Review of Climate Change Scenarios

GEO Report No. 269

J.K.L. Chan & F.C.Y. Tam

Geotechnical Engineering Office
Civil Engineering and Development Department
The Government of the Hong Kong
Special Administrative Region

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Preface

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Y.C. Chan
Head, Geotechnical Engineering Office
July 2012

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Foreword

In May 2010, the Geotechnical Engineering Office (GEO) commissioned AECOM to undertake a project called “Review of Studies on Climate Change and Its Implications on Slope Safety”. One of the studies of the project was to review climate change scenarios pertaining to Hong Kong and its surrounding region. Professor Johnny K.L. Chan of City University of Hong Kong was engaged as a sub-consultant to undertake the study.

This report presented the results of the study, which included a summary of key findings of past studies of climate change, an overview of the relevant projected climate change scenarios and comments on methodologies for future climate projections.

The Hong Kong Observatory provided support throughout the study. Many staff of GEO provided useful comments on the draft version of the report. All contributions are gratefully acknowledged.

Y.K. Shiu
Chief Geotechnical Engineer/Standards & Testing

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1 Introduction

1.1 Background

AECOM was commissioned by GEO to undertake the "Review of Studies on Climate Change and Its Implications on Slope Safety" in May 2010, under Agreement No. CE 9/2009 (GE), Study of Landslides Occurring in Hong Kong Island and Outlying Islands in 2010 and 2011 - Feasibility Study. As part of the study, Prof. Johnny Chan of Guy Carpenter Asia-Pacific Climate Impact Centre, School of Energy and Environment, City University of Hong Kong was engaged as a sub-consultant to undertake one of the sub-tasks of the study, "Review of Climate Change Scenarios".

The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007) indicates a projected increase of precipitation in the Asian monsoon, as well as an increase of intense precipitation events under global warming. Also, the strength of the strongest tropical cyclones and their associated rainfall are likely to increase in a warmer climate. The June 2008 extreme rainfall event causing 2,500 landslides on both man-made slopes and natural terrain in Hong Kong, and the extensive damage and loss of life resulting from landslide disasters triggered by Typhoon Morakot on Taiwan in August 2009 are a vivid reminder that the adverse impacts of climate change on slope safety should not be underestimated.

1.2 Study Objectives

The scope of this study is to provide a review of climate change studies pertaining to Hong Kong and its surrounding region. Objectives of this study are to:

(a) carry out a literature review and critique of studies on the change in patterns of rainfall, wind, temperature, storm surge, sea level, typhoon and monsoon of Hong Kong in the 21st Century due to climate change. The review should include relevant studies carried out by the following organizations, including but not limited to:

- (i) Intergovernmental Panel on Climate Change (IPCC);
- (ii) Hong Kong Observatory (HKO);
- (iii) National Climate Center, China Meteorological Administration (CMA); and
- (iv) Relevant research institutes/ universities.

(b) provide an overview of the relevant prevailing projected climate change scenarios in association with the weather elements mentioned in (a), together with comments on the level of uncertainties involved; and

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(c) comment on the methodology of the current studies that are intended to arrive at more realistic and definitive climate change scenarios, and areas for improvements, if any.

1.3 Structure of the Report

In addition to this Introductory Chapter which gives the background, study objectives and the report structure, the rest of this report consists of the following chapters:

Chapter 2: Methodologies for projecting the future climate. This chapter provides an overview of the different methodologies for predicting the future climate state under different emission scenarios, both for the global and regional/local climate projections.

Chapter 3: Review of key findings. This chapter presents the key findings on climate change impacts on parameters relevant to slope safety, including air temperature, rainfall, monsoon, tropical cyclone activity and sea-level rise.

Chapter 4: Gaps between current projections and practical applications. This chapter presents the uncertainties in model climate projections, as well as challenges for predicting the climate change impact on Hong Kong.

Chapter 5: Conclusions. This summarizes the key findings on climate change impacts and their uncertainty, and presents recommendations for ways forward.

2 Methodologies for Projecting the Future Climate

2.1 Introduction

In this chapter, the methodologies for projecting climate change impacts will be introduced. In order to project the future state of the climate in the broad to global scale with a sufficient degree of realism, atmosphere-ocean general circulation models have to be used. These are comprehensive models in which the basic physics governing the Earth's climate system is contained and its equations are numerically integrated forward in time. However, the spatial resolution of their prediction products might not be high enough to be useful for applications in the regional or local sense. In that case, the downscaling techniques have to be employed, in order to obtain high-resolution, regional-scale climate information based on the coarser-resolution global model outputs.

2.2 Climate Projection in the Global Scale Using AOGCMs

Atmosphere-Ocean General Circulation Models (AOGCMs) are the indispensable tool for projecting future regional to large-scale climate change. In an atmospheric GCM, equations governing the evolution of variables such as temperature, pressure, humidity, winds, are solved numerically in a computer. These equations are derived from the physical laws of thermodynamics, fluid dynamics and that describing an ideal gas. Radiative transfer is also included, which accounts for the absorption and emission of solar radiation or other electromagnetic waves by air molecules and atmospheric particles. Together the aforementioned variables describe the atmosphere at a particular instance, and their model solution gives the time evolution of the atmosphere's three-dimensional state (see, e.g. Trenberth, 1992). Variables are usually defined on a spatial grid; typical atmospheric general circulation models have spatial resolution of about 100 km and 30 levels within 15 km of altitude. For IPCC AR4, models are forced with concentrations of greenhouse gases and other constituents derived from various emissions scenarios (Special Report on the 6 Emission Scenarios, or SRES; see Nakicenovic & Swart, 2000). Their different compositions of greenhouse gases and aerosols give rise to different radiative forcing in the atmosphere, which ultimately result in different projected future climate states.

In ocean GCMs, physical equations for an incompressible fluid flow are solved numerically, analogous to those for an atmospheric model. Most climate models nowadays also include dynamic sea-ice components. It contains physics governing ice movement, heat and salt transfer within the ice. The interaction between the atmosphere and land is also an integral aspect of the climate system (Seneviratne et al, 2006). Modelling such an interaction can be very challenging, and climate model simulations are very sensitive to the choice of land models (Irannejad et al, 2003). In a typical AOGCM, the atmospheric, oceanic, sea-ice and land-surface models are coupled together through the exchange of physical quantities such as heat, momentum, mass, water vapour, salinity, at the interface among components.

Some physical processes, however, are not explicitly resolved by the grids of AOGCMs. These processes are incorporated into models through parameterization schemes. A large part of the vertical transport of heat, water, or other quantities is oftentimes controlled by subgrid-scale parameterizations in models. Some of the most important parameterization schemes in an atmospheric GCM include those representing the formation of clouds, cumulus convection, and turbulence and subgrid-scale mixing. For cloud calculations, liquid water and cloud particles including ice crystals, snow, graupel, cloud water, and rainwater are treated as variables. Empirical relationships are then used to calculate conversions among different particle types. Parameterization itself is a difficult problem and is known to be a major source of uncertainty, partly because there are almost always alternative, but plausible, ways to parameterize the same sub-gird physical process.

The climate of Hong Kong is strongly affected by the Asian monsoon systems. Many AOGCMs, however, have difficulties in simulating the Asian summer monsoon (see, e.g. Kang et al, 2002). For instance, it has been shown that less than half of the AOGCMs covered in IPCC AR4 were able to reproduce the East Asian monsoon rainfall pattern and its evolution along the coast of China toward Korean and Japan (Kripalani et al, 2007). Over the Indian subcontinent, it is found that 6 of 18 AOGCMs can reproduce the correct summertime precipitation pattern and the relationship between monsoon and the El Nino and Southern Oscillation (Annamalai et al, 2007). As will be seen in the next chapter, a consequence of the difficulty in simulating the summer monsoon is the relatively large variation of precipitation signals in the monsoon region among different AOGCM climate projections.

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2.3 Climate Projection in the Regional Scale

2.3.1 Dynamical Downscaling Using RMCs

When climate change projection information with a resolution higher than that of AOGCM products is needed, a regional climate model (RCM) is most commonly used to add realistic detail at finer scales (Giorgi & Mearns, 1991 & 1999; McGregor, 1997; Gao et al, 2001; Wang et al, 2004; Xu et al, 2006). Other options include the use of stretched-grid models (e.g. Déqué & Piedelievre, 1995; Fox-Rabinovitz et al, 2001 & 2006), or just employing uniformly high resolution atmospheric GCMs (e.g. Brankovic & Gregory, 2001; May & Roeckner, 2001; Duffy et al, 2003; Coppola & Giorgi, 2005). In general, an RCM contains the same representations of atmospheric dynamical and physical processes as in a global model, but is run at a higher resolution (say about 10-20 km) over a sub-global domain. However, lateral boundary conditions are needed for integrating an RCM; i.e. the regional model needs to receive information about the atmospheric circulation outside its computational domain (e.g. Kanamitsu et al, 2002; Uppala et al, 2005). This is obtained from coarse-scale (~100 x 100 km) AOGCM climate projection results. Other information such as the sea surface temperature is also taken from the parent AOGCM. The method is called "time-slice" climate simulation because the model simulates a portion of the period represented by the coarser-resolution AOGCM that supplies the model's boundary conditions.

Regional-scale models can simulate processes that AOGCMs cannot resolve. Inclusion of regional circulation features can lead to better simulated diurnal cycles (e.g. Byerle & Paegle, 2003; Anderson et al, 2007). Proper representations of rapid topographic variation are also found to enhance the realism of model precipitation (e.g. Leung & Wigmosta, 1999; Hay et al, 2006). With finer resolution, mesoscale phenomena contributing to intense precipitation, such as stronger upward motions (Jones et al, 1995) and coupling between regional circulations and convection (e.g. Anderson et al, 2007) can be represented. The higher resolution also includes other types of scale-dependent variability, especially short-term variability such as extreme winds, temperature and intense precipitation events that coarser-resolution models will tend to smooth out.

2.3.2 Statistical Downscaling

An alternative to using an RCM, empirical or statistical downscaling is another approach for obtaining high-resolution climate information (Kattenberg et al, 1996; Hewitson & Crane, 1996; Giorgi et al, 2001; Wilby and Wigley, 1997; Wilby et al, 2004 & references therein). It uses statistical relationships to link the coarse-resolution GCM outputs with climate in a targeted area. As long as significant statistical relationships exist, empirical downscaling can yield information for variables such as the station precipitation and temperature. This approach encompasses a range of statistical techniques including linear regression (e.g. Wilby et al, 2000), weather generators (Wilks & Wilby, 1999), canonical correlation analysis (e.g. von Storch, Zorita, & Cubasch, 1993), or even artificial neural networks (e.g. Crane & Hewitson, 1998). The analogue approach is another method to downscale AOGCM products (Lorenz, 1969; Cubasch et al, 1996; Zorita & von Storch, 1999). In this weather typing scheme, the large-scale circulation model is matched with historical circulation states, in order to obtain local weather/climate information. Overall, empirical downscaling is relatively inexpensive compared to running an RCM, and is applied in a variety of cases of regional climate change assessment.

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2.3.3 Urbanization Effects

The study of Wu et al (2008, in Chinese) for the Hong Kong Observatory indicates that the difference between the daily mean temperature for urbanized and rural areas in Hong Kong is about 0.8°C. Urbanization will certainly be a factor while considering climate change impacts on highly developed locales like Hong Kong. Of particular interest is the precipitation enhancement effect due to urbanization (see Shepherd et al, 2010). This can be due to:

(a) enhanced convergence due to increased surface roughness in the urban environment;

(b) enhanced sensible heat fluxes;

(c) destabilization due to urban heart island (UHI)-thermal perturbation of the boundary layer and resulting downstream translation of the UHI circulation or UHI-generated convective clouds;

(d) enhanced aerosols in the urban environment for cloud condensation nuclei sources; or

(f) bifurcation or diversion of precipitating systems by the urban canopy or related processes.

However, there is still no conclusion on these mechanisms controls urban rainfall process, and how they enter into the picture of climate change impacts on urbanized areas.

3 Review of Key Findings

3.1 Air Temperature

3.1.1 Studies Covered by IPCC AR4

For all three non-mitigated IPCC SRES (B1, A1B & A2) scenarios (for reference of CO_2 concentrations for different scenarios, see Figure 3.1), the global mean surface air temperature is projected to continue to increase over the 21st century. This is mainly driven by increases in anthropogenic greenhouse gas concentrations; there is thus warming due to the associated radiative forcing. The greatest temperature rise occurs in high-latitude land regions in the northern hemisphere.

Figure 3.2 shows the average surface air temperature anomalies recorded over the 20th century, as well as those projected by AOGCMs for the A1B scenario till the year 2100 over East Asia. The surface air temperature in this region is projected to rise by about 3°C by the end of the 21st century.

Focusing on China, Hu et al (2003) analyzed climate projections from 16 different models. They reported an obvious warming trend when the atmospheric CO_2 is doubled in the model experiments. Particularly strong is the surface warming over north-eastern China

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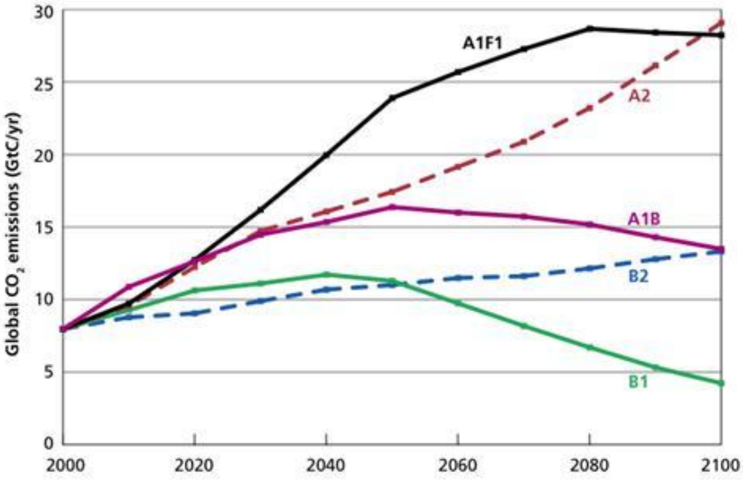
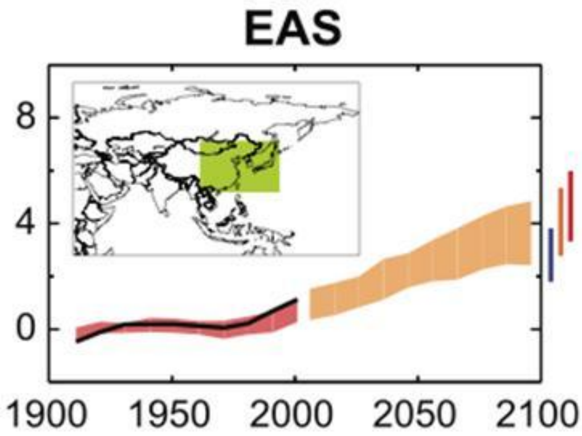


Figure 3.1 Global CO_2 Concentrations for Different Emission Scenarios



Note: Temperature anomalies with respect to 1901 to 1950 for the East Asian land region for 1906 to 2005 (black line) and as simulated (red envelope) by AOGCMs; and as projected for 2001 to 2100 for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100 for the B1 scenario (blue), the A1B scenario (orange) and the A2 scenario (red). The black line is dashed where observations are present for less than 50% of the area in the decade concerned. From IPCC AR4 WG report.

