CLIMATE CHANGE AND ISLAND AND COASTAL VULNERABILITY

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Edited by: J. Sundaresan • S. Sreekesh • AL. Ramanathan
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Foreword

In the 21^{st} century, the coastal zone is increasingly becoming very significant due to growing world population living near coasts. They are continually changing because of the dynamic interaction between the oceans and the land. In recent years they get degraded by multiple stresses arising from local to global scale changes in water use, influx of sediments and pollutants, ecosystem degradation, river flooding, shoreline erosion, storms, tsunamis, relative sea level rise, aggregate extraction etc. The islands near coastal environs are fragile and highly vulnerable to some of the most devastating hydro meteorological and geological disasters. Islands experience long-term, more chronic vulnerabilities such as maintaining adequate water and energy supplies, preventing emigration which depletes the population and removes a needed skill base, maintaining self-sufficient economies, and preserving their culture.

Changing sea level and tropical cyclones in their destructive power can engulf entire island groups and cause devastation on a proportional scale on agricultural and occupational lands unknown in large and sub-continental countries. Climate change predictions show the shift in rainfall patterns causing prolonged droughts in severe allocations near coastal regions. The potential socio-economic impacts of climate change on the smaller island countries mainly due to sea level rise has shown negative impacts on tourism, freshwater availability and quality, aquaculture, agriculture, human settlements, financial services and human health. Storm surges are likely to have a harmful impact on low-lying islands. In this context more than 200 scientists and professionals from all over the globe came together for this International Conference on $28\text{-}31^{st}$ October 2010 to discuss all aspects of climate change impact on coastal and island issues for making these regions more sustainable. Each of the paper in this book discusses the contemporary issue which needs urgent attention of the planners.

This book explicitly discusses the impact of climate change on coastal and island ecosystem which will affect all components of ecosystem in totality. The book captures the reality and the climate change issues daunting this sector's traditional ecosystem through the ecosystem management approach. This book brings out integrated articles covering the real time issues of this vast region involved with multifaceted ecosystem. This book is an asset to all academic and research libraries and will be of great benefit to researchers, policymakers and administrators.

(Prof. K.V. Thomas)
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Preface

In recent times climate change is believed to play a major role in modifying the coastal/marine ecosystems with implications on their ecological and economical aspects that also support the high density populations living there. Thus the coastal and marine environments are closely linked to climate in numerous ways. The resultant sea-level rise is expected to increase at an alarming rate in the 21st century with severe impacts on low-lying regions where salt water inundation/intrusion, soil salinity, coastal ecosystem biodiversity, subsidence and erosion and host of problems get enhanced. Added to these are the impacts of increasing pollution load; and the GHGs increase also have major impact on mangroves, lagoons, coral reefs, etc.

In the last decade, the various reports and research works identified several small island nations that are in a vulnerable position due to climate change. India has around eleven hundred islands and islets in the Arabian Sea and the Bay of Bengal. Hence, there is an urgent need for an integrated attempt to address these issues systematically along with a strategy to develop adaptation and mitigation in islands and with islander's aspects to combat with climate change. The IWCCI conference was organised and the recommendations for specific action plans based on the research submissions in various sessions brought out this edited volume. We hope it will be highly beneficial to the researchers on climate change especially on islands and coast as well as the public who are interested in Climate Change Science.

The book consists of four parts viz. Hydrological Regime Changes and Water Woes; Biotic Changes and Responses (Stresses and Vulnerability); Coastal Dynamics; and Livelihood Options. The chapters are arranged in the sequence of the occurrence of climate change in a system. The status of coastal and island hydrological regimes are examined, followed by the biotic changes and their responses to coastal dynamics and the vulnerability due to sea level rise—the most conspicuous aspects of climate change. The last part, the impact of climate change on livelihood options, incorporates mitigation and adaptation scenarios of these regions.

Many researchers from various national and international institutions have contributed to this volume which reflects their own views and ideas. The editors thank all the contributors, reviewers and the publisher for their support. Peer reviewers of the volume helped greatly in improving the quality of the articles. The articles in this volume will be very useful to managers, researchers and stake-holders belonging to these regions. It will be a great asset to all the libraries of colleges, universities, institutions and also useful for individual collections as well.

J. Sundaresan
S. Sreekesh
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About the Editors

J. Sundaresan

Head, Climate Change Informatics in CSIR-NISCAIR, an autonomous institution under Council of Scientific and Industrial Research (CSIR), Ministry of Science & Technology, Govt of India. He is the Editor of Indian Journal of Geo-Marine Sciences, a publication of CSIR. He is a PhD in Oceanography from Cochin University of Science & Technology, India. Has thirty years research experience in coastal oceanography and twenty two years experience in island studies. Associated with science education, science popularisation and ecological activities for the last 36 years. Actively associated with scientists' associations to sustain ethics, truth and scientific temper in scientific institutions. Published more than fifty publications, an examiner for doctoral thesis evaluation and member of national and international committees. Invited for key note address and invited talk in many universities. Travelled in many countries.

S. Sreekesh

S. Sreekesh has about 18 years of experience in teaching and research. He obtained his PhD in land degradation in Periyar river basin from the Jawaharlal Nehru University, New Delhi and worked with The Energy and Resources Institute, New Delhi. He is currently working as an Associate Professor in the Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India. He is actively engaged in teaching and research in the field of climate, climate change and water resources management. He has expertise in application of geospatial techniques in resource and environment management. He has published many research papers in the national and international journals and written several chapters in books. He also has vast experience in collaborative research with the support from the national and international funding agencies.

