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Climate Forecasting - What the Temperature and Rainfall in Hong Kong are Going to be Like in 100 Years?

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Climate Forecasting –
What the temperature and rainfall in Hong Kong are going to be like in 100 years?

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Abstract

Global warming has become a popular issue in recent years, not only because of its scientific interest but also its potential impact on biodiversity and human health. The global mean temperature has increased by 0.6 ± 0.2°C in the 20th century, and might increase by a further 1.4°C to 5.8°C before the end of 2100 depending on the emission scenarios. Against this background, attempts were made by the Hong Kong Observatory to estimate the change in temperature and rainfall respectively in Hong Kong up to the end of the 21st century. This paper summarizes the estimates obtained for Hong Kong.

By downscaling temperature and rainfall forecasts made by global climate models, it was found that by 2090-2099, relative to the 1961-1990 normal, the annual mean temperature in Hong Kong would rise by 1.7°C to 5.6°C, with an ensemble mean of 3.5°C. The annual number of very hot days in summer would rise from the 1961-1990 normal of 11 days to 24 days and the annual number of hot nights in summer would rise to 30, roughly 4 times the 1961-1990 normal of 8 nights. However, the annual number of cold days in winter would drop from 21 days to less than a day. While the annual rainfall in Hong Kong would increase at about 1% per decade in the 21st century, the year-to-year variability in rainfall would also increase. In the 21st century, there would be 6 years with annual rainfall exceeding 3343 mm, the highest rainfall recorded at the Hong Kong Observatory's Headquarters in the past 120 years, and 3 years with annual rainfall less than the historical lower-bound figure of 901 mm. By 2070-2099, the number of days in a year with hourly rainfall exceeding 30 mm would increase from about 5.6 to 6.5.

1. Introduction

Global warming and its associated impacts on biodiversity and human health has become a popular issue in recent years. The Intergovernmental Panel on Climate Change (IPCC) concluded in its Third Assessment Report that the global mean surface temperature has increased by 0.6 ± 0.2°C in the 20th century, and might increase by a further 1.4°C to 5.8°C before the end of 2100 depending on the emission scenarios. In line with the global and

China's warming trends (Wang *et al*. 2004), southern China has also experienced warming in the last fifty years (Wang *et al*. 2003) and the warming would be continued till the end of this century (Hui and Erda 2006).

The IPCC report also pointed out that in association with global warming, the global average precipitation would increase and larger year to year variations in precipitation are very likely to occur over most areas. A likely reason for the projected increase in global precipitation is the enhancement in the water cycle associated with global warming. In East Asia and China, past model simulation studies have revealed that the rainfall would increase under the scenario of doubled carbon dioxide concentration (Zhao *et al*. 2005).

Against this background, attempts were made by the Hong Kong Observatory (HKO) to estimate the change in temperature and rainfall respectively in Hong Kong up to the end of the 21st century. This paper presents the estimates obtained for Hong Kong including the annual mean temperature, number of cold days (days with daily minimum temperature of 12°C or below), very hot days (days with daily maximum temperature of 33°C or above), hot nights (daily minimum temperature of 28°C or above), annual rainfall and the number of heavy rain days (days with hourly rainfall greater than 30 mm which is one of the criteria for issuing the Amber Rainstorm Warning).

2. Data and Methodology

2.1 Data

Historical temperature and rainfall data as well as temperature and rainfall forecasts made by global climate models are employed in this study. The historical temperature data used are the monthly data recorded between 1951 and 2000 at the HKO Headquarters and 28 stations in southern China (Figure 1a). For rainfall, the monthly data between 1951-2000 at the HKO Headquarters and 81 stations in southern and central China are used (Figure 1b). These temperature and rainfall data were sourced from HKO and the National Climate Centre (NCC) of the China Meteorological Administration (CMA).

Temperature and rainfall forecasts are the gridded monthly forecasts made by the seven global climate models CSIRO-Mk2, ECHAM4/OPY3, HadCM3, NCAR DOE-PCM, GFDL (consisting of the low resolution GFDL-R15 and the high resolution GFDL-R30), CCCma (consisting of CGCM1 & CGCM2) and CCSR/NIES. These forecasts are sourced from the Data Distribution Centre (DCC) of IPCC. The resolutions and parent organizations of these models can be found in Leung *et al*. (2004). Table 1 shows the emission scenarios for which grid point temperature and rainfall forecasts generated by the seven models are available from DCC. Details of the emission scenarios are in Houghton *et al.* (1994) and Nakicenovic *et al.* (2000).

2.2 Methodology

Statistical downscaling technique is a commonly employed technique to obtain local and regional scale climate projections from global climate model forecasts. Statistical downscaling demands less on computational resources (see Benestad 2001) and has a skill on par with the dynamical approach (Murphy 1999).

Regression is often used in statistical downscaling (see Wigley *et al*. 1990, Wilby *et al.* 2005). This is also the technique used to project Hong Kong's temperature and rainfall to the end of this century. Details can be found in Leung *et al.* (2004) and Wu *et al.* (2005) respectively. The projections are summarized below.

3. Results

3.1 Temperature

(a) Annual mean temperature

The annual mean temperature at the HKO Headquarters has a rising trend of 0.12°C per decade in the past 121 years (Figure 2). For southern China, Empirical Orthogonal Function (EOF) analysis shows that there is a generally warming mode over southern China from 1951 to 2000 (Figure 3). This result is consistent with the findings of Wang *et al*. (2003).

