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1. Introduction

In its Third Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) indicated 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 scenario (IPCC 2001).

The temperature in Hong Kong has seen a rising trend in the past 120 years (Leung *et al.* 2004). The Empirical Orthogonal Function (EOF) analysis performed in this study and the work of Wang *et al.* (2003) show that southern China has also experienced warming in the last fifty years. Against this background, an attempt is made for the first time to estimate the change in temperature in Hong Kong up to the end of the 21st century using statistical downscaling techniques. The study covers the annual and seasonal mean temperature, minimum temperature, maximum temperature as well as the number of cold days, very hot days and hot nights.

2. Data

Based on the work of Leung *et al.* (2004), this paper first gives an overview of the temperature rise in Hong Kong in the past. The meteorological station with the longest record is situated at the Hong Kong Observatory Headquarters (abbreviated HKO thereafter, see Figure 1 for its location). The station was established in 1884, and has been continuous in operation apart from a break between 1940 and 1946 during the Second World War. The trend analysis done by Leung *et al.* (2004) is mainly based on the temperature recorded at HKO.

To examine whether the rising temperature trend in Hong Kong is due to local characteristics such as topography and land-sea difference etc., or if it is part of a broader pattern over southern China, temperatures observed between 1951 and 2000 at HKO and 28 land stations in southern China are analyzed using the Empirical Orthogonal Function (EOF) technique. The data over southern China originated from the National Climate Centre (NCC) of the China Meteorological Administration (CMA). They are also used in this study for statistical downscaling (see Section 3 below). The locations of these 28 stations are shown in Figure 1.

The information used to assess Hong Kong's future temperature change comes from the temperature projections made by the seven global climate models CSIRO-Mk2, ECHAM4/OPYC3, 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. The grid point values of the simulated monthly mean temperature, monthly mean minimum temperature and monthly mean maximum temperature are sourced from IPCC (http://ipcc-ddc.cru.uea.ac.uk/).

The centres operating these seven global climate models and their parent organizations are listed in Table 1. The spatial resolutions of the temperature projections of these models, ranging from 7.5° x 4.4° in longitude and latitude for GFDL-R15 model to 2.8° x 2.8° for both the NCAR DOE-PCM and ECHAM4/OPYC3 models, are shown in Table 2. Table 3 shows the emission scenarios for which grid point temperature data generated by the seven models can be obtained from IPCC. Details of the IS92a and SRES emission scenarios listed in Table 3 can be found in Houghton *et al*. (1994) and Nakicenovic *et al*. (2000) respectively.

3. Methodology

3.1. Trend analysis

As in Karl *et al*. (1993), Easterling *et al*. (1997) and others, trends were estimated by Leung *et al*. (2004) using regression analysis. Statistical significance of the trend is examined using the two tail t-test.

The present study employs the EOF technique to analyze the temperature time series over southern China. The advantages of EOF are reduction in the dimensionality of the data, and that it allows the fifty years of observations at HKO and the 28 land stations in southern China to be analyzed concomitantly. For descriptions of the use of EOF analysis in meteorology, see von Storch and Zwiers (1999), Wilks (1995), and Wei (1999). The EOF software employed in this study is that made available by the International Research Institute (IRI) on its web site http://iri.columbia.edu/outreach/software/index.html.

3.2. Statistical downscaling

Statistical or empirical downscaling is a frequently used technique for obtaining local scale meteorological information from large scale information. The pros and cons of this technique have been discussed by Hewitson and Crane (1996), von Storch and Zwiers (1999), Murphy (1999) and Solman and Nunez (1999) and others. The merit of statistical downscaling over dynamic downscaling is that it is less demanding in computational resources and easier to apply. As such, the statistical approach is chosen for the present study.

Statistical downscaling techniques include linear regression, the single grid point method, extrapolation, etc. In this paper, linear regression is used to downscale to Hong Kong the global temperature projections from the seven models mentioned in Section 2. For comparison purposes, projections are also made using the single grid point method and extrapolation from the past trend. These three methods are briefly described below.

(a) *Regression*

Following the approach used by Wigley *et al*. (1990), a regression equation with past large scale temperature as the predictor and the past local scale temperature as the predictand is first derived. The global forecasts are then fed into the regression equation as predictors to give the local scale temperature projections.

In this study, the average temperature in southern China is used as the large scale predictor while HKO's average temperature is used as the predictand. The average temperature over southern China in the past is calculated from the temperature recorded by the 28 stations mentioned in Section 2. The average temperature over southern China in the future is calculated from the model grid point values.

(b) *Single grid point method*

The single grid point method takes the temperature forecast at the grid point closest to the location of interest as the projection for that location. An example of the use of this method can be found at http://hsu.as.ntu.tw/new/My%20Webs/index.htm. The single grid point method is simple to use but limited in accuracy. Figure 2 shows the positions of the grid points in each of the seven models selected to represent the future temperature of Hong Kong.

(c) *Extrapolation*

In this method, the temperature trend established from past data is extrapolated to a future time. Extrapolation has been employed to study, for example, the future temperature projection in the New York metropolitan area (see http://metroeast_climate.ciesin.columbia.edu/climate.html). The main assumption in extrapolation is that the temperature trend holds for the future as it has been in the past, without major changes in the climate system.

4. Results and Discussion

4.1. Past temperature change

Figure 3 shows that the annual mean temperature at HKO has a rising trend of 0.12°C per decade in the 118-year period from 1885 to 2002, in line with the global and China's warming trend (Wang *et al*. 2004). Between 1947 and 2002, the trend is higher at 0.17°C per decade. In the recent period 1989 to 2002, the warming has become significantly faster, at a rate of 0.61°C per decade. All the trends are statistically significant at the 5% level, and the results are in line with those of Ding *et al*. (2002).

Seasonally, the temperature at HKO is found to be rising in all seasons between 1947 and 2002. The trend in winter (December to February) is 0.21°C per decade, spring (March to May) 0.19°C per decade, summer (June to August) 0.14°C per decade, and autumn (September to November) 0.12°C per decade. All the trends are statistically significant at 5% level, with a faster rate of rise in winter and spring than in summer and autumn.

As for the southern China temperature field, EOF analysis shows that the first EOF accounted for 72% of the variance (Figure 4a). The amount of variance explained decreased rapidly with the second (9.2%) and third EOFs (4.8%). Thus, information in the southern China temperature field is contained largely in the first EOF.

The temporal scores associated with the first EOF indicate an increasing trend with time (Figure 4b). The spatial loadings in Figure 4c suggest that there is a generally warming mode over southern China.

The result of EOF analysis in the present study is consistent with the work of Wang *et al.* (2003) who find that as a whole southern China has warmed between 1951 and 2000.

4.2. Projected temperatures and number of cold days, very hot days and hot nights

(a) *Annual mean temperature*

The regression equations of the annual and also the seasonal mean temperatures at the HKO with that of the average over the 28 stations are shown in Figure 5. The highest correlation coefficient (r = 0.93) was found in winter while the lowest (r = 0.42) in summer.

Table 4a gives the temperature projections using the regression method. The annual mean temperature in Hong Kong is projected to rise till the end of this century, with the magnitude depending on the emission scenario and the model. CCCma CGCM1 gives the largest mean temperature rise in Hong Kong under the IS92a GG and GS scenarios. For the A2 and B2 scenarios, the largest rise is predicted by CCSR/NIES. By 2090-2099, the multi-model ensemble mean is about 3.5°C, and the range is between 1.7°C and 5.6°C (Figure 6).

The temperature projections given by the single grid point method are listed in Table 5a. As for the regression method, the highest temperature rise by 2090-2099 is predicted by CCCma CGCM1 model for the IS92a GG and GS scenarios, and by CCSR/NIES for the A2 and B2 scenarios.

Figure 7 compares the temperature projections to the end of the century given by the regression, single grid point and extrapolation methods. The single grid point method generally gives higher predictions. By 2090-2099, the single grid point method gives an ensemble mean of 4.0°C, 0.5°C higher the 3.5°C given by the regression method. Extrapolation (from the trend line between 1947 and 2002) yields the lowest projection, with an ensemble mean of 2.0°C.

Table 6 compares the temperature rise in Hong Kong with that of the global average for a given model and scenario in the three 30-year periods 2010-2039, 2040-2069 and 2070-2099. The difference between the temperature rise in Hong Kong (based on regression method) and the global average is generally small, with a maximum deviation of 0.8°C.

The mean temperature projections for Hong Kong based on the regression method here is in closely agreement with those given for Hong Kong by the Climate Research Unit (CRU), University of East Anglia of the United Kingdom (http://www.cru.uea.ac.uk/%7Etimm/climate/ateam/TYN_CY_3_0.htm) (Table 7). CRU has used the weighted average of projections at 0.5? resolution (Mitchell *et al.*, 2002).

(b) Seasonal mean temperature

Using the regression method on seasonal mean temperatures, the ensemble mean for spring, summer, autumn and winter are 4.4°C, 1.4°C, 2.4°C and 4.2°C respectively by 2090-2099. Figure 8 shows the seasonal mean temperature rise to the end of the century for Hong Kong as given by different models under the IS92a GG scenarios. In general, the temperature rise is higher for spring and winter and lower for summer and autumn.

