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1. Background

In 2005, the Hong Kong Observatory (HKO) carried out a study on rainfall projections for Hong Kong (Wu *et al.*, 2005) based on the projections made in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) (IPCC, 2001). Since then, higher resolution and more sophisticated global climate models were developed and expanded data sets have emerged. These are reported in the IPCC Fourth Assessment Report (AR4) published in 2007 (IPCC, 2007).

In view of the new and better data which became available after IPCC AR4, the rainfall projections for Hong Kong have been re-assessed. This paper describes the methodology and presents the main results.

2. Data and Methodology

2.1 Data

Historical rainfall data and rainfall projections made by global climate models were used in this study. The historical rainfall data used is the monthly rainfall between 1951 and 2000 at the HKO Headquarters and 41 stations in southern China bounded by 20-30^{o}N and 105-120^{o}E (Figure 1). The data is sourced respectively from HKO and the National Climate Centre (NCC) of the China Meteorological Administration (CMA). Unless otherwise stated, the observed rainfall in Hong Kong, the rainfall anomaly, the projected rainfall anomaly and the projected rainfall in Hong Kong refer to the corresponding values at the Hong Kong Observatory Headquarters (HKOHq).

Gridded monthly rainfall projections made by 16 global climate models in AR4 are obtained from IPCC's Data Distribution Centre Website http://www.ipcc-data.org/ (see Table 1). As the performance of global climate models in forecasting rainfall over East Asia varies widely (Xu *et al.*, 2007), one approach to reduce the error in the calculation of ensemble mean projected rainfall is to discard less skilful models which are likely to produce large forecast errors. In this study, we have assessed the performance of the 16 IPCC AR4 models by comparing their simulations for 1950-2000 based on the historical greenhouse gas concentrations (20C3M scenario) with the actual rainfall observations over the area bounded by 20-30°N and 105-120°E. Further details of the 20th century simulations of the IPCC AR4 models and the 20C3M scenario are respectively documented in the Program for Climate Model Diagnosis and Intercomparison website (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php) and the IPCC data distribution website. Figure 2 shows the root-mean-square errors of the models in simulating the historical rainfall. It can be seen that there are 4 models (namely CSMK3, NCCCSM, NCPCM and HADGEM) with projection errors exceeding one standard deviation (476 mm) of the annual rainfall of HKOHq (1885-2008). Data from these 4 models with relatively large forecast errors is not used in the present study and only data from the remaining 12 models (as highlighted in Table 1) is used.

The "Special Report on the 6 Emission Scenarios (SRES)" (Nakicenovic *et al.*, 2000) for greenhouse gas employed in IPCC TAR remains applicable in AR4. The 6 scenarios from low to high greenhouse gas emissions are B1, A1T, B2, A1B, A2 and A1FI. The emission scenarios B1, A1B and A2 under which rainfall projections are available are listed in Table 1. Unlike TAR, the gridded data of AR4 models for the remaining 3 scenarios, viz. A1T, B2 and A1FI is, up to the time of writing this paper, not available on the Internet for access.

As some of the models used in this study do not have forecasts for all three emission scenarios, there are a total of 26 combinations of emission scenarios and model forecasts available for this study (Table 1).

2.2 Methodology

2.2.1 Annual rainfall

Statistical downscaling technique is used to generate local and regional scale climate projections from global climate model forecasts which are usually made at relatively low spatial resolution, typically 300 km x 300 km (e.g., Kilsby *et al.*

1998). It has become popular because of its computational economy compared with the alternative approach of dynamical downscaling (see for example Fan *et al.* 2005), and has a level of skill on par with the dynamical approach (Murphy 1999). Rainfall and temperature are two of the variables most frequently downscaled statistically (e.g., Hanssen-Bauer *et al.* 2005). Regression is often employed in statistical downscaling (see for example Wilby *et al.* 2005).

Statistical downscaling usually involves two main steps (e.g., Mullan *et al.* 2001). Firstly, an empirical relationship between a local or regional predictand, such as rainfall or temperature, and some large-scale predictors which may be sea level pressure, air temperature, geopotential height (von Storch *et al.* 1993, Kidson and Thompson 1998, Wilby and Wigley 2000) or rainfall (Widmann *et al.* 2003) is established using historical data. Secondly, global model forecasts of the selected large-scale predictors are fed into a statistical model, such as linear regression, to give projected values of the local or regional predictand.

Similar to the study on temperature projection for Hong Kong undertaken by Leung *et al.* earlier in 2008 (Leung *et al.* 2008), this study uses regression–based downscaling of the rainfall forecasts of global climate models to project Hong Kong's annual rainfall to the end of the century.

A linear regression relationship between annual rainfall anomaly at HKOHq as the predictand and the averaged annual rainfall anomaly over southern China as the predicator was established using historical data. In this study, the annual rainfall anomaly for any station is defined as :

$$\Delta R_{OBS} = R_{OBS} - \langle R_{OBS} \rangle \qquad (1)$$

where R_{OBS} is the annual rainfall and $\langle R_{OBS} \rangle$ is the average annual rainfall between 1980 and 1999. The period 1980-1999 is used as it is chosen by IPCC AR4 as the reference period for the evaluation of projections into the 21st century.

After a detailed examination of the data of the 41 stations in the area bounded by 20-30^{o}N and 105-120^{o}E, only the rainfall anomalies of 16 stations over southern China (white dots in Figure 1) were found to have a statistically significant correlation (at 5 % level) with that of Hong Kong. The average annual rainfall anomaly (relative to 1980-1999, similar to Leung *et al.* 2008) over southern

China is defined as the average of the annual rainfall anomaly of the 16 selected stations where the annual rainfall anomaly of each station was calculated from equation (1). The average annual rainfall anomaly of the 16 stations over southern China is adopted as the predictor because the occurrence of precipitation over southern China and Hong Kong is brought about by the same synoptic systems. Therefore the rainfall anomaly in southern China and that of Hong Kong should share the same trend to a large extent.

Using the data from 1951 to 2000, the regression equation for annual rainfall anomaly (relative to 1980-1999) at HKOHq y is established as

$$y = 1.55x + 2.50 \tag{2}$$

where x is the average annual rainfall anomaly over southern China. The coefficient of determination R^2 is 0.44. That is, the proportion of variation in the annual rainfall anomaly at HKO Headquarters accounted for by the variation in x is 44% and the correlation is statistically significant at 5% level (Wilks 1995).

