การประเมินความเปราะบางอุทกภัยโดยการย่อส่วนภูมิอากาศจากแบบจำลอง CMIP3 และ CMIP5 กรณีศึกษา มหาอุทกภัย 2554

Flood Vulnerability Assessment Using CMIP3 and CMIP5 Climate Downscaling : Case Study of the 2011 Great Flood of Thailand

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บทคัดย่อ

จากผลกระทบของพายุที่เกิดขึ้นอย่างต่อเนื่องจำนวน 5 ลูกตั้งแต่เดือนมิถุนายนจนถึงเดือนตุลาคมในลุ่มน้ำเจ้าพระยาได้สร้างความเสียหายอย่างรุนแรงในเหตุการณ์มหาอุทกภัย 2554 และจากข้อจำกัดด้านความสามารถในการระบายน้ำ ทำให้ปริมาณน้ำไหลล้นข้ามคันกั้นน้ำ ทำให้คันกั้นน้ำหลายแห่งพังทลาย ปริมาณน้ำไหลบ่าเข้าท่วมพื้นที่ชุมชนหลายแห่ง สร้างความเสียหายทั้งชีวิต และทรัพย์สิน โดยมีผู้เสียชีวิตจากเหตุการณ์ 815 คน ผู้ได้รับผลกระทบกว่า 13.6 ล้านคน มีพื้นที่น้ำท่วมประมาณ 20,000 ตารางกิโลเมตร นับเป็นเหตุการณ์ที่ได้รับการจดบันทึกว่ารุนแรงที่สุดโดยมีความเสียหายทางเศรษฐกิจประมาณ 1.4 ล้านล้านบาทจากรายงานของธนาคารโลก บทความนี้อธิบายถึงพฤติกรรมน้ำหลาก จากเหตุการณ์ 2554 และในอนาคตจากสภาพภูมิอากาศที่เปลี่ยนแปลงไป โดยทำการย่อส่วนจากแบบจำลองสภาพภูมิอากาศโลก 2 รุ่น คือ CMIP3 และ CMIP5 สำหรับพื้นที่กรุงเทพมหานคร ผลการศึกษาพบว่าแบบจำลองทั้งสองรุ่นให้ผลการคำนวณไม่แตกต่างกันมากนัก แต่ที่สำคัญแบบจำลองทั้งสองให้ผลการคำนวณปริมาณฝนที่จะเพิ่มขึ้นอย่างมีนัยสำคัญซึ่งบ่งชี้ถึงความเสี่ยง และความเปราะบางต่ออุทกภัยในอนาคต นอกจากนี้จากการศึกษาถึงมาตรการต่างๆในการป้องกัน และลดผลกระทบพบว่าไม่สามารถป้องกันอุทกภัยได้อย่างสมบูรณ์ ดังนั้นมาตรการที่เหมาะสมที่สุดสำหรับชุมชนที่มีความเสี่ยงสูงจึงควรมีการปรับตัวด้วยการสร้างบ้านใต้ถุนสูงเพื่อให้อยู่กับอุทกภัยได้อย่างยั่งยืน

คำสำคัญ: *มหาอุทกภัย 2554 CMIP3 CMIP5*

Abstract

The severe flooding in Thailand in 2011 was triggered by continuous five storms from June to October along the Chao Phraya River basin. Due to limited capacity of the river, several overbank flows and broken dikes were observed causing excessive flow to several communities. The consequence was a total of 815 deaths with 13.6 million people affected and over 20,000 km^2 of farmland were devastated. This event has been recorded as the most economically damaging, approximately US$45.7 billion reported by the World Bank. The present paper examines the flood behavior in 2011 and flood impact from the changing climate. Two generations of the global climate model ensembles, CMIP3 and CMIP5, were downscaled through historical twentieth century and future projections of Bangkok. Overall, our results suggested that the performance of CMIP5 models cannot be readily distinguished from CMIP3 models. Both CMIP3 and CMIP5 models gave high potential for future flood vulnerability in Bangkok. Several flood control measures were studied, implying that flood cannot be completely avoided. Therefore, the best practice for high flood risk communities is by raising the house with open space in the first floor as one of the flood resilient approach.