(c) Annual and seasonal mean minimum and mean maximum temperature

Tables 4b and 4c show respectively the projected annual mean minimum and maximum temperatures obtained using the regression method. The projections based on the single grid point method are given in Tables 5b and 5c. As in the case of the annual mean temperature, both the annual mean minimum and annual mean maximum temperatures are projected to rise till the end of this century.

Ensemble averages of the annual mean minimum and annual mean maximum temperatures based on the regression method are both 3.7°C by 2090-2099, close to the value of 3.5°C for the annual mean temperature. Seasonally, the rate of rise is higher for winter and spring than for summer and autumn (Figures 9a and 9b).

(d) *Number of cold days in winter, and of very hot days and hot nights in summer*

Following Leung *et al*. (2004), cold days refer to days with a daily minimum temperature of 12°C or below while very hot days refer to days with a daily maximum temperature of 33°C or above.

Because no model projections are available for daily minimum temperature, a regression relationship is first derived between the mean minimum temperature in winter and the number of cold days in winter in the past. The number of cold days in a given winter in the future is then estimated from the regression relationship using model projections of the mean minimum temperatures for that winter.

Likewise, a regression relationship is derived between the mean maximum temperature and the number of very hot days in summer in the past. The number of very hot days in a given summer in the future is then estimated from the regression relationship using model projection of the mean maximum temperature for that summer. The number of hot nights (daily minimum temperature of 28°C or above) in summer in the future is similarly estimated using model projected mean minimum temperatures in summer as the predictor in the regression relationship between the mean minimum temperature and the number of hot nights in summer in the past.

The number of cold days in winter is found to be strongly correlated with the mean minimum temperature in winter ($r = -0.89$). Figure 10 shows the projections of the number of cold days in winter as obtained by the regression method from the mean winter minimum temperature projections of different models under various emission scenarios. It can be seen that the number of cold days decreases gradually with time. By 2090-2099, only 16% of model projections has the number of cold days in winter greater than zero (Figure 11). This means the probability that there will not be a single cold day in any given winter is 84%.

The projected number of very hot days based on the regression method is given in Figure 12, which shows that the number of very hot days increases with time. In 2090-2099, the model ensemble mean is 24 days, about twice the 1961-1990 normal of 11 days. For the number of hot nights, the ensemble mean is 30 nights in 2090-2099 (Figure 13), about 4 times the 1961-1990 normal of 8 nights.

5. Conclusion

Hong Kong has been warming up during the past 118 years, in line with the global trend. Based on all the global models and emission scenarios covered in this study, the annual mean temperature, annual mean minimum temperature and annual mean maximum temperature can all be expected to continue to rise till the end of this century. Seasonally, the temperature will generally rise faster in spring and winter than in summer and autumn. The number of cold days in winter will decrease while the number of very hot days and the number of hot nights in summer will increase.

By 2090-2099, relative to the 1961-1990 normal, the annual mean temperature in Hong Kong would have risen 1.7°C to 5.6°C, with an ensemble mean of 3.5°C. The number of very hot days in summer would have increased to 24 days, about twice the 1961-1990 normal. The number of hot nights in summer would have risen to 30, roughly 4 times the 1961-1990 normal. In addition, there is more than 80% chance that there will not be a single cold day in any given winter.

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Table 1. **Originating centres and parent organizations of the seven global climate models.**

Model	**Originating Centre**	**Parent Organization**
CSIRO-Mk2	Commonwealth Scientific and Industrial Research Organization (CSIRO)	Australian Government
ECHAM4/OPYC3	Deutsches Klimarechenzentrum (DKRZ)	Max Planck Institute for Meteorology, Hamburg (MPIfM)
HadCM3	Hadley Centre for Climate Prediction and Research (HCCPR)	United Kingdom Meteorological Office (UKMO)
NCAR DOE-PCM	National Centre for Atmospheric Research (NCAR)	University Corporation for Atmospheric Research (UCAR)
GFDL-R15, GFDL-R30	Geophysical Fluid Dynamics Laboratory (GFDL)	National Oceanic and Atmospheric Administration (NOAA)
CCCma GCM1, CCCma CGCM2	Canadian Center for Climate Modelling and Analysis (CCCma)	Climate Research Branch of the Meteorological Service of Canada of Environment Canada
CCSR/NIES	Japan Center for Climate Research Studies (CCSR)	University of Tokyo
	National Institute for Environmental Studies (NIES)	Formerly part of Japan's Environment Agency, launched as an independent administrative institution in 2001

Table 2. **Spatial resolutions of the temperature data sourced form IPCC (shaded in grey).**

Model		Horizontal resolution (no. of grids and longitude by latitude) Coarse — Fine						
		48 *x* 40	64 *x* 32	64 *x* 56	96 *x* 48	96 *x* 73	96 *x* 80	128 *x* 64
		7.5^{o} *x* 4.4^{o}	5.6^{o} *x* 5.5^{o}	5.6^{o} *x* 3.2^{o}	3.8^{o} *x* 3.7^{o}	3.8^{o} *x* 2.5^{o}	3.8^{o} *x* 2.3^{o}	2.8^{o} *x* 2.8^{o}
GFDL	R15							
	R30							
CCSR/NIES								
CSIRO-Mk2								
CCCma	CGCM1							
	CGCM2							
HadCM3								
NCAR DOE-PCM								
ECHAM4/OPYC3								

Table 3. **Types of temperature data sourced from IPCC for different global climate models under different emission scenarios (L represents monthly mean minimum temperature, M represents monthly mean temperature, H represents monthly mean maximum temperature).**

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

* 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.

Table 4a. **Projected annual mean temperature rise for Hong Kong using the regression method. The temperature rise is with reference of the 1961-1990 normal.**

Scenario		Model*	10-year		30-year		
			2040-2049	2090-2099	2010-2039	2040-2069	2070-2099
IS92a	GG	GFDL-R15	1.91		1.56		
		CCSR/NIES	1.55	2.90	1.06	1.88	2.68
		CSIRO-Mk2	1.55	3.13	1.13	1.67	2.65
		CCCma GCM1	2.42	5.64	1.47	3.16	5.13
		HadCM3	1.58	3.30	1.02	2.10	3.17
		ECHAM4/OPYC3	1.62	3.28	1.13	2.09	2.92
	GS	GFDL-R15	2.08		1.59		
		CCSR/NIES	1.28	2.44	0.96	1.52	2.13
		CSIRO-Mk2	0.78	2.34	0.61	1.17	1.98
		CCCma GCM1	1.11	4.27	0.82	1.71	3.57
		HadCM3	1.44	3.95	0.90	1.74	3.15
		ECHAM4/OPYC3	1.07		0.77		
SRES	A1FI	CCSR/NIES	1.71	5.36	0.79	2.74	4.84
	A1B	CCSR/NIES	2.32	4.67	1.20	3.09	4.15
		CSIRO-Mk2	1.31	3.19	0.75	1.86	2.77
	A1T	CCSR/NIES	2.07	4.21	0.99	2.56	4.05
	A2	GFDL-R30	1.52	2.38	0.49	1.48	2.30
		CCSR/NIES	1.87	5.05	0.91	2.54	4.49
		CSIRO-Mk2	1.36	3.53	0.67	1.70	3.02
		CCCma GCM2	1.74	4.11	0.86	2.22	3.56
		HadCM3	1.35	4.11	0.87	2.05	3.48
	B1	CCSR/NIES	1.56	3.59	0.79	2.02	3.46
		CSIRO-Mk2	1.29	2.20	0.83	1.37	2.16
	B2	GFDL-R30	1.31	1.67	0.38	1.26	1.65
		CCSR/NIES	2.28	3.93	1.12	2.55	3.57
		CSIRO-Mk2	1.33	2.65	0.99	1.54	2.32
		CCCma GCM2	1.32	2.96	1.13	1.84	2.41
		HadCM3	1.32	2.60	0.85	1.66	2.49
Ensemble lower limit			0.78	1.67	0.38	1.17	1.65
Ensemble mean			1.57	3.50	0.95	1.98	3.12
Ensemble upper limit			2.42	5.64	1.59	3.16	5.13

* Results of NCAR DOE-PCM model are not given as the model's temperature data from 1961-1990 are not available from the IPCC DCC website.

Table 4b. **Projected annual mean minimum temperature rise for Hong Kong using the regression method. The temperature rise is with reference of the 1961-1990 normal.**

Scenario		Model*	10-year		30-year		
			2040-2049	2090-2099	2010-2039	2040-2069	2070-2099
IS92a	GG	GFDL-R15					
		CCSR/NIES	1.55	2.95	1.02	1.89	2.71
		CSIRO-Mk2	1.55	3.11	1.15	1.70	2.67
		CCCma GCM1	2.67	5.40	1.51	3.09	4.83
		HadCM3					
		ECHAM4/OPYC3	1.70	3.40	1.25	2.17	2.97
	GS	GFDL-R15					
		CCSR/NIES	1.37	2.50	1.01	1.58	2.24
		CSIRO-Mk2	0.81	2.37	0.62	1.17	2.03
		CCCma GCM1	1.29	4.04	0.95	1.77	3.46
		HadCM3					
		ECHAM4/OPYC3	1.18		0.85		
SRES	A1FI	CCSR/NIES	1.72	5.35	0.88	2.70	4.82
	A1B	CCSR/NIES	2.32	4.48	1.28	2.97	4.05
		CSIRO-Mk2	1.47	3.55	1.03	2.19	3.13
	A1T	CCSR/NIES	2.05	4.18	1.06	2.53	3.99
	A2	GFDL-R30					
		CCSR/NIES	1.92	5.04	1.00	2.52	4.46
		CSIRO-Mk2	1.45	3.82	0.89	2.04	3.42
		CCCma GCM2	1.62	4.15	0.92	2.17	3.49
		HadCM3	1.37	4.20	0.87	2.05	3.54
	B1	CCSR/NIES	1.56	3.58	0.85	2.05	3.36
		CSIRO-Mk2	1.35	2.54	1.13	1.58	2.48
	B2	GFDL-R30					
		CCSR/NIES	2.20	3.79	1.23	2.51	3.47
		CSIRO-Mk2	1.75	3.15	1.29	1.84	2.77
		CCCma GCM2	1.46	2.92	1.11	1.84	2.43
		HadCM3	1.31	2.65	0.83	1.68	2.50
Ensemble lower limit			0.81	2.37	0.62	1.17	2.03
Ensemble mean			1.62	3.67	1.03	2.10	3.28
Ensemble upper limit			2.67	5.40	1.51	3.09	4.83

* Results of NCAR DOE-PCM model are not given as the model's temperature data from 1961-1990 are not available from the IPCC DCC website.