AL. Ramanathan

AL. Ramanathan is a Professor in School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India. He is leading the group working on coastal biogeochemistry and hydro geochemistry and has worked extensively on mangroves, estuaries and coastal ground waters of India for the past two decades. He is actively engaged in coastal research with different institutions in India and from various parts of the world such as Australia, Russia, USA, on nutrient dynamics, biomarkers, paleo environment, nutrient source identification etc. He has guided two dozen PhDs in these aspects and published more than seven dozen papers in referred reputed journals like Estuaries, Wetland Ecology and Management, Estuarine, Coastal and Shelf Science, Journal of Coastal Research, Bull of Marine Sciences, Indian Journal of Marine Sciences, Marine Pollution Bulletin, Hydrogeology Journal, Water Soil and Air Pollution, Hydrological Process, Geofluids Applied Geochemistry, Journal of Geochemical Exploration etc. He has also published five books and written several chapters in books of national and international repute. He was a post-doc fellow under STA Japan program, UGC Russian Academy of Science Program, CSIR, INSA, DST, etc. He was a member of editorial board in Indian Journal of Marine Sciences and is a referee for many national and international journals.

Leonard Sonnenschein

Forty-six years experience in keeping fish, 35 years experience in scientific research, 23 years experience in science education innovation, over 100 publications, and extensive performance in conservation collaboration, climate change issues and public awareness. Leonard Sonnenschein opened St. Louis Children's Aquarium in 1993 and on June 8, 2004 (World Ocean Day) opened its expansion facility, the World Aquarium. Leonard regularly supervises students from over 45 universities which collaborate with the research component of the aquarium in facility development, exhibit design, fisheries, aquatic sciences, ecology, aquariology, legal frameworks, consumer awareness, cultural comprehension of environmental issues, and public understanding through field, conference and inter-governmental work. In 2006, Sonnenschein founded the Conservation for the Oceans Foundation to expand the World Aquarium's focus. The mission of the Conservation for the Oceans Foundation (CFTO) is to support grassroots-level conservation, education and research projects that bring about positive changes to ecosystems worldwide through local and multi-stakeholder actions. In 2009, Youth Voices in Conservation was developed for additional youth engagement opportunities (ages 3-50). In 2011, based upon the Low Carbon Lifestyles' campaign, the Youth Voices in Conservation's GreenLeaf Program was developed to allow for raising capital for residual support mechanism based upon the carbon offset credit from worldwide projects' actions. Leonard regularly collaborates with international agencies such as UNESCO, UNEP, WHO, International Ocean Institute, and the Global Forum on Ocean, Coasts and Islands and is a co-founder of the World Ocean Network. Leonard recently started innovative drug manufacturing, LLC to bring new patented technology to the pharmaceutical, nutraceutical, cosmetic and aquaculture industries.

Ram Boojh

Programme specialist at the UNESCO Office in New Delhi, responsible for Ecological and Earth Sciences, World Heritage Biodiversity and Natural Heritage Programmes and is also the focal point for the UN Decade for Education for Sustainable Development (DESD). He has over 30 years of working experience with the academic institutions, voluntary sector, government and international organizations. He has a distinguished academic career with Doctorate in Ecology and recipient of many awards and honours including the Indian National Science Academy Medal presented by Mrs Indira Gandhi, the then Prime Minister of India in January 1984. He has travelled widely and has been visiting fellow at many European and US universities and academic institutions. He has published over 100 research/technical papers/popular articles and 11 books.

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PART I

Hydrological Regime Changes and Water Woes

CHAPTER

1

Projected Precipitation Changes over Malaysia by the End of the 21st Century Using PRECIS Regional Climate Model

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INTRODUCTION

Malaysia is situated at the western part of the Maritime Continent. The surface climate and weather fluctuation over the Maritime Continent is modulated mainly by the Asian-Australian monsoon. This large scale circulation is reported to be weakened by the elevated global temperature in numerous observational and modelling studies (e.g. Gong and Ho, 2004; Wu et al., 2007; Xu et al., 2006; Yu and Zhou, 2007; Hu et al., 2000; Hori and Ueda, 2006). Juneng and Tangang (2010) indicated possible association between the weakened winter monsoon and the synoptic circulations changes over the southern South China Sea. Future changes associated with the monsoon circulation are expected to incur modification of precipitation regimes over the Malaysia regions (Juneng and Tangang, 2010).

The changes of precipitation regimes can have a substantial impact on nation's water resources availability. Proper addressing of the issue requires quantitative assessment of the sensitivity, adaptive capacity and vulnerability to climate change in order to support formulation of sustainable water resource

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management strategies. To systematically pursue such assessments, the most fundamental requirement is the availability of future climate information on regional and local scales.

The Global Circulation Models (GCMs) are important tools in the study of climate change and climate variability. They model the responses of the climate system to scenarios of greenhouse gas and aerosol concentrations or some other hypothetical forcings. Current version of GCMs can generally simulate well the large and continental scale present-day climate (Houghton et al., 2001; McGuffie and Henderson-Sellers, 1997; McCarthy et al., 2001). Over the decades, there have been considerable improvements in GCMs performance to simulate the climatic consequences of increasing atmospheric concentrations of greenhouse gases (Kumar et al., 2006). However, their application to regional studies is restricted by their coarse resolutions and limited capability in capturing local and regional scales dynamic. Hence, direct utilization of GCMs output to assess climate change at regional and local scale, which is crucial at national level, is rather infeasible. These impact assessment applications often require detail climate projection information (Robinson and Finkelstein, 1991) in order to capture fine scale climate variations, particularly in the regions with complex topography, coastal or island locations, and in areas of highly heterogeneous land-cover and irregular landmasses (Wilby et al., 2004) such as the Southeast Asia maritime continent.