***Keywords**: The 2011 great flood, CMIP3, CMIP5*

1. Introduction

The impact of global warming is likely to increase vulnerability to potentially damaging impacts of climate change, especially increase the frequency and harshness of weather events such as heavy rainfall, shifting in rainy season, increasing in number wet days. Therefore, it would need rather long-term future climate projection to be able to clearly detect the change in future climate pattern. Several communities in the coastal area are vulnerable to a range of hazards, especially, coastal flooding. An increase in mean sea level and sea level extremes will mainly affect the terrestrial landscape, increasing the risk of inundation of low-lying coastal area. Coastal areas in both developing and more industrialized economies face a range of risks related to climate change and variability. Potential risks include accelerated sea level rise, increase in sea surface temperatures, intensification of tropical and extra tropical cyclones, extreme waves and storm surges, altered precipitation and runoff, and ocean acidification. The Intergovernmental Panel for Climate Change Fourth Assessment Report (IPCC 2007a) points to a range of outcomes under different scenarios. It identifies a number of hotspots including heavily urbanized areas situated in the low-lying deltas of Asia and Africa as especially vulnerable to climate-related impacts. The number of major cities located near coastlines, rivers, and deltas provides an indication of the population and assets at risk. Thirteen of the world's 20 largest cities are located on the coast, and more than a third of the world's people

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live within 100 miles of a shoreline. Low-lying coastal areas represent two percent of the world's land area, but contain thirteen percent of the urban population (McGranahan et al. 2007). A recent study of 136 port cities showed that much of the increase in exposure of population and assets to coastal flooding is likely to be in cities in developing countries, especially in East and South Asia (Nicholls et al. 2008a).

Since the Coupled Model Intercomparison Project (CMIP) was launched in 1995, coupled ocean-atmosphere general circulation models developed in dozens of research centers around the world have been compared and analyzed extensively. The program has improved our scientific understanding of the processes of Earth's climate system and of our simulation capabilities in this field. CMIP also plays an important social role by contributing to the Intergovernmental Panel on Climate Change (IPCC). The CMIP phase three (CMIP3) provided the scientific base for the Fourth Assessment Report (AR4) of IPCC published in 2007. CMIP phase 5 (CMIP5) was initiated in 2008, and the CMIP5 data are now available for analyses and are expected to provide new insights on our climate for the Fifth Assessment Report (AR5).The latest generation of Global Climate Models (GCMs), the framework of the fifth phase of the Coupled Model Intercomparison Project (CMIP5), reflects 5–6 years of effort by multiple climate modeling groups around the world. Compared to CMIP3, CMIP5 models typically have finer resolution processes, incorporation of additional physics, and better-developed or well-integrated earth system components (Taylor et al., 2012).Emerging literature on CMIP5 (Taylor et al., 2011a) has reported improvements in simulating certain key processes.

This paper is organized as follows : Firstly, the flood history and flood behavior of the 2011 great flood are examined. Then, the future vulnerability and climate downscaling are explained. Subsequently, hydrological simulations are described and results of several adaptation measures are given. The paper closes with a summary and short discussion.

2. Flooding history in Bangkok and vicinity

Bangkok covers an area of 1,569 km^2 located in the delta of the Chao Phraya River Basin, which is the largest basin in the country, covering an area of 159,000 km^2 or about 35% of the total land area of the country. There are two main rivers bisecting the delta area: the Tha Chin River on the west and the Chao Phraya River (the main stream) on the east. The basin forms up by four large tributaries: the Ping, Wang, Yom, and Nan originate from the mountainous terrain in the northern part of the country. These four tributaries flow southward to join each other in NakhonSawan to become the Chao Phraya River. The river flows southward through a large alluvial plain to reach the sea at the Gulf of Thailand as illustrated in Figure 1.