Table 4c. Projected annual mean maximum temperature rise for Hong Kong using the regression method. The temperature rise is with reference of the 1961-1990 normal.

Scenario		Model*	10-year		30-year		
			2040-2049	2090-2099	2010-2039	2040-2069	2070-2099
IS92a	GG	GFDL-R15					
		CCSR/NIES	1.58	2.92	1.10	1.89	2.70
		CSIRO-Mk2	1.59	3.28	1.14	1.68	2.71
		CCCma GCM1	2.27	6.36	1.55	3.54	5.90
		HadCM3					
		ECHAM4/OPYC3	1.53	3.15	1.01	1.99	2.69
	GS	GFDL-R15					
		CCSR/NIES	1.22	2.42	0.93	1.49	2.06
		CSIRO-Mk2	0.78	2.42	0.64	1.23	2.02
		CCCma GCM1	1.01	5.06	0.74	1.84	4.11
		HadCM3					
		ECHAM4/OPYC3	0.97		0.68		
SRES	A1FI	CCSR/NIES	1.76	5.47	0.76	2.85	4.96
	A1B	CCSR/NIES	2.39	4.92	1.18	3.26	4.32
		CSIRO-Mk2	1.33	2.79	0.56	1.69	2.44
	A1T	CCSR/NIES	2.14	4.30	0.96	2.66	4.15
	A2	GFDL-R30					
		CCSR/NIES	1.89	5.15	0.87	2.61	4.62
		CSIRO-Mk2	1.39	3.44	0.51	1.47	2.72
		CCCma GCM2	2.03	4.37	0.89	2.43	3.92
		HadCM3	1.31	4.04	0.86	2.04	3.45
	B1	CCSR/NIES	1.60	3.64	0.76	2.04	3.59
		CSIRO-Mk2	1.07	1.98	0.63	1.22	1.93
	B2	GFDL-R30					
		CCSR/NIES	2.42	4.14	1.06	2.64	3.72
		CSIRO-Mk2	1.13	2.32	0.86	1.45	2.13
		CCCma GCM2	1.24	3.21	1.28	1.98	2.57
		HadCM3	1.32	2.58	0.88	1.65	2.48
Ensemble lower limit			0.78	1.98	0.51	1.22	1.93
Ensemble mean			1.54	3.71	0.90	2.08	3.29
Ensemble upper limit			2.42	6.36	1.55	3.54	5.90

* Results of NCAR DOE-PCM model are not given as the model's temperature data from 1961-1990 are not available from the IPCC DCC website.

Table 5a. **Projected annual mean temperature rise for Hong Kong using the single grid point method. The temperature rise is with reference of the 1961-1990 normal.**

Scenario		Model*	10-year 2040-2049	10-year 2090-2099	30-year 2010-2039	30-year 2040-2069	30-year 2070-2099
IS92a	GG	GFDL-R15	2.20		1.71		
		CCSR/NIES	1.86	3.07	1.20	2.10	2.87
		CSIRO-Mk2	1.86	3.73	1.34	2.05	3.13
		CCCma GCM1	2.69	6.82	1.75	3.64	6.26
		HadCM3	1.72	3.64	1.16	2.32	3.57
		ECHAM4/OPYC3	1.74	3.56	1.36	2.28	3.22
	GS	GFDL-R15	2.37		1.79		
		CCSR/NIES	1.58	2.59	1.07	1.78	2.24
		CSIRO-Mk2	1.12	2.85	0.84	1.55	2.48
		CCCma GCM1	1.31	5.09	0.94	1.96	4.24
		HadCM3	1.65	4.24	0.83	1.88	3.27
		ECHAM4/OPYC3	1.49		1.01		
SRES	A1FI	CCSR/NIES	1.82	5.93	0.88	3.01	5.26
	A1B	CCSR/NIES	2.42	5.23	1.14	3.33	4.62
		CSIRO-Mk2	1.54	3.65	0.98	2.16	3.23
	A1T	CCSR/NIES	2.14	4.71	1.14	2.66	4.50
	A2	GFDL-R30	1.60	2.72	0.51	1.79	2.68
		CCSR/NIES	1.90	5.35	0.96	2.67	4.86
		CSIRO-Mk2	1.66	4.03	0.84	2.00	3.53
		CCCma GCM2	2.25	4.93	1.09	2.69	4.51
		HadCM3	1.81	4.43	0.98	2.41	3.88
	B1	CCSR/NIES	1.62	4.05	0.84	2.04	3.79
		CSIRO-Mk2	1.53	2.58	0.94	1.63	2.52
	B2	GFDL-R30	1.28	2.20	0.53	1.40	1.96
		CCSR/NIES	2.42	4.38	1.20	2.74	3.96
		CSIRO-Mk2	1.66	3.13	1.12	1.80	2.80
		CCCma GCM2	1.45	3.63	1.24	2.32	3.03
		HadCM3	1.56	2.97	1.10	1.89	2.83
Ensemble lower limit			1.12	2.20	0.51	1.40	1.96
Ensemble mean			1.79	3.98	1.09	2.24	3.57
Ensemble upper limit			2.69	6.82	1.79	3.64	6.26

* Results of NCAR DOE-PCM model are not given as the model's temperature data from 1961-1990 are not available from the IPCC DCC website.

Table 5b. **Projected annual mean minimum temperature rise for Hong Kong using the single grid point method. The temperature rise is with reference of the 1961-1990 normal.**

Scenario		Model*	10-year		30-year		
			2040-2049	2090-2099	2010-2039	2040-2069	2070-2099
IS92a	GG	GFDL-R15					
		CCSR/NIES	1.84	3.23	1.17	2.15	2.98
		CSIRO-Mk2	1.98	3.84	1.42	2.19	3.26
		CCCma GCM1	2.95	6.42	1.72	3.57	5.74
		HadCM3					
		ECHAM4/OPYC3	1.92	3.78	1.49	2.45	3.38
	GS	GFDL-R15					
		CCSR/NIES	1.66	2.70	1.23	1.83	2.43
		CSIRO-Mk2	1.15	2.93	0.88	1.58	2.60
		CCCma GCM1	1.42	4.58	1.06	1.98	3.91
		HadCM3					
		ECHAM4/OPYC3	1.57		1.08		
SRES	A1FI	CCSR/NIES	1.93	6.06	1.03	3.03	5.36
	A1B	CCSR/NIES	2.51	5.03	1.32	3.27	4.55
		CSIRO-Mk2	1.90	4.37	1.46	2.74	3.84
	A1T	CCSR/NIES	2.22	4.74	1.27	2.73	4.50
	A2	GFDL-R30					
		CCSR/NIES	2.06	5.52	1.13	2.74	4.93
		CSIRO-Mk2	2.17	4.87	1.31	2.76	4.34
		CCCma GCM2	2.01	4.81	1.09	2.54	4.22
		HadCM3	1.90	4.92	1.12	2.59	4.26
	B1	CCSR/NIES	1.72	4.08	0.98	2.19	3.73
		CSIRO-Mk2	2.01	3.09	1.38	2.18	3.05
	B2	GFDL-R30					
		CCSR/NIES	2.36	4.27	1.41	2.74	3.91
		CSIRO-Mk2	2.26	4.08	1.75	2.30	3.63
		CCCma GCM2	1.66	3.38	1.18	2.13	2.87
		HadCM3	1.72	3.22	1.17	2.07	3.10
Ensemble lower limit			1.15	2.70	0.88	1.58	2.43
Ensemble mean			1.95	4.28	1.26	2.46	3.84
Ensemble upper limit			2.95	6.42	1.75	3.57	5.74

* Results of NCAR DOE-PCM model are not given as the model's temperature data from 1961-1990 are not available from the IPCC DCC website.

