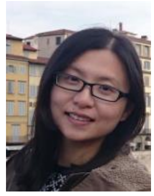

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Temporal and Spatial Structure of Urban Heat Island in Subtropical City of Hong Kong

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1. Introduction

The process of urbanization has been associated with the transformation of land surface structure and increase of anthropogenic heat release, which contribute to urban heat island effect. High level of heat island effect has been observed in high-density city of Hong Kong, which is considered as one of the major climatic problems in recent years. Previous UHI studies have revealed the physical process and the influencing factors of UHI generation as a general information support for climatic planning. However, many studies also pointed out that UHI development, influenced by local meteorology, land use, and surface geometry, shows variability across cities. Thus, further investigation of the UHI evolution pattern under local climate condition and understanding of the spatial and temporal distribution of UHI intensity is necessary for planning decision making.

2. Objective

This study aims to firstly identify and quantify the prevailing weather conditions of Hong Kong based on the long term statistics of the meteorological observation from Hong Kong Observatory headquarters station. Secondly, ten-year archives of six stations are analyzed in month sequence to identify the local meteorological conditions influenced by the complicated urban morphology and topography in Hong Kong, and characterize the seasonal variation patterns in subtropical climate. Finally, diurnal UHI profiles under clear sky and partly cloudy conditions of six weather stations during summer time are calculated and compared.

3. Method

3.1 Context

Hong Kong has monsoon-influenced subtropical climate along with seasonal variation in temperature, precipitation, humidity and wind direction. It is moderate in autumn, winter and spring with mean temperature spanning from 16°C to 26 °C, but hot and humid in summer with maximum air temperature higher than 30 °C. Monthly average cloud amount maintains above 50% for whole year, and reaches peak in spring and early summer exceeding 75%. Precipitation is most concentrated in spring and summer from April to September. Relative humidity remains at high level from February to September with daily range of 70% - 90%. Autumn and winters period from October to January are relatively drier with daily RH range of 60% - 80% (HongKongObservatory, 2015). Wind environment in Hong Kong is greatly influenced by monsoon circulation and the hilly-coastal topography. Annual prevailing winds come from east, while during summertime wind direction is also modified by southwest air stream (HKPD & CUHK, 2009).

3.2 Data

Long term stationary observation data: 47-year archives (1965-2012) in HKO headquarters (HKO), and 10-year archives (2002-2012) in Kings Park (KP), Sha Tin (SHA), Tuen Mun (TM), Ta Kwu Ling (TKL), and Waglan Island stations (WGL), has been analyzed to identify the typical summer weather and quantify the thermal pattern of the weather stations (Fig.1, Fig.2 & Table 1.). HKO, KP, SHA, and TUN stations have been classified as urban stations in previous studies (Leung & Ng, 1997; Siu & Hart, 2013). HKO headquarters is located in the central urban area in Kowloon peninsula, surrounded by compact high-rise buildings and close to Kowloon Park. Value of SVF at HKO is relatively high because the equipment are located in park-like open area. Close to HKO, KP station lies in the slightly elevated Kings Park with polygonal boundary surrounded by expressways and dense high-rise buildings. SHA station lies in an urban open space close to Penfold Park and Shing Mun River in Sha Tin District，with which TUN station shares much similarity in its proximity to Tuen Mun Park and Tuen Mun River. TKL and WGL stations have been mostly acknowledged as rural stations of Hong Kong (Fung, 2010; Memon, Leung, & Liu, 2009; Siu & Hart, 2013). WGL is normally regarded as the reference station of background wind condition by wind engineers(HKPD & CUHK, 2009).