Figure 3.2 Average Surface Air Temperature Anomalies

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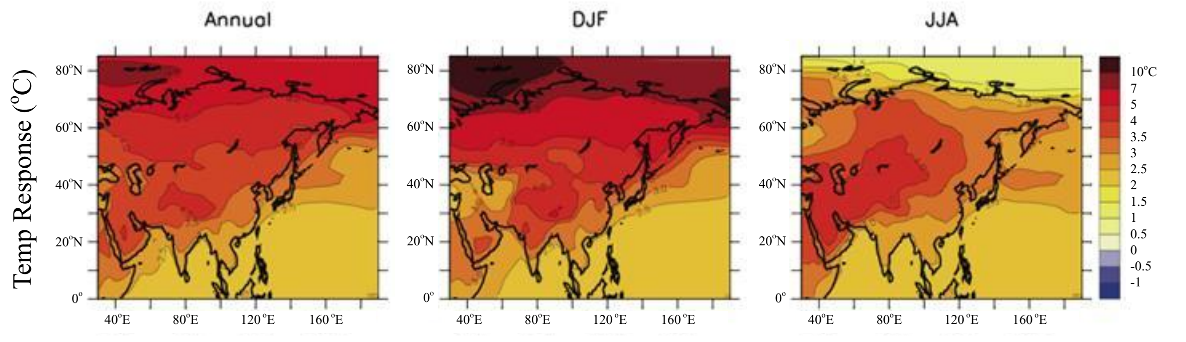
during winter. That there is stronger warming during winter is also evident in the IPCC AR4 multi-model projection for the A1B scenario (see Figure 3.3). Min et al (2004), by analyzing model climate projections under various emission scenarios, also found a robust increase in annual mean surface temperature over the whole East Asia. Xu et al (2006) made use of a regional climate model to project the future climate of China under the SRES B2 scenario. They found that the extreme maximum temperature is projected to increase, while the number of minimum surface temperature events will decrease. China's National Report on Climate Change indicates that the country-averaged annual mean temperature is projected to increase by 3.9-6.0°C by 2100, compared to the 1961-1999 mean value (Ding et al, 2007). Strongest warming is expected over the northern part of China during wintertime. For the Guangdong region, the annual mean temperature is expected to rise by 2.8°C by 2071-2099 (Guangdong Provincial Meteorological Bureau, 2007).



Note: Projected annual mean (left), DJF (middle) and JJA (right) temperature changes over Asia by AOGCMs for the A1B scenario (2080 to 2099 compared to 1980 to 1999 values, averaged over 21 models). From IPCC AR4 WG report.

Figure 3.3 Projected Temperature Changes over Asia for the A1B Scenario

Climate change also affects surface temperature extremes. There is strong evidence that heat waves will be more intense, more frequent and longer lasting in a future warmer climate. Kharin & Zwiers (2005) showed that the frequency of temperature extremes increases in the future except where surface properties change. Tebaldi et al (2006), based on an ensemble of nine models contributing to IPCC AR4, showed that the increasing trends of heat waves and warm nights will continue in most regions over the latter part of the 21st century. Furthermore, they show that in most instances the warm extremes correspond to increases in daily maximum temperature. On the other hand, cold episodes are projected to decrease significantly in a future warmer climate. Almost everywhere, daily minimum temperatures are projected to increase faster than daily maximum temperatures, leading to a decrease in the diurnal range of temperature.

3.1.2 More Recent Studies

Kharin et al (2007) analyzed an ensemble of coupled climate model projections. They showed that the return period of warm temperature extreme is expected to decrease (i.e. more

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frequent occurrence of warm extremes) over most East Asian locations. On the other hand, cold extremes are projected to occur less frequently. These observations are consistent with the above findings.

Ginn et al (2010) from the Hong Kong Observatory employed the technique of statistical downscaling to project the future climate of Hong Kong. They expected the annual mean surface temperature to rise by 3.0-6.8^{o}C by 2090-2099, compared to its 1980-1999 value. Both the number of very hot days and hot nights are expected to increase, while the number of cold days in winter will decrease under global warming. In general, their results are consistent with other climate change projections for the region, such as those of Hu et al (2003).

In summary, the above studies indicate an increased surface temperature or more hot (and less cold) extremes over China/East Asia. Their results are summarized in Table 3.1.

Table 3.1 Summary of Results from Climate Change Projection Studies on the Surface Temperature and Temperature Extremes Relevant to Regions Including Hong Kong

Researchers	Institution of Lead Author	Methodology	Conclusion
Hu et al (2003)	Center for Ocean-Land-Atmosphere Studies, Institute of Global Environment and Society, George Mason University, USA	Compare doubled CO_2 climate with "present-day" control run, using 16 CMIP2 models	Obvious warming trend; esp. in north-eastern China during winter.
Min et al (2004)	Meteorologisches, Universitat Bonn, Germany	Compare SRES A2 and B2 with 1961-1990 climate, using 7 AOGCM ensembles	Robust increase of the annual mean surface temperature in East Asia.
Tebaldi et al (2006)	National Center for Atmospheric Research, USA	Compare extreme indices between SRES A1B, A2 and B1 and 20C3M, using 9 AOGCMs	Increasing trends of heat waves and warm nights.
Xu et al (2006)	Chinese Academy of Agricultural Sciences, China	Compare SRES A2 and B2 with 1961-1990 climate, using the regional model PRECIS driven by HadAM3H	Increase of extreme max. temperature and min. surface temperature.
Kharin et al (2007)	Canadian Centre for Climate Modelling and Analysis, Environment Canada, Canada	Compare SRES A1B, A2 and B1 with 1981-2000 climate, using 16 IPCC ensemble of global coupled models	Decrease of the return period of warm temperature extreme; increase of return period of cold extremes.
Ding et al (2007)	China Meteorological Administration	Projections of future climate by NCC, IAP and other models	Annual mean temperature in China projected to increase by 3.9-6.0^{o}C by 2100.
Composing Team for Assessment Report on Climate Change of Guangdong	Guangdong Meteorological Bureau	Projections of future climate by AOGCMS (with results from National Assessment Report for Climate Change)	Annual mean temperature for Guangdong projected to increase by 2.8^{o}C by 2071-2099.
Ginn et al (2010)	Hong Kong Observatory	Statistical downscaling based on IPCC AR4 and analyzing observed data	Annual mean surface temperature of HK to rise by 3.0-6.8^{o}C by 2090-2099; no. of very hot days and hot nights (cold days in winter) are expected to increase (decrease).

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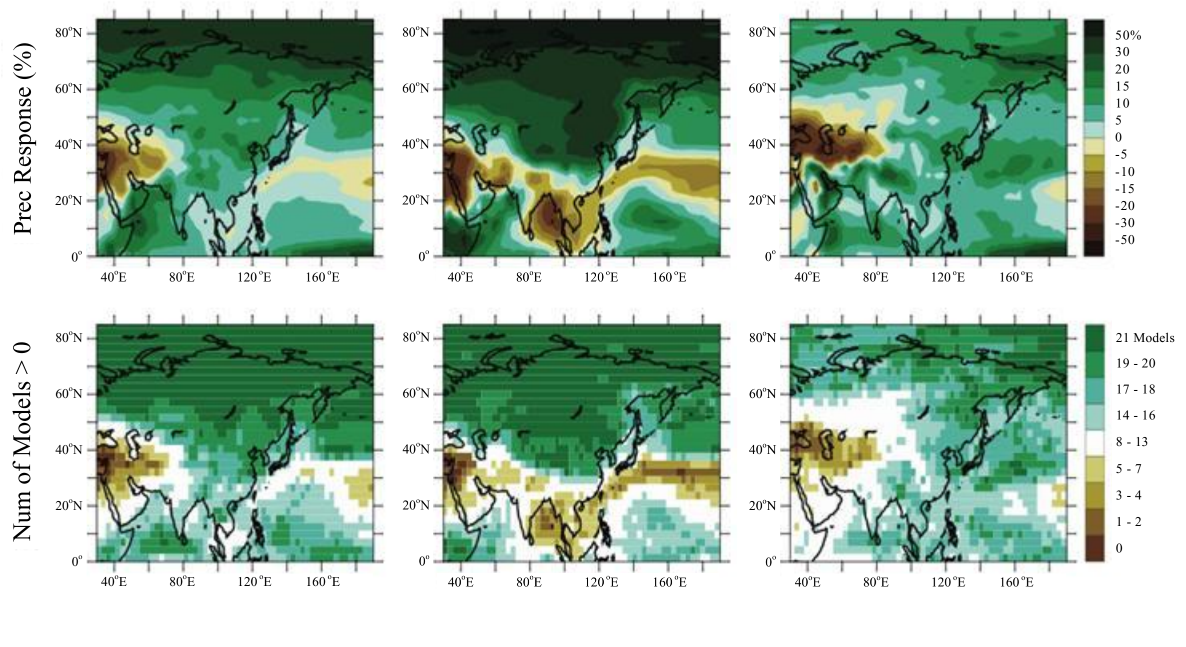
3.2 Rainfall and Monsoon

3.2.1 Seasonal Mean Rainfall - Studies Covered by IPCC AR4

The global mean precipitation is projected to increase under global warming. In general, for a warmer climate, AOGCMs indicate that a precipitation increase in the areas of regional tropical precipitation maxima (such as the monsoon regions) and over the tropical Pacific, as well as in high latitudes, while a reduced rainfall is found in the subtropics as a consequence of a general intensification of the global hydrological cycle. The globally averaged mean water vapour, evaporation and precipitation are projected to increase. Compared to its counterpart in temperature, however, the rainfall projection varies substantially in both the spatial and seasonal sense. There is also more variation in the magnitude of change among projections from different AOGCMs. Figure 3.4 shows the multi-model results of AOGCM rainfall projections for the SRES A1B scenario. It can be seen that a majority of models projected higher summer rainfall in South China. However, it is also noteworthy that a number of models produce a drying signal, indicating large uncertainties in the rainfall projection in this region.



Note: Top row: multi-model projected annual mean (left), DJF (middle) and JJA (right) fractional precipitation changes over Asia for the A1B scenario. (2089-2099 compared to 1980-1999 values, averaged over 21 models). Bottom row: number of models out of 21 that project increases in the annual mean (left), DJF (middle) and JJA (right) precipitation. From IPCC AR4 WG report.

Figure 3.4 AOGCM Rainfall Projections for the SRES A1B Scenario

As the projected warming will be more rapid over land than over the oceans, continental-scale land-sea thermal contrast is expected to become larger in summer and

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smaller in winter. Based on this idea, the summer monsoon would be stronger and the winter monsoon would be weaker in the future than the present. In fact, using eight AOGCMs, Ueda et al (2006) demonstrated that the Asian summer monsoon circulations are indeed weakening in relation to a reduction in the thermal gradients between the Asian continent and adjacent oceans. However, the change in atmospheric moisture content due to increased temperature in a warmer climate also results in a larger moisture flux and hence more precipitation. Thus, overall, an increase in precipitation over the East Asian Monsoon region is projected. Kimoto (2005) and Ueda et al (2006) investigated the multi-model Asian monsoon response to global warming. Both reported a significant increase of the summer monsoon rainfall in most Southeast and East Asian locations. The regional climate model study of Xu et al (2006) indicates that, in South China, the summertime rainfall is likely to increase. Ding et al (2007), who considered AOGCMs from IPCC AR4 (see Table 3.2) and also the Institute of Atmospheric Physics (IPA) T63 AOGCM, in the China's National Climate Change Report (see also 丁一汇 等, 2007), showed that ~10% increase of precipitation over China is expected by 2100. For the Guangdong province, the annual mean precipitation is projected to increase by 8% during 2071-2099 (Guangdong Provincial Meteorological Bureau, 2007). Kripalani et al (2007) analyzed 21 climate model runs contributing to IPCC AR4. Their multi-model projection indicates increased seasonal mean rainfall over the Southern Chinese coastal region in summer. A similar situation is found for the Indian monsoon (Douville et al, 2000; IPCC, 2007; Ashrit et al, 2003; Meehl & Arblaster, 2003; May, 2004; Ashrit et al, 2005). Associated with the enhanced monsoon rainfall, most model results also project increased interannual precipitation variability (see e.g. Hu et al, 2000; Räisänen, 2002; Meehl and Arblaster, 2003).

Table 3.2 Table Showing AOGCMs from IPCC AR4 Being Considered by Ding et al (2007)

Model	Center/Country
CGCM3.1(T47)	Canadian Centre for Climate Modelling & Analysis, Canada
CGCM3.1(T63)	Canadian Centre for Climate Modelling & Analysis, Canada
CNRM-CM3	Météo-France / Centre National de Recherches Météorologiques, France
CSIRO	CSIRO Atmospheric Research, Australia
GFDL-CM2.0	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, United States
GFDL-CM2.1	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, United States
GISS-EH	NASA / Goddard Institute for Space Studies, United States
GISS-ER	NASA / Goddard Institute for Space Studies, United States
FGOALS-g1.0	LASG / Institute of Atmospheric Physics, China
INM-CM3.0	Institute for Numerical Mathematics, Russia
IPSL-CM4	Institut Pierre Simon Laplace, France
MIROC3.2(medres)	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan
MIROC3.2(hires)	Same as above
ECHAM5/MPI-OM	Max Planck Institute for Meteorology, Germany
MRI-CGCM2.3.2	Meteorological Research Institute, Japan
CCSM3	National Center for Atmospheric Research, United States
PCM	National Center for Atmospheric Research, United States
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research / Met Office, United Kingdom
UKMO_hadgem1	Hadley Centre for Climate Prediction and Research / Met Office, United Kingdom