Compared with the regression method used earlier by Wu *et al.* in 2005 (Wu *et al.* 2005), in which two predictors (namely, the averaged annual rainfall anomaly over southern China and the averaged annual rainfall anomaly over central China) were used, the regression equation adopted in this study has a slightly higher coefficient of determination than that of the previous study (R^2 = 0.42). Furthermore, the regression equation used in the present study has been tested with the cross validation method (Neter *et al*, 1989; Jolliffe and Stephenson, 2003) for different periods from 1951 to 2000. During cross validation, one year of data is omitted when establishing the regression equation and the resultant regression equation was applied to the omitted year to produce the validation rainfall forecast. This procedure was repeated for each year between 1951 and 2000. The validation forecast data were then verified using the actual rainfall observations to calculate the R^2 and root mean square error. The R^2 and root-mean-square error of the cross validation for the regression scheme of this study are 0.40 and 358 mm respectively. The corresponding figures for the regression scheme used in the earlier study on rainfall projections in Hong Kong by Wu *et al.* in 2005 (Wu *et al.* 2005) are 0.34 and 407 mm. This indicates that the regression scheme employed in this study has a slightly higher skill and lower root mean square error than that of the earlier work by Wu *et al*.

Similar to Equation (1), the projected annual rainfall anomaly over southern China ($\Delta R_{M\text{-}SC}$) is defined as:

$$\Delta R_{M\text{-}SC} = R_{M\text{-}SC} - \langle R_{M\text{-}SC} \rangle$$

where $R_{M\text{-}SC}$ is the average of the model grid point projected rainfall bounded by 20-30^{o}N and 105-120^{o}E and $\langle R_{M\text{-}SC} \rangle$ is the average of $R_{M\text{-}SC}$ for 1980-1999 under the 20C3M scenario.

Model grid point values bounded by 20-30^{o}N and 105-120^{o}E were used because it has been recommended by IPCC that the minimum effective spatial resolution for downscaling purpose should be defined by at least four model grid boxes, due to the lack of confidence in regional model estimates (IPCC-TGCIA, 1999).

This projected annual rainfall anomaly over southern China ($\Delta R_{M\text{-}SC}$) is then fed into the regression equation (2) to give the downscaled rainfall anomaly for Hong Kong ($\Delta R_{D\text{-}HK}$).

$$\Delta R_{D\text{-}HK} = 1.55\Delta R_{M\text{-}SC} + 2.5$$

Furthermore, in order to adjust for the difference of variance between the observed and downscaled rainfall anomaly (e.g. Karl *et al*, 1990; Huth, 1999), the downscaled rainfall anomaly for Hong Kong ($\Delta R_{D\text{-}HK}$) is multiplied by a factor (σ_o/σ_d) to give the projected annual rainfall anomaly for Hong Kong, where σ_o and σ_d are the standard deviation of annual rainfall for Hong Kong in 1980-1999 and the standard deviation of downscaled rainfall anomaly for Hong Kong in 1980-1999 respectively. The projected annual rainfall for Hong Kong (R_{HK}) is then determined as the sum of the projected annual rainfall anomaly for Hong Kong and the normal annual rainfall for Hong Kong in 1980-1999 ($\langle R_{HK} \rangle$ = 2324mm). That is :

$$R_{HK} = (\sigma_o/\sigma_d)\Delta R_{D\text{-}HK} + \langle R_{HK} \rangle$$

Similar to the approach in IPCC AR4, the multi-model ensemble mean approach was adopted in presenting and evaluating the results of this study as the use of multi-model ensembles has been shown in other modeling applications to produce simulated climate features that are improved over single models alone (IPCC, 2007).

2.2.2 Extreme annual rainfall

A common way of classifying extreme values is to use two standard deviations as boundary (e.g., Palmer and Räisänen 2002, Wang and Xu 1997). Adopting this classification and using the mean and standard deviation in the period 1885-2008, a year with an annual rainfall at HKOHq greater than 3187 mm will be classified as an "extremely wet" year in Hong Kong, and an annual rainfall at HKOHq less than 1282 mm as an "extremely dry" year. Furthermore, the absolute maximum and minimum annual rainfall for the 124 years (1885-2008) of record at HKOHq are 3343 mm and 901 mm respectively. The annual rainfall projection for each model and for each scenario is first found as in Section 2.2.1 and the number of years with annual rainfall outside the above thresholds is counted.

2.2.3 Number of heavy rain days

The projected number of heavy rain days per year (N_h), viz., the number of days with hourly rainfall exceeding 30 mm at HKOHq is derived from the projected annual rainfall (y). The linear regression equation, constructed from the number of heavy rain days and annual rainfall observed in the period 1951-2000 at HKOHq, is

$$N_h = 0.0035\ y - 2.39 \qquad (3)$$

The corresponding coefficient of determination R^2 is 0.66, indicating that some 66% of the variation in N_h is accounted for by the variation in y.

3. Results

3.1 Past rainfall

Rainfall record at the HKOHq dated back 124 years to 1885 (data not available from 1940 to 1946). As shown in Figure 3, the annual rainfall at the HKO Headquarters has a rising trend of 25 mm (about 1.1%) per decade between 1885 and 2008 and this trend is statistically significant at 5% level. Between 1947 and 2008, the trend is higher at 56 mm per decade, but it is not statistically significant at 5% level. The 1980-1999 normal of annual rainfall is 2324 mm.

3.2 Projected rainfall

3.2.1 Annual rainfall

Table 2, Table 3, Figure 4 and Figure 5 give the projected change in mean annual rainfall in Hong Kong relative to the average of 1980-1999 for different models and emission scenarios.

The multi-model ensemble mean annual rainfall anomalies in 2070-99 are positive for the three emission scenarios B1, A1B and A2 (see Table 3 and Figure 4). Past model simulation studies also pointed out that the rainfall in East Asia and China would increase under the scenario of doubled carbon dioxide concentration (Zhao *et al*. 2005). Moreover, Ding *et al*. indicated that the annual precipitation of most parts of China would have an increasing trend in the 21st century (Ding *et al.* 2007).

In the 30-year period 2070-99, 19 out of the 26 (i.e. 73%) different scenarios and models combinations forecast the mean annual rainfall anomaly to be positive. This is quite different from the case for temperature projection in which all scenarios/forecasts combination projected positive annual mean temperature anomalies (Figure 6). For the scenario mean of different models (Table 3), 9 out of the 12 models forecast a positive mean annual rainfall anomaly in 2070-99. Similar results have also been reported in IPCC AR4 that, for the A1B scenario, about 70% of the models project an increase in the precipitation in southern China (IPCC, 2007).

Although the model average of the projected rainfall of Hong Kong increases in the 21st century, there are large variations between the model simulation results for the three emission scenarios. Some of the models, such as GFCM20, projected that rainfall of southern China during 2070-2099 for the A2 (high emission) scenario would be less than that of the B1 (low emission) scenario (Figure 7). Simulations of MRCGCM and MIMR also have a similar characteristic (figures not included). Other simulation studies for East Asia (Bueh, 2003; IPCC, 2007) suggested that global warming could enlarge the land-sea thermal contrast and enhance (weaken) the East Asian summer (winter) monsoon circulation, resulting in a more significant increase in precipitation over Yangtze River Basin and northern China (see Figure 8(a)). In contrast, the projected precipitation change in southern China would be relatively small and the trends amongst models were less consistent (see Figure 8(b)).