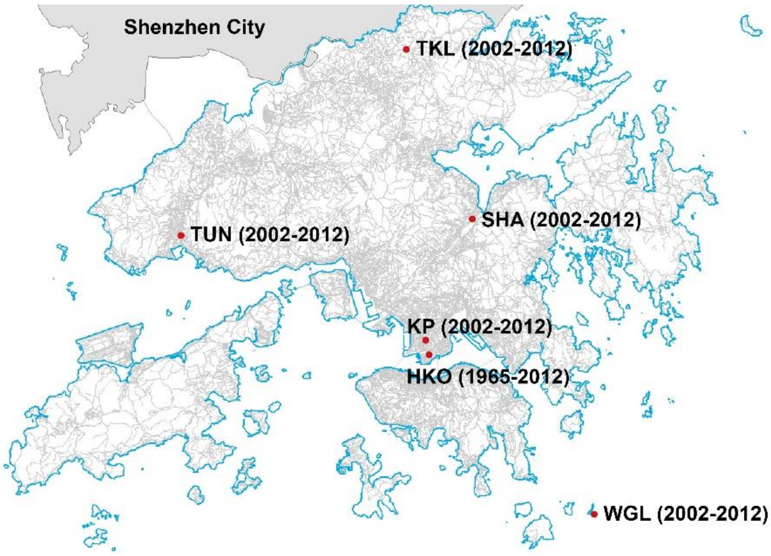

Fig. 1 Location and data period of reference weather stations.

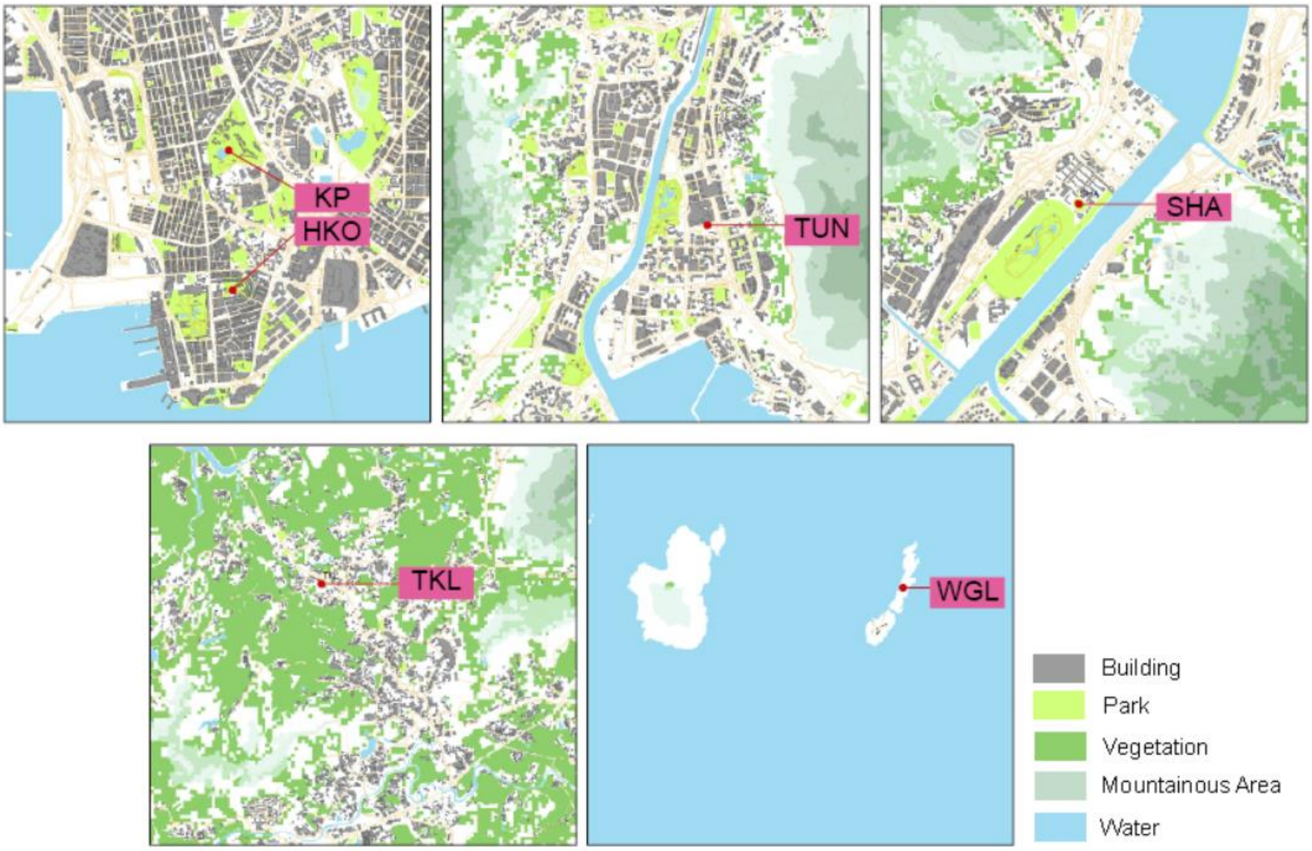

Fig. 2 surroundings of reference weather stations.