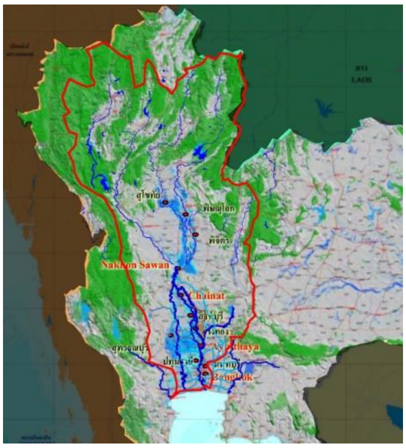

Figure 1 Chao Phraya river basin

The basin area is flat at an average elevation of 1 to 2 m from the mean sea level (m.MSL), with certain spots where the elevation is lowered down to the sea level due to land subsidence. There are a number of canals crossing the whole basin. Bangkok straddles the Chao Phraya River 33 km north of the Gulf of Thailand. Due to the flatness of the area and close proximity to the seashore, the area annually faces the problems of floods from rivers from the north and inundation due to the high tide from the sea. Bangkok is located near the Gulf of Thailand where Chao Phraya river goes into the sea. As the capital and largest city, it has about 7 million people and 12 million people in Bangkok Metropolis, and contributions to 43% GDP. Over the past three decades, severe flooding in Thailand has become increasingly common. Figure 2 shows the flood extents of five of the most severe floods in the Thailand's recent history. Not shown in this figure are the floods of 2010 and 2011. The 2011 floods in the Chao Phraya basin were the worst floods ever recorded in the country, and the estimated US$ 45.7 billion in costs make it more expensive than Hurricane Katrina (World Bank 2011).After the 1983 floods, and again after the 1995 and 2006 floods, the Thai government began massive projects to prevent future floods in the Chao Phraya basin. The so-called "Master Plan" for flood mitigation after 1983 led to the creation of a polder system of levees and pumps surrounding Bangkok (Vongvisessomjai, 2007). However, Bangkok is still under threat of flooding, especially the increasing flood risk due to climate change and the rapid urbanization in the floodplain. The frequency of devastating floods tends to be higher and the loss of human lives and property show increasing sign.

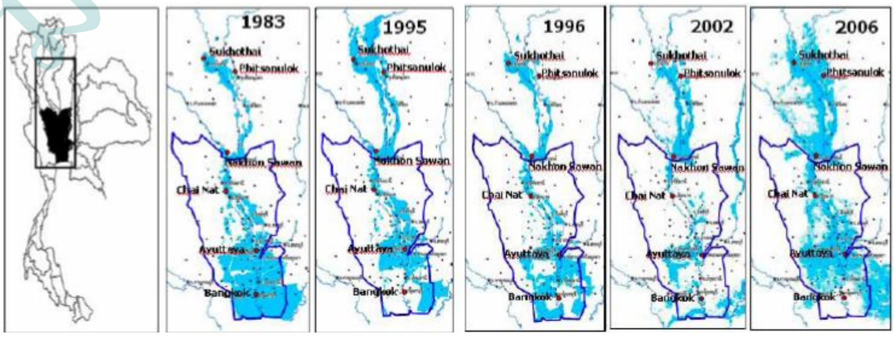

Figure 2 Past severe floods in the Chao Phraya river basin

3. Looking back on Thailand 2011 flood

Although efforts have been made to mitigate the flood damage in the Chao Phraya River Basin through several structural measures (construction of dams, reservoirs, dikes and pumping stations), flooding still causes much more impact as a result of deforestation, farmland expansion and urban development. The flood damage potential is increasing due to rapid urbanisation and land development in downstream areas; particularly in Ayutthaya and its municipalities along the Chao Phraya River.

The 2011 rainy season was influenced by both the northwest monsoon and the tropical storm, commencing with Nock-Ten which made landfall at Vietnam and became a tropical depression before moving to Thailand at the end of July (Nan province). In addition, there were four storms (Haima, Haitan, Nesat and Nalgae) that caused medium to heavy rainfall from June to October in the north and northeast of Thailand. The continuous rainfall in the north accumulated nearly 1,675 mm of water, which is 42% more than the 30-year average value (see Figure 3).