As shown in Table 2, in the last 10 years (2090-2099) of the 21st century, the multi-model ensemble mean of the projected changes in mean annual rainfall in Hong Kong relative to the average of 1980-1999 for the A2, A1B and B1 scenarios (in a descending order of greenhouse gas emission concentration) are 156.8 mm, 262.9 mm and 325 mm respectively. The ensemble mean of these three emission scenarios is 248.2 mm (say 248 mm), i.e. a 10.7% increase relative to the 1980-1999 average of 2324 mm. This result is slightly higher than that of the projected 8% increase in rainfall over Guangdong in 2070-2090 as estimated by the Guangdong Meteorological Bureau based on AR4 (Guangdong Meteorological Bureau, 2007).

3.2.2 Extreme annual rainfall

In the 21st century, the multi-model ensemble mean number of extremely wet years (annual rainfall > 3187 mm) and extremely dry years (annual rainfall < 1282 mm) are expected to be 9.7 and 3.6 respectively. This is an increase from 3 extremely wet years and 2 extremely dry years during the period 1885-2008. Figure 9 shows the mean number of extremely wet years and extremely dry years which would occur in three successive 30-year periods in the 21st century. It was found that the ensemble mean number of extremely wet year would rise to 5.1 in 2070-2099. The mean number of extremely dry years would be 1.1 in 2070-2099. Also, the standard deviation for the distribution of the projected annual rainfall of Hong Kong in the 21st century for the three emission scenarios would increase to over 600 mm when compared to the 476 mm for the period from 1885 to 2008 (Table 4). The year-to-year rainfall variability in Hong Kong is therefore expected to increase during the 21st century.

Moreover, the multi-model ensemble mean number of occurrences of extremely dry, extremely wet and alternative extremely dry and extremely wet year patterns in two consecutive years for the three scenarios are summarized in Table 5. While these events have not happened in the 20th century, and indeed since records begin in 1885, the multi-model ensemble mean number of occurrences of consecutive extremely wet years would be about 2 in the 21st century. The mean number of occurrences of two consecutive extremely dry years and alternative extremely dry and extremely wet year are both 0.4.

In the past 124 years, the highest and lowest annual rainfall recorded at HKO Headquarters was 3343 mm and 901 mm respectively. In the 21st century, the multi-model ensemble mean number of years of the occurrence of annual rainfall above 3343 mm is 6.9 while that of the occurrence of annual rainfall below 901 mm is 0.8.

3.2.3 Number of heavy rain days

The number of heavy rain days was projected by using equation (3). In 2070-2099, the mean number of days in a year with hourly rainfall greater than 30 mm will be 6.5 days, slightly higher than the 1980-1999 mean of 5.8 days.

3.3 Comparison of the results with those based on TAR

Table 6 summarizes the results in the present assessment with those based on TAR as presented in the report of Wu *et al.* (Wu *et al.* 2005). Compared with the average of 1980-1999, the mean annual rainfall is projected to increase by 248 mm (i.e. +10.7%) in 2090-2099. This is higher than the projected increase of 106 mm (i.e. +4.6%) in the previous result using TAR. The difference in the result could be attributed to the higher projected rainfall over southern China by the models in AR4 and the tuning of the downscaling method used in the study.

As in the previous results using TAR data, the year-to-year rainfall variability is forecast to be higher in the future when compared with the past. In the 21st century, the multi-model ensemble mean number of years of occurrence of annual rainfall above 3343 mm is 6.9, slightly higher than the 5.7 in the previous results using TAR. On the other hand, the mean number of years of occurrence of annual rainfall below 901 mm is 0.8, less than the 2.9 in the previous results using TAR.

In 2070-2099, the mean number of days in a year with hourly rainfall greater than 30 mm will be 6.5 days, the same as the previous result based on TAR data.

4. Conclusion

Rainfall projections in Hong Kong for the 21st century were made by downscaling the global climate model projections of the IPCC AR4 for the three available greenhouse gas emission scenarios, namely A2, A1B and B1, giving a total of 26 sets of projections.

Using the ensemble mean method, the projected changes in the mean annual rainfall for Hong Kong towards the end of the 21st century are positive for all of the three emission scenarios. Furthermore, relative to the 1980-99 average of 2324 mm, the mean annual rainfall for Hong Kong will increase by 248 mm in the last 10 years of this century (2090-2099).

Another key finding in this study is that the year-to-year rainfall variability in Hong Kong would increase. It is expected that in the 21st century, there would be 9.7 (say 10) extremely wet years with annual rainfall exceeding 3187 mm and 3.6 (say 4) extremely dry years with annual rainfall less than 1282 mm. Moreover, it would be possible to have 2 occasions with two consecutive extremely wet years in the 21st century. The chances of having extremely dry condition in two consecutive years and that of alternative extremely dry/extremely wet condition in successive years are relatively low but could not be ruled out.

For the number of heavy rain days, the number of days in a year with hourly rainfall exceeding 30 mm in 2070-2099 would be 6.5 days, higher than the 1980-1999 mean of 5.8.

Finally, it should be noted that the skills of global climate models in forecasting rainfall vary widely and the confidence in model estimates is usually low at the regional level (IPCC, 2007; Kharin, 2007). Furthermore, the choice of models and downscaling methodology would also affect the projected rainfall amount. The above rainfall projection results are subjected to higher uncertainties than those for temperature projections.

The present study is an assessment of the rainfall projection for Hong Kong in the 21st century based on available monthly projection data of IPCC AR4. Further studies would be conducted using higher temporal resolution model data, especially in the assessment of likely changes in extreme precipitation events.

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Table 1. Rainfall forecasts sourced from IPCC AR4 for different global climate models and different emission scenarios. A total of 26 combinations of emission scenarios and model forecasts (highlighted in green) are used in this study.

Country	Originating Centre	Model	A1B	A2	B1
Norway	Bjerknes Centre for Climate Research	BCM2			√
Canada	Canadian Center for Climate Modeling and Analysis	CGMR	√		
France	Centre National de Recherches Meteorologiques	CNCM3	√	√	
Australia	Australia's Commonwealth Scientific and Industrial Research Organization	CSMK3		√	
USA	Geophysical Fluid Dynamics Laboratory	GFCM20	√	√	√
	Goddard Institute for Space Studies	GIAOM	√		√
	National Centre for Atmospheric Research	NCCCSM	√	√	√
		NCPCM	√	√	
UK	UK Meteorological Office	HADCM3	√	√	√
		HADGEM	√	√	
Japan	National Institute for Environmental Studies	MIHR	√		√
		MIMR	√	√	√
	Meteorological Research Institute	MRCGCM	√	√	√
Korea, Germany	Meteorological Research Institute of KMA, Meteorological Institute, University of Bonn, Model and Data Group at MPI-M	ECHOG	√	√	
Germany	Max Planck Institute for Meteorology	MPEH5	√	√	√
Russia	Institute for Numerical Mathematics	INCM3	√		

	Models used in this study	√	Emission scenarios available

Table 2. Projected change in mean annual rainfall in Hong Kong for different models under A1B, A2 and B1 scenarios. The change is with reference to the 1980-1999 average of 2324 mm.

