described as the Urban Heat Island (UHI) effect (e.g., Oke and Maxwell 1975). Based on numerical simulation, Taha (1997) found that the UHI is a result of the changes in surface albedo and vegetation cover owing to urbanization. As controlled by different assemblages of energy exchange processes, the characteristics of UHI can vary from place to place and from time to time (Arnfield 2003).

Hong Kong, located at the south China coast, is a metropolitan city which has gone through a period of major urbanization in the past several decades. Due to the coastal setting, the air temperature at Hong Kong is regulated by the influence of land-sea breezes (Chang 1997) and the secondary circulations generated by the land-sea thermal contrast (Wai 1993). The UHI effect in Hong Kong, as highlighted by Oke (2008), is related to the density and height of the buildings that block the sea breeze. On the other hand, Gonzalez et al. (2005) reported that the sea breeze effect in coastal cities could be dominated by the UHI. Utilizing remote sensing techniques, Nichol (2005) pointed out that in Hong Kong, meso-scale climatic factors appeared to have greater influence than micro-scale factors at night but the reverse was true for the daytime. As reviewed in Souch and Grimmond (2006), the UHI remains the most intensively studied climatic feature of cities.

Recent studies carried out by the Hong Kong Observatory show that the rising trend of air temperature in Hong Kong in the past century was mainly a result of the combined effect of the global warming due to enhanced greenhouse effect and the high density urban development in Hong Kong (Lam 2006; Leung et al. 2004). Wu et al. (2009) conducted a study to determine the characteristics of the difference between the air temperatures in rural and urban areas, that is the intensity of the UHI effect (more specific, the canopy layer UHI, simply refer to UHI hereafter) by using the temperature readings recorded at the Hong Kong Observatory Headquarters (located at Tsim Sha Tsui, the centre of the urban area in the Kowloon Peninsula) and Ta Kwu Ling (located at the rural area of the New Territories). The results of the study show that UHI effect varied in different seasons in Hong Kong with high UHI intensity generally exceeding 10oC in fine weather with light winds in winter.

The characteristics of UHI in Hong Kong would not be unique for the facts that Hong Kong has a complex topography and that there is a significant spatial variation in the degree of urbanization within the territory. This study analysed the characteristics of UHI effect at different regions in Hong Kong and classified the territory into different categories according to the identified characteristics with a view to portraying the spatial morphology of UHI effect in Hong Kong. As UHI effect has seasonal variation in Hong Kong (Wu et al., 2009), this study also compared the findings in summer and in winter.

METHODOLOGY

Case study approach was used for the study. One summer case and one winter case with meteorological conditions typical for UHI effect, namely calm wind, clear sky and a stable atmosphere were selected for the study. Although it is not uncommon to refer UHI as a nocturnal phenomenon (e.g., Gedaelman et al., 2003, Bonacquisti et al. 2006) because of the lower UHI intensity in daytime (e.g., Alonso et al., 2003), there were studies focusing on daytime UHI (e.g., Giridharan et al 2004, Hidalgo et al 2009). The UHI effect at a particular location was therefore characterized by the daytime warming rate (WR), nocturnal cooling rate (CR) and diurnal range (DR) in this study.

The in-situ temperature readings measured by the automatic weather stations operated by the Hong Kong Observatory for these two cases were analysed to determine the WR, CR and DR for characterizing the UHI effect at each of the stations. The automatic weather stations were then classified as Urban, Rural or otherwise (hereafter refer to as Hybrid for short) by means of the method of k-means cluster analysis (e.g., Wilks 1999) in terms of WR, CR and DR.

DATA

Figure 1 shows the locations and altitudes above mean sea level of the automatic stations. Stations at high altitudes and at offshore islands were considered as reference stations and would not be classified in this study. As the effect of UHI is most pronounced during nighttime (Wu et al, 2009), the period of interest for each of the selected cases also covered the early morning of the following day.