A possible approach to bridge the scale gap is by a technique called downscaling, which uses either dynamical or statistical approaches to relate the large-scale information from GCMs to reproduce regional or local climate (Karl et al., 1990; Giorgi and Mearns, 1991; Joubert et al., 1999; Zorita and von Storch, 1999). While the historical data-based statistical approaches link large scale climatic field (usually called predictor) to the local climate variables using empirical relationship (Benesterd et al., 2008), the dynamic approaches require the use of regional climate models (RCM) nested within a GCM simulation. These RCM simulations are conditioned at the boundaries by the GCMs output (Georgi and Hewitson, 2001; Jones et al., 2004b). Although it requires higher computational cost, RCM downscaling provides local climate information taking in account physical interaction between various local features and is more favourable over areas without observational data.

The present work examines projected changes of seasonal precipitation by the end of 21st century over the Malaysia region based on the IPCC SRES A1B emission scenario. The Hadley Centre regional climate model known as PRECIS (Providing Regional Climate for Impacts Studies) nested within the UKMO HadCM3 were used to produce the rainfall projection at resolution of 0.22° × 0.22°. This paper also describes briefly the model, data and analysis methods employed in the study. Following section elaborates and discusses the simulation results and the last section summarizes the study.

MATERIALS AND METHODS

Model Description and Simulation Experiment Design

PRECIS (Providing Regional Climate for Impacts Studies) is a regional climate modelling system developed by the Hadley Centre. The regional climate model component, HadRM3P, is a land-atmosphere coupled model similar to the HadRM3H described by Hudson and Jones (2002). The atmospheric model is based on hydrostatic primitive equations discretized on a regular longitude-latitude grid (Arakawa B grid) of 0.22° × 0.22° (a coarser resolution of 0.44° × 0.44° is also available) and configured with 19 levels of hybrid vertical coordinates set from ground up to 0.5 hPa (Simon et al., 2004). In current study, the model has been configured for a domain extending from about 95°E to 123°E and 7.5°S to 14°N (Fig. 1.1), covering both Peninsular Malaysia and East Malaysia. The convective scheme used is the mass flux penetrative scheme with an explicit downdraught (Gregory and Rowntree, 1990; Gregory and Allen, 1991). The Met Office Surface Exchange

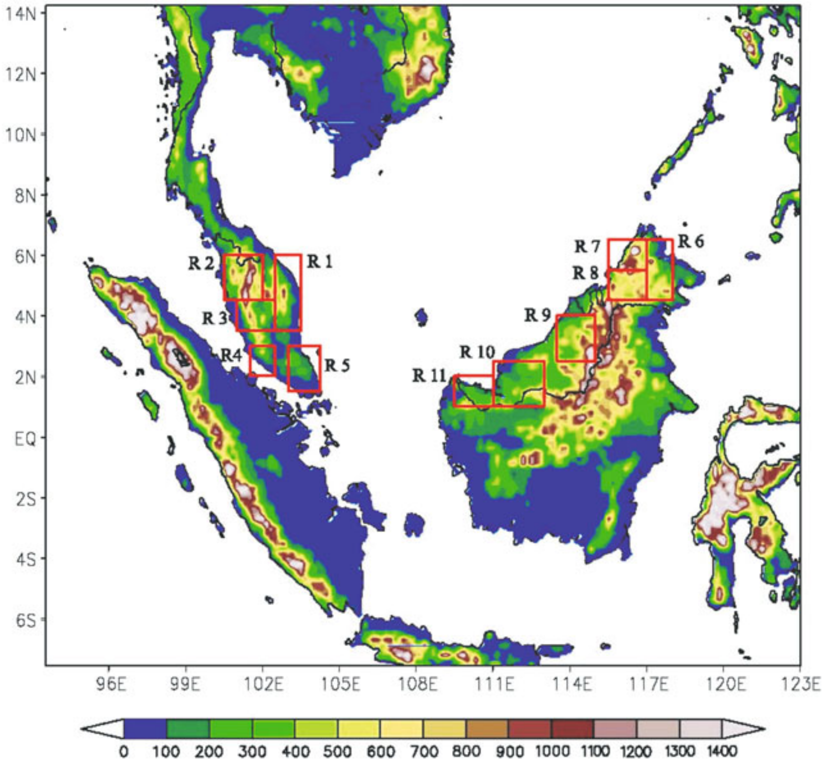

Fig. 1.1: The geographical extend of the domain used for HadCM3/PRECIS simulations. The topography within the domain is also provided (unit in m). The red boxes represent the 11 regions selected for area-averaged analysis. Refer text for further information.

Scheme (MOSES) (Cox et al., 1999) is used as the land surface model component. A detail description of the model is given in Jones et al. (2004b).

For current simulation experiment, the HadRM3P is forced at its lateral boundaries by the Hadley Centre Coupled Model version 3, HadCM3 running for the IPCC SRES A1B emission scenario. A relaxation method implemented across four points buffer zone are used to drive the RCM (Davies and Turner, 1977). The lateral boundary conditions are updated every six hours whilst the surface boundary conditions were updated every 24 hours. The simulation was integrated for 141 years from 1960-2100. However for the climate change analysis in current study, the baseline climate is calculated from the 30 years period of 1961-1990 allowing one year of spin up integration. The end of 21^{st} century climate was defined from a 30-year period of 2071-2100. To facilitate discussion, the downscaled product is referred to as HadCM3/PRECIS throughout the subsequent text.