Figure 4 shows the past and projected annual mean temperature anomalies for Hong Kong. The annual mean temperature is projected to rise till the end of this century, with the magnitude depending on the emission scenario and the model. By 2090-2099, the range is between 1.7°C and 5.6°C with an ensemble mean of 3.5°C.

(b) Number of cold days in winter, very hot days and hot nights in summer.

Based on the regression relationship between the mean minimum temperature in winter and the number of cold days in winter (December to February) in the past, the number of cold days in a given winter in the future is then estimated from the regression relationship using the downscaled model projections of the mean minimum temperatures for that winter (see Leung *et al.*, 2004).

Results show that the number of cold days in winter decreases gradually with time. By 2090-2099, it would drop from 1961-1990 normal of 21 days to less than a day (Figure 5).

Using the past relationship between the mean maximum temperature and the number of very hot days in summer (June to August), the annual number of very hot days in summer would rise from the 1961-1990 normal of 11 days to 24 days by the decade 2090-2099 (Figure 6).

Similarly, using the past relationship between the mean minimum temperature and the number of hot nights in summer, the annual number of hot nights would rise to 30 nights in 2090-2099 (Figure 7), about 4 times the 1961-1990 normal of 8 nights.

3.2 Rainfall

(a) Annual rainfall

As shown in Figure 8, the annual rainfall at the HKO Headquarters has a rising trend of about 1% of the 1961-1990 normal of 2214.3 mm per decade between 1885 and 2005.

Figure 9 shows the projected annual rainfall in Hong Kong under different models and scenarios. Using the ensemble mean, the annual rainfall in Hong Kong would increase at a rate of about 1% per decade in the 21st century. This result is similar to that obtained by NCC of CMA for Guangdong (http://www.ipcc.cma.gov.cn/cn/MapSys/) (Figure 10).

In the 30-year period 2070-2099, 83% (20 out of 24) of different scenarios and models combinations forecast the annual rainfall anomaly to be positive, despite all forecasting positive annual mean temperature anomalies (Figure 11). In the last 10 years (2090-2099) of this century, the ensemble mean annual rainfall is 2430 mm, or 216 mm above the 1961-1990 average of 2214.3 mm.

In addition, the year-to-year variability in rainfall would also increase. In the past 120 years, the annual rainfall at the Hong Kong Observatory Headquarters lied between 901 mm and 3343 mm. In the 21st century, the ensemble mean number of occurrences of annual rainfall above 3343 mm is 5.7 (i.e. about 6), while the number of occurrences of annual rainfall below 901 mm is 2.9 (i.e. about 3).

(b) Number of heavy rain days

From the regression relationship between the annual number of heavy rain days (hourly rainfall greater than 30 mm) and the annual rainfall observed at the HKO Headquarters in the past (see Wu *et al*., 2005), the number of heavy rain days in a year is projected to increase from the 1961-1990 normal of 5.6 to 6.5 in the period 2070-2099.

4. Conclusion

Hong Kong's annual mean temperature has increased at 0.12°C per decade, and annual rainfall at 1% per decade in the past 121 years. Using global projection data available from IPCC and the statistical downscaling, it was found that by 2090-2099, relative to the 1961-1990 normal, the annual mean temperature in Hong Kong would rise by 3.5°C. The annual number of very hot days (days with daily maximum temperature of 33°C or above) in summer would rise from the 1961-1990 normal of 11 days to 24 days. The annual number of hot nights (daily minimum temperature of 28°C or above) would also rise to 30, about 4 times the 1961-1990 normal of 8 nights. However, the annual number of cold days (days with daily minimum temperature of 12°C or below) in winter would drop from 21 days to less than a day. Likewise, the annual rainfall in Hong Kong is projected to increase at about 1% per decade in the 21st century. There would be 6 years with annual rainfall exceeding 3343 mm, the highest rainfall recorded at the Hong Kong Observatory's Headquarters in the past 120 years, and 3 years with annual rainfall less than the historical lower-bound figure of 901 mm. By 2070-2099, the number of heavy rain days (days with hourly rainfall greater than 30 mm) in a year would increase from about 5.6 to 6.5.

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Table 1. Temperature and rainfall forecasts sourced from IPCC for different global climate models and different emission scenarios (T stands for temperature data and R stands for rainfall data).

Model		IS92a		SRES					
		GG	**GS**	**A1FI**	**A1B**	**A1T**	**A2**	**B1**	**B2**
GFDL	R-15	**T R**	**T R**						
	R-30						**T**		**T R**
CCSR/NIES		**T R**	**T R**	**T R**	**T R**	**T R**	**T R**	**T R**	**T R**
CSIRO-Mk2		**T R**	**T R**		**T R**		**T R**	**T R**	**T R**
CCCma	CGCM1	**T R**	**T R**						
	CGCM2						**T R**		**T R**
HadCM3		**T R**	**T R**				**T R**		**T R**
NCAR DOE-PCM			**T R**		**T R**		**T R**		**T R**
ECHAM4/OPYC3		**T R**	**T R**				**T**		**T**

[*] IS92a: '*Business as Usual*' emission scenario. GG: cooling by sulphates not included, GS: cooling by sulphates included. SRES: *Special Report on Emission Scenarios*. A1FI: fossil fuel intensive, A1B: balanced fossil and non-fossil fuel usage, A1T: emphasis on non-fossil fuels; A2: most rapid population growth but comparatively slow economic and technological growth; B1: global solutions to sustainability; B2: increasing population with regional and local solutions to sustainability.