Scenario	Model	2010-2019	2050-2059	2090-2099
B1	BCM2	-296.3	-365.6	442.4
	GFCM20	-213.9	56.2	469.2
	GIAOM	40.7	239.8	-124.2
	HADCM3	23.8	329.5	665.2
	MIHR	-397.8	4.9	546.4
	MIMR	-229.6	-157.5	-47.5
	MRCGCM	-202.5	172.5	275.7
	MPEH5	190.1	753.8	372.4
	Model ensemble mean for B1 (M_{B1})	-135.7	129.2	325.0
A1B	CGMR	115.3	207.1	679.4
	CNCM3	-581.4	-359.0	-560.9
	GFCM20	146.5	414.7	501.1
	GIAOM	-543.7	113.3	-146.8
	HADCM3	17.0	464.0	911.3
	MIHR	216.9	833.7	559.4
	MIMR	-119.8	87.7	-273.9
	MRCGCM	-386.3	347.5	423.3
	ECHOG	87.9	190.7	584.3
	MPEH5	195.6	669.7	396.6
	INCM3	205.6	-34.9	-181.4
	Model ensemble mean for A1B (M_{A1B})	-58.8	266.8	262.9
A2	CNCM3	-273.7	-533.6	-240.2
	GFCM20	32.8	-16.8	440.2
	HADCM3	-101.4	647.6	866.5
	MIMR	-445.4	-212.8	-268.0
	MRCGCM	-501.3	-229.3	-8.0
	ECHOG	-0.1	251.4	-69.1
	MPEH5	109.0	339.2	376.2
	Model ensemble mean for A2 (M_{A2})	-168.6	35.1	156.8
Ensemble upper limit		216.9	833.7	911.3
Ensemble mean for 3 scenarios (mean of M_{B1}, M_{A1B} and M_{A2})		**-121.0**	**143.7**	**248.2**
Ensemble lower limit		-581.4	-533.6	-560.9

Table 3. Projected change in 30-year mean annual rainfall from 1980-1999 (2324 mm) to 2070-2099 for different climate models and for different emission scenarios. Scenarios are ranked according to the atmospheric carbon dioxide concentration from low to high, SRES B1 being the lowest and SRES A2 the highest.

Scenarios / Model	Atmospheric carbon dioxide concentration low → high			Scenario mean
	B1	A1B	A2	
BCM2	52.3			**52.3**
CGMR		567.4		**567.4**
CNCM3		-334.9	-532.6	**-433.8**
GFCM20	474.8	531.1	329.0	**445.0**
GIAOM	132.8	-197.6		**-32.4**
HADCM3	528.9	703.1	754.8	**662.3**
MIHR	493.5	254.7		**374.1**
MIMR	-42.8	-177.1	-147.2	**-122.4**
MRCGCM	210.0	289.6	-91.5	**136.0**
ECHOG		563.6	121.7	**342.7**
MPEH5	330.1	497.2	466.5	**431.3**
INCM3		120.3		**120.3**
Model ensemble mean	**272.5**	**256.1**	**128.7**	

Table 4. Mean and standard deviation of the projected annual rainfall for the three scenarios in 2010-2099. Mean and standard deviation of annual rainfall of Hong Kong in 1885-2008 are 2235 mm and 476 mm respectively.

Scenarios	Mean	Standard Deviation
B1	2448.6	621.8
A1B	2469.7	649.2
A2	2309.9	678.9

Table 5. Multi-model mean number of occurrences of extremely dry, extremely wet and alternative extremely dry and extremely wet year patterns in two consecutive years for the three scenarios in 2010-2099

Scenarios	Consecutive extremely dry	Consecutive extremely wet	Alternative extremely dry and extremely wet
B1	0	1.6	0.5
A1B	0.5	2.1	0.3
A2	0.6	1.7	0.3
Mean	0.4	1.8	0.4

Table 6. Comparison of the results (average of models and emission scenarios concerned) on the projected mean annual rainfall, number of years with annual rainfall above 3343 mm and below 901 mm respectively, and the annual number of days with hourly rainfall exceeding 30 mm based on AR4 with that of the previous results based on TAR.

Parameter	HKO 2008 Assessment (based on AR4)	HKO 2005 Assessment (based on TAR)
Annual rainfall in 2090-2099 compared with 1980-1999	+ 248 mm (+ 10.7 %)	+106 mm (+ 4.6 %)
Number of years with annual rainfall above 3343 mm in the 21st century	6.9 years	5.7 years
Number of years with annual rainfall below 901 mm in the 21st century	0.8 years	2.9 years
Annual number of days with hourly rainfall > 30 mm in 2070-2099	6.5 days	6.5 days

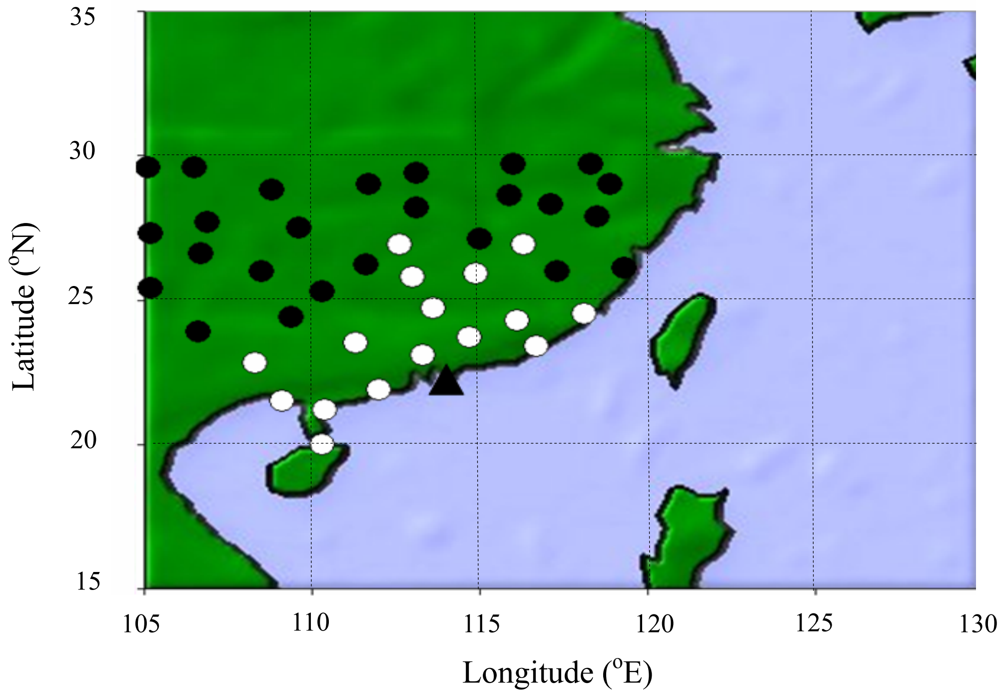

Figure 1. Location of the Hong Kong Observatory Headquarters (indicated by the solid triangle) and 41 rainfall recording stations over the area bounded by 20-30^{o}N and 105-120^{o}E. The rainfall anomalies of the 16 stations over southern China (indicated by white dots) were found to have a statistically significant correlation (at 5% level) with that of Hong Kong Observatory Headquarters.