Table 5c. **Projected annual mean maximum temperature rise for Hong Kong using the single grid point method. The temperature rise is with reference of the 1961-1990 normal.**

Scenario		Model*	10-year		30-year		
			2040-2049	2090-2099	2010-2039	2040-2069	2070-2099
IS92a	GG	GFDL-R15					
		CCSR/NIES	1.92	2.97	1.25	2.08	2.80
		CSIRO-Mk2	1.79	3.75	1.30	1.96	3.08
		CCCma GCM1	2.54	7.66	2.04	3.99	7.28
		HadCM3					
		ECHAM4/OPYC3	1.55	3.27	1.22	2.08	2.83
	GS	GFDL-R15					
		CCSR/NIES	1.51	2.52	1.02	1.75	2.09
		CSIRO-Mk2	1.07	2.85	0.82	1.54	2.44
		CCCma GCM1	1.34	6.31	0.94	2.24	5.18
		HadCM3					
		ECHAM4/OPYC3	1.40		0.92		
SRES	A1FI	CCSR/NIES	1.77	5.88	0.79	3.04	5.24
	A1B	CCSR/NIES	2.43	5.46	1.04	3.44	4.77
		CSIRO-Mk2	1.51	3.20	0.70	1.88	2.82
	A1T	CCSR/NIES	2.11	4.79	1.06	2.66	4.56
	A2	GFDL-R30					
		CCSR/NIES	1.82	5.27	0.89	2.67	4.88
		CSIRO-Mk2	1.72	3.65	0.69	1.73	3.01
		CCCma GCM2	2.72	5.23	1.18	3.09	5.32
		HadCM3	1.72	4.00	0.84	2.23	3.53
	B1	CCSR/NIES	1.54	4.09	0.75	1.94	3.89
		CSIRO-Mk2	1.16	2.32	0.72	1.43	2.25
	B2	GFDL-R30					
		CCSR/NIES	2.54	4.58	1.09	2.79	4.09
		CSIRO-Mk2	1.42	2.77	0.94	1.77	2.49
		CCCma GCM2	1.20	4.25	1.44	2.74	3.55
		HadCM3	1.42	2.75	1.02	1.73	2.61
Ensemble lower limit			1.07	2.32	0.69	1.43	2.09
Ensemble mean			1.74	4.17	1.03	2.32	3.75
Ensemble upper limit			2.72	7.66	2.04	3.99	7.28

* Results of NCAR DOE-PCM model are not given as the model's temperature data from 1961-1990 are not available from the IPCC DCC website.

Table 6. **Comparison of the annual mean temperature rise between Hong Kong and that of the global average (temperature rise for Hong Kong by regression method minus global temperature rise) for three 30-year periods 2010-2039, 2040-2069 and 2070-2099. Negative values (shaded) represent changes for Hong Kong that are projected to be lower than the global average.**

Period	Model	Scenarios							
		IS92a		SRES					
		GG	GS	A1FI	A1B	A1T	A2	B1	B2
2010-2039	GFDL-R15	-0.16	0.20						
	GFDL-R30						-0.44		-0.59
	CCSR/NIES	-0.06	-0.09	-0.15	0.00	-0.05	-0.11	-0.08	-0.09
	CSIRO-Mk2	-0.06	-0.48		-0.30		-0.34	-0.23	-0.16
	CCCma CGCM1	-0.01	-0.37						
	CCCma CGCM2						-0.19		0.05
	HadCM3	-0.04	-0.02				-0.01		-0.05
	ECHAM4/OPYC3	-0.08	-0.22						
2040-2069	GFDL-R15						-0.46		-0.47
	GFDL-R30								
	CCSR/NIES	-0.22	-0.33	0.05	0.36	0.16	0.21	0.12	0.22
	CSIRO-Mk2	-0.42	-0.67		-0.29		-0.32	-0.41	-0.42
	CCCma CGCM1	0.16	-0.49						
	CCCma CGCM2						0.07		0.09
	HadCM3	0.03	-0.08				0.12		0.07
	ECHAM4/OPYC3	-0.08							
2070-2099	GFDL-R30						-0.81		-0.63
	CCSR/NIES	-0.31	-0.51	-0.10	0.14	0.26	0.01	0.38	0.20
	CSIRO-Mk2	-0.43	-0.72		-0.42		-0.42	-0.36	-0.38
	CCCma CGCM1	0.20	-0.26						
	CCCma CGCM2						-0.04		-0.08
	HadCM3	0.17	0.30				0.24		0.11
	ECHAM4/OPYC3	-0.10							

Table 7. **Comparison of the annual mean temperature rise for Hong Kong in 2070-2099 obtained in the present study with that of the Climate Research Unit (CRU), University of East Anglia. Temperature rise is referred to the 1961-1990 normal.**

Model	Scenario	Present study (by the regression method)	CRU
CSIRO-Mk2	A2	3.0	3.1
	B1	2.2	2.1
	B2	2.3	2.4
CCCma CGCM2	A2	3.6	3.2
	B2	2.4	2.3
HadCM3	A2	3.5	3.4
	B2	2.5	2.4

Figure 1. **Locations of Hong Kong Observatory (marked by the solid triangle) and the 28 land stations in southern China (marked by circles).**

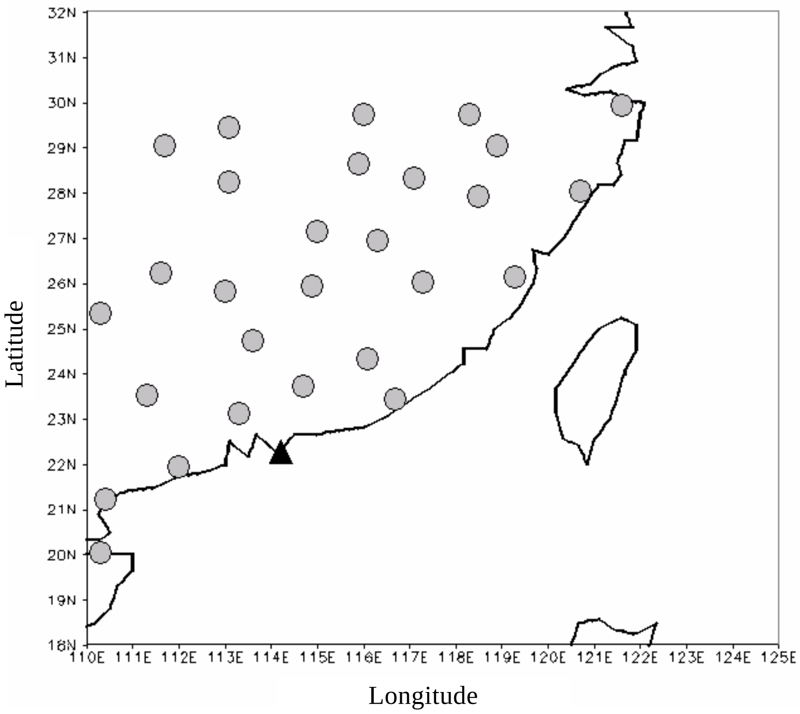


Figure 2. Locations of the land grids of different models nearest to Hong Kong.

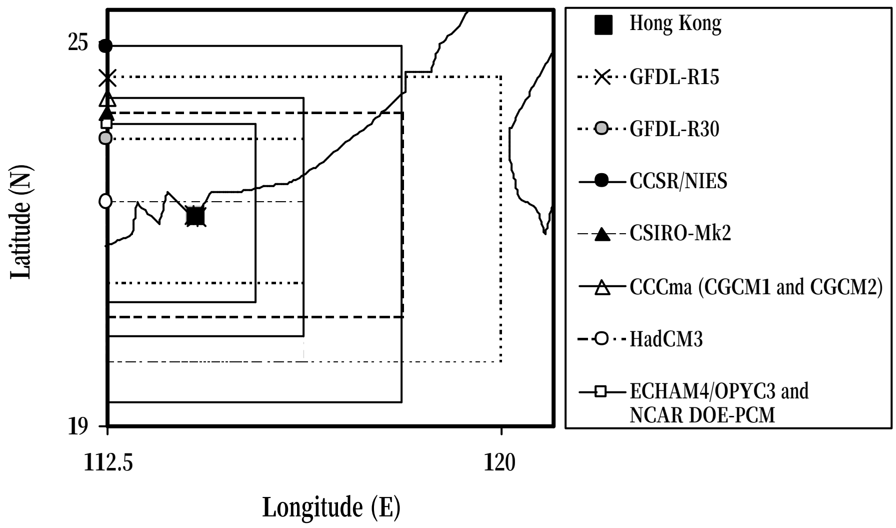


Figure 3. **Time series of the annual mean temperature at the Hong Kong Observatory Headquarters. Trends are statistically significant at 5% level.**