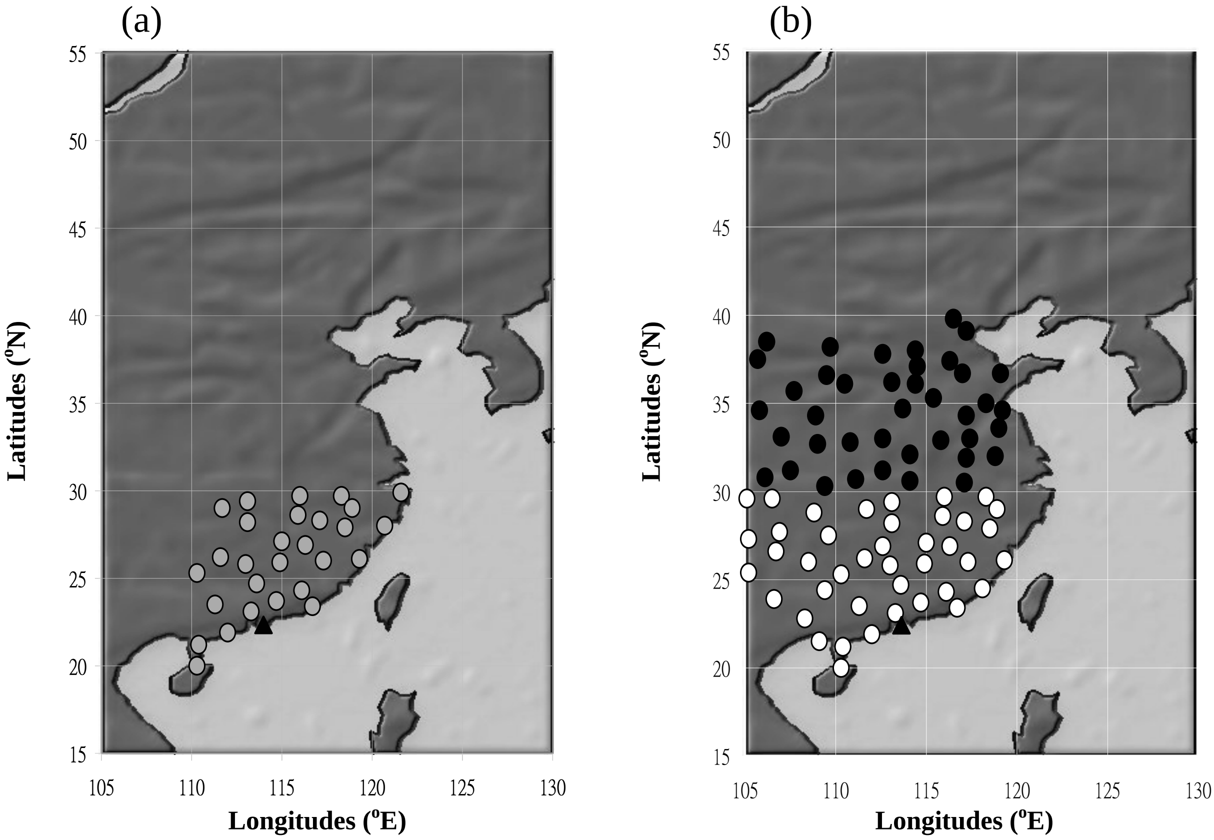

Figure 1. (a) Locations of the Hong Kong Observatory Headquarters (indicated by the solid triangle) and the 28 temperature stations in southern China. (b) Locations of the Hong Kong Observatory Headquarters (indicated by the solid triangle) and 81 rainfall recording stations in Mainland China (indicated by dots). White dots (a total of 41) denote stations in southern China (defined as region X1:20-30^{o}N and 105-120^{o}E). Black dots (a total of 40) denote stations in central China (defined as region X2: 30-40^{o}N and 105-120^{o}E).

