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Evaluation and Projection of Changes in Temperature over Northern Thailand Based on CMIP5 Models

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Abstract

This study evaluates changes of temperature using the sixth selected statistical downscaling CMIP5 models under the RCP4.5 and RCP8.5 scenarios. The analyses are focused over northern Thailand during the years 1970-2005 to ensure higher reliability in the observations, and during the years 2006-2099 to project future temperature changes. Overall, the selected CMIP5 models reproduce the observed monthly temperatures well with some slightly cold biases. The future projection indicates seasonal warming over northern Thailand. The increases in both projected maximum and minimum temperatures are higher under RCP8.5 scenario compared to that under RCP4.5 scenario.

Keywords: Evaluation; Projection; Temperature; Northern Thailand; CMIP5 Models

1. Introduction

The increase in concentration of global atmospheric greenhouse gases is the main reason for global warming and climate changes. Climate projections and climate change impacts have become an interesting research topic during the recent decades. Several research institutes worldwide have been developing their climate models to simulate the current and future climate across the different greenhouse gas emission scenarios. Recently, the new set of climate model experiments for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) have been available for the public. These experiments called the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (Taylor, Stouffer, and Meehl 2012). The scientific questions that arose during preparation of the IPCC AR4 are expected to be addressed in the CMIP5 model (Taylor, Stouffer, and Meehl 2012). Climate change is also the great interesting topic in Thailand research community. Some of the previous studies have been focused on downscaling the early model experiments of the IPCC AR4 scenarios (Chotamonsak *et al.* 2011; Manomaiphiboon *et al.* 2013). The evaluation and projection of climate changes over northern Thailand, using the updated IPCC AR5 GCM models (CMIP5) are missing in this literature reviewed. However, the latest updated climate change information is required by policymakers for planning and building the community resilience to climate change and variability. In order to mitigate the impacts of temperature changes, we must understand how such changes are manifested at the local to regional scale. Therefore, the downscaled CMIP5 models that have been publicly available through the NASA Earth Exchange (NEX) projects are used in this study. These datasets are derived from the CMIP5 models that have been run across the new greenhouse gas emissions scenarios named the Representative Concentration Pathways (RCPs) (Meinshausen *et al*., 2011). The Bias-Correction Spatial Disaggregation (BCSD) method (Wood *et al*. 2004) is used to generate these datasets. The downscaled resolution is 30 arc-second or about 25 km grid resolution. These downscaled datasets were used for climate change and its impacts studies by researchers worldwide (Ahmadalipour, Moradkhani, and Svoboda 2017; Bao and Wen 2017; Huo-Po, Jian-Qi, and Hui-Xin 2017). The goals of this study are as follows: (1) to evaluate the performance of the downscaled CMIP5 models in reproducing the historical temperature and (2) to project changes of temperature in the future climate over northern Thailand.

2. Materials and Methods

2.1 Study area

The study area of this paper is northern Thailand as shown in Figure 1, where the regional climate is highly influenced by the northeast monsoon and the southwest monsoon. The topography of northern Thailand is complex terrain and is under the effect of the cool air mass caused by the northeast monsoon in cool season during November-February and the hot dry air in summer during March-May. The moist air mass dominates the area by the wind-driven southwest monsoon in rainy season during June-October. Northern Thailand covers 17 provinces and is surrounded by mountain ranges. Because of the geophysical position and complex topography, the North is more vulnerable to climate change compared to other parts in Thailand.

2.2 Data

Observed daily maximum temperatures (Tmax) and minimum temperatures (Tmin) from 31 meteorological stations in the North are obtained from Thai Meteorological Department. The time period of observed data is from the years 1970 to 2005. This observed data is used to evaluate the performance of selected CMIP5 models. The sixth downscaled CMIP5 temperature data are the NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30) dataset (available at https://portal.nccs.nasa.gov/portal_home/published/NEX.html). In this study, the selected downscaling historical climatology and climate projections are obtained from the top sixth CMIP5 models that potentially capture climate variability over the southeast Asia region (Xu *et al*. 2017) and another areas (Jena, Azad, and Rajeevan 2016; Roy 2017) as shown in Table 1. In order to analyze the lowest and highest ranges of temperature changes, the emission scenarios RCP 4.5, a stabilization emission scenario, and RCP 8.5, a highest emission scenario are selected in this study.