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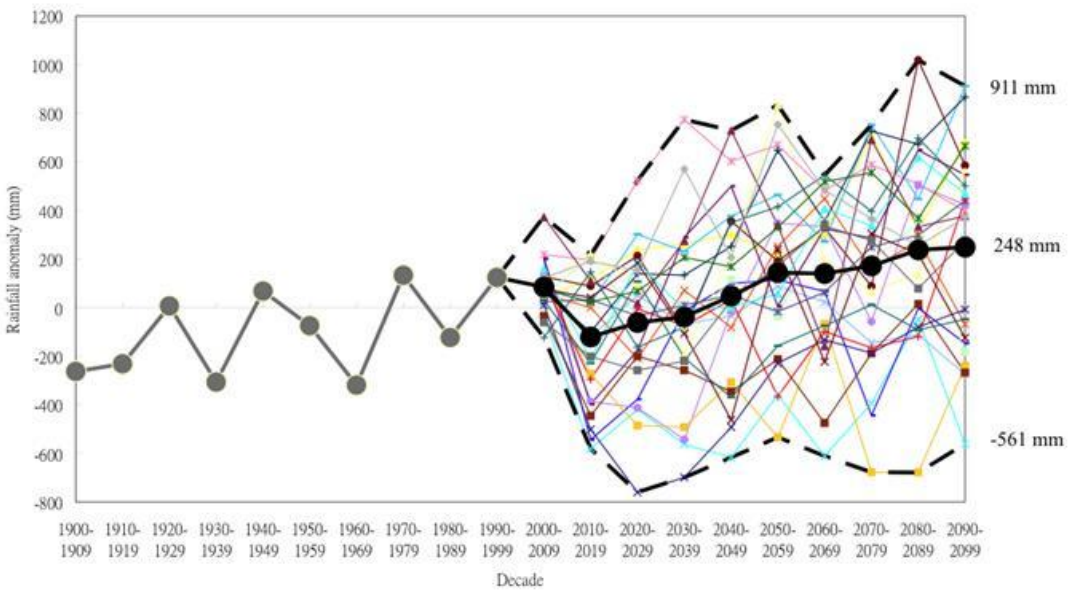
3.2.2 Seasonal Mean Rainfall - More Recent Studies

Lee et al (2008) from the Hong Kong Observatory (see also Ginn et al, 2010) projected the future rainfall characteristic in Hong Kong, including annual mean rainfall, occurrence of extremely wet and extremely dry years, number of heavy rain days per year. This is carried out based on statistical downscaling, using annual mean AOGCM results as inputs. The method is a standard one, given the annual mean model product as the input data. The simulation products of 12 AOGCMs for three different emission scenarios (A1B, A2, B1) are statistically downscaled and then averaged to obtain the final results for Hong Kong. Their result is shown in Figure 3.5. It is projected that the Hong Kong summertime rainfall will decrease in the first half of 21st century until 2040, followed by an enhanced precipitation later. However, it is also noticed that there is a considerable amount of scatter among the results based on individual model outputs (which is consistent with the large inter-model variability of rainfall projections in this region; see Figure 3.5). Again, this highlights the large degree of uncertainty in projecting the precipitation of Hong Kong in the future climate. Finally, it should be mentioned that the urbanization effects also plays a role in enhancing the mean precipitation in urban areas, based on the observational study of Mok et al (2006). (On the other hand, Kaufmann et al (2007) found that the urbanization effects lead to a reduced rainfall amount over the Pearl River Delta during its dry season.) Such urbanization effects, the mechanisms of which are not fully understood, will inevitably lead to further uncertainties in projecting the future precipitation.



Note: Projected changes in the mean annual rainfall in Hong Kong based on statistical downscaling from different AOGCM simulations 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. From Lee et al (2008).

Figure 3.5 Projected Changes in the Mean Annual Rainfall in Hong Kong

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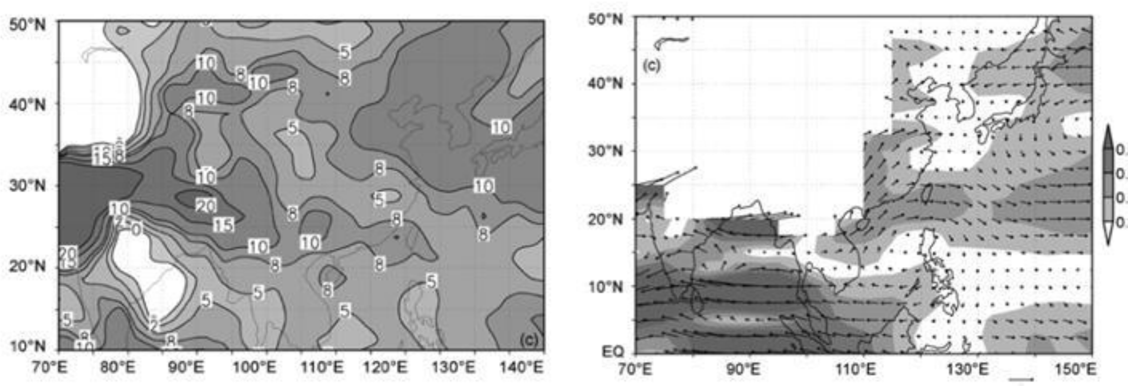
Sun & Ding (2009), from the China Meteorological Administration, have examined in detail the future climate projections from 19 AOGCMs under the SRES A1B scenario, focusing on the summer monsoon in China. Figure 3.6 shows the projected change of the JJA precipitation and moisture flux from their analysis. Overall, South China will experience increased summertime rainfall, consistent with the findings of Lee et al (2008) for Hong Kong. This is due to the increased water vapour content in the atmosphere for a warmer climate, and also the presence of an anomalous anti-cyclone over the South China Sea which leads to enhanced southwesterly wind in summer. Regarding the decadal-scale changes over the 21st century, Sun & Ding (2009) found an abrupt transition of the summer monsoon over South China (marked by a sudden increase of rainfall) around 2040s in the multi-model climate projections.

Overall, these studies discussed above indicate increased rainfall in China or South China. Their results are summarized in Table 3.3.



Note:	Left: percentage changes (%) of the JJA precipitation for 2080-2099, relative to the 1980-1999 average. Right: changes of JJA water vapor transport at 850 hPa (kgm-1 s-1hPa-1) for 2080-2099, relative to 1980-1999 average. From Sun & Ding (2009).

Figure 3.6 Projected Change of the JJA Precipitation and Moisture Flux

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Table 3.3 Summary of Results from Climate Change Projection Studies on the Annual/Seasonal Mean Precipitation Relevant to Regions Including Hong Kong

Researchers	Institution of Lead Author	Methodology	Conclusion
Kimoto (2005)	Center for Climate System Research, U of Tokyo, Japan	Compare SRES A1B with 1971-2000 climate, using 17 CGCMs	Significant increase of the summertime rainfall in most East Asian locations.
Ueda et al (2006)	U of Tsukuba, Japan	Compare SRES A1B with 1981-2000 climate, using 8 GCMs	Same as above.
Xu et al (2006)	Chinese Academy of Agricultural Sciences	Compare SRES A2 and B2 with 1961-1990 climate, using PRECIS driven by HadAM3H	Summertime rainfall in South China is likely to increase.
Ding et al (2007)	China Meteorological Administration	Projections of future climate by NCC/IAP and other models	~10% increase of precipitation over China by 2100.
Kripalani et al (2007)	Indian Institute of Tropical Meteorology, India	Compare doubled CO_2 scenario with 20C3M, using output from 22 coupled ocean-atmosphere GCMs	Increased summer rainfall in coastal Southern China.
Lee et al (2008)	Hong Kong Observatory	Statistical downscaling based on IPCC AR4 and observed data	Annual mean rainfall in Hong Kong will decrease until 2040, after which there will be an increasing trend.
Composing Team for Assessment Report on Climate Change of Guangdong	Guangdong Meteorological Bureau	Projections of future climate by AOGCMS (with results from National Assessment Report for Climate Change)	Annual mean precipitation will increase by 8% by 2071-2099.
Sun & Ding (2009)	China Meteorological Administration	Compare SRES A1B with 1980-1999 climate, using 19 climate model ensemble	South China will experience increased summertime rainfall.

3.2.3 Rainfall Extremes - Studies Covered by IPCC AR4

The rainfall characteristics, in terms of its frequency, intensity and duration, are also found to be affected by global warming based on the model projections of the future climate (see e.g. Trenberth, 1992; Cubasch et al, 1996; Emori & Brown, 2005). In particular, the intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas. In an earlier multi-model analysis, Palmer & Räisänen (2002) showed an increased likelihood of very wet summers with implications for greater flooding in the Asian monsoon region in a future warmer climate. The analysis has confirmed earlier results that precipitation intensity is projected to increase over most regions (Wilby & Wigley, 2002; Kharin & Zwiers, 2005; Meehl et al, 2005; Barnett et al, 2006). Gao et al (2001), using a regional climate model for dynamical downscaling, reported an increase in number of heavy rain days over Fujian and the western part of Jiangxi province in a double CO_2 experiment. Also focusing on the East Asian region, Kitoh et al (2005) showed that the summertime precipitation intensity in South China is expected to increase. Tebaldi et al (2006) showed simulated increases in precipitation intensity during the 20th century continuing through the 21st century. Sun et al (2007) also found very similar results. On the other hand, it is noteworthy that some of the above mentioned studies indicate a decrease of wet day frequency. In other words, the duration of dry days are expected to increase (Kitoh et al, 2005; Tebaldi et al, 2006). Thus, even in areas where the mean precipitation is projected to decrease (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but there would be longer periods between rainfall events. Kharin & Zwiers (2005) showed that there is a substantially greater increase in precipitation extremes than that in the annual mean precipitation. This can be attributed to the fact that extreme precipitation relates to increases in moisture content and thus the nonlinearities involved with the Clausius-Clapeyron relationship such that, for a given increase in temperature, increases in extreme precipitation can be more than the mean precipitation increase. On the other hand, the increase in large-scale mean precipitation is constrained by the energy budget of the atmosphere (see e.g. Allen & Ingram, 2002).

3.2.4 Rainfall Extremes - More Recent Studies

Based on dynamical downscaling of AOGCM projections, Zhang et al (2006) reported that the south-eastern coastal part of China is expected to experience more extreme rainfall events. Kharin et al (2007) showed that precipitation intensities will become higher based on mutli-model climate projections. Jiang et al (2007 & 2009), also analysing multi-model results, reported that the strength of extreme precipitation will increase over China. Feng et al (2010) & Li et al (2010), using a single high-resolution GCM and multi-model projections, respectively, found that extreme rainfall events are expected to become more frequent in future. For Hong Kong, Lee et al (2008) showed that heavy rain days (defined as those days with hourly rainfall exceeding 30 mm) are projected to be 6.5 days/year in 2070-2099, compared to 5.8 days/years from 1980-1999. Ginn et al (2010) projected that there will be 10 extremely wet years and four extremely dry years in the 21st century (compared to two extremely wet and two extremely dry years from 1855-2001).

Wong & Mok (2009), Wong et al (2010) from the Hong Kong Observatory, carried out Generalized Extreme Value distribution (GEV) analysis of historical rainfall record at the Observatory. Figure 3.7 gives the results of their analysis, which shows the maximum hourly rainfall for different return periods. The steadily rising trend of the extreme hourly rainfall can be clearly seen. They have also found that the return periods for the extreme 1, 2 and 3-hourly rainfall have decreased significantly from 1885 to 2008. Based on the calculation of Wong & Mok (2009) (see also Lee et al, 2010), the return periods of 1-hr, 2-hr and 3-hr rainfall is approximately reduced by half from 1900 to 2000 (see Figure 3.8).

Finally, a few recent studies suggest that characteristics of heavy rainfall events might be modified due to urban effects. In particular, the modelling study of Miao et al (2010) suggests that urbanization can either change the maximum rainfall amount or modify convective cell structures, depending on the degree of urbanization. Kishtawal et al (2010) provided observational evidence that urbanization can lead to heavier rainfall events over the Indian monsoon region. However, research on the control of urban rainfall and its interaction with the changing background climate is still in its infancy, and estimating the urbanization effect on extreme rainfall remains a very challenging task.

Overall, the above studies show that precipitation may become more extreme, while number of dry days will increase. A summary is presented in Table 3.4.

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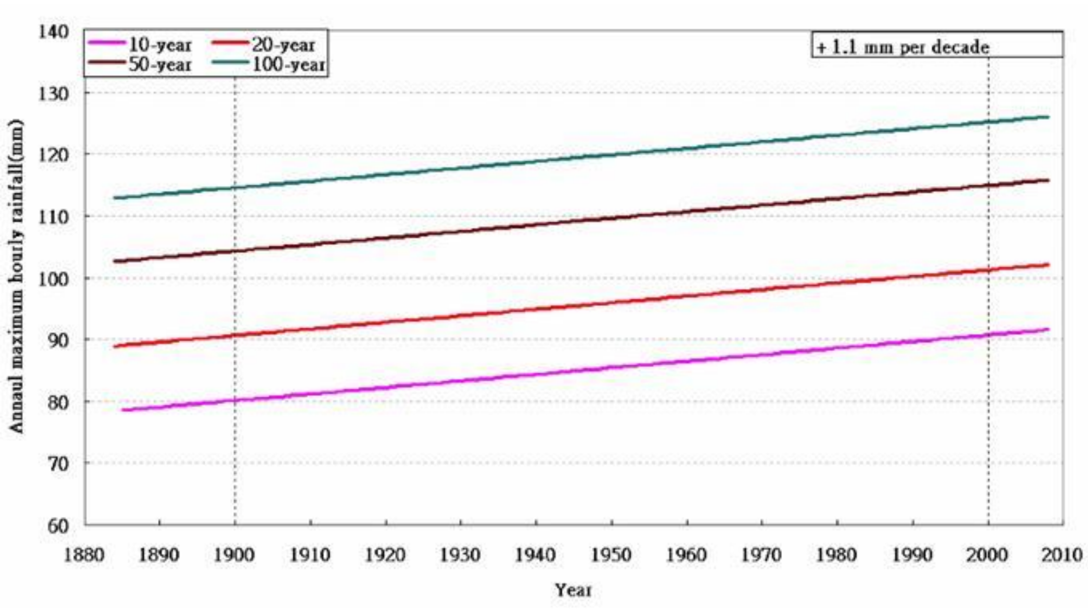

Note: Long term trends of the return values for the annual maximum one-hourly rainfall with return periods of 10-year, 20-year, 50-year and 100-year. From Wong & Mok (2009).

Figure 3.7 Long Term Trends of the Return Values for the Annual Maximum One-hourly Rainfall

Extreme rainfall events	Return Periods (year)	
	in 1900	in 2000
1-hour rainfall >= 100 mm	37	18
2-hour rainfall>= 150 mm	32	14
3-hour rainfall>= 200 mm	40	21

Note: Return periods of 1-hour rainfall of 100 millimetres or above, 2-hour rainfall of 150 mm or above and 3-hour rainfall amount of 200 millimetres or above in 1900 and 2000. From Wong and Mok (2009).