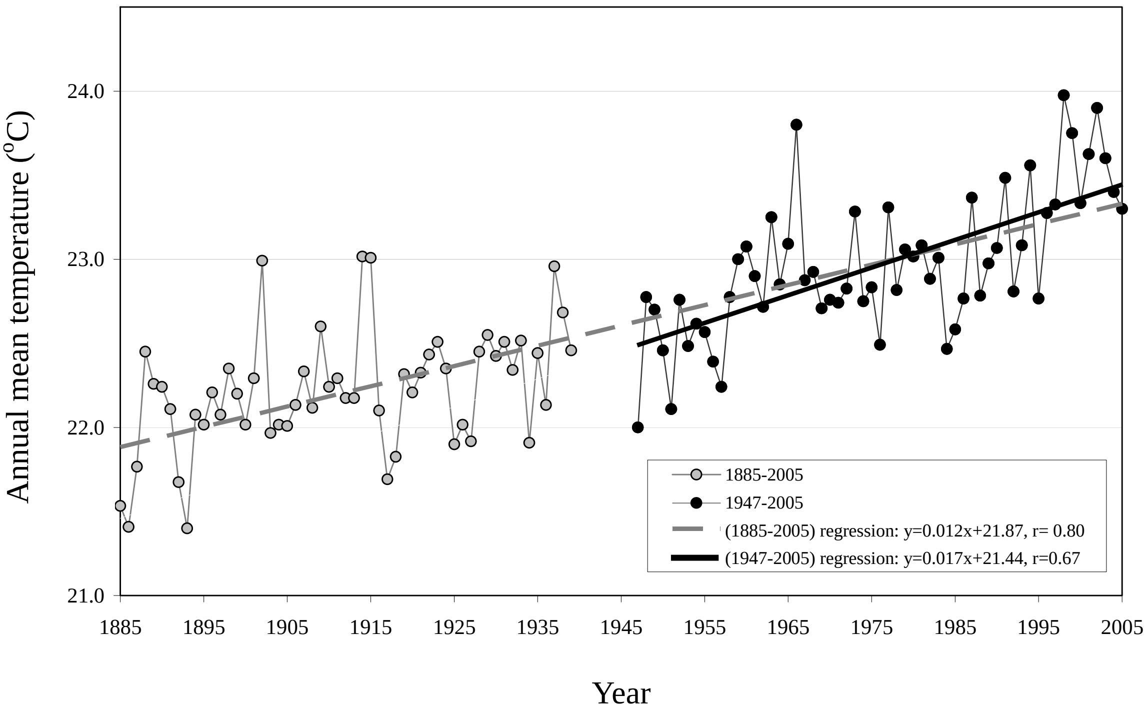

Figure 2. Time series of annual mean temperature at the Hong Kong Observatory Headquarters. Trends are statistically significant at the 5% level for 1885-2005 as well as 1947-2005.

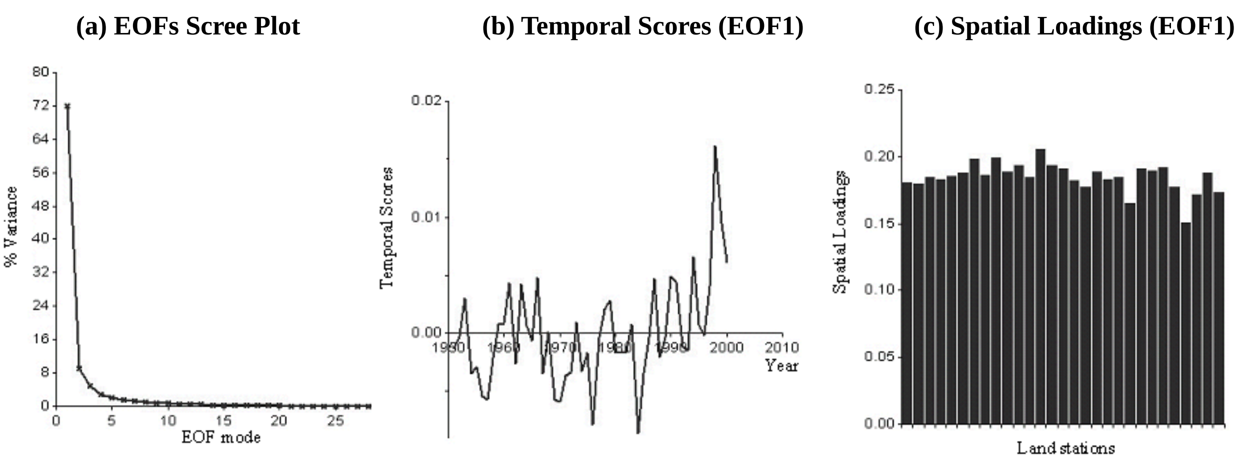

Figure 3. Empirical Orthogonal Function (EOF) analysis of the annual mean temperature at the Hong Kong Observatory Headquarters and the annual mean temperature over the 28 stations in southern China (1951-2000).

