A Study of Climate Change in Hong Kong by Extending Past Temperature Record from 1971 to 2010

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Abstract

The present study aims to extend the past temperature record of designated meteorological stations in Hong Kong using regression techniques in order to supplement the understanding of past climatic conditions at district level where observational records are generally lacking. The temperature trend was found to be associated with land conversion into concrete surface in surrounding areas and reduction in vegetation cover. Findings of the present study contribute to the understanding of the effect of climate change on areas with various land use and provide baseline conditions for temperature projection of future climate change scenarios. Such information will be useful to the incorporation of microclimatic conditions into the urban planning and design framework, especially for potential development in country areas and redevelopment of inner urban areas in the future.

Keywords: Temperature Trend, Climate Change, Regression, Urban Planning and Design

1. Introduction

The effects of climate change on air temperature are often described at a global scale as described by the near-surface air temperature on annual basis. The increasing global mean surface temperature has resulted in a wide range of impacts such as rising sea level, extreme weather events, and altered pattern of urban heat island effect [1,2]. As people are intrinsically affected by local climate, it is important to describe climatic variations on regional to local scales. Local climate is highly influenced by urban fabrics, air ventilation, and local temperature profile. Therefore, it should be of research focus in order to provide information to government authorities and associated parties to assist urban planning and design for adaptation measures in the future.

The present study aims to extend the past temperature record of designated meteorological stations in Hong Kong using regression techniques in order to supplement the understanding of past climatic conditions at district level where observational records are generally lacking. Linear regression was conducted to estimate the air temperature of the periods without observational records. Findings of the present study contribute to the understanding of the effect of climate change on areas with various land use and provide baseline conditions for temperature projection of future climate change scenarios. Such information will be useful to the incorporation of microclimatic conditions into the urban planning and design framework, especially for potential development in country areas and redevelopment of inner urban areas in the future.

2. Data and Methodology

2.1 Data

Hourly temperature data were obtained from the Hong Kong Observatory meteorological stations. The Hong Kong Observatory Headquarter (HKOHq) has the longest data period since it was established more than a century ago. Therefore, it was employed as the reference station in the present study. Urban stations include Shatin (SHA) and Wong Chuk Hang (HKS) while Lau Fau Shan (LFS) and Ta Kwu Ling (TKL) are regarded as rural stations. The forty-year period from Jan 1971 to Feb 2011 of the HKOHq station was extracted for the use of extending past temperature records of the four selected stations.

2.2 Linear regression

Hourly temperature data were divided into two categories, namely daytime and night-time. Monthly means were then calculated for each of the two categories for subsequent regression analysis. The multi-year time-series of monthly mean temperature of the four stations was used as the dependent variable (y) and the reference station, HKOHq, was selected as the independent variable (x). Regression models were then created using Equation (1) to calculate values for estimated y.

$$y = a_0 + a_1x_1 \qquad (1)$$

where a_1 represents a multiplicative coefficient for independent variable x_1 and a_0 represents the constant term. This process was carried out for four different seasons (Spring, MAM; Summer, JJA; Autumn, SON; Winter, DJF) respectively.

2.3 Tables

Regression models developed by Equations (1) were validated by 5-fold cross-validation. Model performance was assessed by their corresponding root mean square error (RMSE) values. The model with the lowest RMSE values was then employed for extending past temperature series. The advantage of this method is that all the data in the dataset are eventually used for both training and testing. A 5-fold cross-validation was therefore adopted for a reasonable balance between computational time of regression analysis and the bias of the regression models.

3. Results

3.1 Model performance

The regression models for the four different seasons were trained by 5-fold cross-validation and the results were recorded in Table 1 and 2 for daytime and night-time models respectively. The model with the lowest RMSE values were then chosen to perform the extension of past temperature records for the four seasons and the annual data. It is found that the regression coefficients are considerably lower for summer months and the daytime models performed better than night-time models.