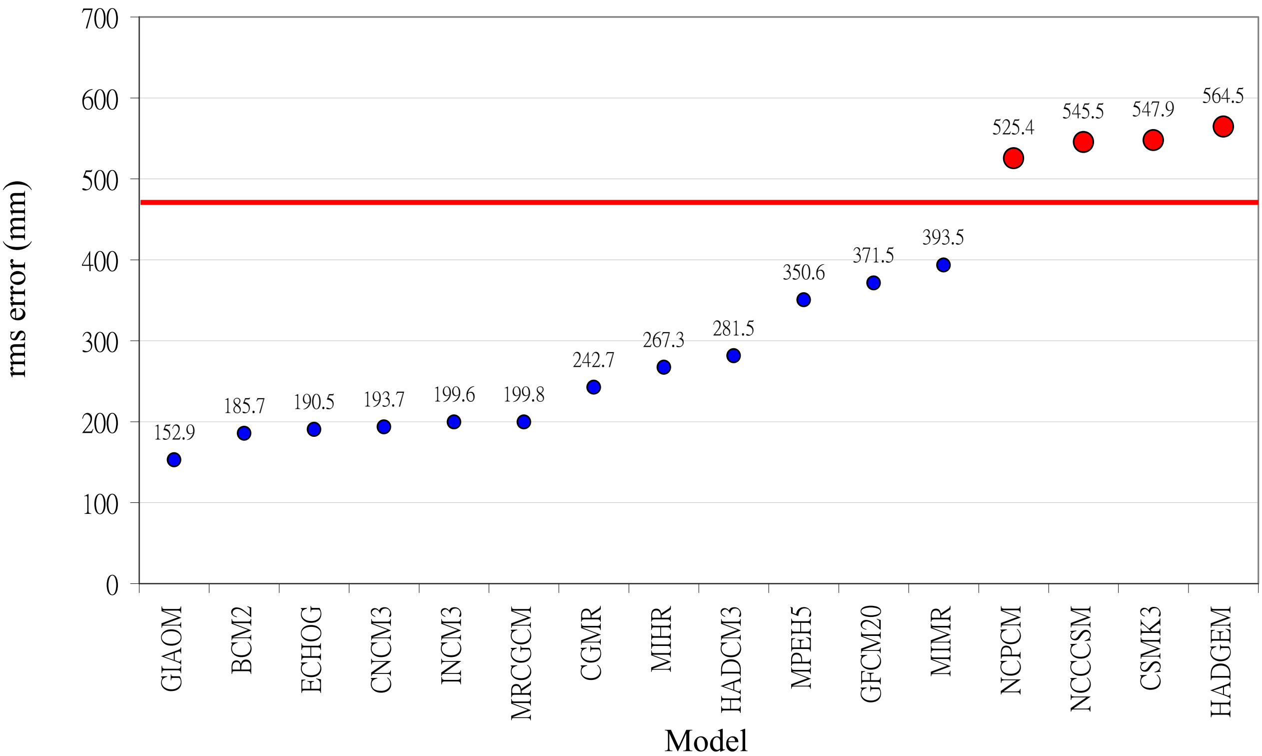

Figure 2. A plot of the root mean square (rms) errors of the 16 models from IPCC AR4 in simulating the annual mean rainfall over the area bounded by 20-30^{o}N and 105-120^{o}E during 1951-2000. The red dots above the red line represent models with rms error more than 476 mm (one standard deviation of the annual rainfall of Hong Kong, 1885-2008) and data from these models are not used in the present study.

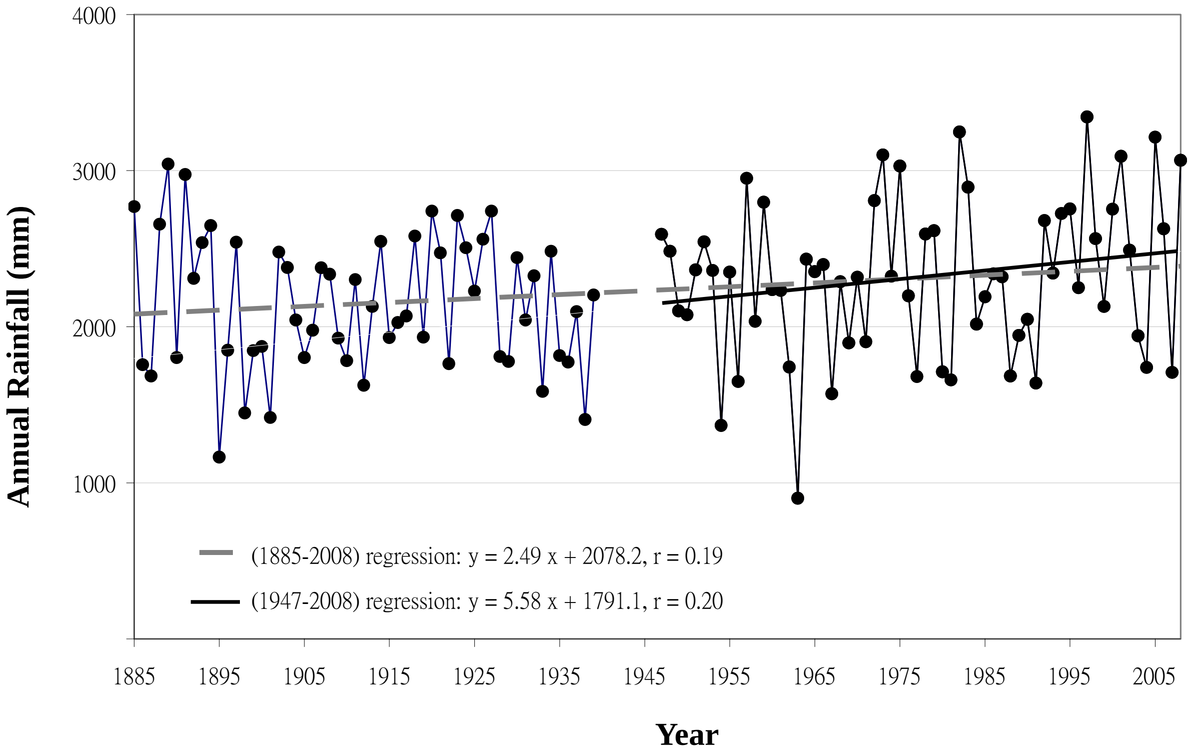

Figure 3. Time series of the annual rainfall in Hong Kong from 1885 to 2008 (data not available from 1940 to 1946). The 1885-2008 trend is statistically significant at the 5% level, but the 1947-2008 trend is not.