Figure 3.8 Return Periods for Rainfall

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Table 3.4 Summary of Results from Climate Change Projection Studies on the Extreme Rainfall Relevant to Regions Including Hong Kong

Researchers	Institution of Lead Author	Methodology	Conclusions
Palmer & Räisänen (2002)	European Centre for Medium-Range Weather Forecasts, UK	Compare doubled CO_2 climate with 20th century climate, using 19 CMIP2 model ensemble	Precipitation extremes will increase.
Gao et al (2001)	National Climate Center, China	Dynamical downscaling of AOGCM projection using RegCM2	No. of heavy rain days will increase.
Emori & Brown (2005)	National Institute for Environment Studies, Japan	Compare SRES A1B, A2 and doubled CO_2 with 1969-1990, 1979-1998 and 20C3M climate, using 4 PCMDI model and CCSR/NIES/FRCGC AGCM and HadAM3P	Same as above.
Kitoh et al (2005)	Meteorological Research Institute, Japan	Compare SRES A2 and B2 with 1981-2000 climate, using MRI CGCM2	Rainfall intensity, as well as duration of dry days will increase.
Tebaldi et al (2006)	National Center for Atmospheric Research, USA	Compare extreme indices between SRES A1B, A2 and B1 and 20C3M, using 9 GCMs	Stronger rainfall intensities and extremes; decrease of wet day frequency.
Zhang et al (2006)	Institute of Atmospheric Physics, Chinese Academy of Sciences, China	Dynamical downscaling using the PRECIS climate model system	Increasing trend in extreme precipitation events.
Kharin et al (2007)	Canadian Center for Climate Modelling and Analysis	Compare SRES A1B, A2 and B1 with 1981-2000 climate, using 16 IPCC ensemble of global coupled models	Stronger rainfall intensities and extremes; decrease of wet day frequency.
Jiang et al (2007)	Nanjing University of Information Science & Technology	IPCC AR4 5 climate model ensemble	Extreme precipitation will become more intense over China.
Sun et al (2007)	China Meteorological Administration	Compare SRES A1B, A2 and B1 with 1980-1999 climate, using 17 climate model ensemble	Frequency of very heavy rainfall will increase.
Lee et al (2008)	Hong Kong Observatory	Statistical downscaling based on IPCC AR4 and observed data	No. of heavy rain days per year expected to increase.
Jiang et al (2009)	Nanjing University of Information Science & Technology	IPCC AR4 7 climate model ensemble	Extreme precipitation will become more intense over China.
Feng et al (2010)	Institute of Atmospheric Physics, Chinese Academy of Sciences, China	Compare SRES A1B precipitation in 2080-2099 with 1980-1999 data, using ECHAM5 with T319 resolution	Heavy and torrential precipitation days will increase.
Li et al (2010)	Institute of Atmospheric Physics, Chinese Academy of Sciences, China	Compare 2 X CO_2 climate with pre-industrial control simulations, using 24 AOGCMs from 20C3M and CMIP3 runs	Robust increase of precipitation extreme projected.

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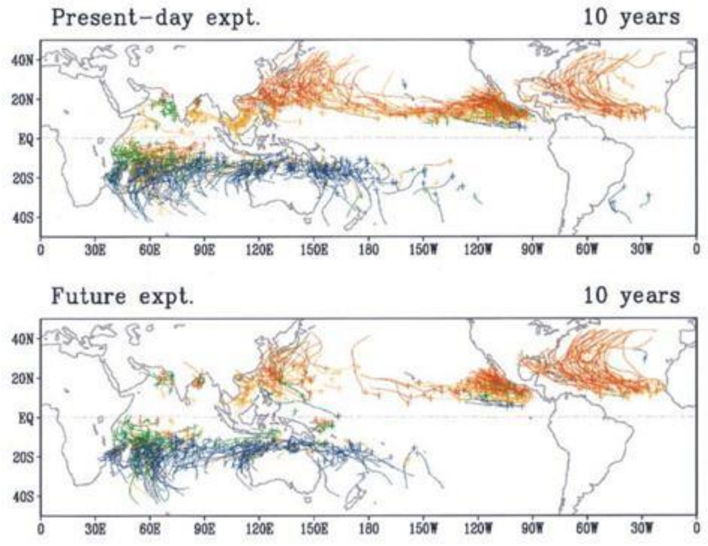
3.3 Tropical Cyclone Activities

3.3.1 Studies Covered by IPCC AR4

One of the challenges for predicting the future tropical cyclone activity is that high-resolution numerical models are needed. Typical AOGCMs are usually not adequate for simulating tropical cyclones. Hasegawa & Emori (2005), using a 100 km resolution model, reported that tropical cyclone-associated precipitation in the western north Pacific from simulations increases when the CO_2 concentration is doubled in their atmospheric model. In general, studies from coarser-grid AOGCMs tend to give a consistent response of more intense precipitation from storms in a warmer climate, but there is no consistent response for large changes in either frequency or intensity of these models' representation of tropical cyclones. Knutson & Tuleya (2004) conducted very-high resolution (down to 9 km) regional model simulations, trying out a number of different convection schemes. Their results for all model combinations show an increase of tropical cyclone strength (as measured by the central minimum pressure fall or the surface wind speed) in a warmer climate. Knutson & Tuleya (2004) also showed more intense maximum rainfall associated with their simulated tropical storms.

Most studies based on higher-resolution GCMs simulate a decrease in the overall number of storms, together with an increase in the numbers of the most intense tropical cyclones. Using the 20 km global atmospheric model from Japan Meteorological Agency/Meteorological Research Institute of Japan, Oouchi et al (2006) compared the present day and future tropical cyclone activity in a model-simulated environment. Figure 3.9 and Figure 3.10 show the highlights of their results. In particular, it is found that the number of



Note: Tropical cyclone tracks of the present-day (top), and the future GCM climate experiments (bottom). The initial positions of tropical cyclones are marked with ''plus'' signs. The tracks detected at different seasons of each year is in different colors (blue for January, February and March; green for April, May, and June; red for July, August, and September; orange for October, November and December). From Oouchi et al (2006).

Figure 3.9 Tropical Cyclone Tracks

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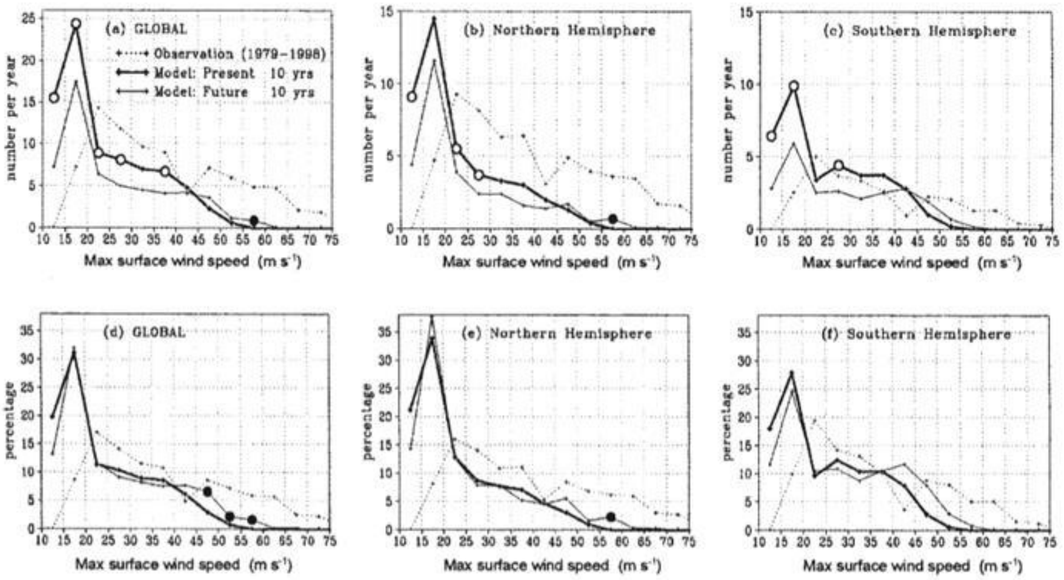

Note:	(a, b, c) Annual mean occurrence frequency, (d, e, f) Occurrence rate (%) normalized by the total number of GCM simulated tropical cyclones counted in the region specified as functions of the tropical cyclone intensities (abscissa) for (a, d) global, (b, e) Northern Hemisphere, and (c, f) Southern Hemisphere. The abscissa is the largest maximum surface wind speed, and the maximum wind speed attained in the lifetime of a tropical cyclone is plotted. Dotted lines indicate the observation; results from the present-day experiment are shown by thick solid lines, and those from the future experiment, by thin solid lines. For the difference between the ‘‘present’’ and ‘‘future’’ results, the plot at the 95% statistical significance level is marked with an open or closed circle (according to a two-sided Student’s t-test). From Oouchi et al (2006).

Figure 3.10 Comparison of Historical and Predicted Cyclone Occurrence Frequency

intense tropical cyclones increases with increased greenhouse-gas concentration, while the global storm frequency decreased 30% globally. Bengtsson et al (2007), based on high-resolution climate model simulations using the IPCC SRES A1B scenario, also reported a marked increase in the number of intense storms in the 21st compared to the 20th century. Again, there is about 10% decrease of the total number of storms in the 21st century found in their simulations.

3.3.2 More Recent Studies

Gualdi et al (2008), using an atmosphere-ocean coupled model of relatively high resolution, showed that increased tropical cyclone related rainfall is expected in the future. The study of Yamada et al (2010), based on a global cloud resolving model, provides further evidence supporting the picture painted above, namely that there will be a reduction of global frequency but an increase in the number of intense tropical cyclones for a warmer climate.

Tropical cyclone activity and its relationship with the global warming remains a topic

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of intense study. Knutson et al (2010) summed up the current knowledge and advances in this topic. Although the frequency of the most intense tropical cyclones and storm-associated rainfall are likely to increase in a warmer climate, the changes of activity on a regional (basin) scale, such as genesis, tracks and duration are still highly uncertain. They can be sensitive to the ability of air-sea coupled models in capturing the large-scale circulation that affects tropical cyclone development (see e.g. Vecchi & Soden, 2007). Overall, there are large uncertainties in the model projections of future basin-scale tropical cyclone activity, genesis locations and area of impacts.

Many studies indicate a projected increase of intense tropical cyclones and their related rainfall, but a decrease of total number of storms. A summary of their results is presented in Table 3.5.

Table 3.5 Summary of Results from Climate Change Projection Studies on Tropical Cyclone Activity

Researchers	Institution of Lead Author	Methodology	Conclusion
Knutson & Tuleya (2004)	National Oceanic and Atmospheric Administration, USA	Compare high CO_2 scenario with "present-day" hurricane activity, using a hurricane model with 4 convection parameterizations and 9 CMIP2+climate model outputs	Increase of TC strength; more intense TC-related rainfall.
Hasegawa & Emori (2005)	Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology	Compare doubled CO_2 climate with late 20^{th} century climate, using the T106, 120 km CCSR/NIES/FRCGC AGCM	Increase in TC-related rainfall; decrease in total TC no.
Oouchi et al (2006)	Advanced Earth Science and Technology Organization, Earth Simulator Center, Japan	Compare SRES A1B with 1979-1998 tropical cyclone climatology, using a 20 km-mesh, global atmospheric model of MRI/JMA	No. of intense TCs will increase, but the overall total no. will decrease.
Bengtsson et al (2007)	Max Planck Institute for Meteorology, Germany	Compare SRES A1B with 20th century climate, using T63 (200km), T213 (60km) and T319 (40km) ECHAM5/MPI-OM	Increase in the number of intense storms; decrease in total TC no.
Gualdi et al (2008)	Istituto Nazionale di Geofisica e Vulcanologia, Bologna, and Centro Euro-Mediterraneo per i Cambiamenti Climatici, Lecce, Italy	Compare TC activity of CO_2 X 4 and doubled CO_2 with 20C3M and pre-industrial age, using a T106 (120 km) SINTEX-G AOGCM	Same as above.
Yamada et al (2010)	Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology	Compare SRES A1B with 1979-2003 TC activity, using cloud resolving global model NICAM	Increase of no. of intense TC; decrease in overall TC no.

3.4 Sea Level Rise and Storm Surge

3.4.1 Results from IPCC AR4

Global warming affects the mean sea level through thermal expansion and also melting of ice caps, mountain glaciers or ice sheets. According to IPCC AR4, the sea level is projected to rise between the present (1980-1999) and the end of this century (2090-2099) under the SRES B1 scenario by 0.18 to 0.38 m, B2 by 0.20 to 0.43 m, A1B by 0.21 to 0.48 m,

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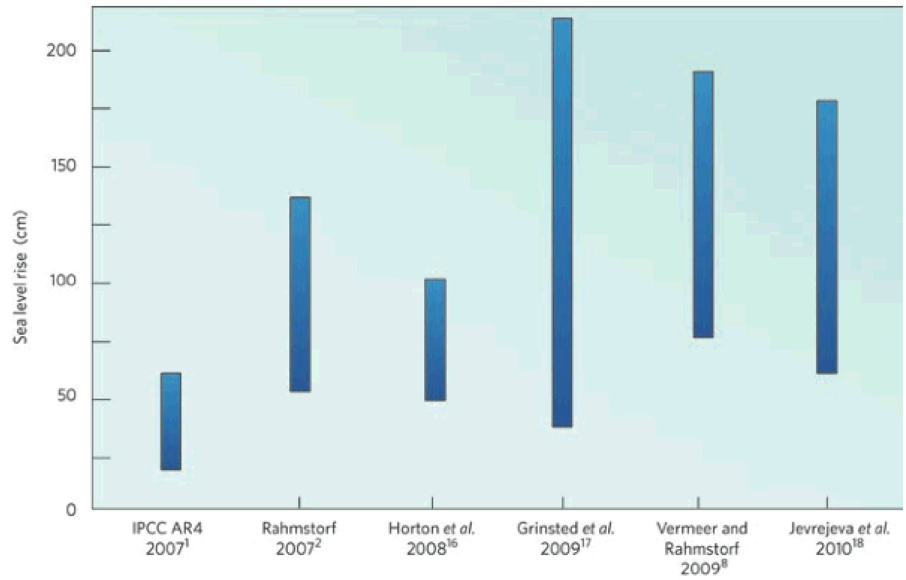
A1T by 0.20 to 0.45 m, A2 by 0.23 to 0.51 m, and A1F1 by 0.26 to 0.59 m. Among all physical factors, the thermal expansion is contributing most to the sea level rise: it account for 70 to 75% of the central estimate in these projections for all scenarios. Glaciers, ice caps and the Greenland Ice Sheet are also projected to contribute positively to sea level.

3.4.2 More Recent Studies

Meier et al (2007) pointed out that glacier melts, which are not adequately represented in climate models, might lead to an additional 0.25 m rise in the global sea level. Recent attempts of temperature-based semi-empirical estimates can give sea level rise to about 1m or more (see e.g. Rahmstorf, 2007 & 2010). Figure 3.11, from Rahmstorf (2010), compares the IPCC results with more recent estimates. It seems plausible that the future sea level rise is beyond the IPCC confidence limit (Grinsted et al, 2009).



Note: Range of rise estimates for twenty-first century sea level rise from semi-empirical models as compared to the IPCC AR4. From Rahmstorf (2010).

Figure 3.11 Range of Rise Estimates for Twenty-first Century Sea Level Rise

For reference, the rate of sea level rise observed in Hong Kong is about 0.24 cm/year during the period of 1958-2001, whereas sea level rise in South China Sea in the past 15 years is 0.42 cm/year based on satellite measurements (Guangdong Provincial Meteorological Bureau, 2007). Shi et al (2008, in Chinese) also reported that over the Pearl River Estuary, the sea level has been increasing with a rate of about 0.3 cm/year within 1993 to 2006. In view of the future sea-level rise, vulnerability of coastal regions to storm surge flooding is expected to increase. For Hong Kong, the typical storm surge induced by a tropical cyclone is about 0.5-1.0 m. According to Lee et al (2010) from the Hong Kong Observatory, a

50-year event with a maximum sea level of 3.5m above Chart Datum (such as that due to typhoon Hagupit in 2008) would become a biennial (2-year) event, if there is a 0.59 m mean sea level rise. In other words, the scale of storm-surge related flooding in Hong Kong is very likely to increase in the 21st century.