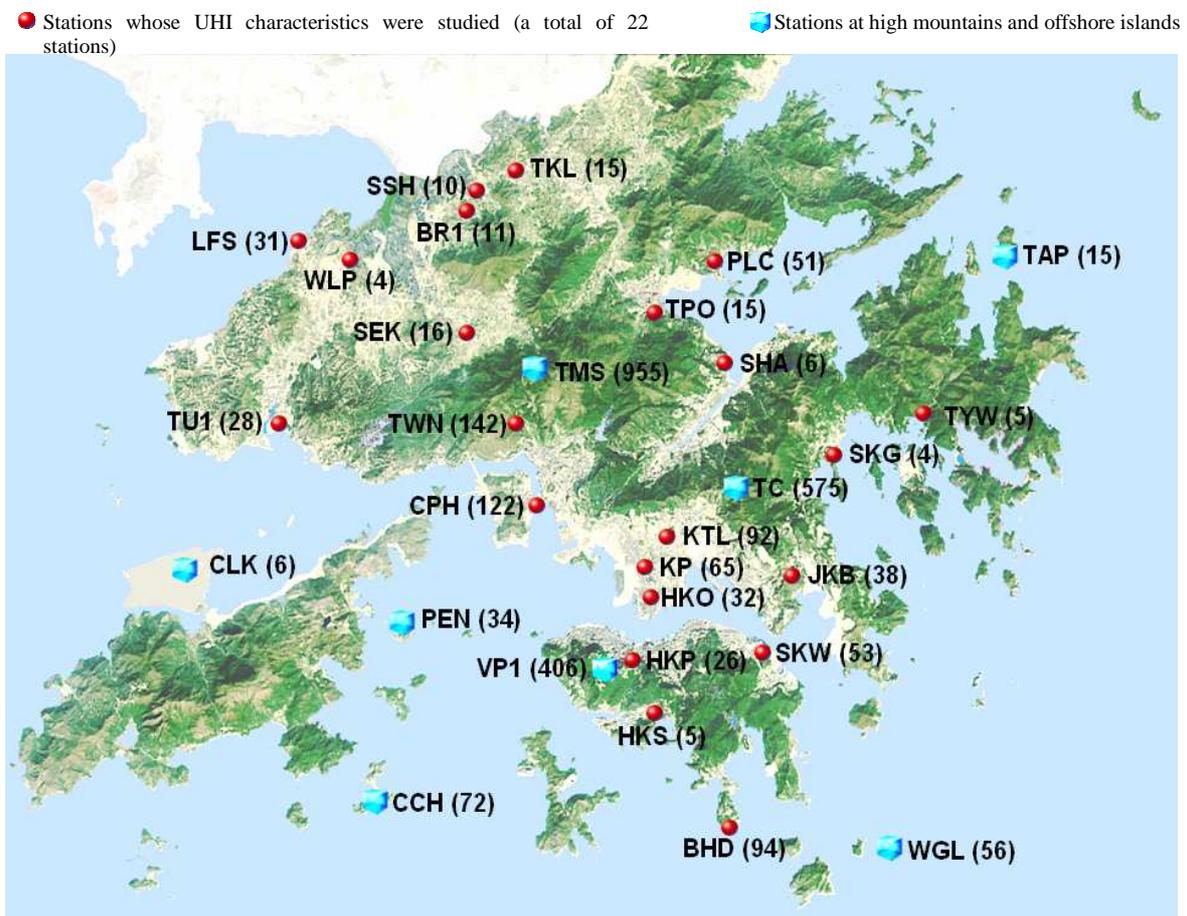


Figure 1 Locations of the automatic weather stations used for this study. Values in the brackets denote the station elevations above sea-level in metres.