Data and Analysis Method

The first part of study evaluates the performance of 19 IPCC coupled ocean-atmosphere GCMs in reproducing large scale rainfall characteristics over the Malaysia region for the baseline climate simulation experiments (20C3M). These GCMs-simulated rainfall were obtained from the multi-model output archive of the Third Climate Models Inter-comparison Project (CMIP3) of the World Climate Research Program (WRCP) (Meehl et al., 2007). The selected GCMs are shown in Table 1.1 with their respective IPCC ID along with the key references and respective atmospheric resolutions. The rainfall spanning 1950-2000 reproduced from these GCMs were compared to the gridded product of Climate Prediction Center Merged Analysis Precipitation (CMAP) (Xie and Arkin, 1997). The resolution of the CMAP precipitation is 2.5° × 2.5°. The CMAP and the GCMs simulations are compared on the basis of the area-averaged precipitation annual cycle and the seasonal spatial pattern of rainfall.

To evaluate the HadCM3/PRECIS downscaling simulation of the baseline climate, gridded precipitation product of Climate Research Unit (CRU), University of East Anglia (Mitchell and Jones, 2005) were used as rainfall observation. The CRU data set is available at 0.5° × 0.5° grid resolution. A total of 11 regions covering both Peninsular and East Malaysia were defined (Fig. 1.1). The model validation and climate change analysis were performed on the basis of rainfall annual cycles of the area averaged values. The selection of these areas was based on the topography setting in the Peninsular Malaysia as well as the East Malaysia, covering the northern Borneo. In addition, the spatial maps of rainfall were also used for clearer picture of the rainfall spatial variations. Seasonal averaged rainfall (DJF, MAM, JJA and SON) was considered for all spatial comparisons. To overcome the difference in grid resolutions, the PRECIS simulation output of 0.22° × 0.22° was interpolated to the coarser CRU precipitation grids before comparisons.

Table 1.1: The 19 GCMs used in current study together with their versions, resolution and key reference

No.	*IPCC ID*	*Approximate resolution*	*Country*	*Key reference*
1	BCCR-BCM2.0	2.8 × 2.8	Norway	Furevik et al. (2003)
2	CGCM3.1	3.7 × 3.7	Canada	Flato et al. (2000)
3	CNRM-CM3	2.8 × 2.8	France	Salas-Melia et al. (2006)
4	CSIRO-MK3.0	1.9 × 1.9	Australia	Gordon et al. (2002)
5	GFDL-CM2.0	2.5 × 2.0	USA	Delworth et al. (2006)
6	GFDL-CM2.1	2.5 × 2.0	USA	Delworth et al. (2006)
7	GISS-AOM	4.0 × 3.0	USA	Russell et al. (1995)
8	GISS-EH	5.0 × 4.0	USA	Schmidt et al. (2006)
9	GISS-ER	5.0 × 4.0	USA	Schmidt et al. (2006)
10	FGOALS-g1.0	2.8 × 3.0	China	Yu et al. (2004)
11	INM-CM3.0	5.0 × 4.0	Russia	Diansky and Volodon (2002)
12	IPSL-CM4	3.7 × 2.5	France	Marti et al. (2005)
13	MIROC3.2 (hires)	1.1 × 1.1	Japan	K-1 Model Developers (2004)
14	MIROC3.2 (medres)	2.8 × 2.8	Japan	K-1 Model Developers (2004)
15	ECHO-G	3.7 × 3.7	Germany/ Korea	Legutke and Voss (1999)
16	ECHAM5/MPI-OM	1.9 × 1.9	Germany	Jungclaus et al. (2006)
17	MRI-CGCM2.3.2	2.8 × 2.8	Japan	Yukimoto et al. (2001, 2002)
18	UKMO-HadCM3	3.7 × 2.5	UK	Jones et al. (2004a)
19	UKMO-HadGEM1	1.9 × 1.2	UK	Johns et al. (2005)

RESULTS AND DISCUSSION

Large Scale Rainfall Simulated by GCMs

Figure 1.2 depicts the seasonal march of the CMAP precipitation (observation) and the 19 GCMs-simulated precipitation averaged over the Malaysia region (95°E to 120°E and 5°S to 7°N). Generally, the performance of the GCMs in simulating the annual cycle of precipitation over the region shows large inter-model variations. Based on the curve of the annual cycles, the performance of the GCMs is intuitively grouped into six different patterns. The GCMs in group 1 (UKMO-HadCM3, UKMO-HadGEM1 and IPSL-CM4) and group 2 (GFDL-CM2.0 and GFDL-CM2.1) generally overestimates the rainfall in the region. However the group 1 GCMs show consistency in terms of the shape of the seasonal curves. The GFDL's climate models (group 2), on the other hand, depict large positive biases in the summer and fall. The GCMs in group 3 (MRI-CGCM2.3.2, CSIRO-MK3.0, CGCM3.1, ECHO-G and ECHAM5/MPI-OM), group 4 (CNRM-CM3, GISS-ER and FGOALS-g1.0) and group 5 (MIROC3.2(medres), MIROC3.2(hires) and BCCR-BCM2.0) show a strong bi-modal precipitation distribution with a secondary peak during the summer months. These groups of models usually produce weaker winter and spring rainfall but higher summer rainfall. This is inconsistent with the observation which shows minimum rainfall during the summer over the region. On the other hand, GCMs in group 6 (GISS-AOM, GISS-EH and INM-CM3.0) are generally more consistent with the observation which the simulated precipitation annual cycles show minimum rainfall during the summer and maximum during winter with less biases.