Table 1: RMSE values of the daytime models

Month	SHA	HKS	LFS	TKL
Jan	0.138	0.191	0.310	0.055
Feb	0.253	0.082	0.194	0.209
Mar	0.132	0.126	0.181	0.167
Apr	0.209	0.081	0.255	0.220
May	0.110	0.103	0.327	0.121
Jun	0.183	0.116	0.146	0.256
Jul	0.314	0.223	0.211	0.224
Aug	0.251	0.175	0.235	0.146
Sep	0.162	0.432	0.378	0.049
Oct	0.149	0.195	0.183	0.099
Nov	0.115	0.196	0.338	0.167
Dec	0.226	0.216	0.231	0.099

Table 2: RMSE values of the night-time models

Month	SHA	HKS	LFS	TKL
Jan	0.369	0.331	0.206	0.442
Feb	0.315	0.238	0.283	0.200
Mar	0.098	0.189	0.141	0.251
Apr	0.228	0.231	0.266	0.297
May	0.180	0.081	0.066	0.210
Jun	0.252	0.198	0.150	0.275
Jul	0.207	0.142	0.131	0.577
Aug	0.208	0.290	0.162	0.160
Sep	0.193	0.290	0.209	0.356
Oct	0.220	0.690	0.113	0.274
Nov	0.268	0.169	0.217	0.111
Dec	0.350	0.170	0.258	0.414

3.2 Multi-year trend

The trend of temperature series of urban, country and reference stations were recorded in Table 4 and four periods (1971-2010, 1981-2010, 1991-2010, and 2001-2010) were separately analyzed. A warming trend is observed for the long- and mid-term periods while a decreasing trend of temperature is generally observed in the last 10 years.

Table 3: Trends of daytime temperature series of urban, country and reference stations

Month	40-yr	30-yr	20-yr	10-yr
Summer				
HKO	0.0031	0.0028	0.0047	0.0080
SHA	0.0078	0.0118	0.0472	0.0523
HKS	0.0105	0.0171	0.0465	0.0107
LFS	0.0020	(0.0010)	0.0181	0.0514
TKL	0.0004	0.0018	(0.0069)	0.0261
Winter				
HKO	0.0283	0.0448	0.0203	(0.0048)
SHA	0.0305	0.0500	0.0654	0.0769
HKS	0.0209	0.0427	0.0553	0.0793
LFS	0.0355	0.0625	0.0730	0.0681
TKL	0.0306	0.0491	0.0184	0.0418

Table 4: Trends of daytime temperature series of urban, country and reference stations

Month	40-yr	30-yr	20-yr	10-yr
Summer				
HKO	0.0168	0.0084	0.0015	(0.0274)
SHA	0.0161	0.0124	0.0320	0.0302
HKS	0.0160	0.0162	0.0275	(0.0106)
LFS	0.0135	0.0037	0.0121	(0.0061)
TKL	0.0112	0.0055	(0.0258)	(0.0117)
Winter				
HKO	0.0408	0.0549	0.0227	(0.0453)
SHA	0.0387	0.0523	0.0623	0.0535
HKS	0.0499	0.0719	0.0613	0.0566
LFS	0.0447	0.0626	0.0607	0.0103
TKL	0.0499	0.0632	0.0086	0.0290

3.2.1 Summer

The long-term daytime temperature series of exhibited a slightly increasing trend with the highest increasing rate observed at HKS station (Fig 1). However, a decreasing trend was observed at LFS station. In the last 20 years, the highest increasing trends were observed at SHA and HKS stations while a decreasing trend was observed at TKL station. The warming trend observed at HKS station was reduced to 0.0107^{o}C per year while that of SHA station was further increased to 0.0523^{o}C per year in the last 10 years. Moreover, the temperature series of TKL station showed an increase of 0.0261^{o}C per year.

The increasing rates of night-time temperature in the last 40 and 30 years were similar to those of the daytime temperature series. For the last 20 years, the increasing rate of temperature was lower than the increasing rates of daytime temperature series while the cooling rate of TKL station was higher at a rate of 0.0258^{o}C per year. Night-time cooling was observed at most of the stations for the last 10 years except that a warming rate of 0.0302°C per year was observed at SHA station.