2.3 Evaluation methods

To evaluate the performance of the selected downscaled CMIP5 models, the scatter plots with bias and correlation are employed (bias: =S-O , where S and O are simulated and observed long-term monthly mean temperature for the 1970–2005 baseline years. The correlation coefficients are considered to describe the temporal and spatial correlation between the observation and the simulation. In addition, the Taylor diagram technique (Taylor 2001) is also used in order to evaluate the selected CMIP5 models performance, the Taylor diagram is quantified in terms of the correlation (R), the root-mean-square-error (RMSE) and the standard deviations (STDEV). The mean differences between simulated and observed temperature in diagram can be described by RMSE.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(O_{mi}-S_{mi})^2}{n}}$$

where O_{mi} and S_{mi} denote observed and simulated temperature or precipitation, and n is the number of pairs in the analysis.

3.Results and Discussion

3.1 Model evaluations

Figure 2 – 3 display scatter plots of the 6 downscaled CMIP5 model simulations in comparison to the 31 TMD observed stations of Tmax (Figure 2) and Tmin (Figure 3), respectively.

Table 2 shows the performance of downscaled CMIP5 models. Overall, the downscaled climate models reproduce the observed monthly temperature well with a cold bias for maximum and minimum temperatures. This cold bias is strongly model dependent. The correlation coefficients R between each downscaled CMIP5 models and the monthly observation are 0.7-0.8 for minimum temperature and reach to 0.9 for maximum temperature (Table 2). On average northern Thailand, all of the modeled temperatures are colder than the observed, especially for the MIROC5 model which mean bias reaches −0.5 °C. In addition, all models simulated colder biases in minimum temperature than in maximum.

Figure 2 shows the Taylor diagrams for maximum and minimum temperatures compared to the 31 TMD observed temperatures for the 1970-2005 historical climatology. The radial distance from the origin is normalized STD, and the angle indicates the correlation coefficient. The distance from the center is the RMSE. The diagrams show the selected downscaled CMIP5 models capture well with the observed temperatures, the spatial correlation coefficients are 0.7-0.8 for minimum temperatures and 0.9 for maximum temperatures over northern Thailand. The correlation coefficients of IPSL-CM5A-LR 0.8 and MPI-ESM-LR 0.8 show higher performance in the maximum temperature simulation, respectively. Moreover, the normalized STD is better when it closes to a value of one (Taylor 2001). For maximum temperature, the MPI-ESM-LR indicates the highest performance, while the MIROC5 shows the lowest performance in simulating spatial distributions. For minimum temperature, the MPI-ESM-LR denotes the highest performance, while MIROC5 shows the lowest performance in stimulating spatial distributions.

3.2 Projection changes of temperatures in the 21st century

Maximum temperature changes

Figure 5 displays trends of seasonal Tmax changes in northern Thailand compared to 1970-2005 historical climatology. Shaded areas represent the ranges of projected Tmax change by the 6 downscaled CMIP5 models from 2006 to 2099. The model ensemble averages for each RCP are shown with thick lines. Solid lines are the multi-model averages of Tmax under the scenarios RCP4.5 and RCP8.5, respectively. The projected seasonal mean maximum temperatures by the end of the 21st century (mean over 2071-2099) are likely to increase 1.0 - 2.4 °C, 0.2 - 3.7 °C and 0.8 - 3.1 °C under the RCP4.5 and 2.3 - 4.7 °C, 1.8 - 6.1 °C and 1.7 - 4.6 °C under the RCP 8.5 for the rainy, summer, and cold seasons, respectively. The averages of the increase in projected Tmax are expected to be 1.9, 2.0 and 1.9 °C under the RCP4.5 and 3.4, 3.9, and 3.3 °C under the RCP8.5 in the rainy, summer, and cool seasons, respectively. Figure 6 shows the seasonal spatial changes of maximum temperature over northern Thailand under RCP4.5 and RCP8.5 scenarios. The results suggest that the highest warming of the projected maximum temperatures takes place in summer for all analyzed scenarios. The warming in summer and cool seasons is higher than rainy season for both the RCP4.5 and RCP8.5. In addition, there is likely much higher variation on daytime warming under the RCP8.5 compared to the RCP4.5.