Table 1 Description of weather stations

Station	Data Period	Location	Classification
Hong Kong Observatory Headquarters (HKO)	1965-2012	Central commercial area of Kowloon peninsula, surrounded by dense high-rise buildings, high traffic density, high population density and intense human activities	Urban station
Kings Park (KP)	2002-2012	Kings Park, close to HKO station, surrounded by expressways and dense high-rise buildings	Urban station

Tuen Mun (TUN)	2002-2012	Residential area of Tuen Mun District, in the New Territories, close to Tuen Mun Park and Tuen Mun River, proximity to mountainous areas	Urban station
Sha Tin (SHA)	2002-2012	Residential area of Sha Tin District, in the New Territories, close to Penfold Park and Shing Mun River, proximity to mountainous areas	Urban station
Ta Kwu Ling (TKL)	2002-2012	Northeastern rural area in the New Territories with small population and lush vegetation	Rural station
Waglan Island (WGL)	2002-2012	Waglan Island, surrounded by the coast	Wind reference station

4. Result and analysis

4.1 Prevailing weather conditions in Hong Kong

47-year (1965-2012) meteorological observation in HKO headquarters has been analyzed in the aspects of cloud amount, rainfall, air temperature, relative humidity, wind direction and wind speed. As Fig. 3(a) and Fig. 3(d) shows, Hong Kong is generally cloudy and humid all the year round. Cloud amount remains above 4 Oktas half the time each year, while late autumn and early winter are the relatively clearer months which experience lower average cloudiness. Relative humidity exhibits similar annual pattern with cloud amount, which maintains higher than 60% throughout the year, and the time period from October to January are the drier months. Though the highest cloud cover distributes in spring (March-May), summertime is the rainiest season, during which monthly total rainfall reaches around 400mm as influenced by high frequency of showers and thunderstorms (Fig. 3(b)). Meanwhile, precipitation in May and September is also significant with total amount around 300mm. Hong Kong endures high thermal pressure from late spring to early autumn, especially severe during the summer months with daily mean air temperature close to 30 °C (Fig. 3(c)). Fig. 3(e) shows that, annual prevailing winds come from southeast direction, while during summer the southwest wind is also significant as influenced by the background oceanic air stream from southwest to southeast (Chung, Chan, Ng, Lam, & Wang, 1999). Meanwhile, wind speed reaches annual minimum level in summer with daily average value mainly distributed in the range from 1m/s to 3m/s, but endures more extreme cases with daily average value above 6m/s due to the occasional tropical depression (Fig. 3(f)).

4.2 Seasonal variation of meteorological elements among weather stations

As Fig. 4 (a) shows, all six stations exhibit higher variation in daily mean air temperature in cool season than hot season. Rural stations of TKL and WGL generally experience lower daily mean air temperature throughout the year as expected. Temperature difference among each two weather stations have been further calculated to quantify urban heat island and intra-urban heat island effect. Seen from Fig. 5, all the four urban stations have suffered urban heat island to varying degrees. TUN station suffers the highest daily mean UHI intensity during the warm months from March to September, while UHI intensity in HKO station only exceeds that in TUN during the cooler months from October to February (Fig. 6). KP station located in the Kings Park in central Kowloon urban areas, shows weakest UHI intensity annually among the four urban stations (Fig.5). In addition, urban stations generally experience highest UHI level during the winter months of November, December and January. In terms of intra-urban thermal difference, HKO station has higher air temperature than the nearby KP station, which indicates the impact of urban construction on temperature elevation. Even with lower urban construction density and higher proximity to the vegetated mountainous areas, the two stations of TUN and SHA in the New Territories keep higher air temperature than HKO station from May until September. It means that during the hot period, the urbanized areas in the New Territories are the critical areas worth planners and researchers paying attention to.