Generally, most of the GCMs have difficulties in simulating the rainfall satisfactorily over the Malaysia region. This is partly due to the convective nature of the rainfall as well as complex topography and coastlines over the

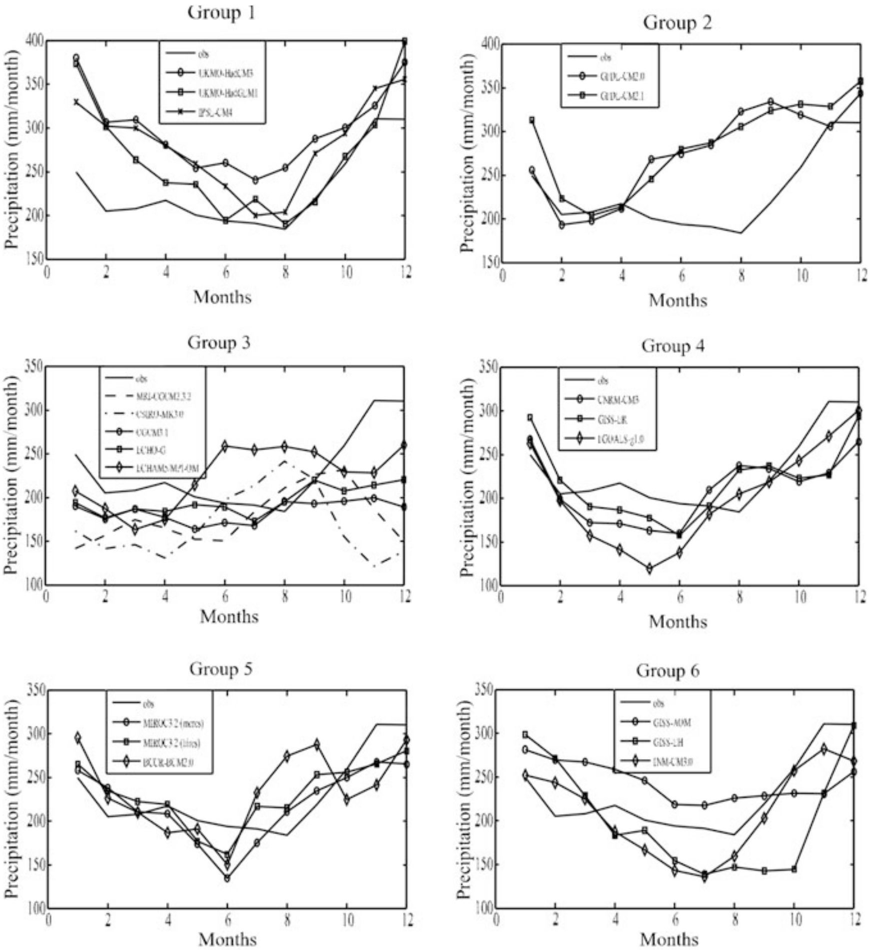

Fig. 1.2: The annual cycle of the averaged monthly rainfall (mm/month) for the CMAP observation (obs: solid line in each group) and the 19 GCMs simulations. Annual cycles are grouped according to their general patterns.

Southeast Asia maritime continent which plays crucial role in the rainfall processes (e.g. Salimun et al., 2010). Among the GCMs, UKMO-HadCM3 is of particular interest because the model data is readily to be used in the PRECIS modelling system for climate downscaling experiments. Despite producing higher rainfall over the considered region, the annual cycle curve and the spatial distribution of rainfall are generally consistent with the observation (CMAP). Figure 1.3 compares the rainfall spatial distribution between the CMAP and the GFDL-CM2.1 as well as UKMO-HadCM3 on seasonal basis. The GFDL-CM2.1 simulates a strong rainfall band over the equatorial region during summer which is inconsistent with the observation. On the other hand, the UKMO-HadCM3 simulated rainfall is spatially more consistent with CMAP except generally higher rainfall over the southern South China Sea area. The report shows consistently higher rainfall over the annual cycle (Fig. 1.2a). The PRECIS modelling system was then used for downscaling experiments using the UKMO-HadCM3 output as boundary conditions. An interesting question is whether the downscaling is able to improve the positive biases from the driving GCMs.