Minimum Temperature changes

In general, seasonal minimum temperatures denote higher warming than maximum temperatures for all seasons as shown in Figure 7. The seasonal mean minimum temperatures by the end of the 21st century (mean over 2071-2099) relative to the 1970–2005 base line years over northern Thailand are expected to increase 1.2 - 2.6 °C, 1.5 - 3.4 °C and 1.0 - 3.5 °C under the RCP4.5 and 2.5 - 5.0 °C, 3.0 - 6.2 °C and 2.4 - 5.4

°C under the RCP 8.5 for the rainy, summer, and cool seasons, respectively. The average warmings are likely to be 1.8 °C, 2.4 °C and 2.3 °C under the RCP4.5 and 3.5 °C, 4.6 °C and 4.0 °C under the RCP8.5 in the rainy, summer, and cool seasons, respectively. Seasonal spatial minimum temperatures changes during 2006-2099 relative to the baseline minimum temperatures over the study area under the RCP4.5 and RCP8.6 are displayed in Figure 8. There is likely the lowest variation of projected minimum temperature changes in the rainy season under the RCP 4.5. The highest minimum temperature changes are expected in the cool seasons with the highest variation both under the RCP4.5 and RCP 8.5

4. Conclusions

This study evaluates the performance of the CMIP5 GCMs in reproducing the historical temperature, and project temperature changes in the future climate over northern Thailand using the statistical downscaled CMIP5 models from NASA Earth Exchange (NEX) Downscaled Climate Projections under different emission scenarios (RCP4.5 and RCP8.5). The statistical

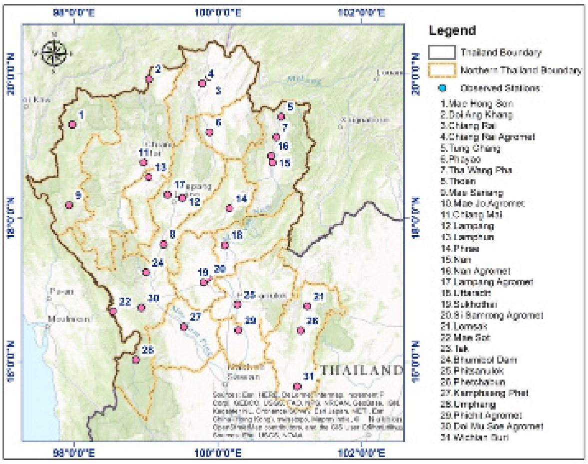

Figure 1. Topography of Northern Thailand, with red dots denoting31 meteorological stations used for model evaluation in this study

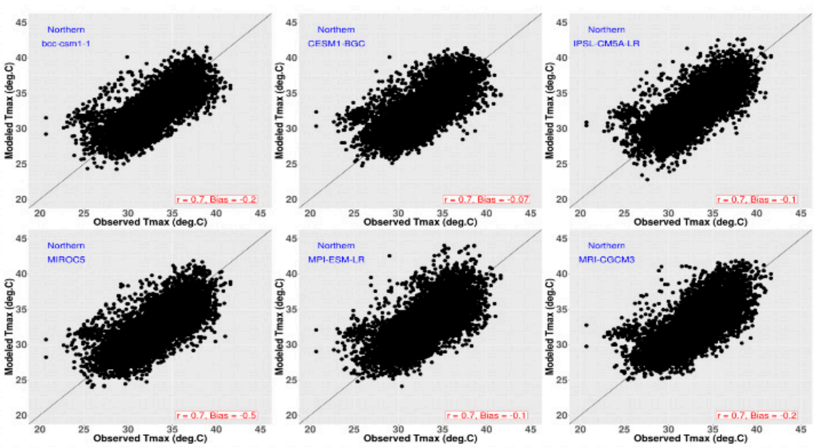

Figure 2. Scattered plots of simulated Tmax from the 6 downscaled CMIP5 models and observed Tmax over northern Thailand.

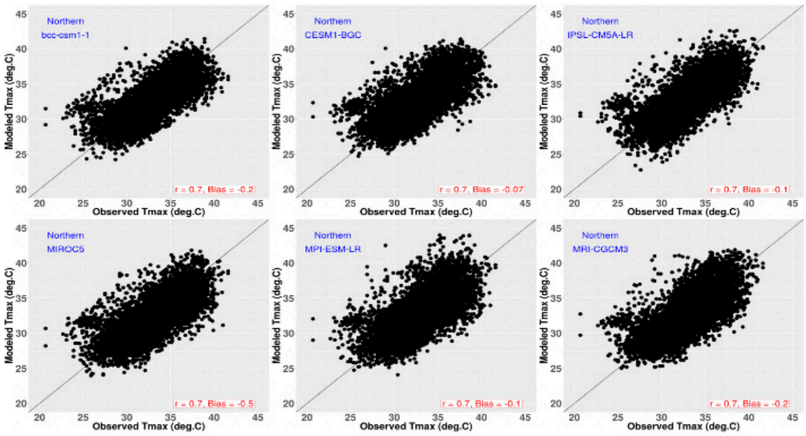

Figure 3. Scattered plots of simulated Tmin from the 6 downscaled CMIP5 models and observed Tmin over northern Thailand.

