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Research article

Impacts of Climate Change and Regional Variations on Future Rainfall Patterns in Thailand by Downscaling Method

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Abstract: In this study, we investigated the impacts of climate change on rainfall patterns in Thailand using the downscaling method. The simulation data was obtained from the Weather Research and Forecasting (WRF) model, using the Community Earth System Model (CCSM) as a boundary condition. The characteristics of rainfall were analyzed in terms of the total annual rainfall, rainfall intensity, the number of days with heavy rain, and the total amount of rainfall in each season in the future compared to the base periods. It was found that the simulation of the climate in upper Thailand was consistent with the reanalysis values, with TCC ranging from 0.6 to 0.9. The simulated annual rainfall amount is underestimated throughout the country. There are indications that rainfall will increase in average and extreme terms in some regions, including the eastern region of the Northeast, the western side of the North, and the upper part of the West. In the southern part of the country, the overall rainfall indices are expected to decrease with low confidence in almost the entire region.

Keywords: WRF model; CCSM; Climate simulation; Rainfall in Thailand; Dynamical downscaling

1. Introduction

Nowadays, many studies provide evidence to support the conclusion that the global climate is changing [1-3]. Numerous studies confirm that global temperatures have risen from the past to the present, and this trend is expected to continue in the future [4–7]. A rise in temperature increases the air's ability to hold water, increasing atmospheric water vapor. The higher storm moisture content results in stronger storms and more severe flooding. Surface heating increases evaporation, which leads to a drier soil surface. This, in turn, can increase the risk of severe and prolonged drought [8].

One interesting topic is the response of rainfall characteristics to climate change, which can vary from region to region. Simulation of the climate using a climate model is an effective tool for studying future climate change. The capability of climate simulation is often evaluated by comparing the outputs of past simulations with observational data. Global climate changes have been simulated using Global Climate Models (GCMs) by numerous renowned climate research organizations. The outputs from the GCMs are too coarse and unsuitable for regional climate change studies. One commonly used approach to improve the resolution of the output is dynamical downscaling using regional climate models (RCMs). RCM simulation utilizes geographical data and GCM output as lateral boundary data to process and obtain an output with sufficient resolution for studying climate at a regional scale. GCMs and RCMs are computational models that employ the principles of fluid dynamics and thermodynamics to calculate the rates of change in various physical attributes, including water vapor, heat, cloud water, temperature, and carbon.

The Intergovernmental Panel on Climate Change (IPCC) has released a statement on the projection of carbon dioxide concentrations. In the Fifth Edition of the Climate Report, the projection of greenhouse gas concentrations under various conditions was referred to as the Representative Concentration Pathway (RCP2.6, 4.5, 6.0, and 8.5) [9]. The numbers at the end of each RCP (2.6, 4.5, 6.0, and 8.5) represent the concentrations in 2100 relative to the pre-industrial level. Therefore, RCP8.5 is considered the worst-case scenario. A new set of climate scenarios has been developed concerning the sixth IPCC report [10]. The scenarios are indicated as SSPx-y, where 'SSPx' refers to the shared socio-economic pathway (SSP1, SSP2, SSP3, and SSP5), describing the socio-economic trends underlying the scenario, and 'y' denotes the approximate level of radiative forcing resulting from the scenario in the year 2100. There are five main scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5).

Changes in the future climate, as predicted by different models and projection pathways, yield different outputs. The average precipitation may both increase and decrease [11]. The increased heat and humidity results in more precipitation under the RCP4.5 and RCP8.5 projections [12]. An increase in precipitation was observed in both intensity and frequency in almost all East Asian areas under the RCP4.5 projection [13]. Long-term climate projection at high resolution for Southeast Asia at 20x20 km resolution up to the end of the 21st century using a regional climate model from the Hadley Centre based on datasets from the ECHAM4 under the A2 GHG emission scenario was simulated by Chinvanno et al. [14]. Results show that precipitation tends to fluctuate in the first half of the century but shows an increasing trend with higher intensity, which will be seen in the latter half. Maijandee et al. [15] studied the extreme rainfall index in Thailand using the output from the MM5-RCM model. The raw outputs from the MM5-RCM were adjusted using the direct method to reduce biases. The study results suggest that most regions in the North, West, and Northeast will experience an increase in rainfall during the rainy season and a decrease in rainfall during the dry season. The central and eastern regions may experience decreased rainfall during the rainy season and increased rainfall during the dry season. The number of consecutive rainy days for the southern region tends to decrease on the Andaman side and increase on the southeast coast. The predicted extreme precipitation during 2020–2029 relative to 1990–1999 in Thailand under RCP8.5 has been examined using the simulation of the NRCM based on the WRF model forced by the Community Climate System Model version 4 (CCSM4) [16]. The study indicates an increasing pattern of annual precipitation levels in northern Thailand, while significant decreasing trends are projected for the eastern region. A remarkable rising trend in the simple daily intensity index (SDII) is predicted, with statistically significant increases ranging from 5% to 20%. Projected changes in the means and extremes of precipitation over Thailand were discussed under the A2, A1B, and B1 emission scenarios [17]. There is a prediction of a shift to drier conditions over the Central-East and South sub-regions in every season under all scenarios. The projected changes in rainfall over Thailand for the early (2011–2040), middle (2041–2070), and late (2071–2099) periods under the RCP4.5 and RCP8.5 were examined using the high-resolution multi-model simulations from the Coordinated Regional Climate Downscaling Experiment (CORDEX) [18]. The ensemble means of rainfall changes for both RCPs during dry months reveal a clear contrast between the northern-central-eastern and southern parts of Thailand, which generally experience wetter and drier conditions, respectively. In contrast, it is projected that generally drier conditions will prevail throughout the country during the wet season (June to September) for both RCPs. Masud et al. [19] analyzed 24 extreme weather indices in Northern Thailand. The observation data used included the maximum and minimum temperatures and the daily precipitation data from 1960 to 2010. HadCM3 and PRECIS were used as GCM and RCM models, respectively. Climate modeling for 1960–2100 was conducted using the statistical downscaling method. The result shows an insignificant decrease in total annual rainfall, but it is anticipated that annual rainfall will increase in the future compared to the base period. Based on the findings of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), there is anticipated to be an elevation in precipitation levels in regions situated at high latitudes, the equatorial Pacific, and certain areas within the monsoon regions. Conversely, a reduction in precipitation is expected in certain parts of the subtropics and the limited regions within the tropics [10].