This causes signifant accumulated run-off volume passing Nakon Sawan province more than 30,000 mcm compared to approximately 25,000 and 27,000 mcmin 1995 and 2006, respectively as given in Figure 4.

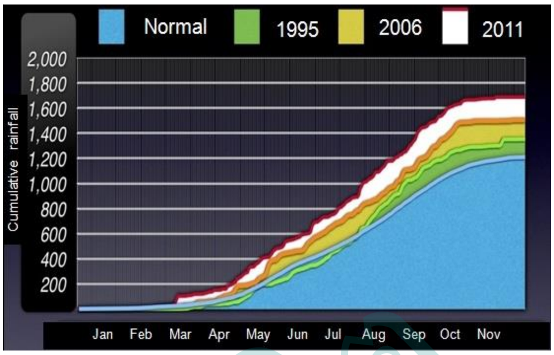

Figure 3 Cumulative rainfall in the northern part

Due to the limited capacity of the Chao Phraya River and the Pasak River, several riverbank overflows occurred, and dykes along the river were broken causing excessive flow to many communities beside the river and downstream. The inundation area was estimated to be 14,000 km^2 with the flood volume of approximately 10,000 mcm in the floodplain from Nakon Sawan to Ayuthaya (see Figure 5). In total, the floods damaged 18,291 km^2 of farmland and 804 factories, and killed 813 people.

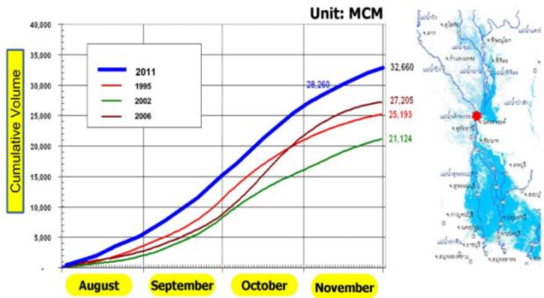

Figure 4 Run-off volume passing NakornSawan

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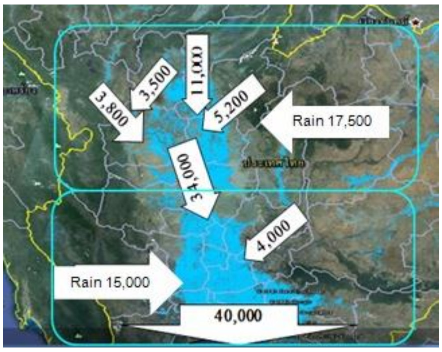

Figure 5 Flood inundation area and flood volume

Within the first 3 weeks of October, seven major industrial estates were submerged 2-3 m during high flood level (see Figure 6). This caused interruption to supply chain to car parts regionally and world-wide, e.g. electronic components and hard disk drives. The Ministry of Industry estimated damage in various industrial estates (i.e. SaharatnaNakorn, Rojana, Hi-tech, Bang Pa-in, Factoryland, Nawanakorn and Bang Kadi) to be approximately THB 237.4 billion, and in affected provinces to be THB 237.3 billion. Combined with the results from the survey, which includes Bangkok, the total damage is estimated to be THB 513.9 billion. Similar to the estimated damages, the Ministry of Industry estimates the losses from reduced production in the aforementioned industrial estates in Ayuthaya and PathumThani to be around THB 328 billion. Combined with the surveyed data in the other of the five provinces and extrapolated33 for 26 affected provinces according to the industry sector GPP data, the losses are estimated at THB 493 billion (World Bank, 2012).

Figure 6 Flood inundated7 industrial estates

4. Looking forward to future flood risk and vulnerability

In this study, precipitation over land compared across two generations of CMIP5 and CMIP3, through historical twentieth century skills and future projections. A performance ranging from time series plots and Taylor diagrams are used for the intercomparisons. Therefore, we use 9 climate model pairs from CMIP3 and CMIP5 downscaling for Bangkok (see Table 1).