Table 1. List of 6 CMIP5 models, variables, emission scenarios and analyzed period years

CMIP5 GCMs	Variables	Emission Scenarios	Analyzed Years
bcc-csm-1	Max. Temperature	Historical	1970 – 2005
	Min. Temperature	RCP4.5	2006 – 2099
		RCP8.5	2006 – 2099
CESM1-BGC1	Max. Temperature	Historical	1970 – 2005
	Min. Temperature	RCP4.5	2006 – 2099
		RCP8.5	2006 – 2099
IPSL-CM5A-LR	Max. Temperature	Historical	1970 – 2005
	Min. Temperature	RCP4.5	2006 – 2099
		RCP8.5	2006 – 2099
MIROC5	Max. Temperature	Historical	1970 – 2005
	Min. Temperature	RCP4.5	2006 – 2099
		RCP8.5	2006 – 2099
MPI-ESM-LR	Max. Temperature	Historical	1970 – 2005
	Min. Temperature	RCP4.5	2006 – 2099
		RCP8.5	2006 – 2099
MRI-CGCM3	Max. Temperature	Historical	1970 – 2005
	Min. Temperature	RCP4.5	2006 – 2099
		RCP8.5	2006 – 2099

Table 2. Statistical summary of the comparisons between the 6 downscaled CMIP5 GCMs simulations and observation over northern Thailand for the period 1970–2005.

CIMIP5	Tmax			Tmin		
GCMs	R	AE	RMSE	R	AE	RMSE
BCC-CSM-1	0.7	-0.2	1.7	0.9	-0.4	1.62
CESM1-BGC1	0.7	-0.1	1.83	0.9	-0.3	1.78
IPSL-CM5A-LR	0.8	-0.1	1.8	0.9	-0.3	1.72
MIROC5	0.7	-0.5	1.81	0.9	-0.5	1.8
MPI-ESM-LR	0.8	-0.1	1.97	0.9	-0.2	1.71
MRI-CGCM3	0.7	-0.2	1.9	0.9	-0.3	1.71

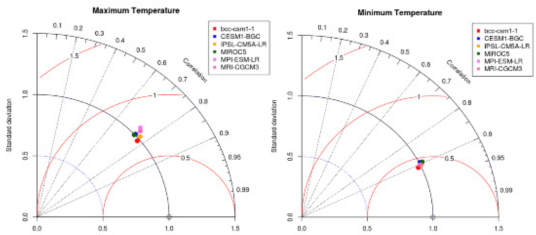

Figure 4. Taylor diagrams for temperature, comparing TMD observed temperatures with CMIP5 simulated temperatures over northern Thailand for the period 1970 – 2005.

measures used to quantify the performance of the downscaled CMIP5 GCMs are biases, correlation coefficient R; and root-mean-square error (RMSE). The Taylor diagram is also considered in order to evaluate the selected CMIP5 models ensemble performance. The simple linear regression is employed to assess the temperature changes over the 21st century. Projected temperature changes are evaluated for the rainy, summer and cool seasons by comparison of the future projection and the baseline temperatures. Most of the downscaled CMIP5 GCMs slightly underestimate the monthly Tmax and Tmin over the study area. The correlation coefficients between each model simulation and the monthly observation are 0.7-0.8 for minimum temperature and reach 0.9 for maximum temperature. There is a dramatically increasing trend to the 21st century for temperature under the RCP4.5 and RCP8.5 scenarios. The future projections show the seasonal warming in temperature over northern Thailand. The average increases in maximum temperatures are 1.9, 2.0 and 1.9 °C under the RCP4.5 and 3.4, 3.9 and 3.3 °C under the RCP8.5 in rainy, summer, and cool season, respectively. The average increases in minimum temperatures are 1.8 °C, 2.4 °C and 2.3 °C under the RCP4.5 and 3.5 °C, 4.6 °C and 4.0 °C under the RCP8.5 in rainy, summer, and cool season, respectively.