The results of more recent studies on the projected sea level rise are summarized in Table 3.6.

Table 3.6 Summary of Results on the Projected Sea Level Rise, Based on Studies Published after IPCC AR4

Researchers	Institution of Lead Author	Methodology	Conclusion
Meier et al (2007)	Institute of Arctic and Alpine Research, University of Colorado at Boulder, USA	Using the whole-glacier continuity equation for the rate of change of glacier ice mass	Glacier melts might lead to a 0.25 m rise additional to IPCC AR4 estimates.
Rahmstorf (2007)	Potsdam Institute for Climate Impact Research, Germany	Based on empirical relationship between global mean sea level and global mean temperature	Sea-level rise of 0.5 to 1.4 m in 2100 above the 1990 level.
Vermeer & Rahmstorf (2009)	Department of Surveying, Helsinki University of Technology, Finland	Using a improved semi-empirical method, similar to Rahmstorf (2007)	Sea-level rise ranging from 75 to 190 cm.
Grinsted et al (2009)	Arctic Centre, University of Lapland, Finland	Using empirical relationship between equilibrium sea level and temperature	Future sea level rise is likely to be beyond the IPCC confidence limits.

4 Gaps between Current Projections and Practical Applications

4.1 Uncertainties

4.1.1 Source of Uncertainties in AOGCM Climate Projections

In general, there are three main sources of uncertainties in AOGCM projected climate change:

(a) **Modelling uncertainty**

It arises from either an incomplete understanding of Earth System processes (see e.g. Palmer et al, 2005) or their inadequate representation in AOGCMs. Parameterization of sub-grid scale processes is a typical example of how uncertainties are introduced in model climate simulations. Oftentimes alternative, but plausible, parameterization schemes for models exist for the same physically process. Moreover, parameter values being used in these scheme are usually loosely constrained, which also contribute to the uncertainties in the model climate state.

(b) **Natural (internal) climate variability**

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It refers to the intrinsic variability of the climate system even without anthropogenic forcing (see e.g. Selten et al, 2004). There is always uncertainty about the future state of the climate due to the stochastic nature of the system.

(c) **Uncertainty in future emissions, land use change, etc.**

Finally, the specification of future emissions of greenhouse gases, aerosols etc. are highly uncertain. Converting these emissions into concentrations of radiatively active species and calculating the associated forcing inevitably introduces uncertainty in the response of the climate system. Also, other sources of future radiative forcing such as that associated with land use change are usually not accounted for in model climate projections.

4.1.2 Sampling Uncertainties

The standard way for quantifying the internal or natural variability is by running AOGCMs many times with slightly different initial conditions (i.e. ensemble integrations). Based on the set of different but equivalent model runs, one can estimate the statistical nature of this natural variability on a range of space and time scales, and hence quantify the consequent uncertainty in the climate projections.

Different ways exist for sampling modelling uncertainties. In the so-called multi-model ensemble approach, the mean of an ensemble of AOGCMs developed at different modelling centres, instead of just a single model, is used for climate projection. To the extent that the errors in different AOGCMs are independent, the mean of the ensemble can be expected to outperform an individual model, thus providing an improved forecast (Palmer et al, 2004; Hagedorn et al., 2005; Lambert & Boer, 2001). By sampling modelling uncertainties, ensembles of AOGCMs should provide an improved basis for probabilistic projections compared with ensembles of a single model sampling only uncertainty in the initial state (Palmer et al, 2005). However, members of a multi-model ensemble might share common systematic biases (Lambert & Boer, 2001; Kennedy & O'Hagan, 2001), and cannot span the full range of possible model configurations due to resource constraints.

Alternatively, modelling uncertainties can also be quantified by "perturbing the physics" of AOGCMs (Murphy et al, 2004; Stainforth et al, 2005). In this approach, parameters are first selected from each of the schemes in the AOGCM's atmosphere and land: layer cloud, convection, radiation, atmospheric dynamics, boundary layer, land surface and sea-ice. Very large model simulation ensembles with systematic sampling of plausible choices of parameter values are then constructed. The resulting distribution of the climate states (here represented by a particular variable, say summer rainfall) is indicated by the blue curve in the Figure 4.1. Next, in order to weight the creditability of the different model simulated climates, model's hindcasts for the last 90 years are compared with observations. Based on the comparison, a weighted distribution of outcomes is then generated (the black curve in Figure 4.1). Recently, in a study by Murphy et al (2009) of the UK Met Office, the

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multi-model ensemble and perturbed physics approaches are combined. This is achieved by merging the projections from alternative models (indicated by the coloured dots) with the perturbed physics ensemble, based on a statistical framework devised by Goldstein & Rougier (2004). The result, in which uncertainties arising from the model parameters and model structural errors are incorporated, is shown as the red curve in Figure 4.1. Finally, it should be mentioned that this approach requires very advanced techniques and a lot of computational resources, and is currently undertaken by the UK Met Office only.

4.2 Challenges for Climate Change Projections for Hong Kong

4.2.1 Monsoon Simulations by AOGCMs

One of the major challenges in projecting the future climate for Hong Kong is that there is still considerable uncertainty in the rainfall projections by current generation of AOGCMs. For East Asian locations such as Hong Kong, the problem is exacerbated by the relatively poor performances of AOGCMs in simulating the summer monsoon. This is mainly attributed to modelling uncertainties, especially those related to the parameterizations of convective and precipitation processes in atmospheric GCMs.

4.2.2 Downscaling Issues

Another problem is that the resolution of typical AOGCM products is simply too coarse (~100 x 100 km). Mesoscale systems which bring very heavy rainfall are not captured in these coarse-resolution models. In order for these projections to be useful for Hong Kong, downscaling techniques have to be applied. Statistical downscaling, though computationally efficient, is highly dependent on the accuracy of meteorological variables produced by the AOGCM. Also, the method is empirical, not physics-based. Thus there is a possibility that it may not capture completely the physics governing changes of extreme rainfall under global warming.

The alternative way is to use an RCM to obtain high-resolution climate information, based on boundary conditions from AOGCMs. Dynamical downscaling is, however, very challenging. First, RCM performance still strongly depends on the physical parameterizations used in the simulation (Yang & Arritt 2002; Vidale et al, 2003; Déqué et al, 2005; Liang et al, 2006). RCM results are dependent on the quality of the boundary-condition source (Pan et al, 2001; de Elía et al, 2002). There is also the so-called buffer zone problem, namely that the ingestion of lateral boundary conditions by RCMs has to be treated carefully. Otherwise there might be inconsistency between the RCM and AOGCM simulations (Giorgi et al, 1993), or that spurious reflections may occur in boundary regions (e.g. Miguez-Macho et al, 2005). The choice of the domain size may also influence the RCM results (Jones et al, 1995; Seth & Giorgi, 1998). Running an RCM also requires lateral boundary data from AOGCMs with high temporal resolution. Some studies indicate that the lateral boundary should be updated more than twice per day (Denis et al, 2003; Antic et al, 2004 & 2006; Dimitrijevic & Laprise, 2005). A full set of meteorological variables from AOGCM projections with such high temporal resolution is usually not available from the public domain. Finally, running very high resolution RCM is extremely computational demanding. This limits the length of typical RCM integrations to two to three decades (e.g. Christensen et al, 2002; NARCCAP, 2007).

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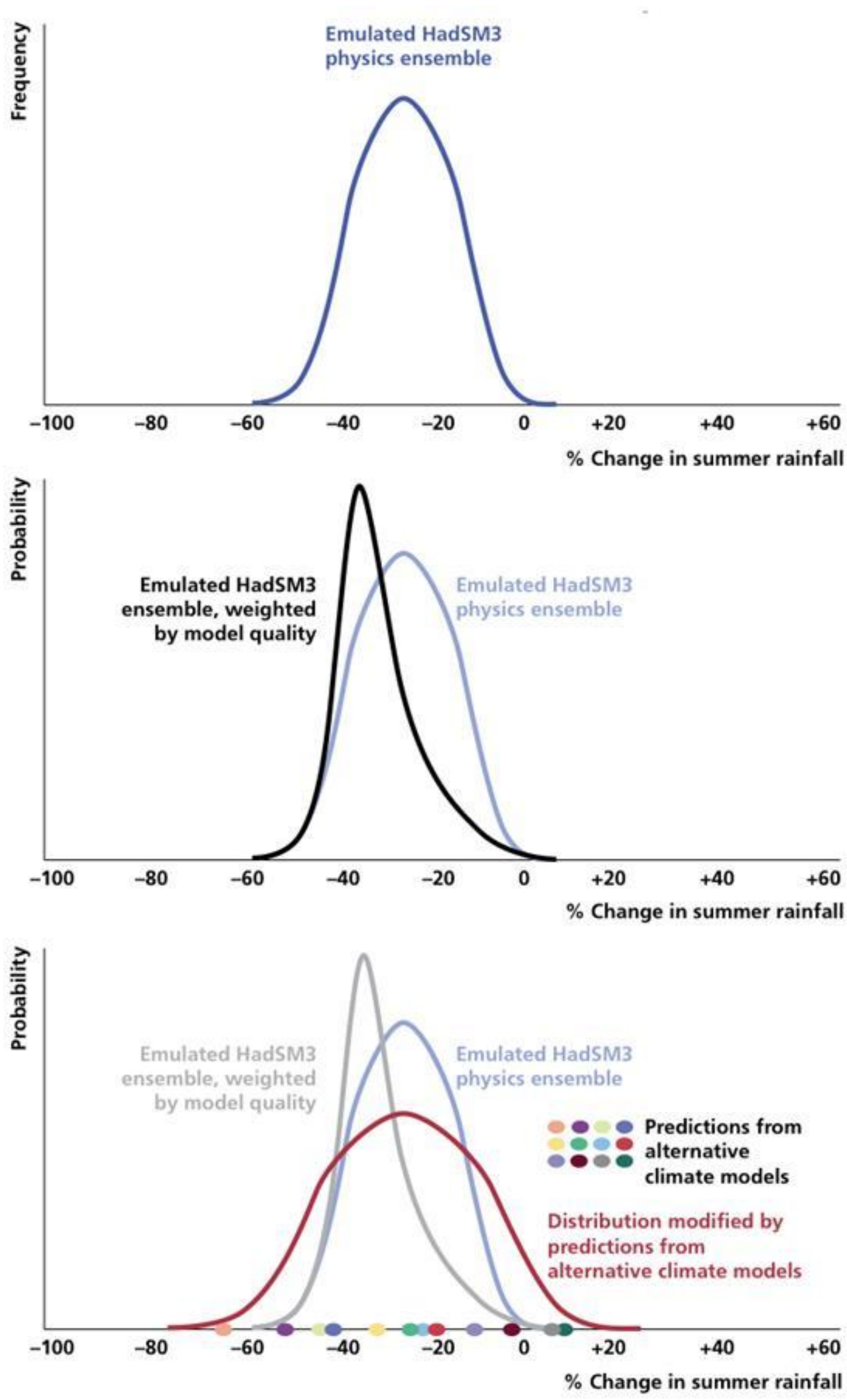

Note: From the UK Climate Projection Science Report, 2009.

Figure 4.1 Schematic Diagram Illustrating the "Perturbed Physics" Approach of the UK Met Office

5 Conclusions

5.1 Study Conclusions

The state-of-the-art climate change studies relevant to Hong Kong slope safety have been collated and reviewed. In particular, the studies on the projected change of air temperature, monsoon and rainfall, tropical cyclone activity and global mean sea-level under global warming, covered by IPCC AR4 as well as those beyond, have been reviewed. The key findings relevant to regions including Hong Kong are given below:

(a) All AOGCM projections indicate an obvious increase of surface air temperature in East Asia or China in the 21st century, compared to the 20th century. More warm and less cold extremes are expected, or that the return period of warm temperature extremes will decrease, while that for cold extremes will increase. For Hong Kong, the annual mean temperature is projected to rise by 3.0-6.8^{o}C. More hot days and hot nights, and less cold days, are expected.

(b) The ensemble-averaged AOGCM projection indicates increased summer-time seasonal mean rainfall in South China including Hong Kong in the 21st century. However, there is a considerable spread among rainfall projections by different models. Based on AOGCM results, rainfall intensities or the frequency of very heavy rainfall are also expected to increase in this region. On the other hand, the duration of dry days will probably decrease. For Hong Kong, the number of heavy rain days per year is also projected to increase.

(c) Most high-resolution modelling results indicate that, in a globally averaged sense, there will be more intense tropical cyclones, while the total number of storms will be reduced in a warmer climate. Also, the rainfall associated with tropical cyclones is expected to increase. However, the future tropical cyclone activity over the regional scale is still highly uncertain.

(d) The global mean sea-level rise estimated by IPCC AR4 for the high-emission scenario of A1F1 is about 0.59 m. More recent estimates, however, gives an even higher estimate of rise ~ 1.5 to 2 m.

There are considerable uncertainties in projecting the change of rainfall characteristics over Asian monsoon locations. First, there is uncertainty in the future emission and other anthropogenic forcing to the climate system. Also, there is uncertainty associated with the intrinsic variability of the system. Finally, uncertainty in the AOGCM-projected climate states is introduced simply because the model representations of physical processes are not perfect. The latter is known to be a serious problem for monsoon rainfall simulations. To obtain useful climate projections for Hong Kong, the AOGCM results have to be downscaled

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to the regional scale. The downscaling techniques are not without their problems and may also introduce more uncertainties. A systematic method to sample these uncertainties has recently been used to provide a regional-scale probabilistic climate change projection for the UK, but it should be noted that it is a major undertaking that requires the support of a national climate centre. Currently, UK Met Office is the only centre taking this approach to sample uncertainties in regional climate projection.

The projected increase of frequency and intensity of extreme precipitation events in a future warmer climate will have strong implications on the built environment and infrastructures, such as slope safety and drainage. In particular, the future changes in the amplitudes of extreme rainfall, rain frequency and antecedent rainfall should be taken into account in engineering design processes. Projected precipitation and sea level (and by implication storm surge magnitude) changes also need to be considered during future planning.

5.2 Recommendations

Estimating the impact of climate change on the rainfall of Hong Kong is a challenging task. Gaps still exist between the best estimates of the future climate projection in the regional- to city-scale and practical applications based on these estimates. For better projections of the future rainfall characteristics, especially regarding extreme values, the possible ways are recommended as follows.

5.2.1 Projection of Current Trends

Based on the observed trends from historical records, Wong & Mok (2009) used GEV distribution analysis and showed that the return periods for the maximum 1, 2 and 3-hourly rainfall had decreased significantly from 1885 to 2008. The HKO presentation to SSTRB (November, 2009) demonstrated that their time dependent return period analysis can be used for projecting the future behaviour of extreme events. Assuming that the currently observed tendencies will remain constant in the future, the future extreme rainfall values could be calculated by simple extrapolation. The methodology, pros and cons, are summarized as follows:

(a) **Method**

Extrapolation based on GEV analysis of the observed trends from historical records.