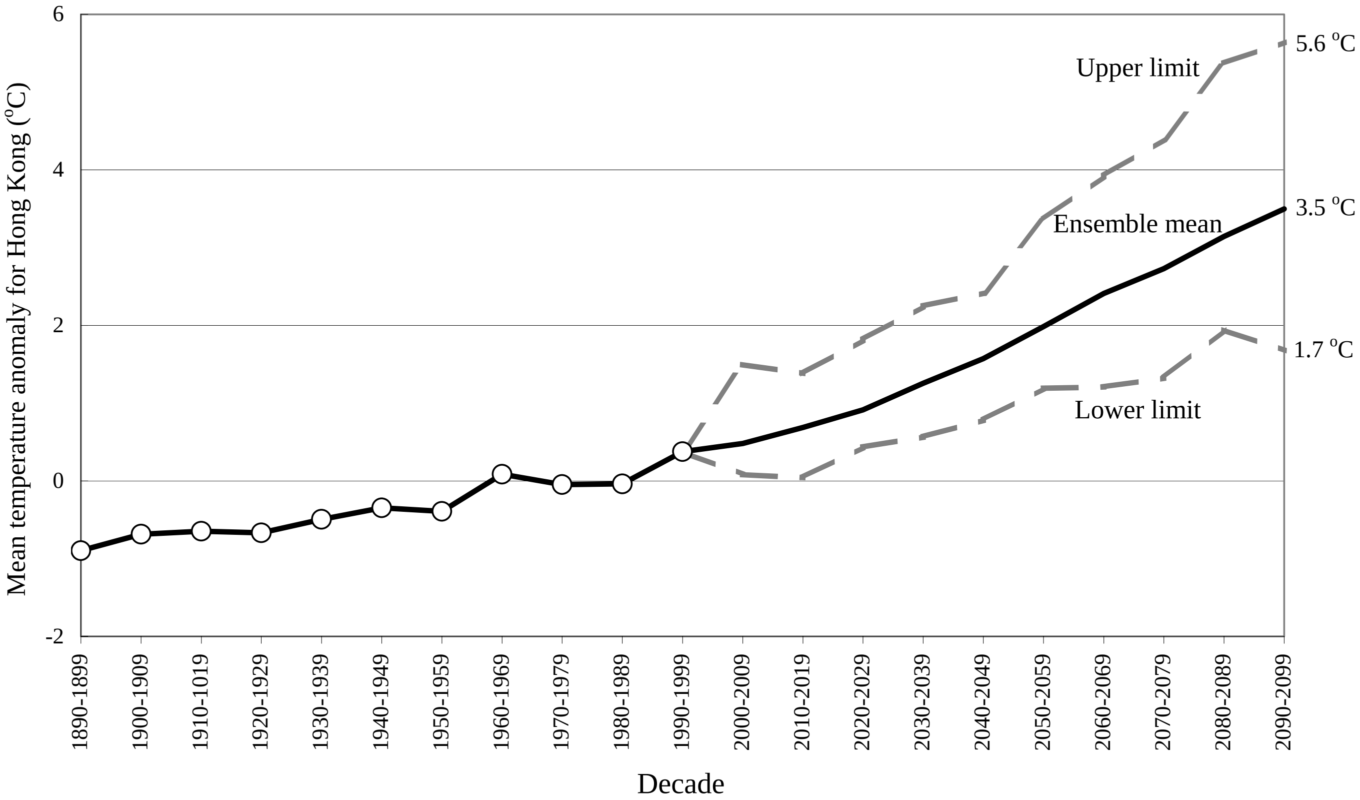

Figure 4. Past and projected annual mean temperature anomaly for Hong Kong. The temperature anomaly is with reference to the 1961-1990 normal.

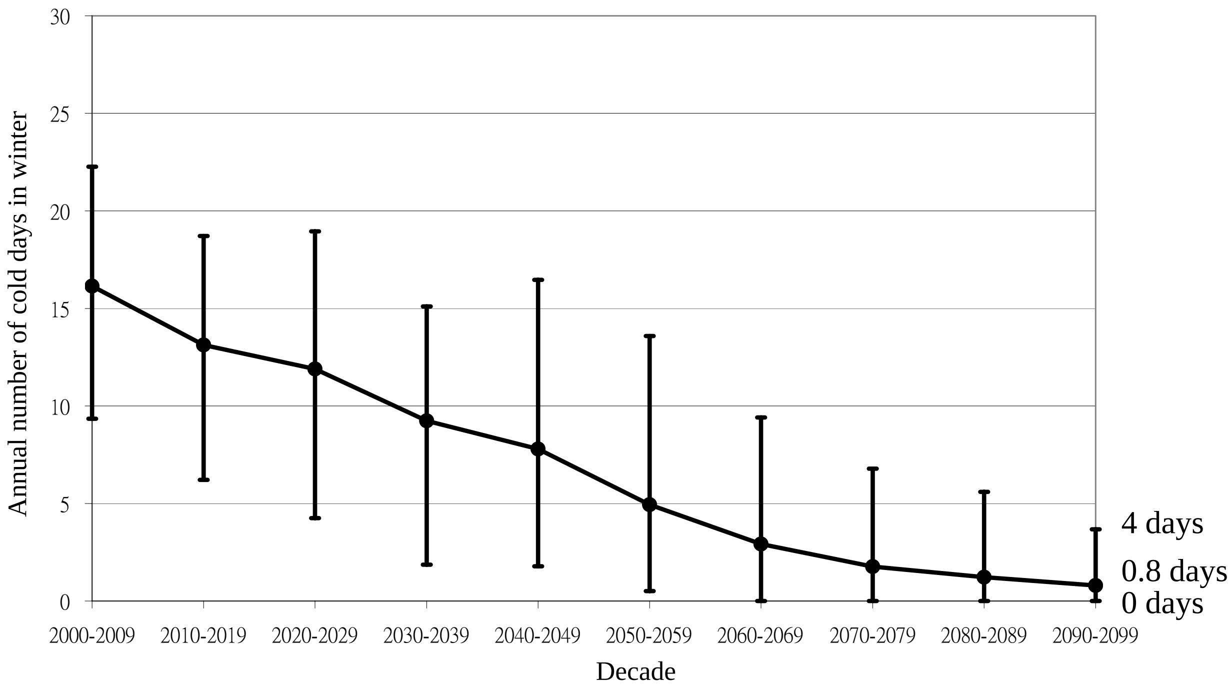

Figure 5. Projection of the annual number of cold days in the winter in the 21st century. Filled circles represent ensemble mean, and the vertical lines give the ensemble upper and lower limits.