Fig. 4(c) shows that, wind speed in WGL is significantly higher than that in other stations, which mainly distributes in the range from 4m/s to 8m/s in daily average. Wind speeds in WGL and rural station of TKL are comparatively weaker during late spring and summer, but this trend is not evident in the four urban stations of HKO, KP, TUN and SHA as the stations share similar level of wind speed annually. Wind captured in the five land stations (HKO, KP, TUN, SHA, and TKL) mainly comes from southeast, south and southwest direction, coincided with the background wind direction in WGL during the months from April to September. However, during the months from October to March, though the background wind directions are east and northeast, prevailing wind directions in the five land stations are still in the ranges from southeast to south. Therefore, the annual prevailing wind direction of the five land stations is south and southeast, while the wind from southwest during summer month (June, July, and August) also needs to be taken into account.

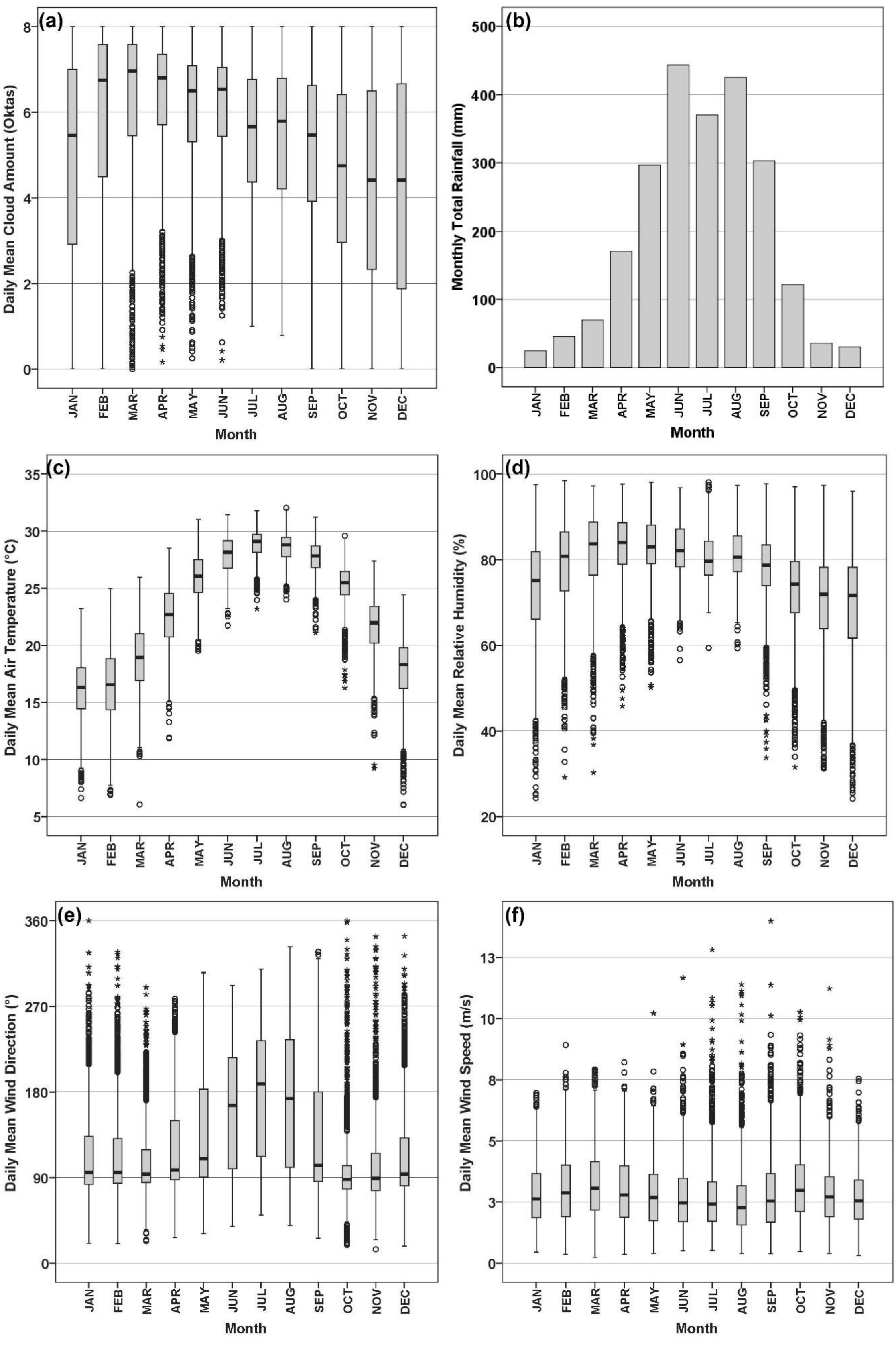

Fig. 3 Monthly meteorological elements statistics (HKO, 1965-2012).