Table 1 List of IPCC CMIP3 and CMIP5 global climate models used in this study

CMIP3	Resolution	CMIP5	Resolution	Center
CNRM-CM3	128 x 64	CNRM-CM5	256 x 128	Centre National de RecherchesMeteorologiques, France
CSIRO-Mk3.0	192 x 96	CSIRO-Mk3.6	192 x 96	CSIRO, Australia
GFDL-CM2.0	144 x 90	GFDL-CM3	144 x 90	Geophysical Fluid Dynamics Laboratory, NOAA
GFDL-CM2.1	144 x 90	GFDL-ESM2M	144 x 90	Geophysical Fluid Dynamics Laboratory, NOAA
GISS-ER	72 x 46	GISS-E2-H	144 x 90	Goddard Institute for Space Studies, USA
INM-CM3.0	72 x 45	INM-CM4	180 x 120	Institute of Numerical Mathematics, Russia
IPSL-CM4	96 x 72	IPSL-CM5A-LR	96 x 96	Institut Pierre Simon Laplace, France
MIROC3.2 (medres)	128 x 64	MIROC5	256 x 128	CCSR/NIES/FRCGC, Japan
MRI-CGCM2.3.2	192 x 96	MRI-CGCM3	320 x 160	Meteorological Research Institute, Japan

Monthly precipitation data have been extracted from 9 climate model pairs from CMIP3 and CMIP5. We have examined mean climatology for historical period 1980-1999, for the mid future period of 2040-2059 and the far future period of 2080-2099 with only one initial condition ensembles, 'run1' from CMIP3 and 'r1i1p1' from CMIP5. In this study, we considered last two decades of the twentieth century and extracted from '20c3m' and 'historical' experiments from CMIP3 and CMIP5 respectively. Future monthly precipitation data has been taken from comparable greenhouse warming scenarios, SRES B1 and A2 from CMIP3 and RCP4.5 and RCP8.5 from CMIP5 models. The IPCC AR4 scenario SRES B1 has been reported to best match the RCP4.5 temperature and total anthropogenic RF projections (Rogelj et al., 2012). All these models were regrided to a 0.5 degree (720-longitude x 278 latitude) as shown in Fig 7. Daily precipitation data for the period 1980-1999 were obtained from Thailand

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Meteorological Department (TMD) for Bangkok station, it is located in the central of Bangkok, with latitude 13.73 N and longitude 100.56 E.

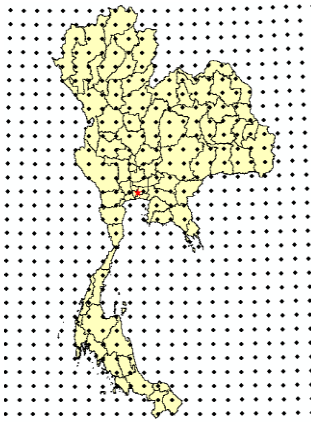


Figure 7 Climate model grid boxes (dots) and the Bangkok station (red star)

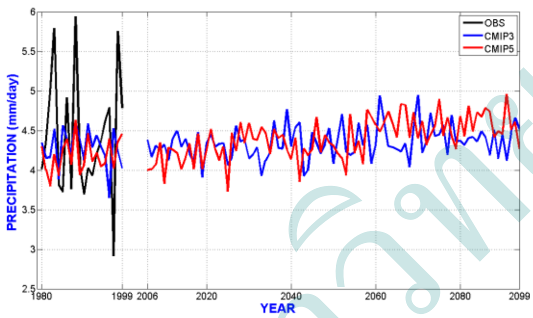


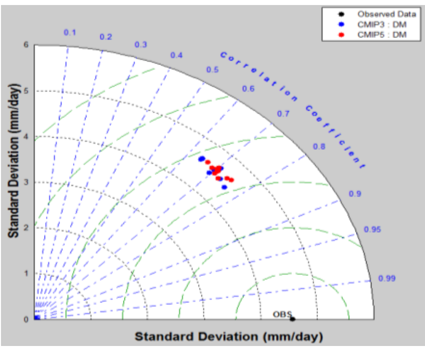
Figure 8 Time series plots and multi model ensemble for annual mean precipitation climatology