The summer case of 25 July 2008 and the winter case of 30 November 2008 were selected for the study. For the summer case, it was almost cloud free over south China under the influence of air subsidence associated with a tropical depression over the western North Pacific to the east of Taiwan. It was also mainly fine over south China for the winter case when the dry winter monsoon affecting the area had been moderating. Figure 2 shows the daily weather maps at 08HKT and the visible satellite imageries taken at 11HKT for the two cases. The meteorological conditions in Hong Kong during these two cases are summarized in Table 1.

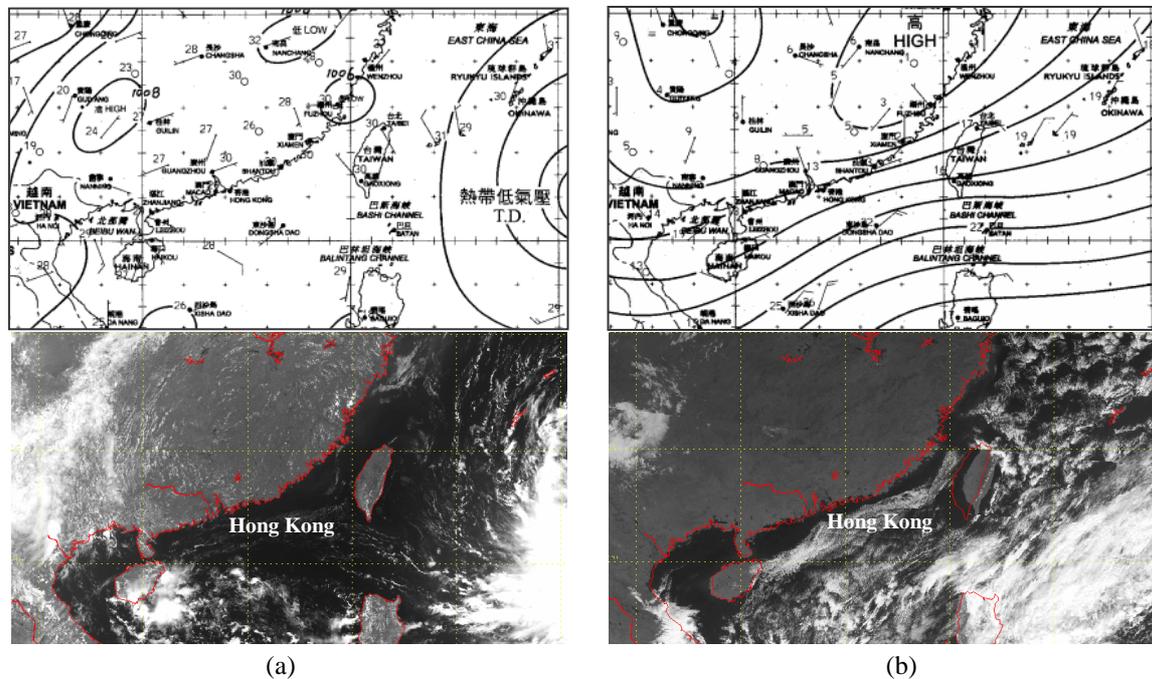


Figure 2 Daily weather map at 08HKT (top) and visible satellite imagery (bottom) at 1100 HKT on (a) 25th July 2008 and (b) 30th November 2008.

Table 1 Meteorological conditions in Hong Kong during the periods of interest of the summer case on 25 July 2008 and the winter case on 30 November 2008

Date	Cloud amount	Rainfall	Wind speed	Beaufort Force	Sweat Index ¹	Nighttime stability ² (Pasquill-Turner Categories)
25 July	13 %	0 mm	2.2 ms ⁻¹	Light	124	Class F (moderately stable)
26 July	10 %	0 mm	2.2 ms ⁻¹	Light	175	Class F (moderately stable)
30 November	0 %	0 mm	1.7 ms ⁻¹	Light	68	Class F (moderately stable)
1 December	5 %	0 mm	1.4 ms ⁻¹	Light	62	Class F (moderately stable)

¹Sweat index below 300 typically indicates no potential for strong convection (Lee 1993)

² the Pasquill-Turner Stability Categories is specified in terms of wind speed and cloudiness (Koo et al 1984).