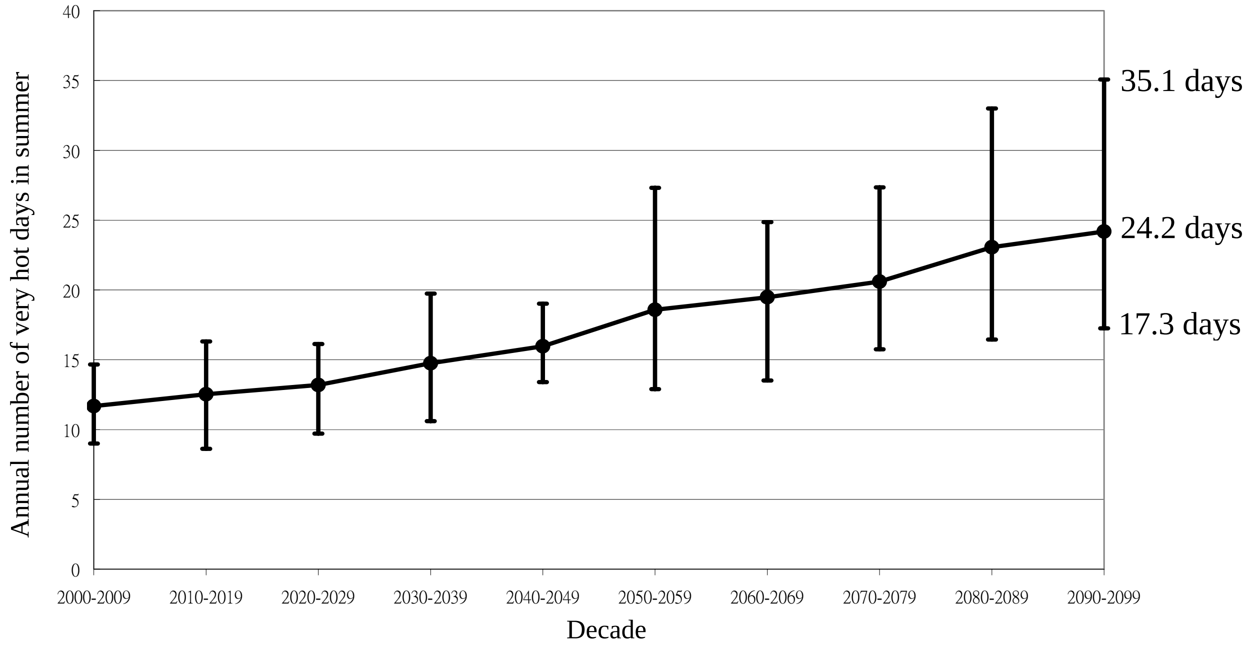

Figure 6. Projection of the annual number of very hot days in the summer in the 21st century. Filled circles represent ensemble mean, and the vertical lines give the ensemble upper and lower limits.

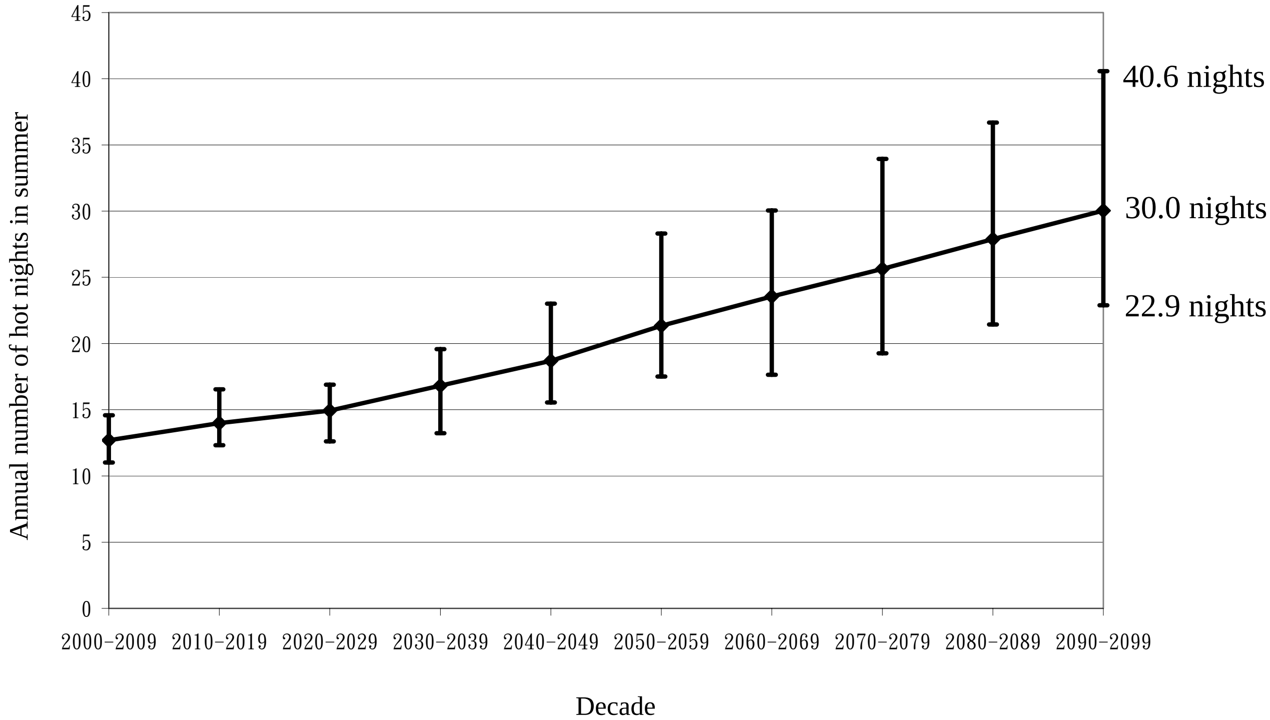

Figure 7. Projection of the annual number of hot nights in the summer in the 21st century. Filled circles represent ensemble mean, and the vertical lines give the ensemble upper and lower limits.