Statistical downscaling by distribution mapping (DM) (Teutschbein and Seibert, 2012) was used in this study. We downscaled precipitation for each 9 model pairs from both generations of models (CMIP3 and CMIP5) and computed with respect to Bangkok station observed data. Then, we also evaluated models agreement on projecting mean climatology at the last two decades of twentieth century (1980-1999). Specifically we generated changes in projection precipitation for all model pairs from CMIP3 and CMIP5 with near future (2010-2039), middle future (2040-2069) and far future (2070-2099).

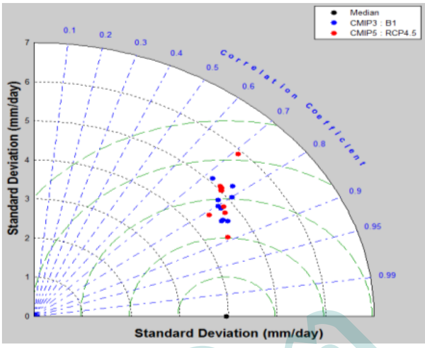
The multi model mean times series plots were generated by calculating the mean value of time series data from 9 model pairs. Time series data from an individual model were generated by taking the average of annual mean precipitation from 1980 to 1999 and 2006 to 2099. Figure 8 show time series plots for CMIP3 and CMIP5. Also shown in this figure is the historical time series plot for annual mean from observation (OBS) data sets: Bangkok station (TMD). A comparison of the time series plot of mean annual rainfall from any of the reference data set shows that CMIP5 models do not show improvement over CMIP3 models.

The similarity between observed and model-simulated field can be described by the Taylor diagram. The reference data set is plotted along the abscissa. The model data set is plotted in the first or second quadrant depending upon whether the correlation coefficient is positive or negative, respectively. The azimuthal position of model data is given by the arccosine of correlation coefficient between reference and model data set. The radial distances of reference and model data points from the origin are proportional to their standard deviations. The centered RMS error is proportional to the distance between the points representing reference and model data sets. The closer a model point is to the reference data point, the lower its centered RMS error; it implies that the model is performing relatively well. High correlation between reference and model data signifies model-simulated seasonal cycles are reasonably phased. In this study we use observations (TMD data) as a baseline for measuring historical performance, while the ensemble medians are used as baseline for multi-model performance measuring in the future.

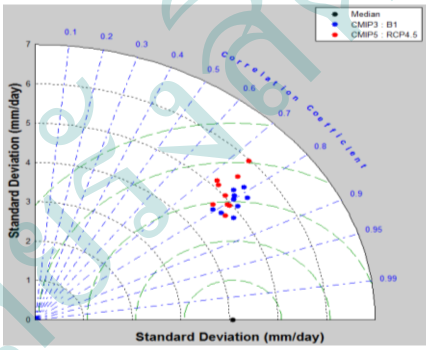
Figure 9 shows Taylor Diagrams of annual mean precipitation for CMIP3 and CMIP5 models. The historical rainfall data over Bangkok is shown in Fig. 9a. It can be seen that both model generations performed reasonably well in capturing the amplitude and phasing of past mean annual precipitation over Bangkok. The correlation coefficient over Bangkok from all models lies between 0.6 – 0.8, implying most of the models simulates the mean rainfall reasonably well. In addition, both model generations have approximately the same standard deviation as the observed, implying similar spatial variability. However, they are different in RMS error. The correlation coefficient for the future periods (Figure 9b-9d) does not change significantly from the historical data. Both CMIP3 and CMIP5 models still simulate the timing of rainfall reasonably well. However, more spatial variability and more RMS error are found for all future periods. Therefore, the past model performance does not guaranteed future results.