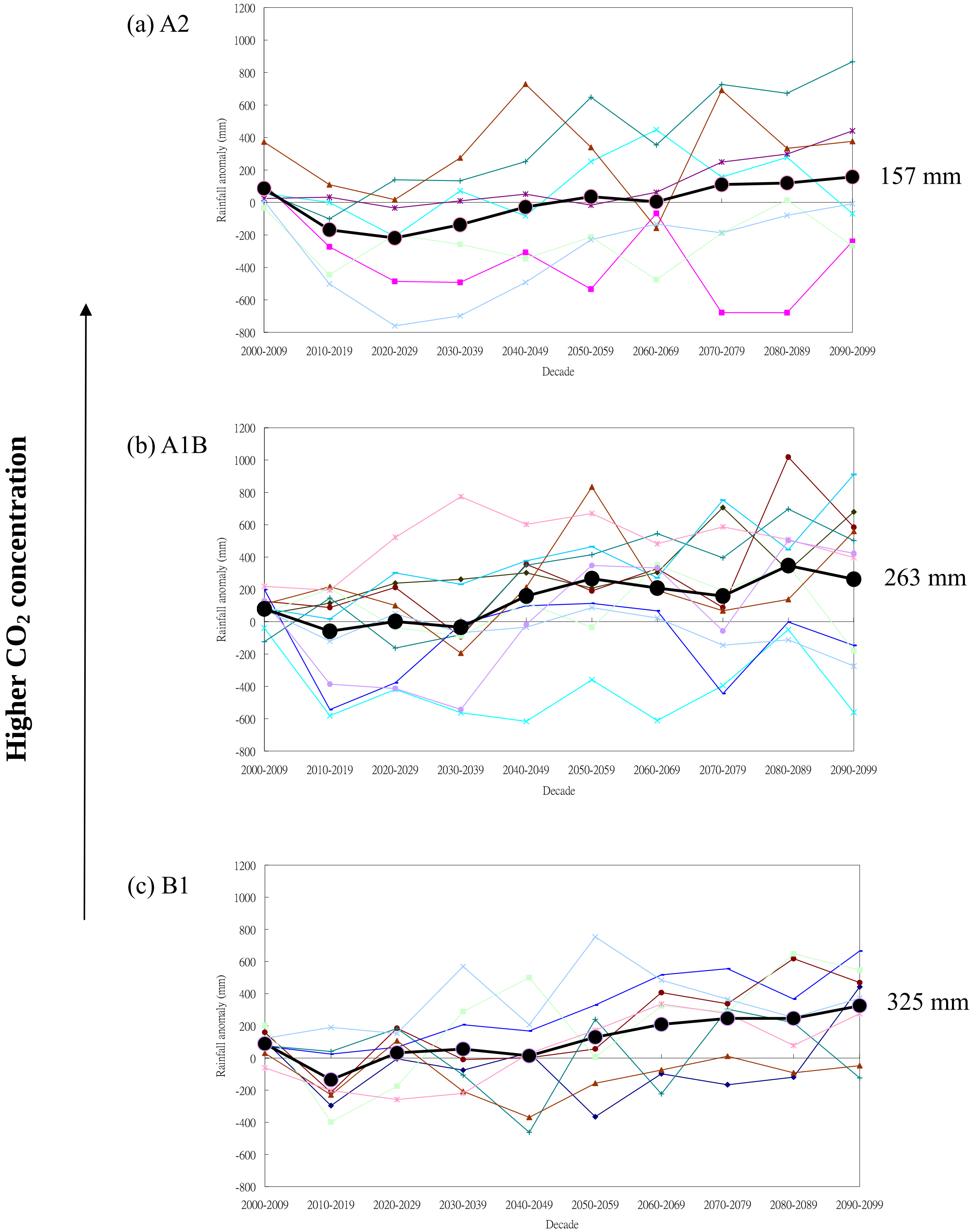

Figure 4. Projected changes in mean annual rainfall in Hong Kong based on different models under (a) A2, (b) A1B, and (c) B1 scenarios. The rainfall change is with reference to the 1980-99 average of 2324 mm. The dark line joining the black dots denotes the multi-model ensemble mean. For the decade 2000-2009, actual observations for 2000-2007 and projected values for 2008-2009 are used.

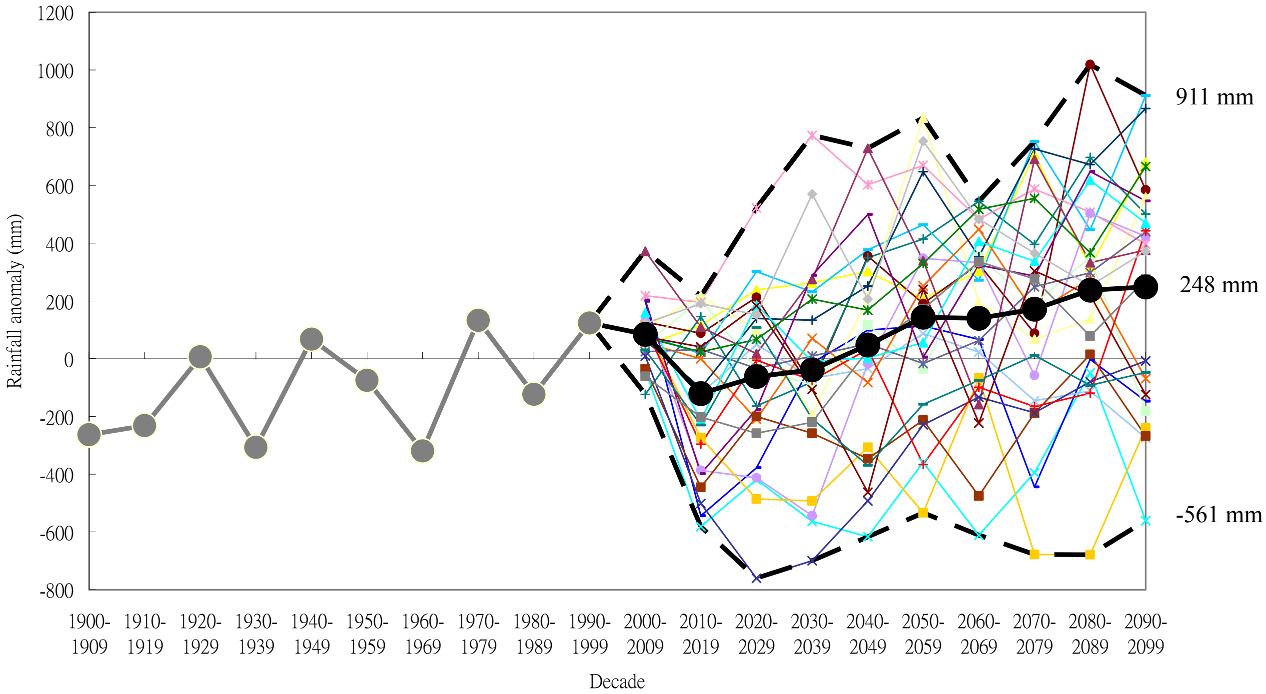

Figure 5. Projected changes in mean annual rainfall in Hong Kong based on different models for all three scenarios (i.e. A1B, A2 and B1). The rainfall change is with reference to the 1980-99 average of 2324 mm. The dark line joining the black dots denotes the average of the multi-model ensemble mean of the three emission scenarios (see Figure 4). For the decade 2000-2009, actual observations for 2000-2007 and projected values for 2008-2009 are used.