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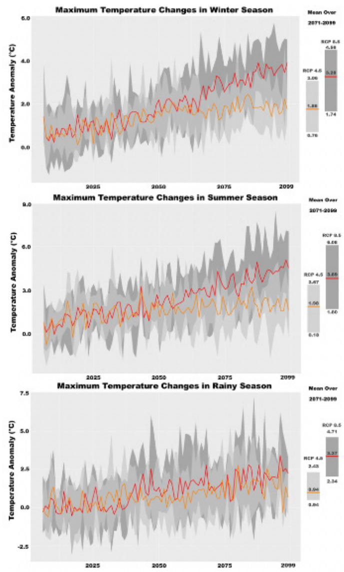

Figure 5. The 6 downscaled CMIP5 model time series of maximum temperature anomalies for the entire northern Thailand from the 2006-2099 relative to the 1970 – 2005 baseline for the RCP4.5 and RCP8.5 scenarios

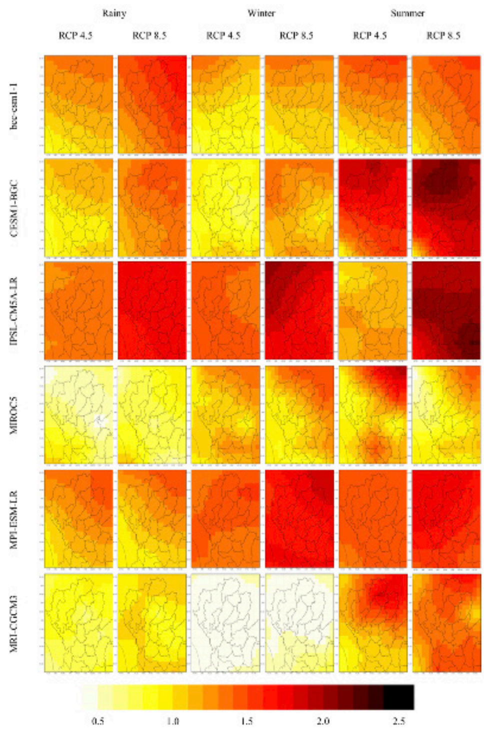

Figure 6. The seasonal spatial changes (the 2006-2099 relative to the 1970 – 2005 baseline) of maximum temperature over northern Thailand under RCP4.5 and RCP8.5 scenarios.

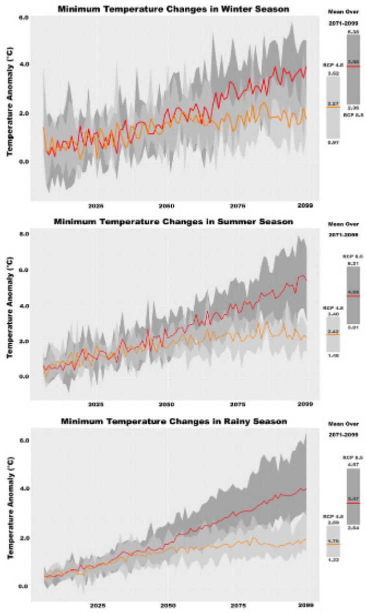

Figure 7. The 6 downscaled CMIP5 model time series of minimum temperature anomalies for the entire northern Thailand from the 2006-2099 relative to the 1970 – 2005 baseline for the RCP4.5 and RCP8.5 scenarios.

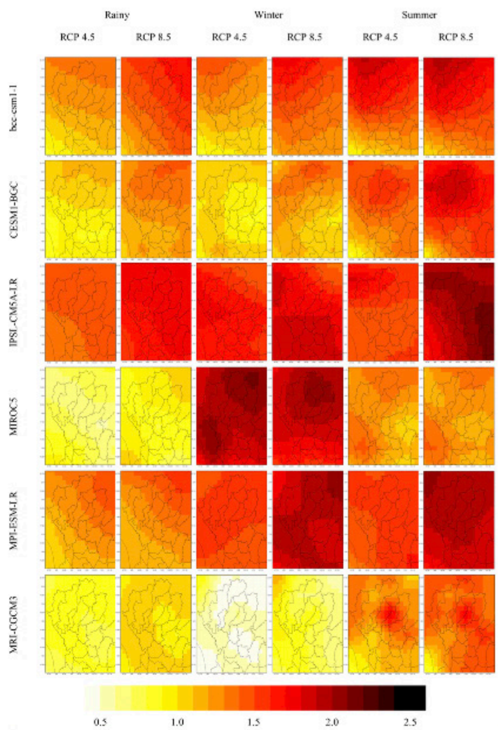

Figure 8. The seasonal spatial changes (the 2006-2099 relative to the 1970 – 2005 baseline) of minimum temperature over northern Thailand under RCP4.5 and RCP8.5 scenarios.

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