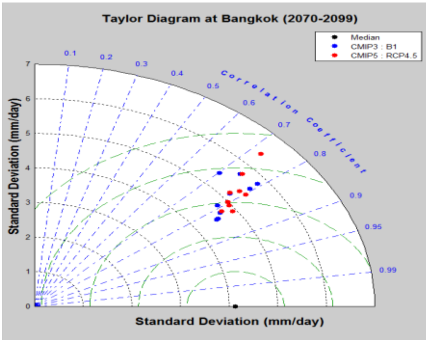
a) The twentieth century(1980-1999)



b) Near future (2010-2039)

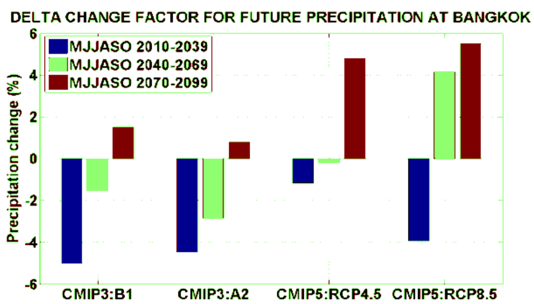


c) Mid. future (2040-2069)



d)Far future (2070-2099)

Figure 9 Taylor diagram of the annual mean precipitation climatology for CMIP3(B1) and CMIP5(RCP4.5)



a) Multi Model Median

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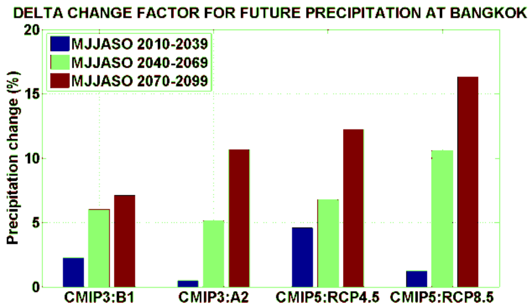

b) Multi Model Mean

Figure 10 Delta change factor of both generations for future mean precipitation at Bangkok.

The future rainfall over Bangkok are analyzed for period 2010-2099 for all scenarios in this study (B1, A2, RCP4.5, RCP8.5). The delta change factor approach was used to indicate the difference between future and reference day climate. The delta change is compiled for seasonal (MJJASO) scale in Fig. 10. It is very interesting to see different results between the use of Muti Model Median and Multi Model Mean. For CMIP3 (B1) model (Figure 10a), the rainfall decreases 5 % and nearly 2% in the near future and the mid. future but increases nearly 2 % in the far future. For CMIP5 (RCP4.5), the rainfall decreases 1% and nearly 0% in the near future and the mid. future but increases nearly 5% in the far future. However, the Multi Model Mean (Fig. 10b), show continuously increased rainfall from 2 % to 7 % for CMIP3 (B1) and from nearly 5% to 12% for CMIP5(RCP4.5). Similar trends are found for CMIP3(A2) and CMIP5 (RCP8.5) models but with different scales. The use of both methods (Multi Model Median and Multi Model Mean) in the historical period does not give significant differences. Reifen and Toumi (2009) recommended the Multi Model Mean for future climate change projection while Kumar et al. (2014) suggested the Multi Model Median. It is still unclear in the present study unless more GCMs are performed through the whole regions in Thailand. The complex terrain and land-sea contrast at Bangkok might contribute to this finding. Further spatial analysis for the whole Thailand will be done in the near future.