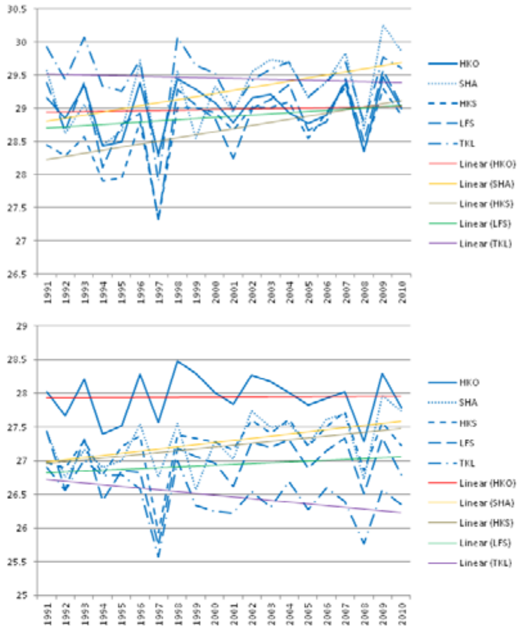

Fig 1. Temperature series of the 20-year summer mean (Top: daytime; Bottom: Night-time)

3.2.2 Winter

Warming trends, both daytime and night-time, were found to be the highest in winter except for the short-term trends observed at the reference station (Fig 2). The long-term increasing trends of mean daytime temperature ranged from 0.0209 (HKS) to 0.0355°C per year (LFS). The 30-year trend showed a higher rate of increase with the highest rate observed at LFS station. Such a high increasing rate was also observed in the last 20 years. The highest rates for urban and rural stations were 0.0654 and 0.073°C per year respectively. In the last decade, a decrease in mean temperature was observed at the reference station. The rates of increase at SHA and HKS (urban stations) were 0.0769 and 0.0793°C per year respectively while those observed at LFS and TKL were 0.0681 and 0.0418°C per year respectively.

For night-time temperature, the increasing trends were higher than those of the daytime temperature. The long-term increasing rates were higher than 0.04oC per year except SHA. The 30-year increasing trends were the highest among the four periods concerned with the highest rate observed at HKS station. A reduction in increasing trend was observed at the reference and TKL station in the last 20 years while those of the other three stations remained at a rate of about 0.06°C per year. The warming trends were found to be reduced at all stations with those of LFS and TKL stations reduced to 0.0103 and 0.029°C per year. Furthermore, a cooling trend was observed at the reference stations.

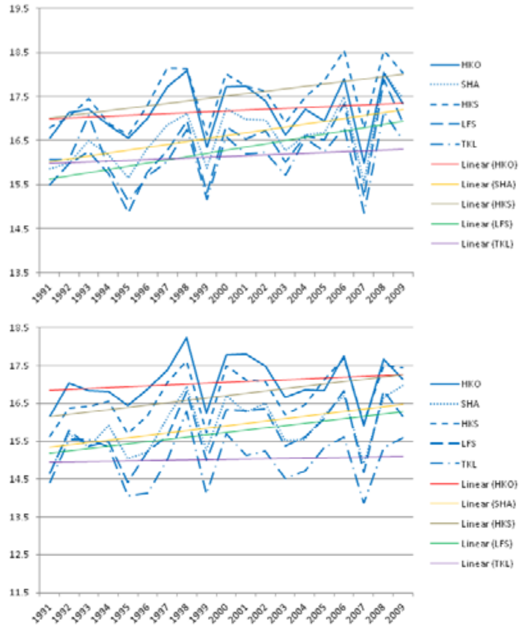

Fig 2. Temperature series of the 20-year winter mean (Top: daytime; Bottom: Night-time)

4. Discussion

The impacts of climate change on mean air temperatures vary across seasons and local urban settings. The warming trends of the two urban areas in the last 20 years were particularly higher in summer, which was primarily due to the extensive development of residential estates in these urban areas in the 1980s. Such residential developments are characterized by high building volumes and coverage in order to accommodate the rapidly increasing population in city centres. The urbanization process involves extensive transformation of rural villages into high-density residential sites which caused an exacerbating urban heat island effect which was reflected by the higher increasing rate of the night-time temperature.