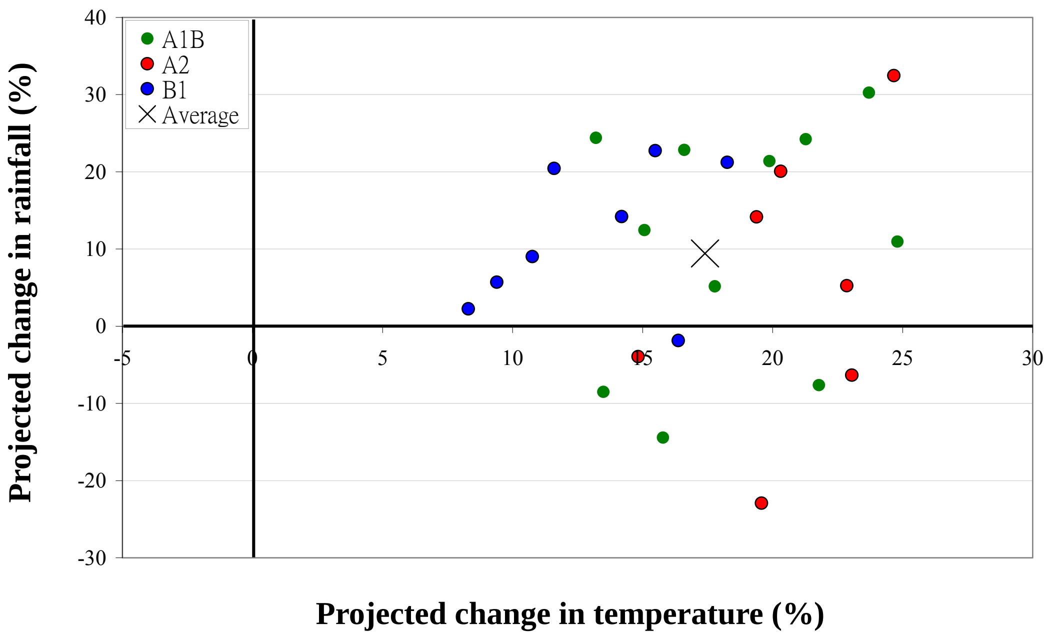

Figure 6. Projected changes in 30-year mean anuual rainfall and annual mean temperature in Hong Kong from 1980-1999 to 2070-2099 for different emission scenarios and models. Dots represent projected changes based on different models under various scenarios. The cross denotes the ensemble mean of all the selected scenarios and models.

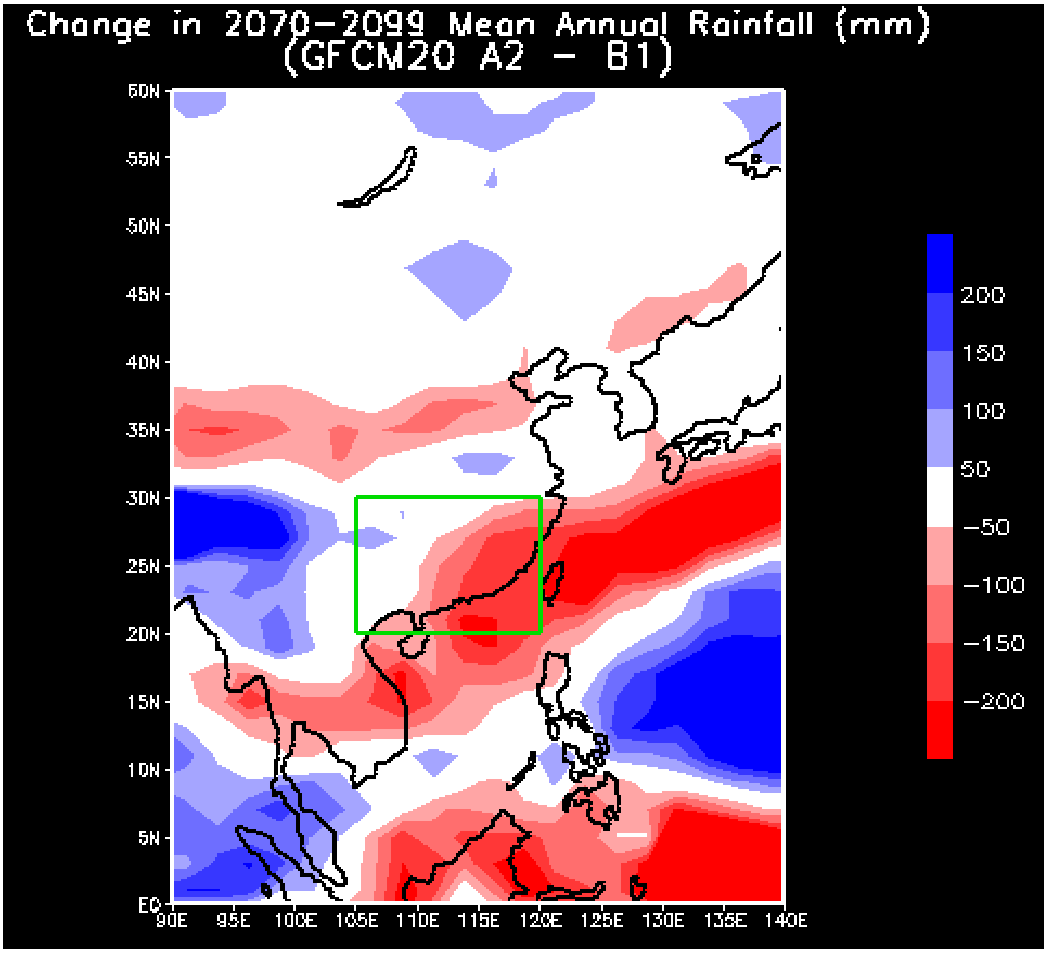

Figure 7. GFCM20 A2 scenario mean annual rainfall minus B1 scenario mean annual rainfall in 2070-2099. Red color indicates that A2's rainfall projection is less than that for B1. The green box shows the area bounded by 20-30^{o}N and 105-120^{o}E.