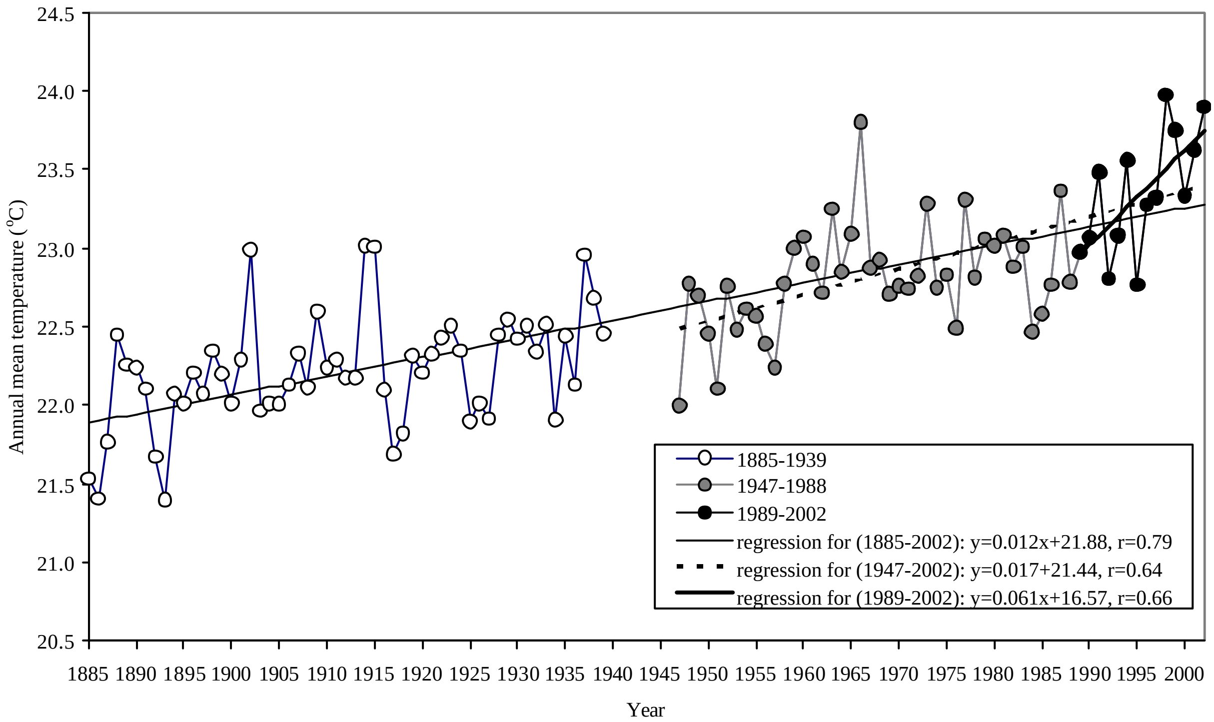


Figure 4. **Empirical Orthogonal Function (EOF) analysis of the annual mean temperature at the Hong Kong Observatory Headquarters and the annual mean temperature averaged over the 28 stations in southern China (1951-2000).**

(a) EOFs Scree Plot **(b) Temporal Scores (EOF1)** **(c) Spatial Loadings (EOF1)**

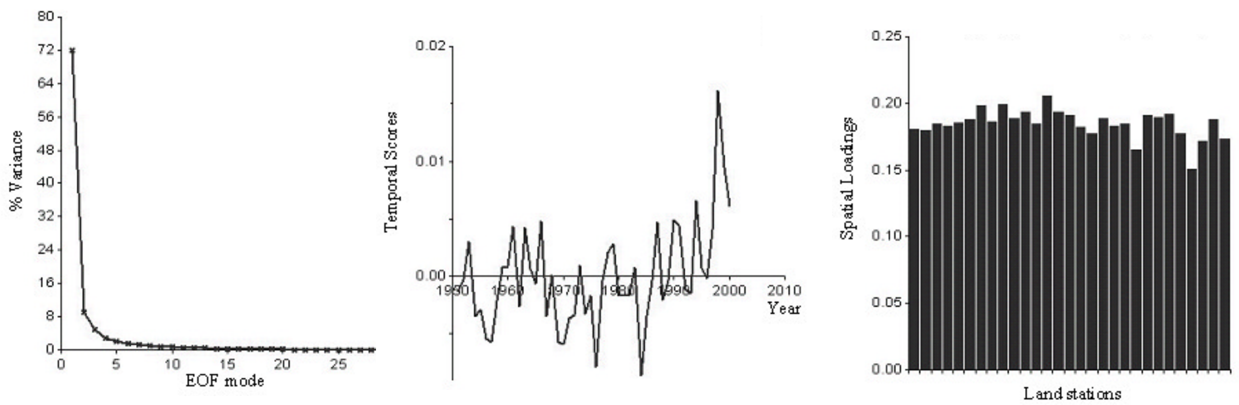


Figure 5. **Regression relationship between the temperature at the Hong Kong Observatory Headquarters and the average temperature at the 28 lands stations in south China (1951-2000) for different seasons and for the entire year. All correlations are statistically significant at 5% level. Temperature anomalies are with reference to the 1961-1990 normal.**

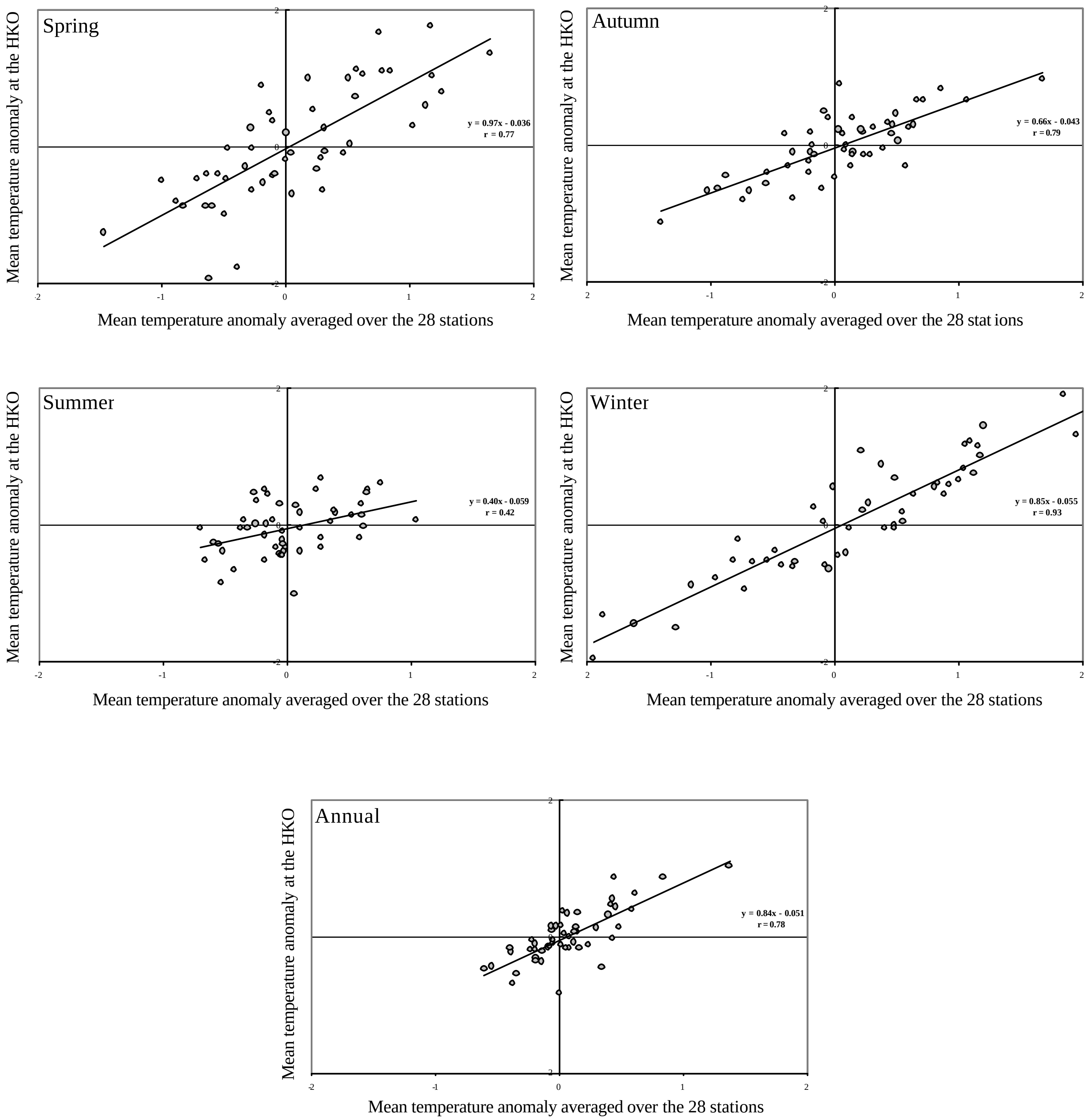


Figure 6. **Past and projected annual mean temperature anomaly for Hong Kong by the regression method. The temperature anomaly is with reference to the 1961-1990 normal.**