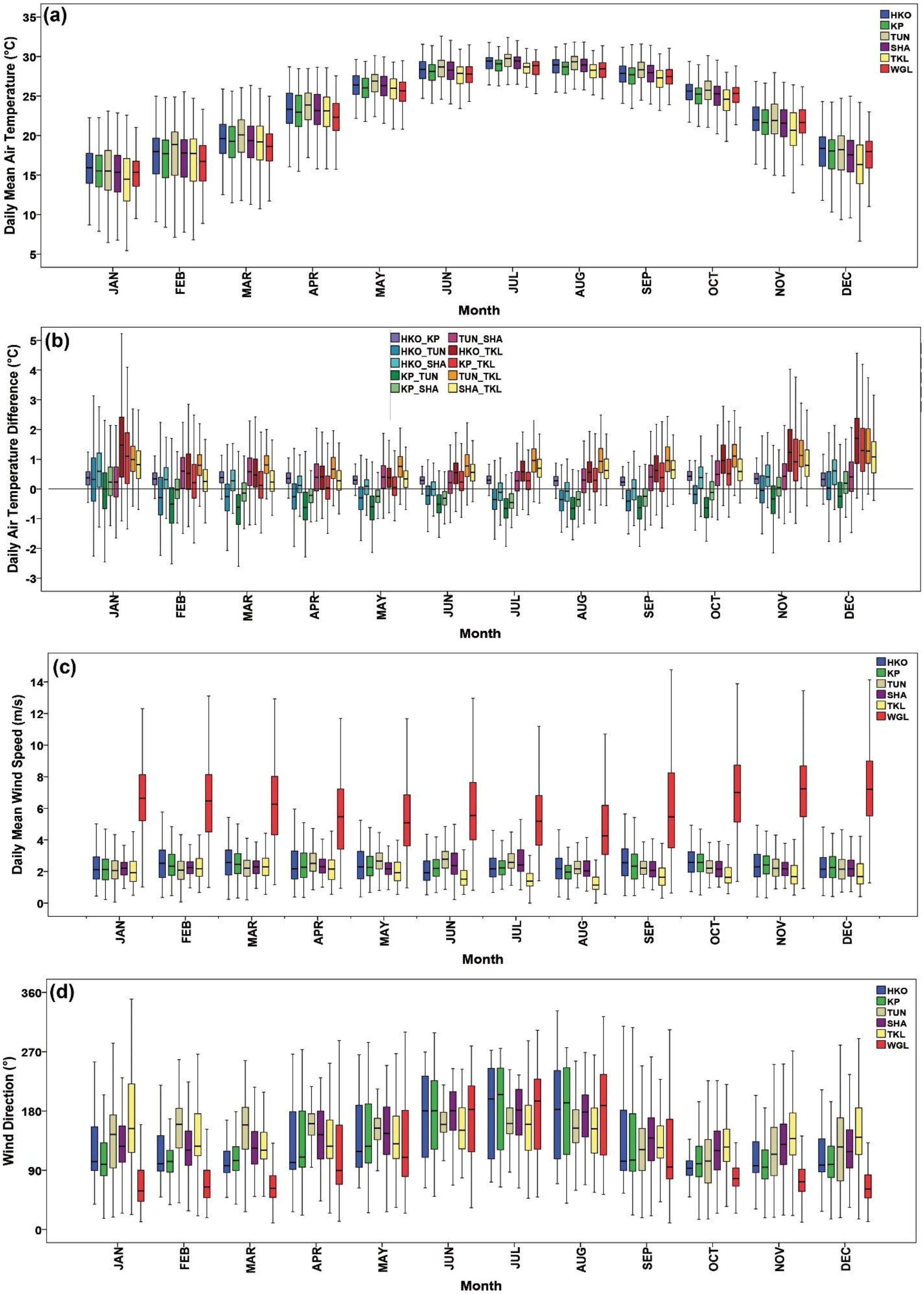

Fig. 4 Seasonal meteorological variation among weather stations (HKO, KP, TUN, SHA, TKL and WGL, 2002-2012).