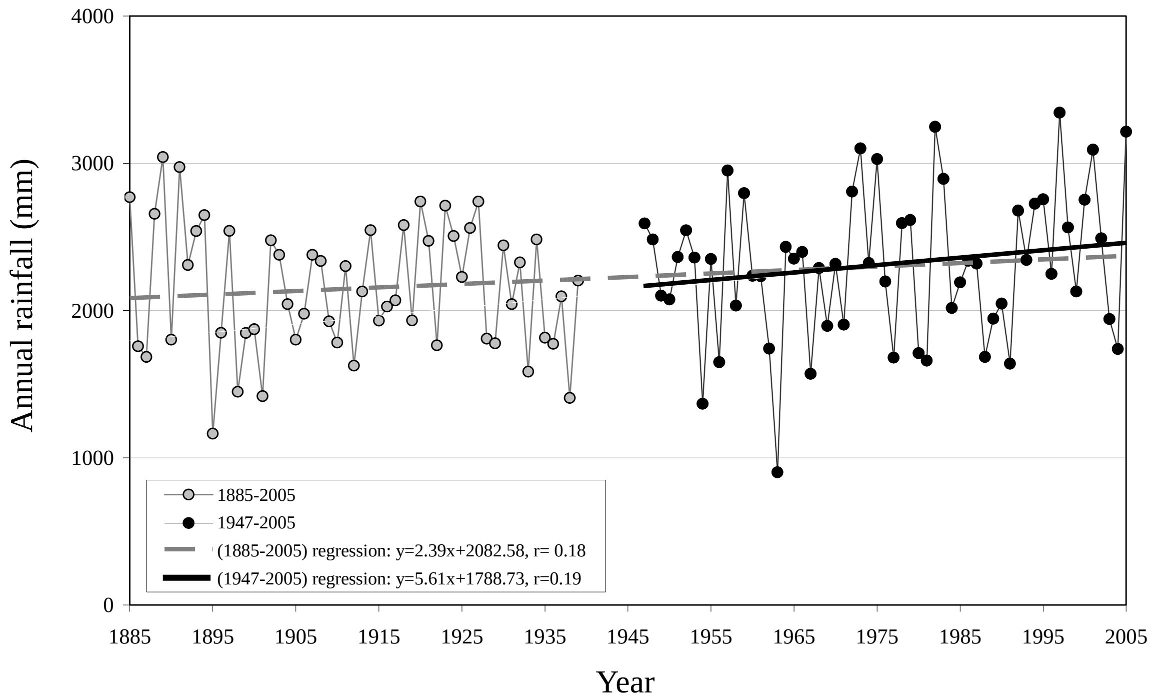

Figure 8. Time series of annual rainfall at the Hong Kong Observatory Headquarters. For both the 1885-2005 and 1947-2005 periods, trends are not significant at the 5% level.

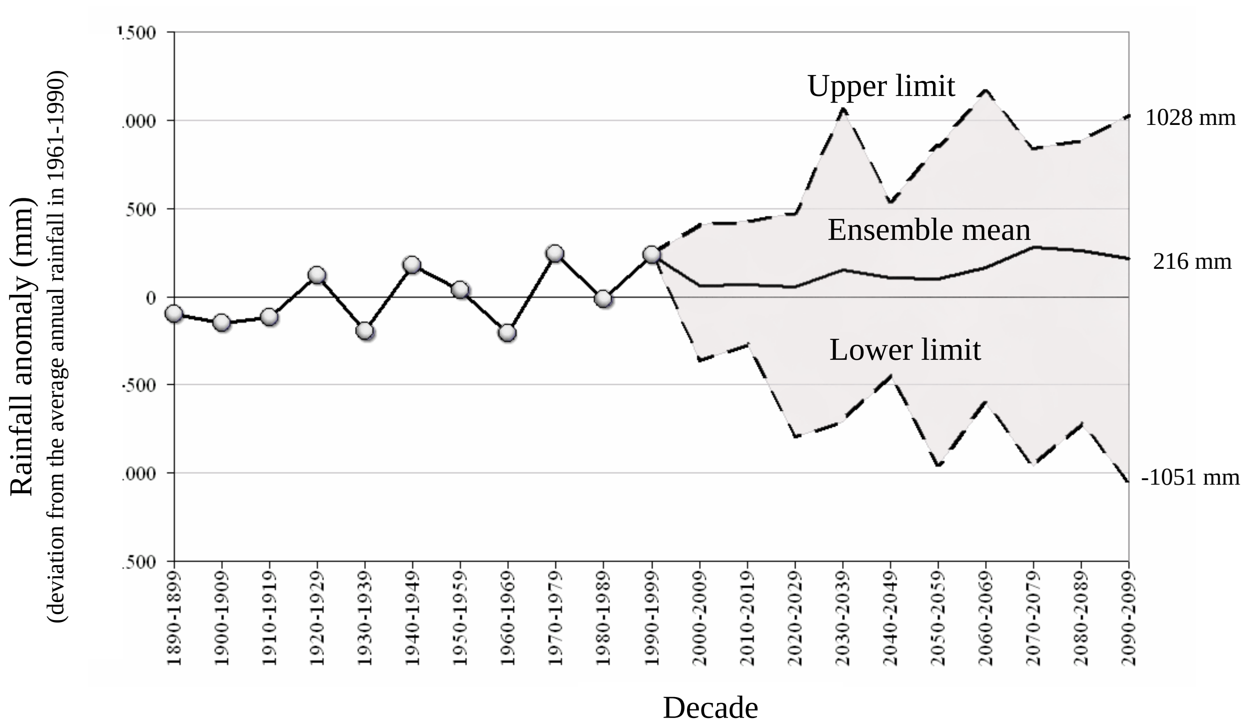

Figure 9. Past and projected changes in annual rainfall in Hong Kong. The change is with reference to the 1961-1990 normal.