(b) **Inputs**

Long-term observations of meteorological variables.

(c) **Output**

Projected characteristics of extreme events (e.g. return periods of extreme values).

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(d) **Advantage**

Computational cost minimal.

(e) **Disadvantage**

Future climate change might not follow the current trend.

This is one way to project the future behaviour of extreme events. However, the working assumption is that the future extreme rainfall values will change following the same trend as observed in the last 100 years. Although this might yield useful estimates about the future extreme events, the assumption itself is not based on any physical principles. Thus, any results from such a trend analysis should be interpreted with caution, and should be compared with those based on more commonly adopted downscaling approaches (see below).

5.2.2 Statistical Downscaling from AOGCM Climate Projections

The alternative is to use empirical or statistical methods to downscale coarse-scale climate projection information from AOGCMs to that pertaining to the Hong Kong location. Assuming that empirical relationships between the large-scale meteorological variables (e.g. rainfall over South China) and the targeted downscaled variable (e.g. station rainfall in Hong Kong) exist, then changes in the locale-scale variables can be inferred from the large-scale circulation changes (which is available from AOGCMs). The commonly used statistical methods include linear/multiple regression, canonical correlation analysis, singular vector decomposition and the weather generator. The methodology, pros and cons, are summarized as follows:

(a) **Method**

Inference based on statistical relationship between station-scale and regional scale climate variables.

(b) **Inputs**

Long-term station observations; AOGCM simulations.

(c) **Outputs**

Station-scale projection of meteorological variables.

(d) **Advantage**

Computationally inexpensive.

(e) **Disadvantage**

Empirical, not physics-based.

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Statistical downscaling is usually not computational intensive; the actual derivation of statistical relationships and calculation of projected changes are a matter of hours or less according to the wall clock. However, this method requires long-term rainfall records for establishing a robust statistical relation. Such a long-term observation might not be available for the location of interests. Also, the approach is empirical and is not physics-based. It may not capture completely the physics governing changes of extreme rainfall under global warming.

Concerning the future rainfall in Hong Kong, Lee et al (2008) used the annual mean rainfall from AOGCMs for downscaling. Their technique is standard among the meteorological community, and thus aligns with international best practice. However, more reliable estimates, especially those concerning extreme events, can be obtained based on statistical downscaling using daily mean AOGCM projection outputs. Also, caution should be taken when mixing multi AOGCM outputs from different emission scenarios (see Shiogama et al, 2010). Besides using the large-scale rainfall as the input variable, other meteorological variables (such as precipitable water, absolute humidity, etc.) can be considered. Multiple predictor-based downscaling is in fact being adopted in the new extreme rainfall projection conducted by HKO (Lee et al, 2011). Besides linear or multiple regression, other methods such as the weather generator may also be useful for tackling this problem (although not necessarily being superior to regression-based downscaling).

5.2.3 Dynamical Downscaling from AOGCM Projections

Dynamical downscaling is a standard and well-established technique for obtaining climate projection information in the regional scale (up to about tens of kilometers). Typically, an RCM is used to obtain higher resolution climate information, with coarse-scale AOGCM projection output as boundary conditions. The methodology, pros and cons, are summarized as follows:

(a) **Method**

By running a high-resolution RCM.

(b) **Inputs**

Three-dimensional meteorological variables with high temporal resolution from GCMs.

(c) **Outputs**

A full set of high-resolution meteorological variables.

(d) **Advantages**

Physics-based method; dynamically consistent outputs.

(e) **Disadvantages**

RCM needs tuning; dependence on GCM output quality;

computationally intensive; large amount of input data required.

The advantage of dynamical downscaling is that the method is physics-based, because all the physical processes are included in the RCM. The output thus comprises a set of dynamically consistent meteorological variables. With finer resolution, an RCM can better simulate mesoscale processes, or capture influences on the regional climate arising from fine features such as mountains and coastlines. As a result, regional climate extremes are better projected, such as localized intense precipitation events, compared to those from AOGCMs.

The disadvantages are that, first, the method can be very computational demanding and expensive. The problem is especially serious for the case of climate projection, which requires a few tens to 100 years of integrations. Also, significant time input is needed for an RCM to be “tuned” in order to realistically simulate the climate of a particular region. The performance of the regional climate simulations also strongly depends on the quality of the AOCGM lateral boundary data. Another problem is that it requires at least 6-hourly input boundary conditions from AOGCM climate projection experiments. Such high temporal resolution GCM outputs (with the basic variables included in a three-dimensional sense) are not easily available. (Note that it is not recommended to use daily-resolution GCM output as lateral boundary conditions for an RCM; see Denis et al, 2003.)

Related to the use of high-resolution numerical models, it is noticed that the Hong Kong Observatory has been undertaking a series of numerical model experiments to examine whether the extreme rainfall associated with Typhoon Morakot which hit Taiwan in August 2009 could occur in Hong Kong. Regarding the cause of extreme rainfall associated with Morakot in Taiwan, three major factors that have been identified in various studies:

(a) The steep topography, which provides strong lifting of air to produce heavy rain (see Ge et al, 2010);

(b) Strong south-westerly flow associated with the southwest monsoon, which when combined with the north-westerly flow associated with the typhoon, converged in southern Taiwan, forcing air to go up rapidly; and

(c) Typhoon Goni near Hainan Island, which provides additional help in supplying moisture.

It is noted that the first two factors are unique to Taiwan. Thus, if in the numerically experiment the Morakot-related vortex is simply transplanted to South China Sea, these two factors are no longer relevant. The third factor could give a complete different effect if the vortex of Goni is transplanted to South China or Indochina along with Morakot such that it will weaken rapidly overland. In other words, the proposed numerical experiments will likely yield significantly smaller amounts of rainfall, and are not likely to provide any useful reference as far as the current study is concerned.

To summarize, projecting the climate change impact on the extreme rainfall characteristics for Hong Kong can be a very challenging task. Projections by extending the GEV analysis can be a gauge of what the extreme rainfall might be in the near future, albeit

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the caveat here that extreme values will increase following the same trend as seen in the past century. Any results from such a simple trend analysis thus need to be compared to more sophisticated downscaled projections. Inference of rainfall extremes based on statistical downscaling from daily mean AOGCM projections certainly needs to be explored. On the other hand, the method of dynamically downscaling, although very demanding in terms of resources, should not be ruled out. It should be considered, if a full set of high-temporal resolution AOGCM output of basic variables can be secured. Finally, for obtaining the most up-to-date climate projections for Hong Kong, downscaling based on the up-coming IPCC AR5 model projections should also be undertaken when the latter become available.

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Appendix A

List of Technical Publications / Presentations on Climate Change

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List of Technical Publications/Presentations on Climate Change

No	Year	Name of Publication	Author(s)	Institution (of the Authors) (Red:National Meteorological Agency) (Blue:National Research Institute)	Periodical / Conference / Seminar / Report	Topic: Rainfall/ monsoon	Topic: Temperature	Topic: Sea level rise/ storm surge	Topic: Tropical cyclone	Topic: Others (please specify)	State-of-the-art (Y/N)	Applicability to HK (Y/N)	Discussion on Extreme Event Estimation	Methodology Discussed: GCM	Methodology Discussed: Statistical Downscaling	Methodology Discussed: Dynamical Downscaling (RCM)	Methodology Discussed: Others (please specify)	Brief Discussion on Methodology	Key Assumptions / Limitations / Uncertainties	Type of uncertainty: Field	Type of uncertainty: Parameter	Type of uncertainty: Human	Type of uncertainty: Others (please specify)	Critique
1	2005	Transient response of ENSO-monsoon teleconnection in MRI.CGCM2 climate change simulations	Ashrit, R.G.[1,2], Kitoh, A.[1], and Yukimoto, S.[1]	1. Meteorological Research Institute, Japan 2. National Centre for Medium Range Weather Forecasting, New Delhi	Periodical	X	O	X	X		Y	Y	N	O	X	X		Compare SRES A2 and B2 climate in 2071–2100 with 1971–2000 climate, using MRI-CGCM2.2.	Regional monsoon rainfall is not well simulated.	X	O	X	X	Regional-to-local scale monsoon rainfall projection result should be compared with those based on higher-resolution models.
2	2003	Response of the Indian monsoon and ENSO-monsoon teleconnection to enhanced greenhouse effect in the CNRM coupled model	Ashrit, R.G.[1], Douville, H.[1], Rupa Kumar, K.[2]	1. Météo-France/CNRM 2. Indian Institute of Tropical Meteorology	Periodical	X	O	X	X		Y	Y	N	O	X	X		Compare the SRES-B2 climate in 2050-2099 with 1950-1999, by CNRM ocean-atmosphere coupled model.	Large uncertainty exists in monsoon rainfall projections by AOGCMs.	X	O	X	X	Regional-scale projection should be based on more recent multi-model simulations.
3	2006	Quantifying uncertainty in changes in extreme event frequency in response to doubled CO2 using a large ensemble of GCM simulations	Barnett, D.N., Brown, S.J., Murphy, J.M., Sexton, David M. H., Webb, M.J.	Hadley Centre for Climate Prediction and Research, Met Office, UK	Commencing the service	X	O	X	X		Y	Y	Y	O	X	X		Compare the 2XCO2 climate with 1XCO2 climate, using different versions of HadSM3.	Uncertainty due to model parameterization is sampled by the perturbed-physics approach.	X	O	X	X	A mixed-layer, instead of a full ocean model, is used.
4	2007	How may tropical cyclones change in a warmer climate?	Bengtsson, L.[1,2], Hodges, K.I.[1], Esch, M.[2], Keenlyside, N.[3], Kornblueh, L.[2], Luo, L.I.[4], Yamagata, T.[4]	1. Environmental Systems Science Centre, University of Reading, UK 2. Max Planck Institute for Meteorology, Germany 3. Leibniz Institute of Marine Sciences, IFM-GEOMAR, Germany 4. Climate Variations Research Program, Frontier Research Center for Global Change, JAMSTEC, Japan	Periodical	X	X	X	O		Y	Y	Y	O	X	X		Compare SRES A1B with 20th century climate, using T63 (200km), T213 (60km) and T319 (40km) ECHAM5/MPI-OM.	The SST in the coupled model has bias, which affects the locations of TC genensis, especially over the Atlantic basin.	X	O	X	X	Results on the regional details in the TC climate projections from this model should be treated with caution.
5	2007	Assessment Report on Climate Change of Guangdong(Selection)	Composing team for Assessment Report on Climate Change of Guangdong	Guangdong Meteorological Bureau	Periodical	O	O	O	O		Y	Y	Y	X	X	X	review	Review of ressults from the National Assessment Report of Climate Change for the Guandong region.	Same as National Assessment Report of Climate Change	X	O	X	X	Summarized the latest findings on climate projections for Guandong province.
6	2007	China's National Assessment Report on Climate Change (I): Climate change in China and the future trend	Ding, Y.H.[1], Ren, G.Y.[1], Shi, G.Y.[2], Gong, P.[3], Zheng, X.H.[3], Zhai, P.M.[4], Zhang, D.[1], Zhao, Z.C.[1], Wang, S.W[5], Wang, H.J.[2], Luo, Y.[1], Chen, D.L.[1], Gao, X.J.[1], Dai, X.S.[6]	1. National Climate Center, China Meteorological Administration 2. Institute of Atmospheric Physics, Chinese Academy of Sciences 3. Nanjing University, China 4. Department of Forecasting Services and Disaster Mitigation, China Meteorological Administration 5. The School of Physics, Peking University, China 6. Department of Scientific and Technological Development, China Meteorological Administration	Periodical	O	O	X	X		Y	Y	N	O	X	O		Projections of future climate by NCC/IAP and other models.	Uncertainties still exist in regional climate projections, and also in extreme weather and climate events.	X	O	X	X	Projections of the future regional climate can only be taken as a general reference, estimates are highly uncertain.
7	2000	Impact of CO2 doubling on the Asian summer monsoon: Robust versus model-dependent responses	Douville, H.[1], Royer, J-F.[1], Polcher, J.[2], Cox, N.[3], Gedney, N.[3], Stephenson, D.B.[4], Valdes, P.J.[4]	1. Centre National de Recherches Météorologiques, Météo-France, France 2. Laboratoire de Météorologie Dynamique du C.N.R.S., Paris, France 3. Hadley Centre for Climate Prediction and Research, Met Office, UK 4. Reading University, Reading	Periodical	X	O	X	X			Y	N	O	X	X		Compare 2XCO2 climate with present-day climate, using 4 different AOGCMs.	AOGCMs have difficulties in realistically simulating the Asian monsoon.	X	O	X	X	More recent multi-model climare projection is needed for resolving the change of regional monsoon rainfall.
8	2005	Dynamic and thermodynamic changes in mean and extreme precipitation under changed climate	Emori, E.[1,2], Brown, S.J.[3]	1.National Institute for Environment Studies, Japan 2.Frontier Research Centre for Global Change, JAMSTEC, Japan 3.Hadley Centre for Climate Prediction and Research, Met Office, UK	Periodical	O	X	X	X		Y	Y	Y	O	X	X		Compare SRES A1B, A2 and doubled CO2 with 1969-1990, 1979-1998 and 20C3M climate, using 4 PCMDI model and CCSR/NIES/FRCGC AGCM and HadAM3P.	Precipitation and vertical velocity, and their relationship, can vary from model to model.	X	O	X	X	Results on the change of extreme precipitation can be used as a reference, but discussion on the dynamical and thermodynamical processes behind might be too theoretical.
9	2010	Projection of Future Precipitation Change over China with a High-Resolution Global Atmospheric Model	Feng, L.[1,2], Zhou, T.J.[1], Wu, B.[1], Li, T.[3], Luo,J-J.[4]	1. State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences. 2. 2.Graduate University of Chinese Academy of Sciences 3. IPRC and University of Hawaii, USA 4. Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology	Periodical	O	X	X	X		Y	Y	Y	O	X	X		Compare SRES A1B precipitation in 2080-2099 with 1980-1999 data, using ECHAM5 with T319 resolution.	The GCM has difficulties in simulating the correct rainfall climatology (rainfall is overestimated in this high resolution model).	X	O	X	X	Results based on a single AGCM
10	2001	Climate Change due to Greenhouse Effects in China as Simulated by a Regional Climate Model	Gao, X.J.[1], Zhao, Z.C.[1], Ding, Y.H.[1], Huang R.H.[2], Giorgi, F.[3]	1. China National Climate Center 2. Institute of Atmospheric Science, Chinese Academy of Science 3. The Abdus Salam International Center for Theoretical Physics, Trieste, Italy	Periodical	O	O	X	X		Y	Y	N	O	X	O		Compare 2xCO2 climate with 1956-1990 climate,using CISRO AOGCM/RegCM2.	Dynamical dowscaling to increase spatial resolution of climate projections.	X	O	X	X	Results should be compared with those based on the more recent version of RegCM.
11	2010	Past and Future Changes in the Climate of Hong Kong	Ginn, W.L., Lee, T.C., Chan, K.Y.	Hong Kong Observatory	Periodical	O	O	X	X		Y	Y	Y	X	O	X		Statistical downscaling based on IPCC AR4 and analyzing observed data.	Statistical downscaling is emperical, and therefore might not capture all the physical processes involved in changes of rainfall characteristics under global warming. There is also a large inter-model discrepancies of rainfall projection over the south China region. Moreover, results are based on a mixture of all 3 emmision scenarios, which might not be desirable.	O	O	X	X	There seems to be large uncertainty in the rainfall projection, especially in terms of its decadal changes (changes in the next 20-50 years).
12	2010	Reconstructing Sea Level From Paleo and Projected Temperatures 200 to 2100 AD	Grinsted, A.[1], Moore, J.C.[2], Jevrejeva, S.[3]	1. Arctic Centre, University of Lapland, Finland 2. Thule Institute, University of Oulu, Finland 3. Proudman Oceangraphic Laboratotry, National Oceanography Centre, UK	Periodical	X	X	O	X		Y	Y	Y	X	X	X	semi-emprical method	Using the relationship: S_{eq}=aT+b and $\partial S/\partial t$ =(S_{eq}-S)/τ;S_{eq}=equilibrium sea leve, a and b = constant,τ=response time.	It is assumed that there is a simple relationship between global sea level and surface temperature. Moreover, calibration based on past record is needed.	O	O	X	X	It is not clear whether such a simple model can capture all the physical processes involved in sea level changes due to global warming.
13	2008	Changes in Tropical Cyclone Activity due to Global Warming: Results from a High-Resolution Coupled General Circulation Model	Gualdi, S.[1], Scoccimarro, E.[2], Navarra, A.[1]	1. Istituto Nazionale di Geofisica e Vulcanologia, Bologna, and Centro Euro-Mediterraneo per i Cambiamenti Climatici, Lecce, Italy 2. Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy	Periodical	X	X	X	O		Y	Y	Y	O	X	X		Compare the TC activity of quardrupled CO2 and doubled CO2 with 20C3M and preindustral age, using a T106 (120km) SINTEX-G AOGCM.	Model with resolution of T106 (about 100x100km) does not simuate realistic TCs.	X	O	X	X	Changes of reginal TC activity in the future are highly uncertain.
14	2005	Tropical Cyclones and Associated Precipitation over the Western North Pacific: T106 Atmospheric GCM Simulation for Present-day and Doubled CO2 Climates	Hasegawa, A.[1], Emori, E.[2]	1. Frontier Research Center for Global Change, JAMSTEC, Japan 2. National Institute for Environment Studies, Tsukuba, Japan	Periodical	X	X	X	O		Y	Y	Y	O	X	X		Compare doubled CO2 climate with late 20th century climate, using the T106, 120km CCSR/NIES/FRCGC AGCM.	There is still large uncertainty in the no. of TCs in the basin scale (say in the westeen north Pacific).	X	O	X	X	The work predicted a slight decrease of TC formation frequency in the western north Pacific due to global warming, but this projection is highly uncertain.