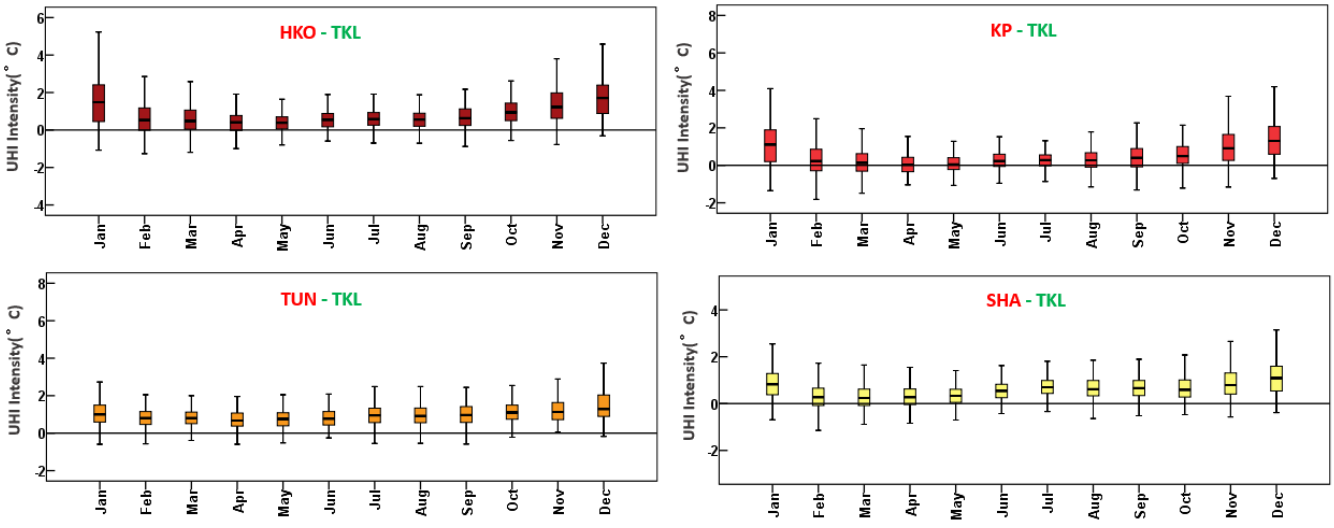

Fig. 5 Seasonal UHI intensity of urban stations (HKO, KP, TUN, SHA, and TKL, 2002-2012).