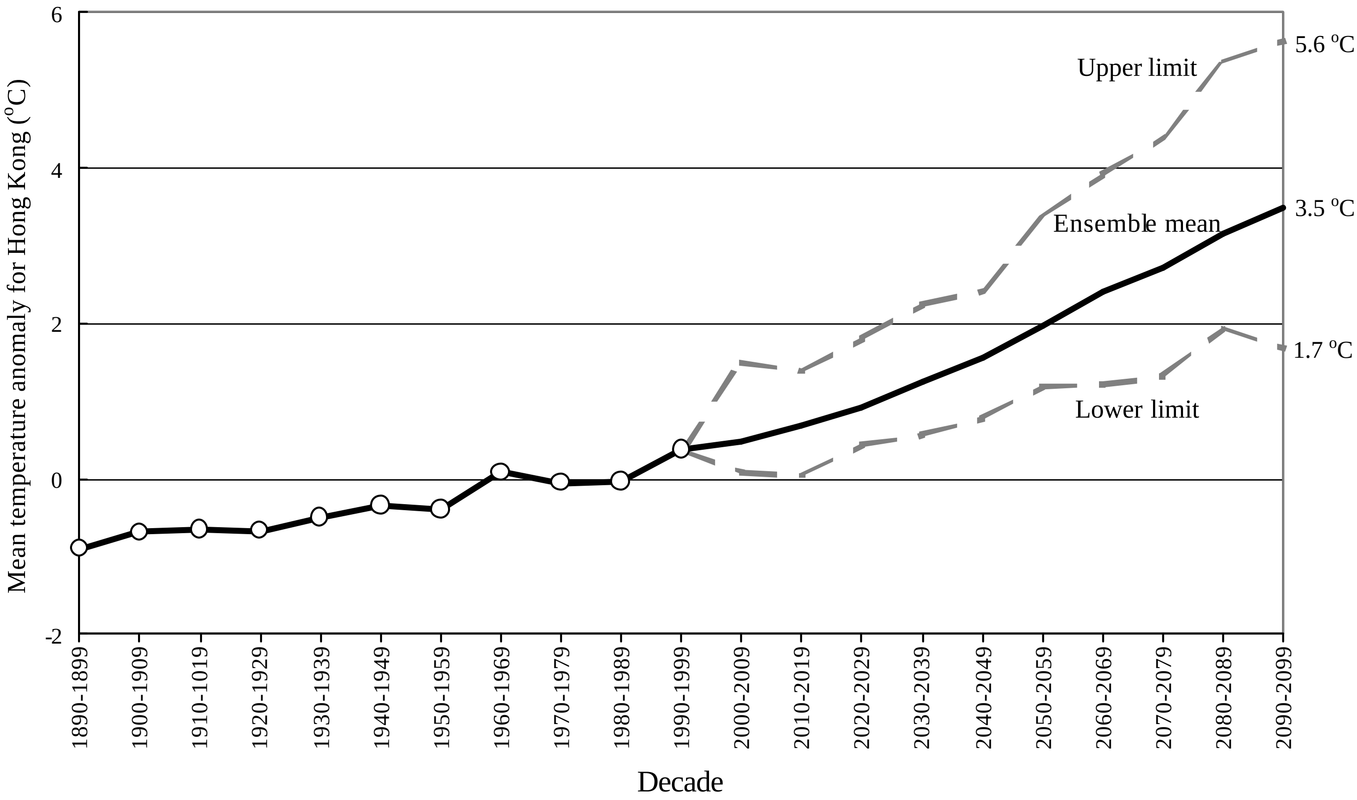


Figure 7. **A comparison of the rise in Hong Kong's annual mean temperature in the 21st century given by the regression method, single grid point method and extrapolation method. Temperature rises are with reference to the 1961-1990 normal. The vertical line represents the ensemble upper and lower limits.**

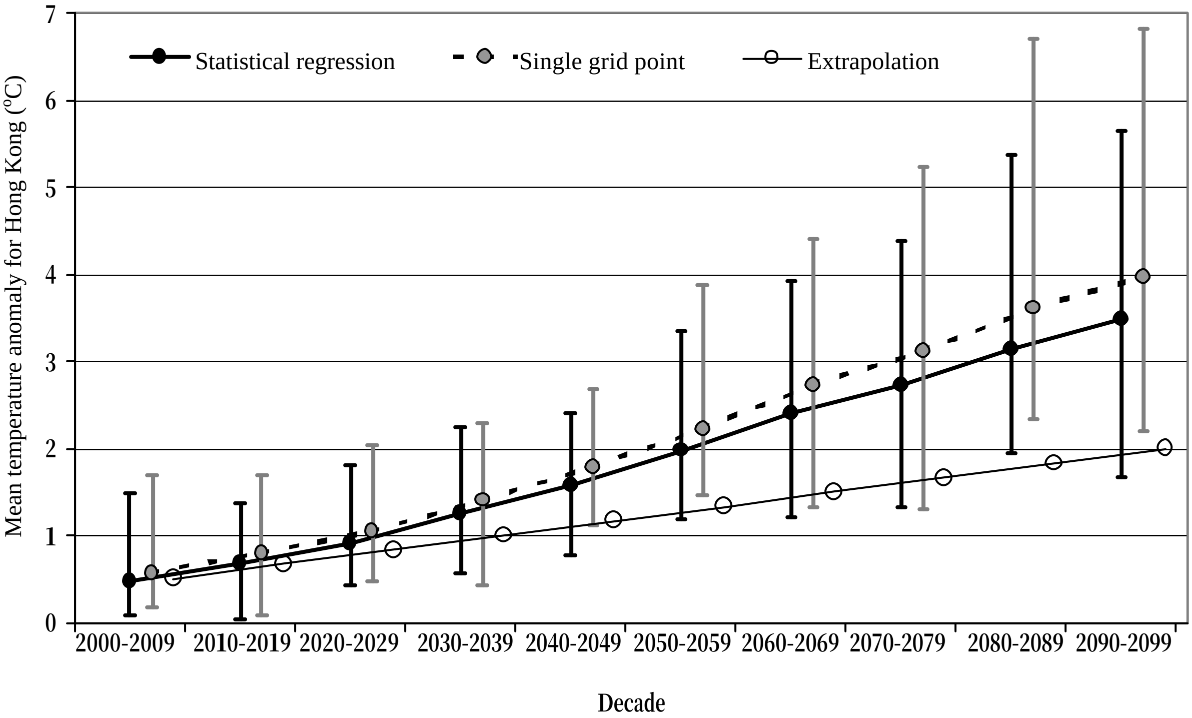
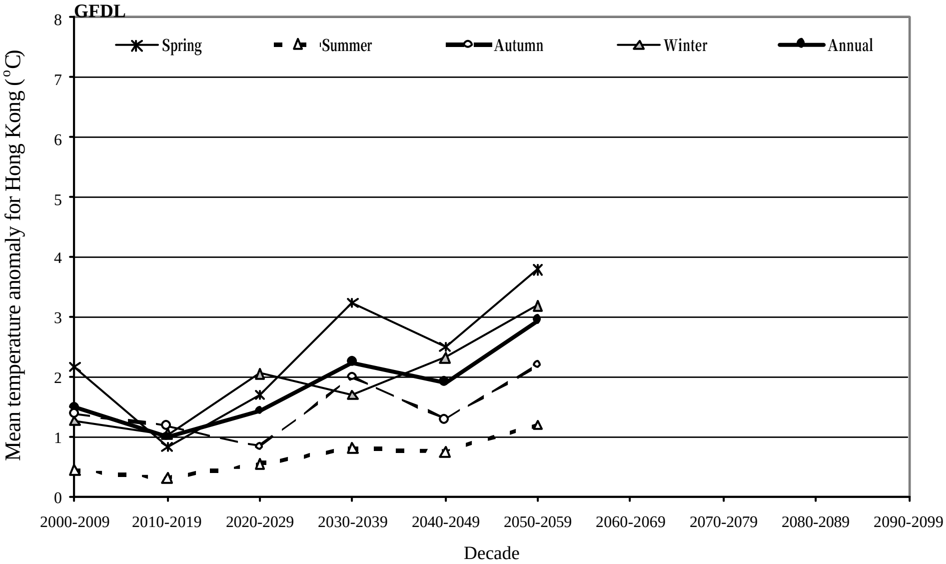
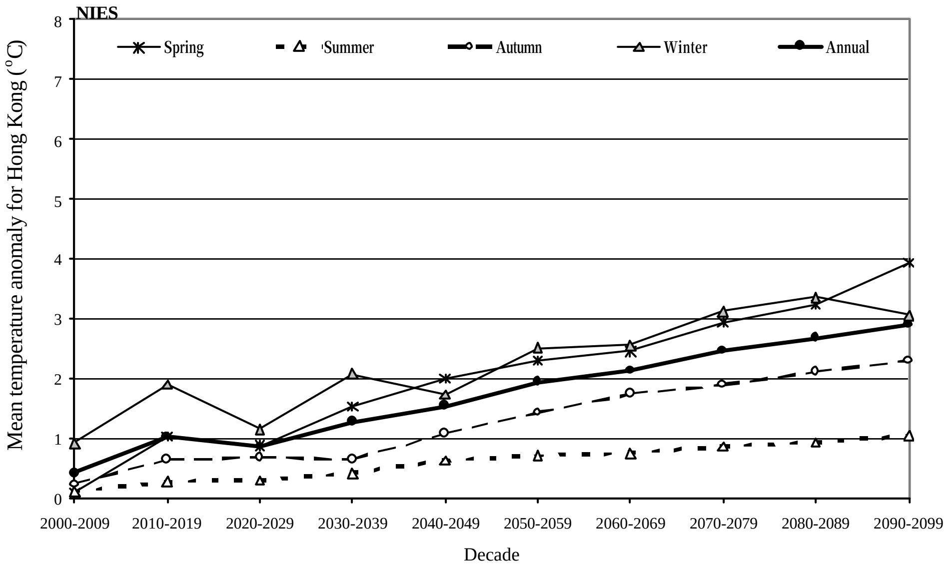


Figure 8. **Seasonal mean temperature anomaly for Hong Kong predicted by different global models under the scenario IS92a GG. Temperature anomalies are with reference to the 1961-1990 normal.**