5. Flood adaptation

Immediately after the 2011 great flood, several adaptation measures (Figure 11) were proposed. In this study we examined 4 case studies by using the Mike11 model. The 1st case study is the base case of the 2011 flood (Do nothing). The inundation area (for the lower Chao Phaya river) was found approximately 8.8 million Rais (14,080 km^2). The use of 2 million Rais (3,200 km^2) as retention basin in the 2nd case study can reduce the inundation area by 18% or 7.2 million Rais (11,520 km^2). The 3rd case study is the use of east floodway of 1,000 cms capacity. This can reduce reduce the inundation area by 35% or 5.7 million Rais (9,120 km^2). The 4th case study is the use of both floodways (East and west of 1,000 cms per each). This can reduce the inundation area by 42% from the 2011 flood event. Therefore, flood cannot be completely avoided in the central part. The Integrated Flood Management in the Chao phraya considering flood-resilient approach has to be adopted for sustainable future. One of the best practices is to raise the house with open space in the first floor as shown in Figure 12.

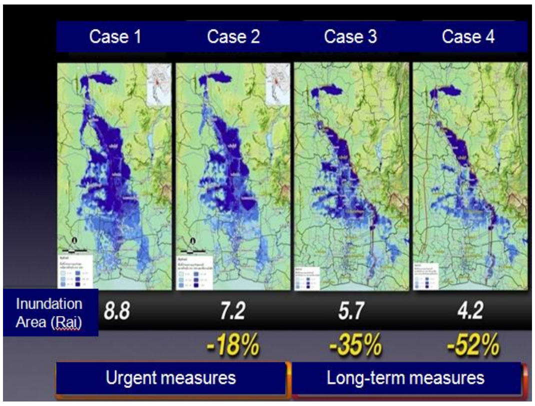

Fig. 11 Adaptation measures

Fig. 12 Raised floor house with open space

6. Conclusions

The 2011 great flood causes tremendous damages to all business sectors including livelihood of Thai people. Official report from the World Bank reveals a figure of US$ 45.7 billion which ranks forth as the world's costliest disaster. In this study, we examine the flood behavior and did lesson learnt, then we look in the future flood risk and flood vulnerability by performing precipitation downscaling and simulating of the flood inundation by hydrodynamic model (Mike 11 and Mike 21 models). The comparison across two generations of the global climate model ensembles CMIP3 and CMIP5, were made through historical twentieth century and future projections. Pairwise were performed for 9 climate models ranging from time series plots and Taylor diagrams. Overall, our results suggest that the performance of CMIP5 models cannot be readily distinguished from of CMIP3 models, although there are clear signals of improvements over Bangkok. Both model generations perform reasonably well in capturing the amplitude and phasing of past mean annual precipitation over Bangkok. The correlation coefficient over Bangkok from all models lies between 0.6 – 0.8, implying most of the models simulates the mean rainfall reasonably well. In addition, both model generations have approximately the same standard deviation as the observed, but more spatial variability and more RMS error are found for all future periods. Therefore, the past model performance does not guaranteed future results. The forecasted precipitation change, in the rainy season, were examined through Multi Model mean and Multi Model median of 9 GCMs. Use of the Multi Model mean show continuously increased rainfall from the near future to the far future. The Multi Model Median shows increased rainfall only for the far future.

Then, we apply a flood simulation model to examine the 2011 flood behavior including conceptual adaptation measures for a changing climate. It was found that several areas in the lower Chao Phraya river basin have to be inundated for 1-2 months.The initial cost of damages was estimated at about 150,000 million baht. Four preliminary adaptation measures are investigated. The 1st case study is the base case of the 2011 flood (Do nothing). The inundation area was found approximately 14,080 km^2. The use of 3,200 km^2 as retention basin in the 2nd case study can reduce the inundation area by 18% or 11,520 km^2. The 3rd case study is the use of east floodway of 1,000 cms capacity. This can reduce the inundation area by 35% or 9,120 km^2. The 4th case study is the use of both floodways (East and west of 1,000 cms per each). This can reduce the inundation area by 42% from the 2011 flood event. Bangkok is still under threat of flooding. The frequency of devastating floods tends to be higher and the loss of human lives and property show increasing sign. In summary, the flood in the Chao Phraya river basin cannot be completely avoided, Therefore, the best practice for high flood risk communities by raising the house with open space in the first floor should be used as one of the flood resilient approach.

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