ANALYSIS AND RESULTS

Definitions of UHI attributes

Figure 3 shows the time series of on-the-hour temperatures and hourly temperature changes averaged for the 22 automatic weather stations with altitudes close to mean sea level. The hourly temperature change is taken as the difference in temperatures between that hour and the preceding one.

The warming rate (WR), cooling rate (CR) and diurnal range (DR) were specially defined for both cases with reference to Figure 3 as follows: WR as the warming rate over the period from one hour after sunrise to the afternoon at 14 HKT during which temperatures generally kept rising, CR as the cooling rate over the period from one hour after sunset to the time when the rate of temperature drop stabilized and became almost steady, and DR as the difference between the minimum temperature after sunset and the maximum temperature after sunrise. In this study, all rates were determined using linear regression method. Values of WR, CR and DR for all the stations in Figure 1 were computed to determine various UHI attributes.

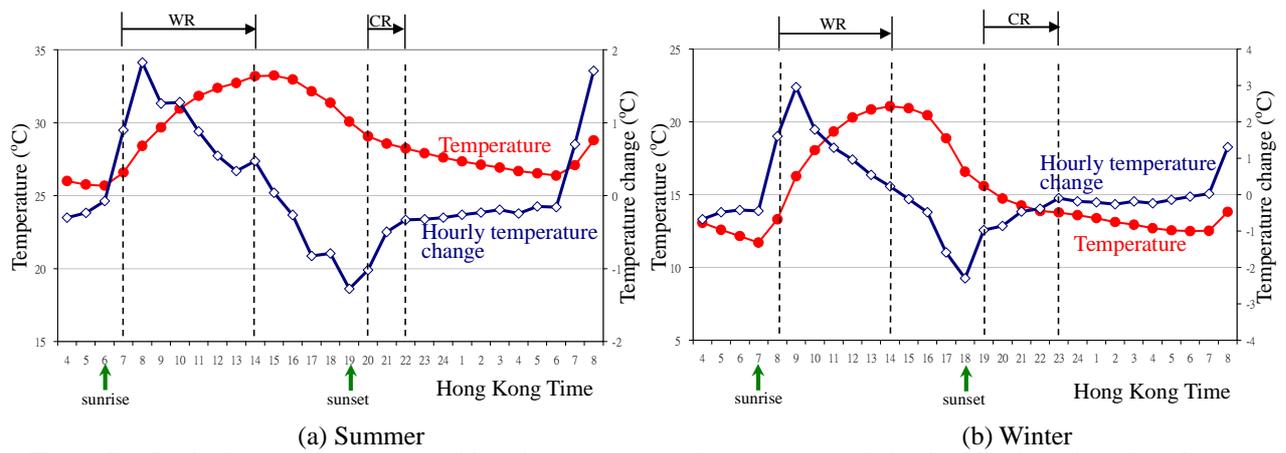


Figure 3 On the hour temperatures and hourly temperature changes averaged for the 22 selected stations for (a) summer and (b) winter case. WR and CR denote respectively the warming rate and cooling rate being considered.

Classification of stations

The 22 stations were classified as Urban, Rural or Hybrid by means of the method of k-means cluster analysis (e.g., Wilks 1999) in terms of WR, CR and DR. A commercial package XLSTAT was used to perform the cluster analysis with the number of clusters set to three. Since several stations had clear and unambiguous thermal properties in the context of UHI (for example HKO is an urban station while TKL is a rural station), the nature of each cluster can be recognized simply by referring to these representative stations. Table 2 shows the results of the cluster analysis.

Table 2 k-means clustering results. Stations belonging to the same cluster in both summer and winter are highlighted in bold. Note that data was not available for HKP for the winter case.