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No	Year	Name of Publication	Author(s)	Institution (of the Authors) (Red:National Meteorological Agency) (Blue:National Research Institute)	Periodical / Conference / Seminar / Report	Topic					State-of-the-art (Y/N)	Applicability to HK (Y/N)	Discussion on Extreme Event Estimation	Methodology Discussed				Brief Discussion on Methodology	Key Assumptions / Limitations / Uncertainties	Type of uncertainty				Critique
						Rainfall/ monsoon	Temperature	Sea level rise/ storm surge	Tropical cyclone	Others (please specify)				GCM	Statistical Downscaling	Dynamical Downscaling (RCM)	Others (please specify)			Field	Parameter	Human	Others (please specify)	
15	2003	Long-term climate variations in China and global warming signals	Hu, Z.Z.[1], Song Y.[2], Wu, R.G.[1]	1.Center for Ocean-Land-Atmosphere Studies,Institute of Global Environment and Society, George Mason University, USA 2.Climate Prediction Center, NOAA, USA	Periodical	X	O	X	X		N	Y	N	O	X	X		Compare doubled CO2 climate with "present-day" control run, using 16 CMIP2 models.	Small signal to noise ratio for summertime rainfall projections in many locations in China	X	O	X	X	Large uncertainty exists in seasonal precipitation change
16	2000	Intensified Asian summer monsoon and its variability in a coupled model forced by increasing greenhouse gas concentrations	Hu, Z.Z.[1], Latif, M., Roeckner, E.[2], and Bengtsson, L.[2]	1. Center for Ocean-Land-Atmosphere Studies,Institute of Global Environment and Society, George Mason University, USA 2. Max-Planck-Institut für Meteorologie, Hamburg, Germany	Periodical	X	O	X	X		Y	Y	N	O	X	X		Compare IS92a climate with current climate, by ECHAM4/OPYC3 CGCM.	AOGCM being used has relatively coarse resolution.	X	O	X	X	Regional details of monsoon rainfall projections should be based on more recent higher-resolution AOGCM projections.
17	2007	Climate Change 2007: The Physical Science Basis. Contribution of the Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change	IPCC Working Group 1- Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)	IPCC Working Group 1	Report	O	O	O	O		Y	Y	Y	O	O	O		Projections of future climate by AOGCM, regional climate models and empirical and statistical downscaling methods.	Using state-of-the-art AOGCM, the report provides the best possible estimates about the future state of the climate.	O	O	X	X	Projections about many phenomena such as tropical cyclone activity, extreme events, chnages of sea ice and regional details of climate variations are still uncertain.
18	2001	Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change	IPCC Working Group 1- Houghton, J.T., et al. (eds.)	IPCC Working Group 1	Report	X	O	X	X		Y	Y	N	O	O	O		Projections of future climate by AOGCM, regional climate models and empirical and statistical downscaling methods.	Future climate projections based on AOGCMs.	O	O	X	X	Not the lastest IPCC assesment.
19	2007	Project of Precipitation Extremes for the 21st Century over China.	Jiang, Z.H., Ding, Y.G., Chen, W.L.	Jiangsu Key Laboratory of Meteorological Disaster, Nanjing University of Information Science & Technology	Periodical	O	X	X	X		Y	Y	Y	O	X	X		Review study; compare SRES A1B, A2 and B1 with 1961-1990 climate, by GFDL-CM2.0, GFDL-CM2.1, INM-CM3.0, IPSL-CM4, MIROC3.2-medres	Coarse resoultion models cannot reproduce well the characteristics of extreme rainfall.	X	O	X	X	Downscaling techniques have to be adopted for better estimation of extreme rainfall projections.
20	2009	Projection and Evaluation of the Precipitation Extremes Indices over China Based on 7 IPCC AR4 Coupled Climate Models	Jiang, Z.H.[1], Chen, W.L.[1], Song, J.[2,1], Wang, J.[1]	1.Jiangsu Key Laboratory of Meteorological Disaster, Nanjing University of Information Science & Technology 2.Northern Illinois University, USA	Periodical	O	X	X	X		Y	Y	Y	O	X	X		Compare 5 extreme precipation indices in SRES A2, A1B, B1 with 1961-1990 observations, using GFDL-CM2.0, GFDL-CM2.1, INM-CM3.0, IPSL-CM4, MIROC3.2_medres, CNRM-CM3, NCAR-PCMI.	Models cannot reproduce well the climatology of extreme rainfall events in China.	X	O	X	X	Large uncertainties exist in projecting future behaviour of extreme rainfall events, especially over the monsoon reigons.
21	2007	Changes in Temperature and Precipitation Extremes in the IPCC Ensemble of Global Coupled Model Simulations	Kharin, V.V.[1], Zwiers, F.W.[1] Zhang, X.B.[2,] Heger[l], G.C.[3]	1.Canadian Centre for Climate Modelling and Analysis, Environment Canada 2.Climate Data and Analysis Section, Environment Canada 3.Nicholas School for the Environment and Earth Science, Duke University, USA	Periodical	O	O	X	X		Y	Y	Y	O	X	X		Compare SRES A1B, A2 and B1 with 1981-2000 climate, using 16 IPCC ensemble of global coupled models.	Physical procesees associated with extreme precipitation might not be well represented in models.	X	O	X	X	There are very large disagreement among models regarding changes of precipitation extremes in the tropics due to global warming. This reduces the confidence in projected changes of extreme precipitation.
22	2005	Estimating extremes in transient climate change simulations	Kharin, V.V., Zwiers, F.W.	Canadian Centre for Climate Modelling and Analysis, Environment Canada	Periodical	O	O	X	X		Y	Y	Y	O	X	X	Using the time-dependent GEV	Compare the IS92, SRES A1 and B2 climate in 2099 with 2000, using CCCma CGCM2, ML method and GEV.	There is large variability among precipitation projections from different models.	O	O	X	X	Results should be compared with multi-model projections for precipitation changes.
23	2005	Simulated change of the east Asian circulation under global warming scenario	Kimoto, M.	Center for Climate System Research, University of Tokyo, Japan	Periodical	O	X	X	X		Y	Y	N	O	X	X		Compare SRES A1B with 1971-2000 climate, using 17 CGCMs.	Large descrepancy still exisits among difference models in terms of regional details of climate projection over the Asian monsoon region.	X	O	X	X	Regional details of future changes of the mean rainfall are not certain, especially for the winter season. On the other hand the increase of summertime rainfall is more robust in East Asia.
24	2004	Future Projections of Precipitation Characteristics in East Asia Simulated by the MRI CGCM2	Kitoh, A., Hosaka, M., Adachi, A., Kamiguchi, K.	Meterological Research Institute, Japan	Periodical	O	X	X	X		Y	Y	Y	O	X	X		Compare SRES A2 and B2 with 1981-2000 climate, using MRI CGCM2.	The GCM being used has a rather coarse resolution, about 300x300km. Also, the results come from a single model, and it is known that there is large inter-model uncertainties for the Asian monsoon region future rainfall projection.	X	O	X	X	Results should be compared with multi-model projections.
25	2010	Tropical Cyclones and Climate Change	Knutson, T.R.[1], McBride, J.L.[2], Chan, J.[3]; Emanuel, K.[4], Holland, G.[5], Landsea, C.,[6], Held, I.[1], Kossin, J.P.[7,] Srivastava, A.S.[8], Sugi, M.[9]	1.Geophysical Fluid Dynamics Laboratory, NOAA, USA 2.Centre for Australian Weather and Climate Research, Australia 3.Guy Carpenter Asia-Pacific Climate Impact Centre, City University of Hong Kong 4.Program in Atmospheres, Oceans, and Climate, MIT, USA 5.National Center for Atmospheric Research, USA 6.National Hurricane Center, NWS, NOAA, USA 7.National Climatic Data Center, NOAA, USA 8.India Meteorological Department 9.Research Institute for Global Change, JAMSTEC, Japan.	Periodical	X	X	X	O		Y	Y	Y	X	X	X	review	Review.	The impact of climate change on TC activity, based on regional model simulations as well as global model projections.	O	O	X	X	Large uncertainties in both how large-scale tropical circulation will change, and how these will impact on TC activity. As a result, e.g., the downscaled projections of TC activity on the basin scale from different large-scale model give different results.
26	2004	Impact of CO2-Induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Parameterization	Knutson, T.R.[1], Tuleya, R.[2]	1.Geophysical Fluid Dynamics Laboratory, NOAA, USA 2.Center for Coastal Physical Oceanography, Old Dominion University, Vitginia, USA	Periodical	X	X	X	O		Y	Y	Y	O	X	X		Compare high CO2 scenario with "present-day" hurricane activity, using 9 CMIP2+ climate model and 4 different convection parameterization.	Uses a high-resolution hurrican model, but in an idealized framwork in which TCs do no interact with the environmental flow.	X	O	X	X	Environmental effects such a wind shear on storm intensity are not accounted for.
27	2007	Response of the East Asian summer monsoon to doubled atmospheric CO 2: Coupled climate model simulations and projections under IPCC AR4	Kripalani, R.H.[1,2], Oh, J.H.[1], Chaudhari, H.S.[1]	1.Integrated Climate System Modeling Laboratory, Department of Environmental and Atmospheric Sciences, Pukyong National University, South Korea 2.Indian Institute of Tropical Meteorology, India	Periodical	O	X	X	X		Y	Y	N	O	X	X		Compare doubled CO2 scenario with 20C3M, using output from 22 coupled ocean-atmosphere GCMs.	Regional climate projections from GCMs still have large uncertainties.	X	O	X	X	The trend of the projected change of the regional rainfallis probably a robust result, but not the detailed figures.
28	2010	Sea-Level Rise abd Storm Surge - Impacts of Climate Change on Hong Kong	Lee, B.Y., Wong, W.T., Woo, W.C.	Hong Kong Observatory	Conference	X	X	O	X		Y	Y	Y	X	X	X		Calculating return period of extreme sea-level based on IPCC AR4 and other publications.	Calculation of retuen period for extreme events based on global sea level rise projections from IPCC AR4 or Rahnstorf (2007).	O	O	X	X	There is currently large uncertainty in the sea level rise projection, although HKO's figures can be taken as a reference.
29	2008	Rainfall Projections for Hong Kong based on the IPCC Fourth Assessment Report	Lee, T.C., Leung W.H., Ginn, E.W.L	Hong Kong Observatory	Periodical	O	X	X	X		Y	Y	Y	X	O	X		Statistical downscaling based on IPCC AR4 and observed data.	Based on statistical downscaling, which assumes a relationship between the large-scale rainfall and the station-scale rainfall at the Hong Kong Observatory.	O	O	X	X	Large uncertainty exists, because of the large discrepancy between different GCM projections; another source of uncertainty is due to the statistical downscaling method.
30	2010	Multi-model Projection of July-August Climate Extreme Changes over China under CO2 Doubling	Li, H.M.[1,2], Feng L.[1,2], Zhou, T.J.[3]	1.State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences. 2.Graduate University of Chinese Academy of Sciences 3. Institute of Atmospheric Physics, Chinese Academy of Sciences	Periodical	O	X	X	X		Y	Y	Y	O	X	X		Compare 2XCO2 climate with preindustrial control simulations, using 20C3M and CMIP3.	AOGCMs cannnot reproduce regional-scale climate variations.	X	O	X	X	Dynamical downscaling using a regional climate model might be needed for accurately projecting regional climate change.