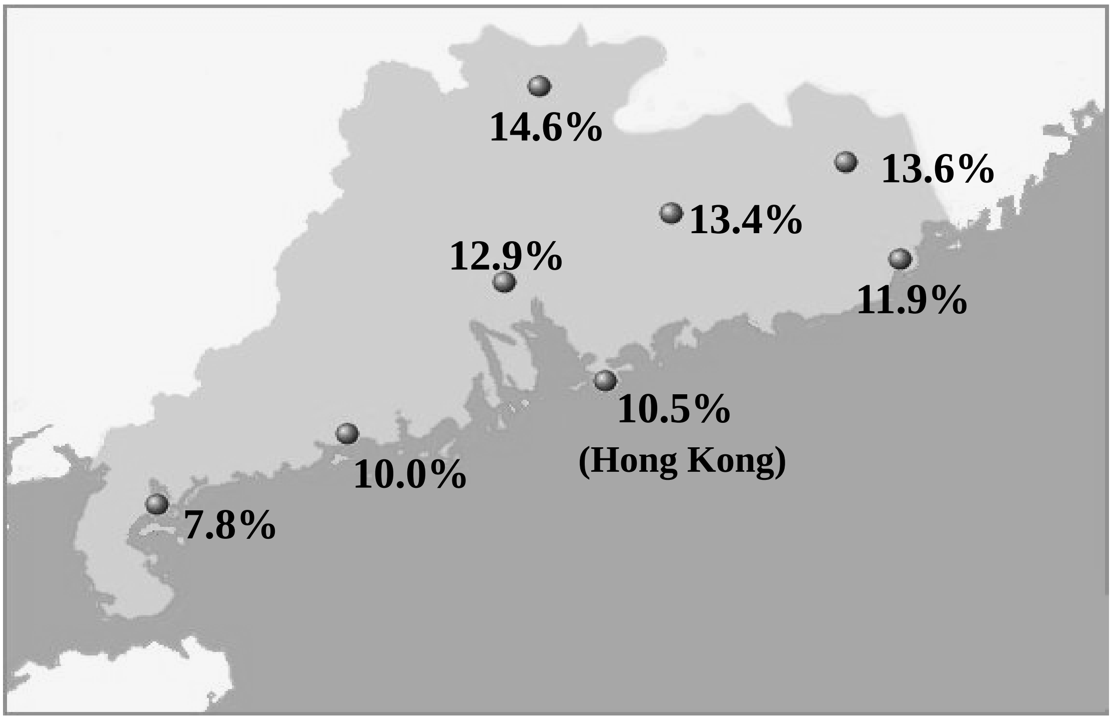

Figure 10. Projected changes in annual rainfall in Hong Kong and in Guangdong in the 21st century (% increase per 100 years). Trends for Guangdong are obtained from http://www.ipcc.cma.gov.cn/cn/MapSys/.

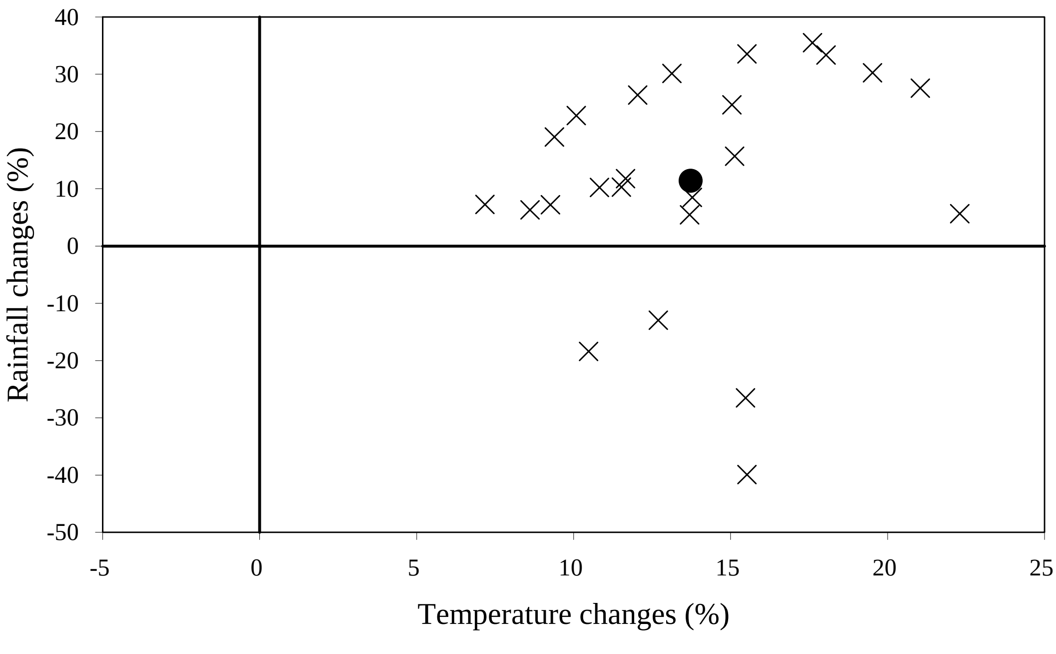

Figure 11. Projected changes in 30-year mean anuual rainfall and annual mean temperature in Hong Kong from 1961-1990 to 2070-2099 for different emission scenarios. Each cross represents the temperature and rainfall projected changes made by a given model for a given scenario. The black dot denotes the ensemble mean of all available scenarios and models.