Cluster (Type)	Summer	Winter
1 Urban stations	SKW,HKS,HKO, KP,KLT,CPH, HKP,LFS,TU1	SKW,HKS,HKO, KP,KLT,CPH, BHD,JKB,TWN,PLC,SKG
2 Hybrid stations	WLP,SHA, BHD,JKB,TWN,PLC	WLP,SHA, TPO,LFS,TU1
3 Rural stations	TKL,BR1,SSH,SEK, TYW, TPO,SKG	TKL,BR1,SSH,SEK, TYW

Thirteen stations were classified distinctly as either Urban, Rural or Hybrid stations irrespective of the season (i.e., those highlighted in bold in Table 2). Figure 4 shows the distribution of the Urban, Rural and Hybrid stations in summer and winter.

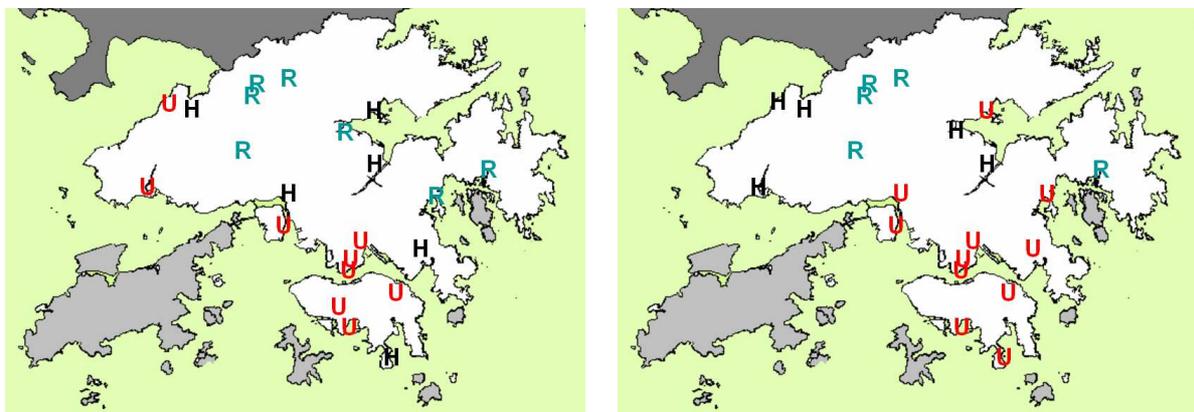


Figure 4 Distribution of Urban (U), Rural (R) and Hybrid (H) stations for summer (left) and winter (right).

It is noted that all stations located in the Kowloon Peninsula (including HKO, KP and KLT) and all stations located in the inland areas of the New Territories (including TKL, BR1, SSH, SEK) were classified as Urban and Rural stations respectively in both summer and winter. On the other hand, both WLP and SHA were Hybrid stations in both summer and winter.

TPO and SKG were examples of stations bearing different UHI characteristics in summer and winter. In particular, SKG was classified as a rural station in summer and an urban station in winter. One possible reason for the seasonal variation in UHI characteristics of these stations was that these stations are close to seashore and prone to the influence of local land-sea breeze circulations. Since the sea is normally warmer than air in winter and cooler in summer, the temperature contrast exerts an influence on the station temperature throughout the year. Besides the land-sea breeze effect, there might be other possible factors such as surface cover which may have seasonal characteristics that caused the observed seasonal variation in UHI characteristics of these stations.

Thus, the classification of stations depends on a number of factors, including the clustering algorithms, the variables considered and the choice of the number of clusters. Nevertheless, the delineation in this study appears to be representative at large for the purpose of distinguishing stations having different temperature change behaviours in a day.

UHI Characteristic of different station types

The average DR, WR and CR of the Urban, Rural and Hybrid stations were also computed and compared with the reference stations (Table 3).

Table 3 Comparison of the average DR, WR and CR for different station types with some reference stations.