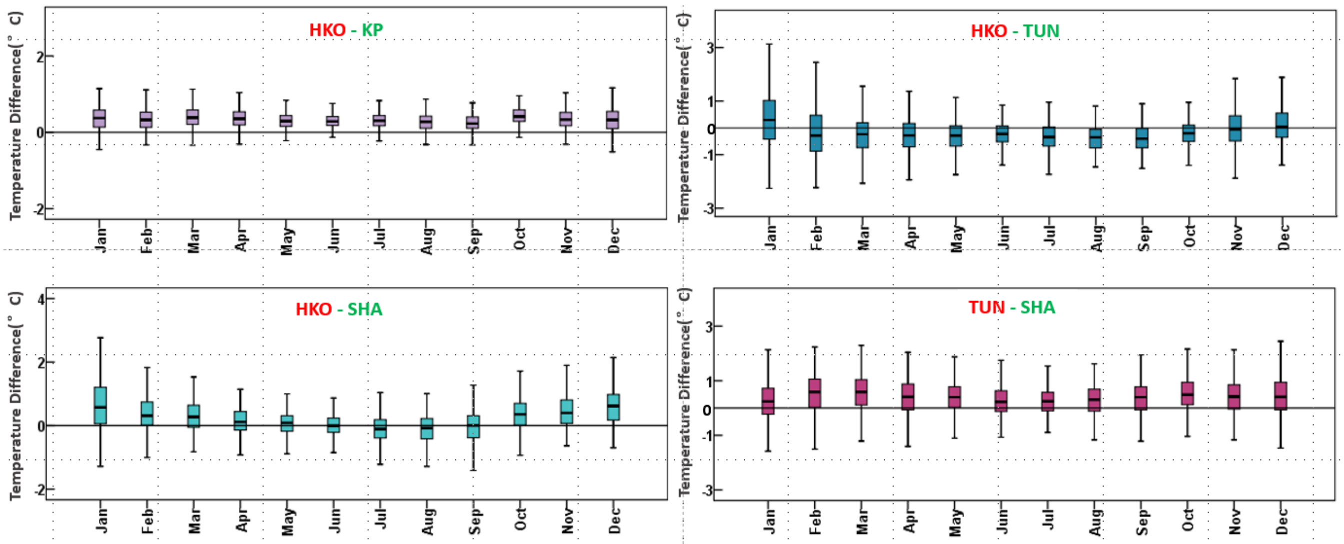

Fig. 6 Seasonal intra-urban temperature differences of urban stations (HKO, KP, TUN, and SHA, 2002-2012).

4.3 Diurnal profiles of UHI under partly cloudy and clear sky conditions in summer

Given that Hong Kong endures high air temperature from late May to early September, hot period from mid-May to mid-September has been included into the summertime statistical calculation in this section. Based on the analysis of 25 clear days (0-2 Oktas) and 1064 partly cloudy days (3-7 Oktas) in hot period (from mid-May to mid-September) during the ten years from 2002 to 2012 (incomplete observation has been excluded), diurnal profiles of air temperature recorded in the six weather stations has been plotted in Fig. 7. All six stations showed lower diurnal range under partly cloudy condition than clear sky. TKL experienced highest diurnal air temperature change as well as the daily maximum and lowest air temperature among the six stations both in clear and partly cloudy days. WGL had the lowest diurnal air temperature variation due to the regulatory influence from coast. HKO and KP exhibited similar pattern during daytime, while KP were cooler during night for its location in the park. SHA and TUN also experience analogous daily thermal cycle due to the topographical and morphological similarities. Intra-urban air temperature differences among the urban stations of HKO, KP, SHA, and TUN, as well as the UHI intensity between urban stations of HKO, KP, SHA, TUN and the rural reference of TKL under partly cloudy and clear conditions have been further calculated (Fig. 8). Diurnal range of intra-urban and urban-rural thermal differences were smaller in partly cloudy days than that in clear days. Under clear sky condition, both intra-urban and urban-rural thermal differences increased during night and reached peak at early morning before sunrise. Under partly cloudy condition, UHI intensity raised at a lower rate compared to clear sky condition while intra-urban air temperature differences remained at a constant level from 20:00 to 6:00 next day morning.