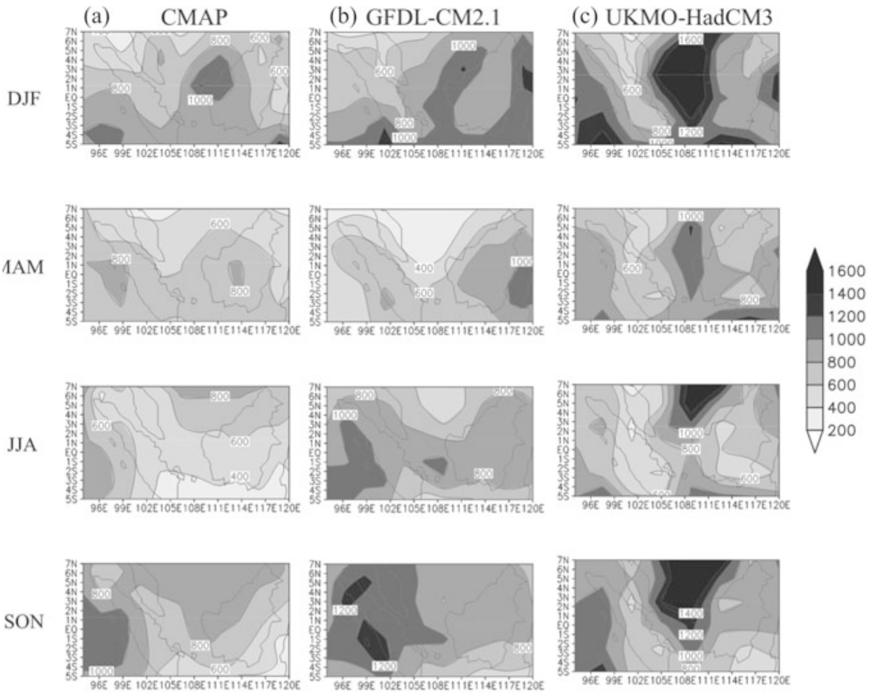

Fig. 1.3: Spatial patterns of seasonal precipitation (DJF, MAM, JJA and SON) of the (a) observation (CMAP), (b) GFDL-CM2.1 simulation and (c) UKMO-HadCM3 simulation.

Baseline Climate from HadCM3/PRECIS Simulation

Figure 1.4 shows the seasonal cycles of averaged precipitation of the CMAP, UKMO-HadCM3 and the HadCM3/PRECIS downscaling simulation. It is noted that the HadCM3/PRECIS improves the overall magnitude of the area-averaged rainfall while maintaining the shape of the seasonal curve. Substantial improvement is attained for spring, summer and fall seasons. There are however still noticeable positive biases during the winter months. These positive biases are probably inherited from the driving HadCM3. During the winter months, the regional rainfall is largely influenced by the northeast monsoon winds when the dynamic and moisture information from northern boundary dominates the climate of the RCM simulations.

Figure 1.5 compares the baseline observed monthly rainfall (CRU) climatology (1961-1990) to those of the HadCM3/PRECIS downscaling simulation averaged over the 11 regions defined in Fig. 1.1. Generally, the HadCM3/PRECIS simulates well the seasonal march of area averaged rainfall over Malaysia. In particular, the simulation reproduces the maximum rainfall during the winter months and minimum during the summer over the northeastern part of Peninsular Malaysia (R1) and western part of Sarawak (R10 and R11). The winter northeast monsoon (Nov(0)-Feb(1)) is an important feature over Malaysia. The strong northeasterly cold surge winds are associated to large amount of rainfall over Malaysia region, particularly over the northeastern coast of Peninsular Malaysia and western coast of Borneo. However, there appears to be consistent negative biases across the seasons over most parts of the western Borneo. Negative biases are also simulated over the northwest regions (R2 and R3) of Peninsular Malaysia during the beginning of the monsoon. Overall, the results indicate slightly drier tendency of the HadCM3/PRECIS simulating rainfall climate over the land. Given that the area averaged rainfall (Fig. 1.4) across the region shows overestimation of rainfall in the winter months, the excessive rainfall is largely produced over the South China Sea.

Figure 1.5 also compares the observed rainfall interannual variability structure to those of the HadCM3/PRECIS simulations. In general, the results indicate maximum interannual variability occurrence during the winter northeast monsoon season with minimum variability during the dry seasons of summer monsoon. This suggests that the precipitation in Malaysia varies the most during the northeast monsoon. Tangang and Juneng (2004) reported that the largest interannual variability of the Malaysia precipitation always coincides with the wet seasons. Overall, the HadCM3/PRECIS simulated the interannual variations reasonably well throughout the Malaysian regions except over the northern Borneo. Over the northern Borneo (R6, R7 and R8) the model simulated weaker interannual variability. Generally speaking, HadCM3/PRECIS performs satisfactorily in simulating the rainfall climatology and the interannual variations over the Malaysian regions.

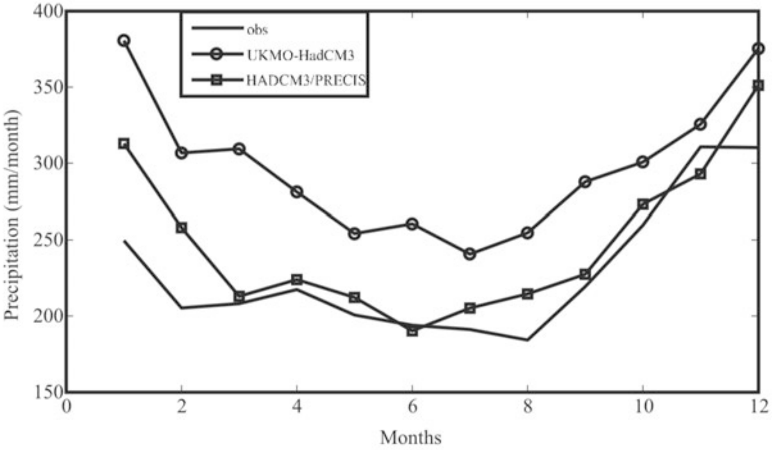

Fig. 1.4: Monthly rainfall climatology (unit in mm/month) of the observation, HadCM3 simulation and HadCM3/PRECIS downscaling simulation.