Types	Summer			Winter		
	DR (°C)	WR (°Chr ⁻¹)	CR (°Chr ⁻¹)	DR (°C)	WR (°Chr ⁻¹)	CR (°Chr ⁻¹)
Urban	5.1	0.7	0.2	6.2	0.9	0.1
Hybrid	7.4	1.0	0.2	9.8	1.1	0.7
Rural	9.3	1.1	0.8	14.5	2.1	0.9
Inner Island (PEN, CCH, TAP)	7.3	0.9	0.4	7.7	1.2	0.3
Outlying Island (WGL)	3.9	0.4	0.3	2.6	0.2	0.1
Hill top (TMS, TC, VP1)	4.6	0.5	0.1	4.2	0.5	0.1
Reclaimed Artificial island (CLK)	5.8	0.8	0.5	5.6	0.9	-0.1

It is apparent from Table 3 that all the average DR, WR and CR for Rural stations were largest both in summer and winter. In summer, Urban stations were characterized by a relatively small daytime warming rate whereas Rural stations registered a large nocturnal cooling rate. In winter, the nocturnal cooling rate for Urban stations was small whereas both the diurnal range and daytime warming rate were large for Rural stations. It is also noted that the behaviour of Hybrid stations with respect to the day time warming rate and nocturnal cooling rate was different between summer and winter. In summer, the warming rate for Hybrid stations was close to that of Rural stations while their nocturnal cooling rates were close to that of Urban stations. However, the warming rate of Hybrid stations assumed urban characteristic while the nocturnal cooling rate was close to that of Rural stations in winter.

It is noted that the smaller WRs for Urban stations in summer and winter as compared with those for Rural and Hybrid stations were comparable to those for CLK which is mainly a reclaimed artificial island, suggesting that the physical properties of the urban environment (such as concrete and asphalt) played one of the important roles in lowering the daytime warming rate. It is also noted that the CR for Urban stations was no greater than that for those for Inner and Outlying Islands in both summer and winter, probably because the cooling for the latter (especially the Outlying Islands) was regulated by the surrounding waters. As a matter of fact, the CR for urban stations in winter (being about one-tenth that of rural stations) was the smallest.

Spatial morphology of the UHI

As mentioned in previous sections, the intensity of UHI was most pronounced in nighttime. Table 3 also shows that the rural-to-urban ratio for CR was the largest among the other parameters in both summer and winter. The CR was then used to portray the UHI morphology of Hong Kong.

Figure 5 shows the spatial variation of the CRs in Hong Kong which was generated by simple interpolation of the CRs of the 22 automatic weather stations. It shows that the cooling rates in the urban hubs over the southern part of the territory were relatively small whereas those in most parts of the New Territories were larger. Furthermore, there was a noticeable change in the relative magnitude of the cooling rate in the western part of the New Territories from summer to winter. The cooling rates at that region were noticeably smaller than those non-urban stations in other parts of the New Territories in summer as compared with those in winter. This

concluded with the analysis results that both LFS and TU1 were classified as Urban stations in summer (refer to Table 2). Owing to the relative location of urban hub and local topography, the structure of the UHI (in terms of CR) in Hong Kong deviates from an idealized UHI of nearly concentric pattern as suggested by Kim and Bak (2005).