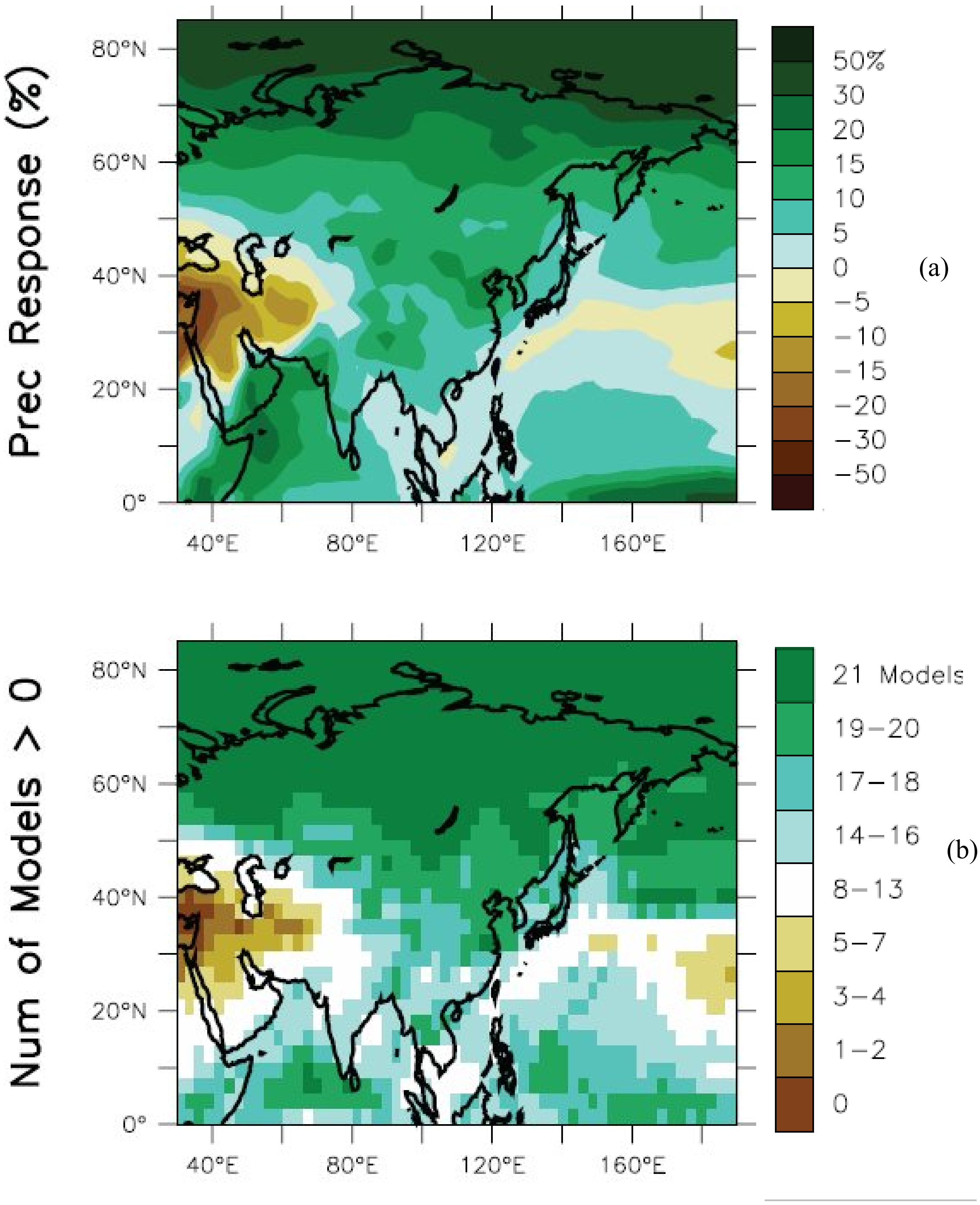

Figure 8. (a) Fractional change in annual precipitation over Asia from the multi model data (A1B simulations) between 1980-1999 and 2080-2099, (b) Number of models out of 21 that project increases in annual precipitation.

(Extracted from IPCC : "Climate Change 2007: The Physical Science Basis", Figure 11.9)

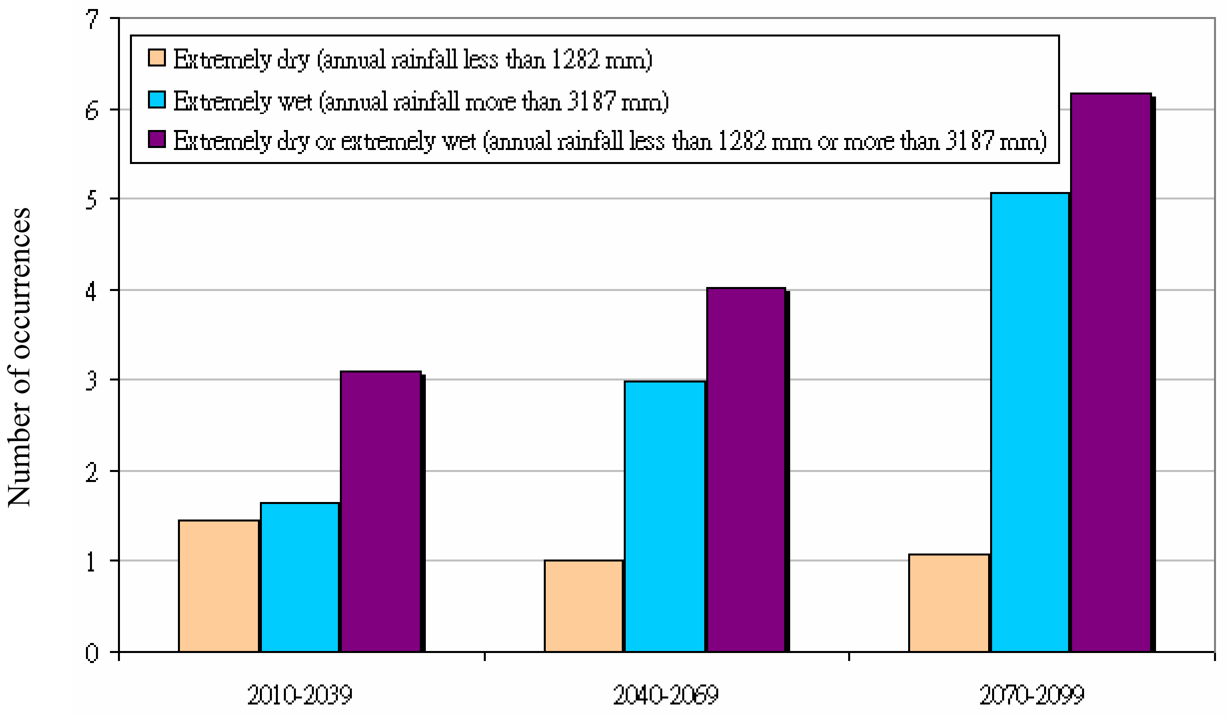

Figure 9. Projected number of occurrences of extremely dry or extremely wet years in three successive 30-year periods in the 21st century.