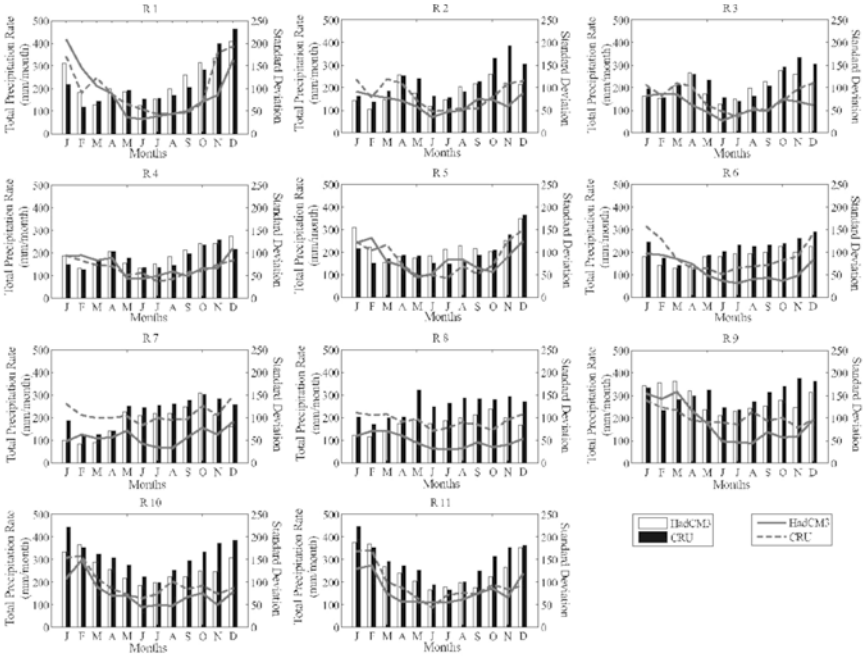

Fig. 1.5: Comparison between baseline monthly rainfall climatology (left ordinates) of the observation (CRU) (black bars) and the HadCM3/PRECIS downscaling simulation (white bars), averaged over the 11 regions (refer Fig. 1.1). The observed (dashed line) and simulated (solid line) interannual variability as indicated by the year-to-year standard deviations (right ordinates) are also plotted.

Figure 1.6 shows the seasonal comparison between the CRU gridded precipitation and the downscaled HadCM3/PRECIS precipitation. For better visual comparison, the HadCM3/PRECIS data was interpolated to the CRU grids and the result is shown in the third column of Fig. 1.6. The HadCm3/PRECIS reproduced the spatial distribution of the seasonal precipitation reasonably well. Generally, better simulation results were attained for MAM and SON when the monsoon influence is minimal. During MAM, HadCm3/PRECIS reproduced the maximum rainfall over the inland of Sarawak consistent with the observation. Over the Peninsular Malaysia, maximum rainfall during MAM over the northwestern region was also reproduced. Although the SON rainfall maximum over the inland Sarawak was generally reproduced, the HadCM3/PRECIS simulated a more concentrated rainfall area slightly eastward to the mountainous area of the central Borneo mountain range. The rainfall peak over the northeastern coast of Peninsular Malaysia during SON was also simulated well by HadCM2/PRECIS.

During DJF and JJA, the simulation shows noticeable spatial and magnitude biases. During DJF, the maximum rainfall over the east coast of Peninsular Malaysia shifted slightly northward in the HadCM3/PRECIS simulation. Although wetter region over the western Borneo was simulated well, there appears to be higher rainfall spread over the central region of Borneo. However, the maximum peak over the western tip of Borneo is well

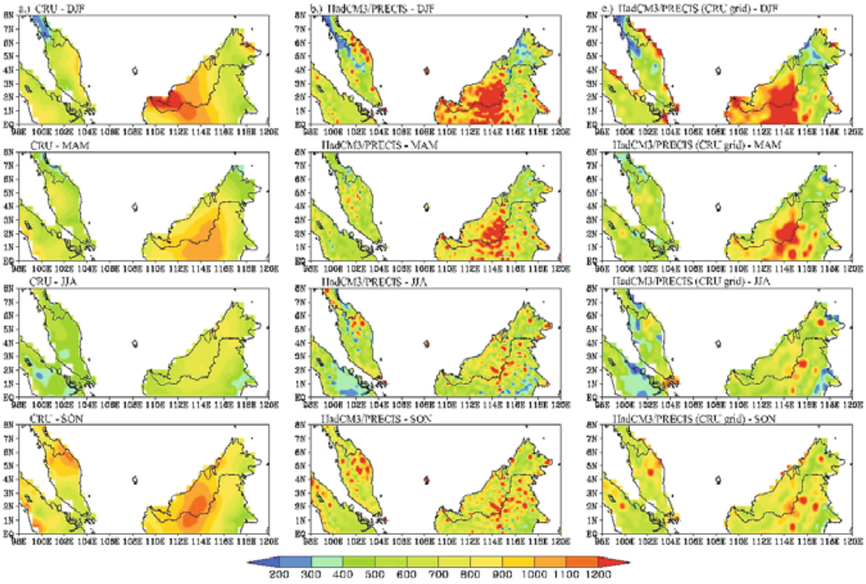
a.) CRU - DJF
b.) HadCM3/PRECIS - DJF
c.) HadCM3/PRECIS (CRU grid) - DJF
CRU - MAM
HadCM3/PRECIS - MAM
HadCM3/PRECIS (CRU grid) - MAM
CRU - JJA
HadCM3/PRECIS - JJA
HadCM3/PRECIS (CRU grid) - JJA
CRU - SON
HadCM3/PRECIS - SON
HadCM3/PRECIS (CRU grid) - SON

Fig. 1.6: Spatial distributions of seasonal averaged rainfall (unit: mm/month) of the observation (CRU) (left panels), downscaled HadCM3/PRECIS data (centre panels) and the downscaled HadCM3/PRECIS interpolated to the CRU grid resolution (right panels).

simulated by the model. During JJA, the model fails to simulate the predominantly dry pattern over Peninsular Malaysia. The model simulates high precipitation at the northeastern region Peninsular Malaysia which is inconsistent with the CRU precipitation. Over the northern Borneo, HadCM3/PRECIS simulated overall wetter climate despite strong positive biases over the inland Sarawak at the central Borneo.