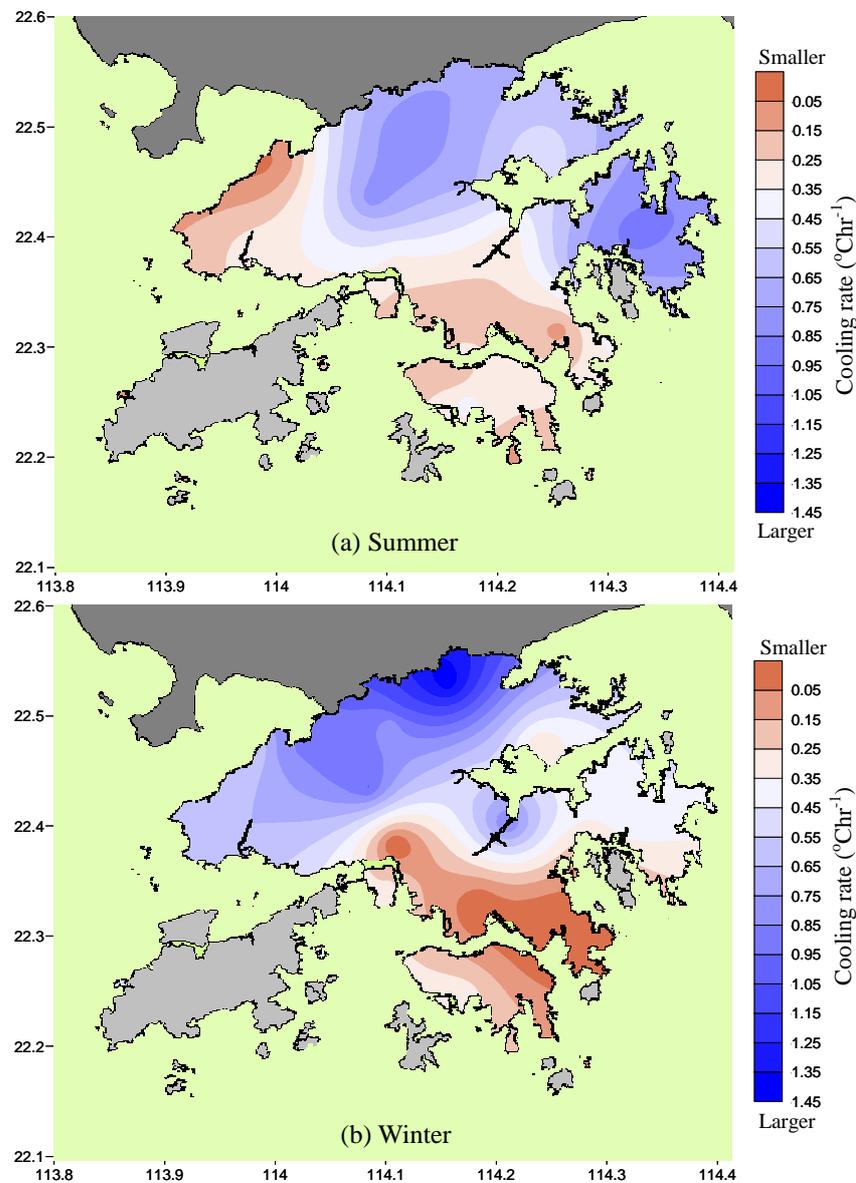


Figure 5 Variation of cooling rates for (a) summer and (b) winter. Conditions for Islands and Highlands were not incorporated to avoid spatial discontinuities arising from their geographical singularities and/or intrinsic characteristics.

CONCLUSIONS

The spatial variation of the characteristics of urban heat island effect (UHI) in Hong Kong was examined through case studies. Cases in summer and winter with meteorological conditions typical for high UHI effect were selected to elicit the seasonal difference. Areas with distinct urban or rural characteristics and areas with mixed rural and urban characteristics in summer and winter were identified in terms of their warming rate, cooling rate and diurnal temperature range. It was found that urban areas were characterized by a small daytime warming rate in summer and a small nocturnal cooling rate in winter. On the other hand, a relatively large nocturnal cooling rate in summer and a large daytime warming rate in winter were the hallmark of rural areas in Hong Kong. Overall speaking, the major impact of the urban heat island effect to urban areas is the noticeably small nocturnal cooling rate in summer, resulting in higher night time temperatures and lower degree

of comfort for people living in these areas. Town planners should take this characteristic of the urban heat island effect into consideration in their development or re-development projects.

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