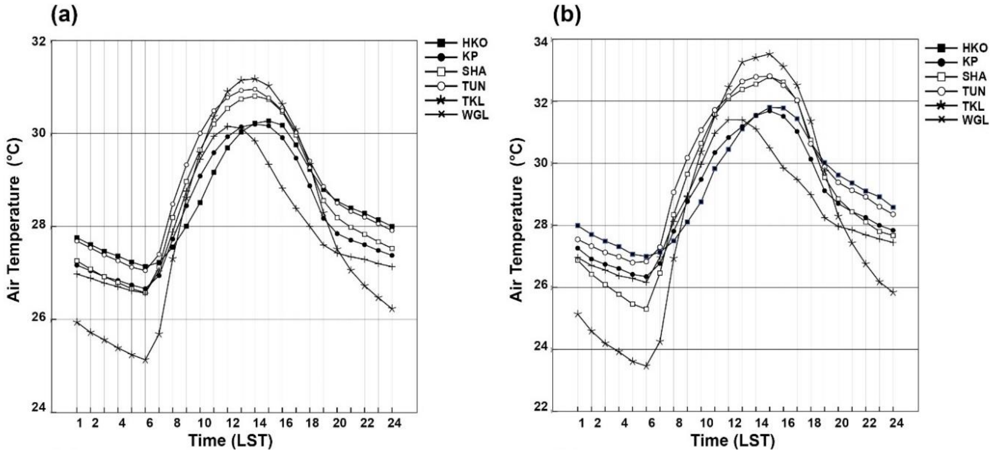

Fig. 7 Diurnal profile of air temperature of weather stations in summer under (a) partly cloudy and (b) clear sky conditions (HKO, KP, TUN, SHA, TKL and WGL, 2002-2012).

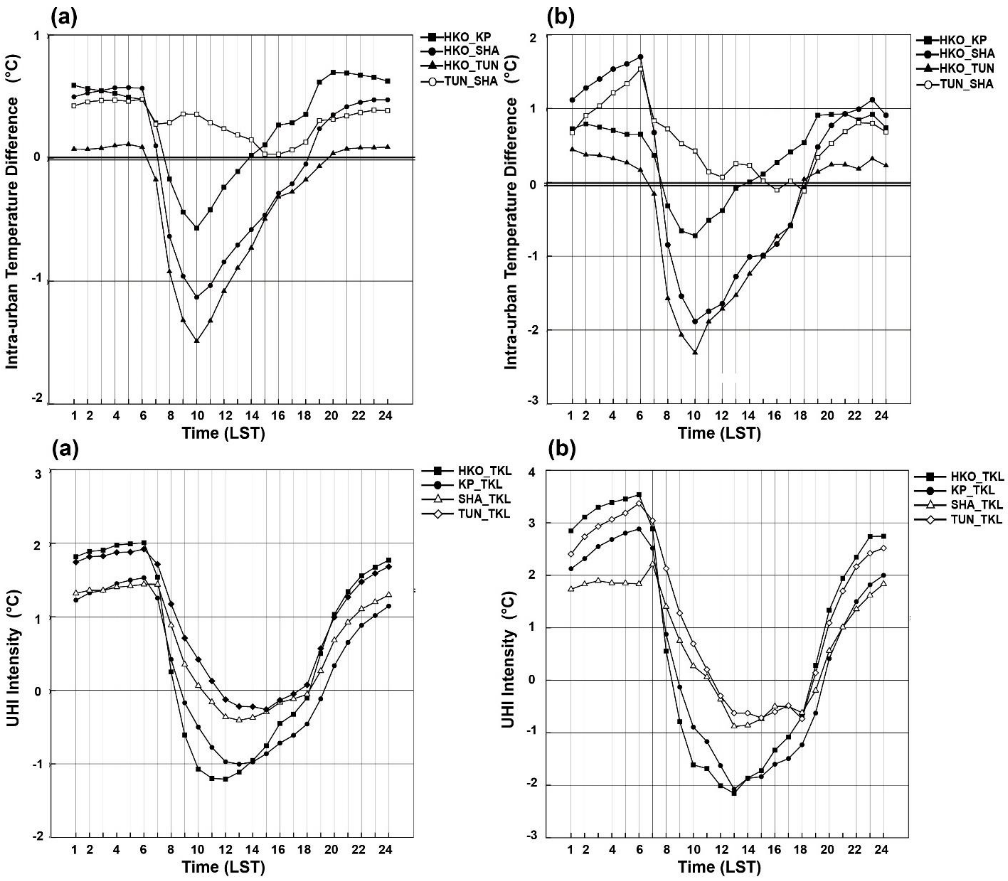

Fig. 8 Diurnal profile of thermal differences between weather stations in summer under (a) partly cloudy and (b) clear sky conditions (HKO, KP, TUN, SHA, TKL and WGL, 2002-2012).

Acknowledgment

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