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No	Year	Name of Publication	Author(s)	Institution (of the Authors) (Red:National Meteorological Agency) (Blue:National Research Institute)	Periodical / Conference / Seminar / Report	Topic					State-of-the-art (Y/N)	Applicability to HK (Y/N)	Discussion on Extreme Event Estimation	Methodology Discussed				Brief Discussion on Methodology	Key Assumptions / Limitations / Uncertainties	Type of uncertainty				Critique
						Rainfall/ monsoon	Temperature	Sea level rise/ storm surge	Tropical cyclone	Others (please specify)				GCM	Statistical Downscaling	Dynamical Downscaling (RCM)	Others (please specify)			Field	Parameter	Human	Others (please specify)	
31	2005	Understanding future patterns of precipitation extremes in climate model simulations	Meehl, G.A.[1], Arblaster, J.M.[1,2], Tebaldi, C.[1]	1. National Center for Atmospheric Research, Boulder, USA 2. Bureau of Meteorology Research Centre, Melbourne, Australia	Periodical	X	O	X	X		Y	Y	Y	O	X	X		Compare the SRESA1B 2080–2099 climate and 1980-1999, using 9 model ensembles.	AOGCMs have relatively coarse resolutions; extreme rainfall events may not be accurately simiulated.	X	O	X	X	Estimates of the projected rainfall intensity change should be interpreted as those averaged over an typical AOGCM grid box, and might not reflecet those on the local/city scale.
32	2003	Mechanisms for projected future changes in south Asian monsoon precipitation	Meehl, G.A., Arblaster, J.M.	National Center for Atmospheric Research, Boulder, USA	Periodical	X	O	X	X		Y	Y	N	O	X	X		Compare the 2XCO2 and 4XCO2 climate and the present day climate, using GCM.	Uncertainty of projections based on a single, coarse-resolution (T42) GCM, could be large.	X	O	X	X	Results should be compared with projections from other models.
33	2007	Glaciers Dominate Eustatic Sea-Level Rise in the 21st Century	Meier, M.F.[1], Dyurgerov, M.B[1,2], Rick, U.K.[1,3], O'Neel S.[1,4,5], Pfeffer, W.T.[1,6], Anderson, R.S.[1,5], Anderson, S.P.[1,7], Glazovsky, A.F.[8]	1.Institute of Arctic and Alpine Research, University of Colorado at Boulder, USA 2.Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden 3.Department of Atmospheric and Oceanic Sciences, University of Colorado at Boulder, USA 4.Geophysical Institute, University of Alaska-Fairbanks, USA 5.Department of Geological Sciences, University of Colorado at Boulder, USA 6.Department of Civil, Environmental and Architectural Engineering, University of Colorado at Boulder,USA 7.Department of Geography, University of Colorado at Boulder, USA 8.Institute of Geography, Russian Academy of Sciences, Russia	Periodical	X	X	O	X		Y	Y	Y	X	X	X	semi-emprical method	Using the whole-glacier continuity equation for the rate of change of glacier ice mass.	Complex dyanmical driving the behaviour of glaciers need to be better characterized. Also, large area of glacier around the edge of ice sheets need to be better examined, in order to better estimate the rate of ice mass loss.	O	O	X	X	The projected sea level rise due to accelarated glacier melt updates the figures provided by IPCC AR4, which gives a smaller estimate.
34	2004	Future Projections of East Asian Climate Change from Multi-AOGCM Ensembles of IPCC SRES Scenario Simulations	Min, S.K.[1], Park, E.H.[2], Kwon, W.T.[2]	1.Meteorologisches, Universitat Bonn, Germany 2.Meteorological Research Institute, Korea Meteorological Adminstration	Periodical	X	O	X	X		Y	Y	N	O	X	X		Compare SRES A2 and B2 with 1961-1990 climate, using 7 AOGCM ensembles.	GCMs are not very skillful in simulating the summer precipitation in East Asia.	X	O	X	X	It would be more desirable if more models were used. Also, the resolution of 5x5deg is rather coarse.
35	2006	Tropical cyclone climatology in a global-warming climate as simulated in a 20km-mesh global atmospheric model: Frequency and wind intensity analyses	Oouchi, K.[1], Yoshimura, J.[2], Yoshimura, H.[2], Mizuta, R.[3], Kusunoki, S.[2], Noda, A.[2]	1.Advanced Earth Science and Technology Organization, Earth Simulator Center, Yokohama, Japan 2.Meteorological Research Institute, Japan 3.Advanced Earth Science and Technology Organization, Tsukuba, Japan	Periodical	X	X	X	O		Y	Y	Y	O	X	X		Compare SRES A1B with 1979-1998 tropical cyclone climatology, using a 20km-mesh, glohal atmospheric model of MRI/JMA.	There is deficiency in the model TC statisitcs in the sense that there is a lack of strong TCs in the model. Cumulus parameterization is still used, even though this is a 20-km mesh model.	X	O	X	X	The TC behaviour in the model may cast some doubt in the details of this projection of TC characteristics.
36	2002	Quantifying the risk of extreme seasonal precipitation events in a changing climate	Palmer, T.N.[1], Räisänen, J.[2]	1.European Centre for Medium-Range Weather Forecasts, UK 2.Rossby Centre, Sweden	Periodical	O	X	X	X		N	Y	Y	O	X	X		Compare doubled CO2 climate with 20th century climate, using 19 CMIP2 model ensemble.	Resolution is too coarse. Also, larger ensembles are needed to provide reliable estimates of probability of extreme evetnts.	X	O	X	X	Results are not applicable for basin-type hydrological models (which require resolution as high as about 10x10km).
37	2010	A new view on sea level rise	Rahmstorf, S.	Potsdam Institute for Climate Impact Resarch, Germany	Periodical	X	X	O	X		Y	Y	Y	X	X	X	review	Review.	Semi-emperical method assumes a simple relationship between sea level change and temperature.	O	O	X	X	Summarizes the latest estimates on sea level changes by semi-emperical models
38	2007	A Semi-Empirical Approach to Projecting Future Sea-Level Rise	Rahmstorf, S.	Potsdam Institute for Climate Impact Research, Germany	Periodical	X	X	O	X		Y	Y	Y	X	X	X	semi-emprical method	From Rahmstorf (2007): $H(t)=a\int_{t0}^{t}(T(t')-T0)dt'$ with the approximation $\partial H/\partial t=a(T-T_0)$ hold; H=global mean sea level, t=time, a=constant, T= mean temperature, T_0=previous equilibrium temperature.	Semi-emperical method assumes a simple relationship between sea level change and temperature.	O	O	X	X	It is not based on actual physical processes, although this can be taken as an alternative way to estimate sea level rise.
39	2002	CO2-induced changes in interannual temperature and precipitation variability in 19 CMIP2 experiments.	Räisänen, J.	Rossby Centre, Swedish Meteorological and Hydrological Institute	Periodical	X	O	X	X		Y	Y	N	O	X	X		Compare the doubling CO2 and present day climate, using 19 CMIP2 models.	Relatively low signal-to-noise ratio for precipitation variability projection among models	X	O	X	X	Results should be compared with more recent projections.
40	2010	A projection of future changes in summer precipitation and monsoon in East Asia	Sun, Y., Ding, Y.H.	National Climate Center, China Meteorological Administration	Periodical	X	O	X	X		Y	Y	N	O	X	X		Compare SRES A1B with 1980-1999 climate, using 19 climate model ensemble.	Based on SRESA1B scenario.	X	O	X	X	General patterns and trends represent the best estimates of the future state of the East Asian summer monsoon.
41	2007	How Often Will It Rain?	Sun, Y.[1,2], Solomon, S.[2], Dai, A.[3], Portmann, R.W.[2]	1.National Climate Center, China Meteorological Administration 2.Earth System Research Laboratory, NOAA, USA 3.National Center for Atmospheric Research, Boulder, Colorado	Periodical	O	X	X	X		Y	Y	Y	O	X	X		Compare SRES A1B, A2 and B1 with 1980-1999 climate, using 17 climate model ensemble.	GCMs have difficlties simulating very heavy precipitation (outsidet the 10-20mm/day range).	X	O	X	X	There is uncertainty about the sensitivity of rainfall intensity to global temperature change (estimated to be about 2% per deg. C from models).
42	2006	Going to The Extremes: An intercomparison of model-simulated historical and future changes in extreme events	Tebaldi, C.[1], Hayhoe, K.[2,3], Arblaster, J.M.[4,5], Meehl, G.A.[4]	1.Institute for the Study of Society and Environment, NCAR, USA 2.Department of Atmospheric Sciences,University of Illinois at Urbana-Champaign, USA 3.Department of Geosciences, Texas Tech University, USA 4.Climate and Global Dynamics Division, NCAR, USA 5.Bureau of Meteorology Research Centre, Australia	Periodical	O	O	X	X		Y	Y	Y	O	X	X		Compare extreme indices between SRES A1B, A2 and B1 and 20C3M, using 9 GCMs.	AOGCMs still have relatively coarse resolutions, thus preventing them from simulating extreme rainfall events which mainly manifest their intensity in the synoptic (or smaller) scales.	X	O	X	X	Results should be interpreted as an indication of the trend of the occurrence of extreme events, but not taken as a realistic projection of their frequency of occurrence in the future climate under global warming.
43	2006	Impact of anthropogenic forcing on the Asian summer monsoon as simulated by eight GCMs	Ueda, H.[1], Iwai, A.[2], Kuwako, K.[2], Hori, M.E.[1]	1.Graduate School of Life and Environment Science, University of Tsukuba, Japan 2.Mater's Program of Environment Sciences, University of Tsukuba, Japan	Periodical	O	X	X	X		Y	Y	N	O	X	X		Compare SRES A1B with 1981-2000 climate, using 8 GCMs.	Multi-model outputs on a 250x250km grid cannot resolve the regional details in future climate projections.	X	O	X	X	Results can only be taken as a reference about the trend of the large-scale mean precipitation under global warming.
44	2009	Global sea level linked to global temperature	Vermeer, M.[1], Rahmstorf, S.[2]	1.Department of Surveying, Helsinki University of Technology, Finland 2.Potsdam Institute for Climate Impact Research, Germany	Periodical	X	X	O	X		Y	Y	Y	X	X	X	semi-emprical method	Using a improved semiempriical method, similar to Rahmstorf (2007).	The semi-emperical method relies on the assumption that sea-level changes and temperature are simply related, although this is an improved version of that adopted by Rahnstorf (2007).	O	O	X	X	The projected sea-level change (about 75-190cm) is much larger than that given by IPCC AR4, but uncertainty still exists.
45	2002	Future changes in the distribution of daily precipitation totals across North America	Wilby, R.L.[1], Wigley, T.M.L.[2]	1. Department of Geography, King's College London, UK 2. National Center for Atmospheric Research, Boulder, USA	Periodical	X	O	X	X		Y	Y	Y	O	X	X		Compare the IS92a, with CO2 and surface albedo changing, climate in 2100 and "present-day" climate by HadCM2 and compare the climate of 2100, CO2, CH4 and N2O reaching 710 ppm, 2500 ppb and 413 ppb respectively, using NCAR CSM.	Gamma distribution model for daily precipitation.	X	O	X	X	Results should be compared with more recent projections.

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						Rainfall/ monsoon	Temperature	Sea level rise/ storm surge	Tropical cyclone	Others (please specify)				GCM	Statistical Downscaling	Dynamical Downscaling (RCM)	Others (please specify)			Field	Parameter	Human	Others (please specify)	
46	2009	Trends in Hong Kong Climate parameters Relevant to Engineering Design.	Wong, M.C., Mok, H.Y.	Hong Kong Observatory	Conference	O	X	X	X		Y	Y	Y	X	X	X	semi-emprical method	Using the time-dependent Generalized Extreme Value (GEV) distribution.	Uses the Genearlizd Extreme Value distribution to eastimate the distribution of extreme values.	O	O	X	X	Not a climate projection, but serves as background information for considering the impact of climate change on rainfall and tempreature extremes in Hong Kong.
47	2010	Observed Changes in Extreme Weather Indices in Hong Kong	Wong, M.C., Mok, H.Y., Lee, T.C.	Hong Kong Observatory	Periodical	O	X	X	X		Y	Y	Y	X	X	X	semi-emprical method	Using the time-dependent Generalized Extreme Value (GEV) distribution.	Uses the Genearlizd Extreme Value distribution to eastimate the distribution of extreme values.	O	O	X	X	Not a climate projection, but serves as background information for considering the impact of climate change on rainfall and tempreature extremes in Hong Kong.
48	2010	Projection of changes in tropical cyclone activity and cloud height due to greenhouse warming: Global cloud-system-resolving approcah	Yamada, Y.[1], Oouchi, K.[1], Satoh, M.[1,2], Tomita, H.[1], Yanase, W.[3]	1.Research Institute for Global Change, JAMSTEC, Japan 2.Center for Climate System Research, University of Tokyo, Japan 3.Ocean Research Institute, University of Tokyo, Japan	Periodical	X	X	X	O		Y	Y	Y	O	X	X		Compare SRES A1B with 1979-2003 tropical cyclone activity, using NICAM.	A global cloud resolving model, which can capture the mesoscale convective processes, is used.	X	O	X	X	The first study using a global-cloud resolving model to study the impact of global warming on TC activity, although results are based on a single model.
49	2006	Statistical Analyses of Climate Change Scenarios over China in the 21st Century	Xu Y.[1], Huang X.[1,2], Zhang Y.[1,3], Lin W.[4], Lin E.[1]	1.Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, China 2.School of Environmental Science and Engineering, Zhongshan University, China 3.Key Laboratory of Regional Climate-Environment for Temperate East Asia, Institute of Atmospheric Physics, Chinese Academy of Sciences, China 4.LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, China	Periodical	O	O	X	X		Y	Y	Y	X	X	O		Compare SRES A2 and B2 with 1961-1990 climate, using PRECIS driven by HadAM3H.	Dynamimcal downscaling using a regional climate model.	X	O	X	X	The regional model uses boundary information of only one GCM. It is known that there are rather large uncertainties for single model results, especially for rainfall in the monsoon region.
50	2006	A future climate scenario of regional changes in extreme climate events over China using the PRECIS climate model	Zhang, Y.[1,2,5], Xu, Y.L.[1], Dong, W.J.[3], Cao, L.J.[2,3,5], Sparrow, M.[4]	1.Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, China 2.Key Laboratory of Regional Climate-Environment for Temperate East Asia, Institute of Atmospheric Physics, Chinese Academy of Sciences, China 3.China National Climate Center, China Meteorological Administration, China 4.International Climate Variability and Predictability Project Office, National Oceanography Centre, UK 5.Graduate University of the Chinese Academy of Science, China	Periodical	O	O	X	X		Y	Y	Y	X	X	O		Compare SRES B2 with 1961-1990 climate, using PRECIS driven by HadAM3H.	Extreme rainfall events in South China are underestimated.	X	O	X	X	The regional model uses boundary information of only one GCM. It is known that there are rather large uncertainties for single model results, especially for rainfall in the monsoon region
51	2009	中国气候变化--科学、影响、适应及对策研究-第五章-21世纪全球和中国气候变化趋势	丁一汇；陈德亮；徐影；高学杰；汪方；许崇海	China National Climate Center	Report	O	O	X	X		Y	Y	Y	O	O	O		Compare SRES A1B, A2 and B1 with 1980-1999 climate, using 7 IPCC AR4 models and NCC/IAP T63. Statistical downscaling of 7 GCM by NCC/GU-WG weather generator under SRES A2. Compare doubled CO2 with 20th century climate, using RegCM2 driven by CSIRO AOGCM R21L9.	Results based on GCMs projections, as well as regional climate models and statistical downscaling.	O	O	X	X	Summarized the latest findings on climate projections of China

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MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

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