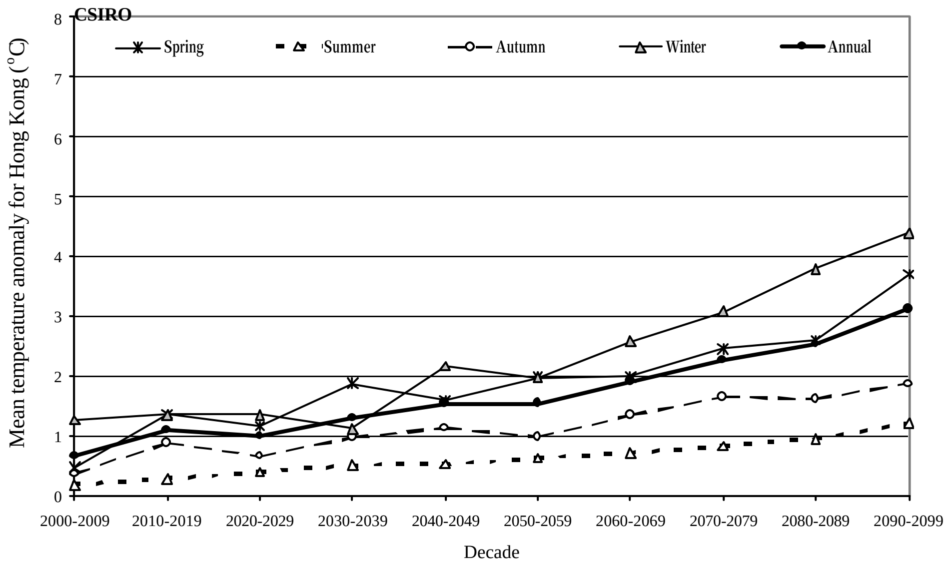
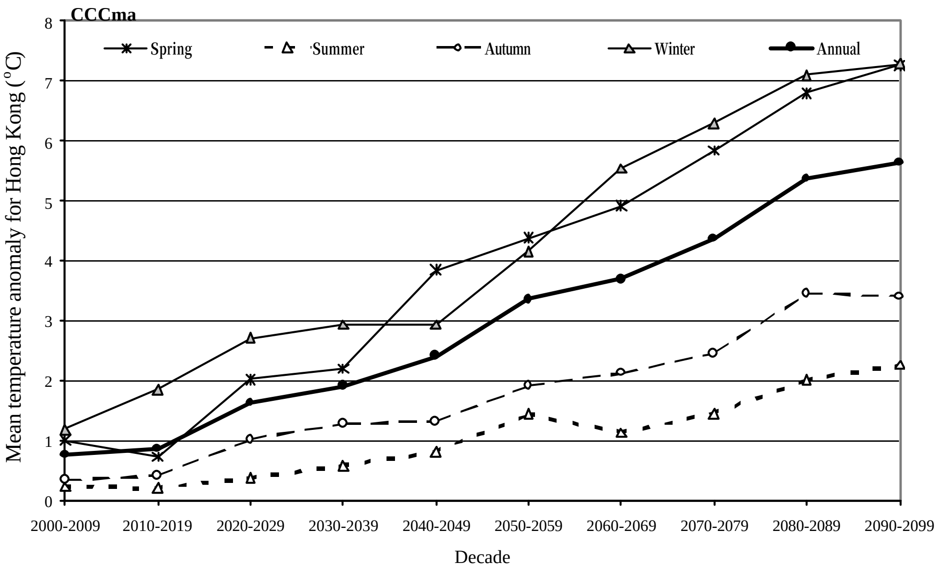
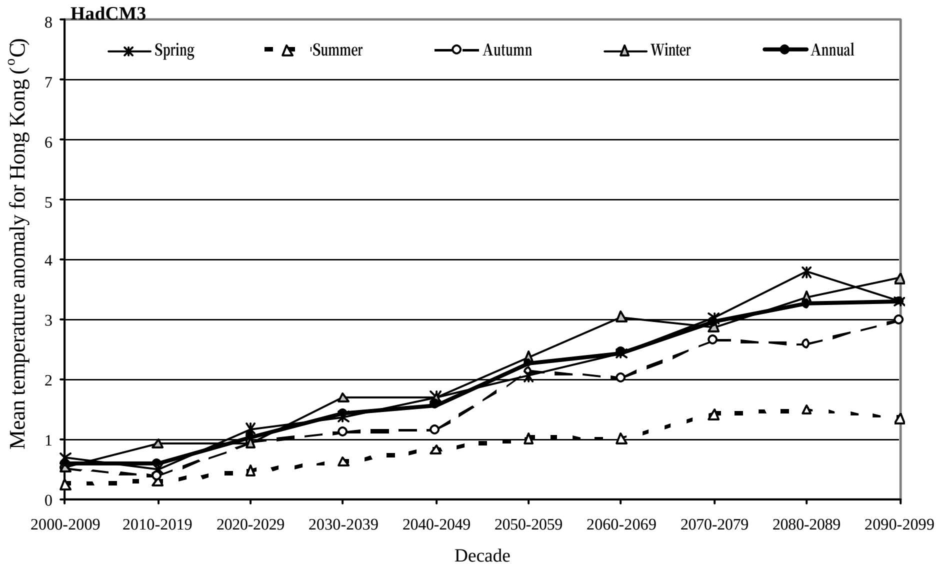


Figure 8. (Cont'd)





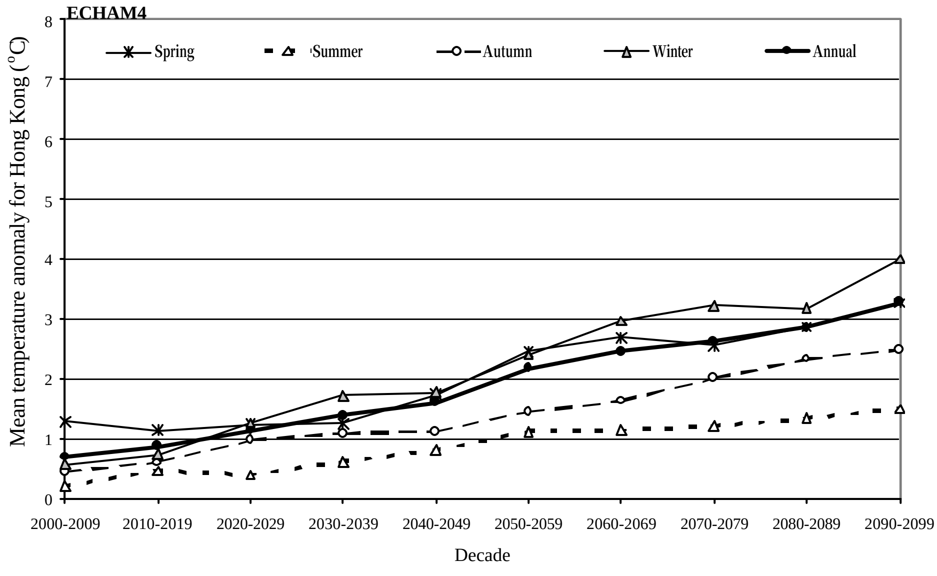


Figure 9. **Ensemble mean of annual and seasonal (a) mean minimum temperature and (b) mean maximum temperature (by the regression method). Temperature anomalies are with reference to the 1961-1990 normal.**