In the rural areas, both stations (LFS and TKL) have exhibited a warming trend since 1990s due to various reasons. For Lau Fau Shan, it has long been a rural village and was developed into a tourist spot in the 1960s. Urban effect was limited in the district. As the population of Hong Kong grew, the government announced the development of a new town, Tin Shui Wai, in the northeast of Lau Fau Shan which accelerated the warming trend and altered local climatic characteristics. The rapid urbanization in Pearl River Delta in the last 20 years also influenced the local climate of Lau Fau Shan. In contrast, the mean air temperature of Ta Kwi Ling (TKL) increased steadily despite of the rapid urbanization of Shenzhen which has turned into a special economic zone in the 1980s. It was likely due to the rapid release of radiative heat absorbed during daytime as the area is dominated by low-lying plains and extensive vegetation. Such a relatively natural environment is preserved since it is located within an administratively closed area with minimal urban footprint.

In addition, the decreasing trend, particularly at the reference station, is primarily due to the canyon effect which is a result of intensified high-rise development nearby. Solar radiation is blocked by high-rise buildings nearby and results in a reduction in ground-level temperature which is generally measured by ground-based meteorological stations. However, it does not reflect the actual situation of the street-level environment since the canyon effect also influences local ventilation and dispersion of in-situ pollutants which have a significant effect on local microclimate.

5. Implications on urban planning and design in Hong Kong

Urban climatic issues have not been sufficiently considered, especially in the context of urban planning and design, until the implementation of air ventilation assessment (AVA) system in Hong Kong in 2005. A technical guide was released to provide a framework to facilitate better air ventilation in compacted urban areas [3]. Various urban issues in Hong Kong were evaluated and experts' comments were provided on several aspects of urban conditions, including the importance of breezeways (air paths) in dense urban areas, the effect of podium coverage on ventilation, the orientation and layout of buildings, and building permeability. All these issues were incorporated into qualitative guidelines which "offer useful design reference for better air ventilation and provide designers with a strategic sense of how to start off their design" [3; p. 1485-86]. These guidelines were further incorporated into the Hong Kong Planning Standards and Guidelines in order to improve air ventilation in densely compacted urban areas.

In addition to the AVA system, the Planning Department of Hong Kong Special Administrative Region Government started a feasibility study on using an urban climatic map (UCMap) to identify climatically sensitive areas and assess the impacts of urban developments on the local wind environment. The study was fostered by the preceding AVA study as a refinement to the existing AVA system by determining a general standard for the wind environment of Hong Kong. Ren *et al.* [4] reviewed the state-of-the-art of the UCMap and its applications in different countries with a wide range of climatic characteristics. The thermal environment and conditions of air ventilation within the urban canopy layer of the city are two major aspects analyzed in the study. Mitigation measures and planning actions will be provided, including increasing urban greenery, creating air paths, and controlling building morphologies. Future developments will therefore have to consider these recommendations in order to improve the urban microclimate.

The present study provides information about the effects of urban development on local air temperature. These effects were found to be varied across seasons as well as daytime and night-time. With increasing redevelopment of older urban areas and development of new towns in the next decade, urban climatic conditions and the effect of climate change should be incorporated into the planning and design stages. The observed effect of urban development on local climatic conditions provides information for urban planners and designers to estimate how local climate will be altered due to proposed developments. The multi-decade temperature series also provide baseline information for the study of the effects of future climate change on individual districts as the projection of future temperature requires extensive record of local climatic parameters. For example, statistical downscaling of particular climatic variables generally requires a minimum of 30 years of past temperature record. As the effects of future climate change on local climate may vary according to urban characteristics, further studies are recommended to examine how these urban characteristics, and the associated processes and mechanisms, affect local climatic conditions.

7. References

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