During the monsoon periods (DJF and JJA), the regional climate is largely dominated by the southwest and northeast monsoon winds and the associated moisture processes. Hence, the quality of the simulation can depend more on the northern and southern boundary conditions as compared to other seasons (MAM and SON). The weaker performance of HadCM3/PRECIS during DJF and JJA may indicate poorer performance of driving HadCM3 during these seasons. Also, there is a general overestimation of rainfall, dominant over the inland areas, where topography is complex such as the central inland Borneo. The biases may be due to inadequate model grid resolution to properly resolve the complex local topographic features that are important to rainfall processes. It is also worth to mention that the CRU dataset were produced from the interpolation of station observations. In the mountainous area of the central Borneo and inland Peninsular Malaysia, the rainfall observations are sparse. These regions are particularly prone to interpolation errors because of the complex topographic forcing and the low-elevation bias to the station network (New et al., 2002). Hence, the gridded CRU rainfall data may not have a good representation of the actual rainfall field. This may also reflect the discrepancies shown in the inland areas of central Borneo (Fig. 1.6). This possible issue related to using CRU dataset is also recognized by Kotroni et al. (2008).

Rainfall Projection by the End of 21st Century

Figure 1.7 shows the comparison of rainfall annual cycle for baseline and projected precipitation over the 11 regions. By the end of the century, the annual precipitation pattern at both Peninsular Malaysia and East Malaysia are not expected to vary much from the present precipitation climatology. However, the HadCM3/PRECIS simulation results suggest an overall drier climate over the Malaysia regions except during the end of summer and fall. A clearer comparison is provided in Fig. 1.8 which shows spatial variations of the percentage of projected rainfall changes. The largest change in the precipitation climate are projected during the month of February (not shown) with a reduction of ~40% over the eastern and southeastern regions of Peninsular Malaysia and inland of Borneo (Fig. 1.8d). This indicates a possibility of shorter and weaker winter monsoon seasons under the SRES A1B emission forcing and hence, produces less monsoon rainfall during the season. Several GCMs studies have indicated possible weaker East Asian winter monsoon due to the weakening of Siberian High and shrinking of the

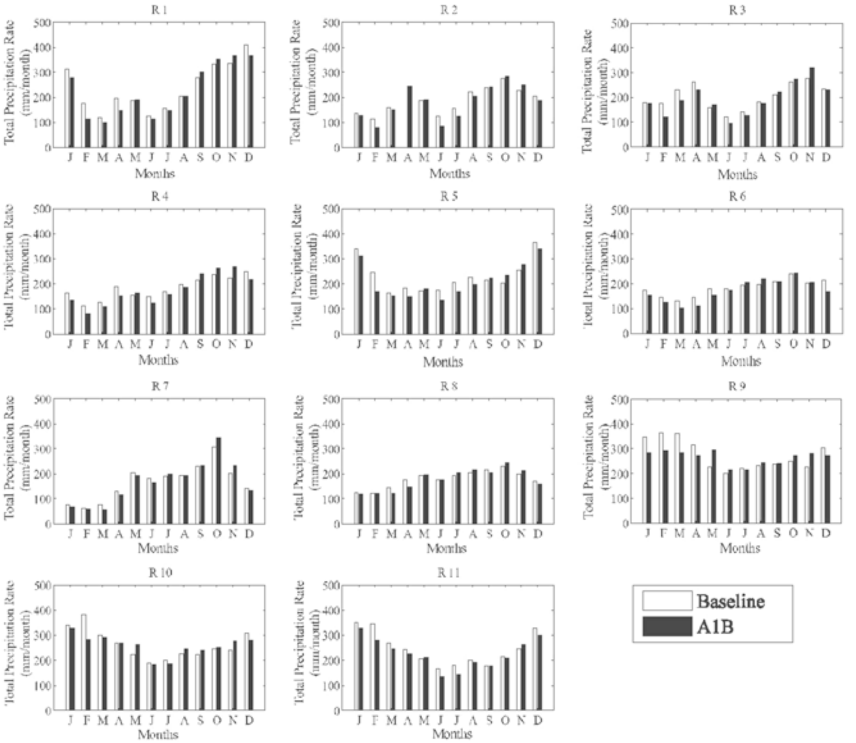

Fig. 1.7: The comparison of rainfall climatology between the HadCM3/PRECIS baseline (1961-1990) (white) and the future projection by the end of the 21st century (2071-2099) (black).

Aleutian Low in a warmer climate (Hu et al., 2000; Hori and Ueda, 2006). Juneng and Tangang (2010) has also reported weakening of the winter monsoon cold surge wind over the South China Sea during the last decades. The overall summer southwest monsoon rainfall shows a maximum decrease of about 20-30%.

Over the inland of central Borneo, wetter condition is expected to start during the spring and persists through the fall with ~30% rainfall surplus compared to that of the baseline climate. Over the seasons, the eastern Borneo regions was projected to be overall drier with considerable spatial variations and changes magnitude, while the regions west of the central Borneo mountain range was projected to be wetter (Figs 1.8b, c and d). This indicates strong climate modulation by the regional topography. The largest rainfall increase was detected during May (not shown). In fact, most of the sub-regions, including those over the Peninsular Malaysia (~10-20%) were predicted to experience an increase in rainfall during SON (Fig. 1.8d) under the SRES A1B emission forcing. On the other hand, regions over the Peninsular Malaysia remain drier throughout the spring and summer.