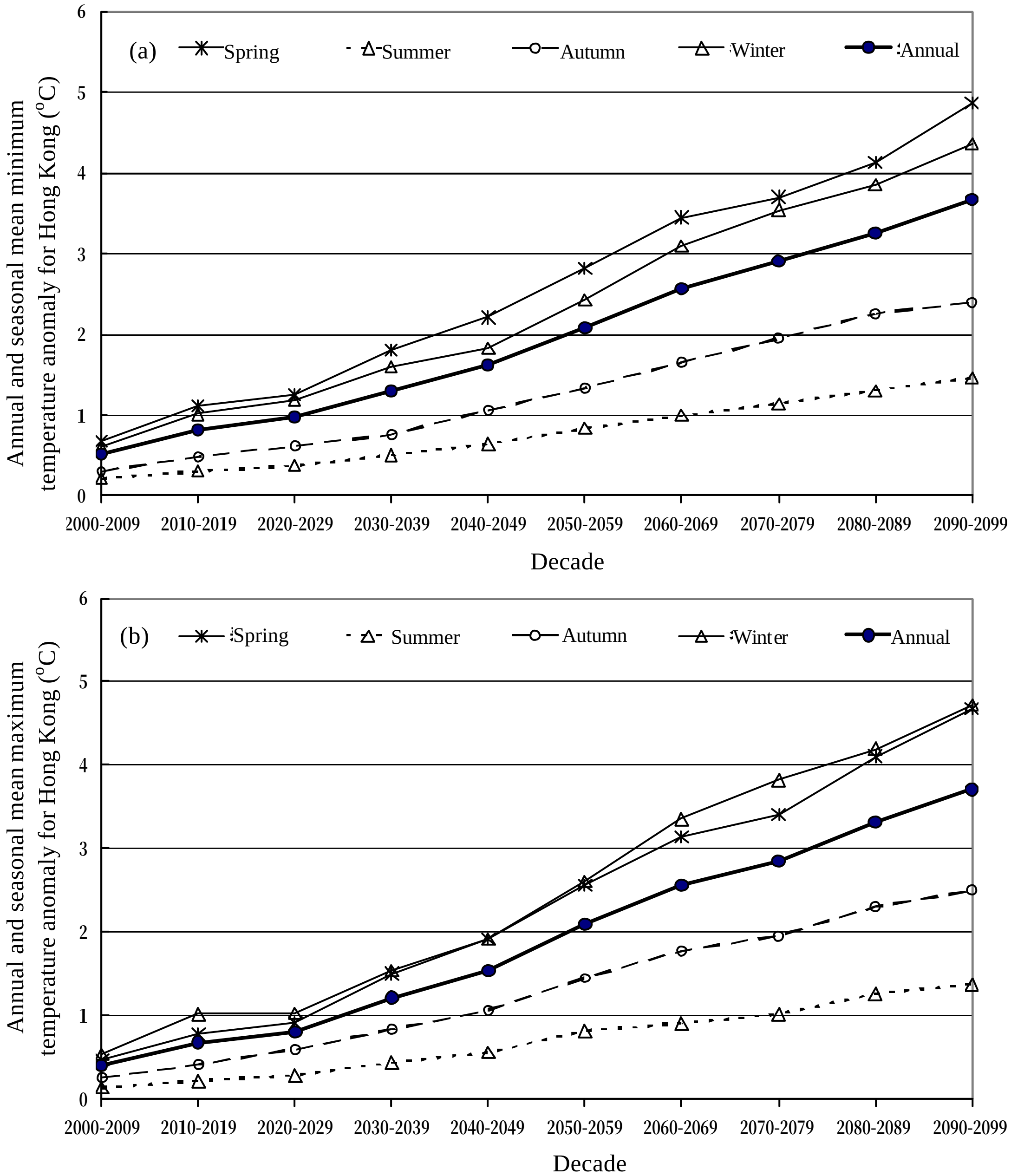


Figure 10. **Annual number of cold days in winter obtained by the regression method from projections made by different global climate models under various emission scenarios (filled circles). The grey line gives the past number of cold days in winter.**

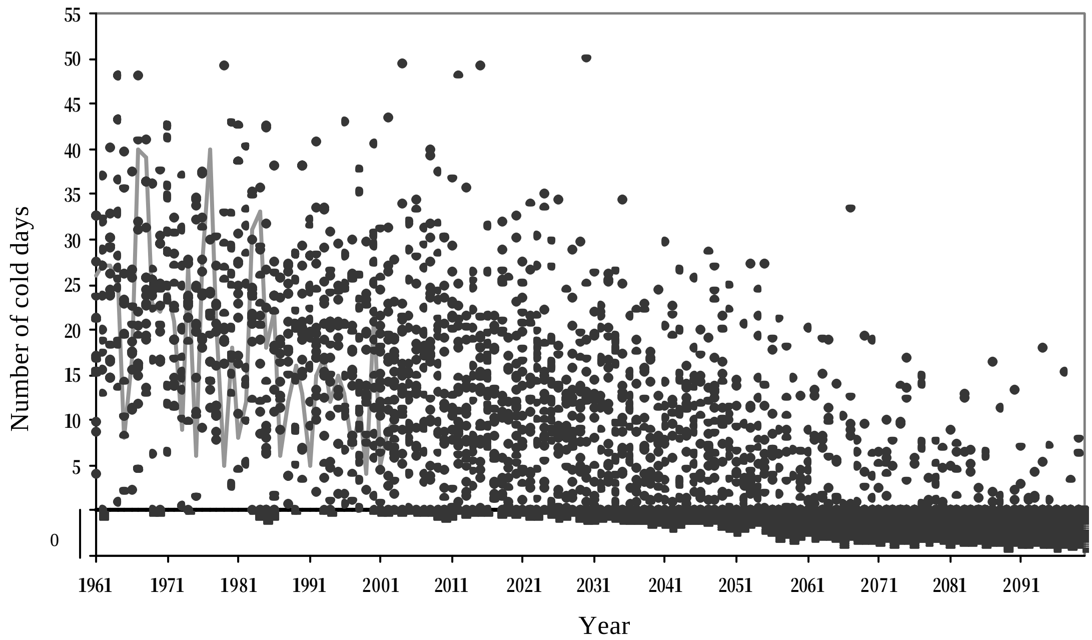


Figure 11. Probability of a cold day occurring in winter in the 21st century.

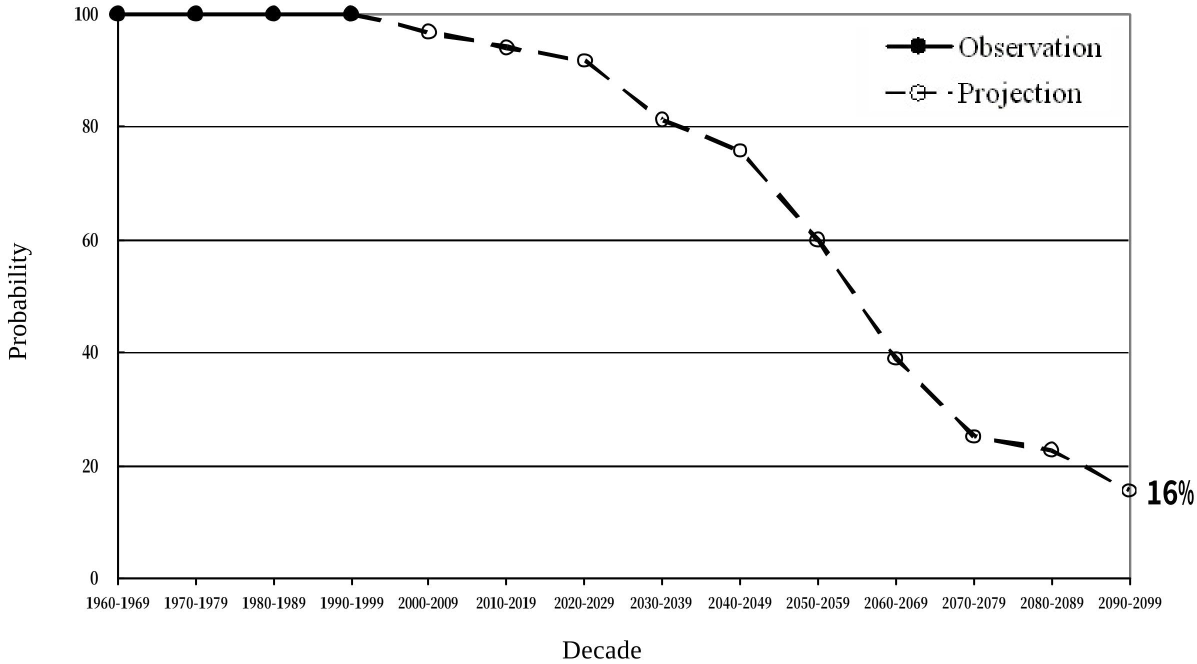


Figure 12. **Projection of the annual number of very hot days in the summer in the 21st century (by the regression method). Filled circles represent ensemble mean, and the vertical lines give the ensemble upper and lower limits.**

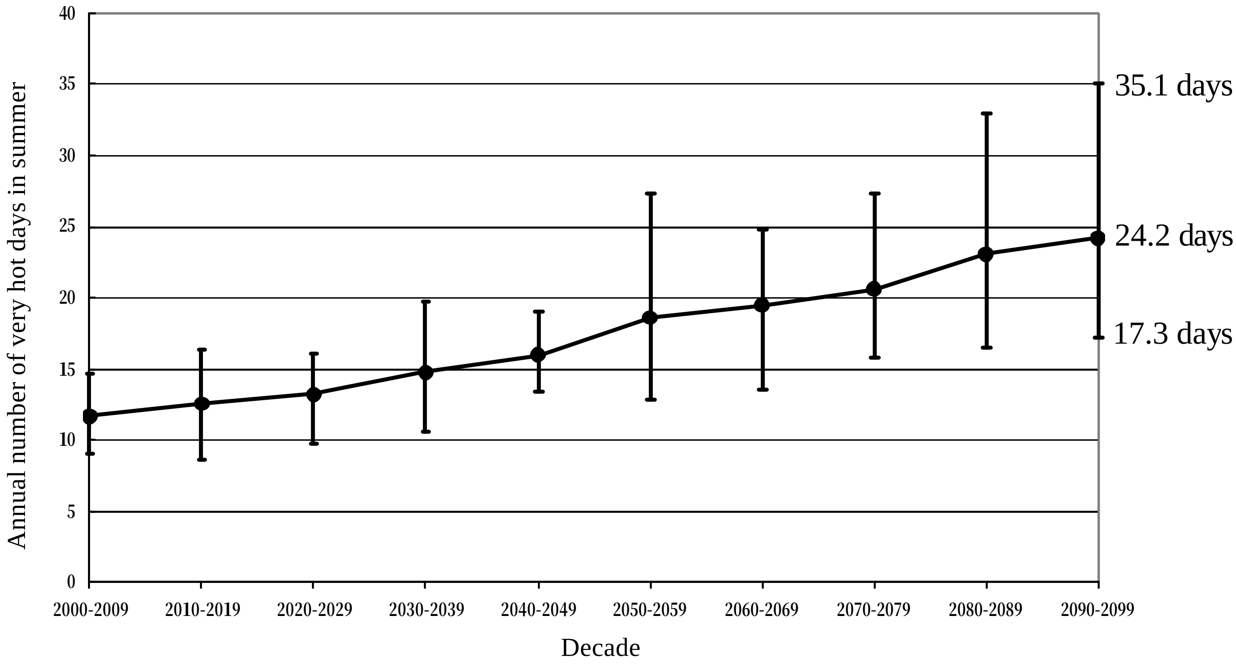


Figure 13. **Projection of the annual number of hot nights in summer in the 21st century (by the regression method). Filled circles represent ensemble mean, and the vertical lines give the ensemble upper and lower limits.**