Rainwater is an important source of water in Thailand. It is important for agriculture, especially crops that rely on rainfall for growth. The country's agriculture is predominantly seasonal. Variations in rainfall patterns can lead to decreased quantities and quality of agricultural products. Dramatic changes in rainfall patterns, such as increased or decreased rainfall, might lead to more frequent and severe floods and droughts. Drought has resulted in farmers being unable to grow crops effectively. Flooding has caused significant damage to the country. These incidents result in losses that harm the economy, national development, quality of life, population health, and ecological balance. Rainfall change data is valuable for planning in various sectors, including agriculture, water management, tourism, public health, and business development.

In this research, we simulated the responses of rainfall characteristics to climate change in Thailand. The downscaling method was used. The regional climate model used is the WRF model. The GCM output is obtained from CCSM4 as boundary data.

2. Materials and Methods

The simulation domain is Thailand, and double-nested domain experiments were conducted. The two domains are indicated in Figure 1. Two periods were selected for simulation to study the changes in rainfall: the base year (1990-1999) and the future years (2020-2029). The simulation was obtained from the Weather Research and Forecasting Model (WRF) version 3.8.1, developed by the National Center for Atmospheric Research (NCAR). The forcing data is from the Community Climate System Model (CCSM), a coupled climate model for simulating the Earth's climate system with components representing the Earth's atmosphere, ocean, land surface, and sea ice [20]. CCSM4 is a subset of CESM1 (The Community Earth System Model). The dataset is also available from NCAR's CISL Research Data Archive (http://rda.ucar.edu/datasets/ds316.0).

The CESM dataset. CESM data has an intermediate file format ready to be imported into the model. The projection used to simulate future rainfall is RCP6.0. The physics options used in WRF include the Kain-Fritsch (new Eta) scheme [21–22] for the Cumulus option, the Monin-Obukhov Similarity scheme [23] for the Surface-layer option, the Noah Land-Surface Model [24] for the Land-surface option, the WRF Single-Moment (WSM) 3-class simple ice [25] for the Microphysics Schemes, the YSU scheme [26] for the Boundary-layer option, the RRTM Radiation [27] for Longwave Radiation, and the Dudhia scheme [28] for Shortwave Radiation.

Most of the parameters chosen for analysis, except the cumulus option, are commonly employed in climate simulations in Southeast Asia [29–32]. For the cumulus option, the author selected the Kain-Fritsch (new Eta) scheme for this study to present an alternative simulation perspective, as several studies have shown that this scheme is also suitable as a good option and has been used in Thailand climate simulation as well [33–34].

The initial 3-month (October–December of 1898) period is designated a spin-up period, and the outputs during this period are not included in the analysis. To evaluate the performance of the WRF simulation, the output with a 20 km grid spacing resolution for the base-year period was compared to the reanalysis data. The temporal correlation coefficients (TCC) between observations and simulations are calculated and used to quantify the performance of RCMs [35]. The correlation coefficient is a quantity that gives the quality of a least squares fit to the original data. This operator correlates each gridpoint of two fields over all timesteps [36].

The characteristics of Thailand's rainfall are analyzed in terms of the total annual rainfall, rainfall intensity (the amount of rainfall per rainy day), the number of days with heavy rain (the days with rainfall exceeding 20 mm in a year), and the average total rainfall in each season. The changes in rainfall are indicated by the annual average percentage change in the future year compared to the base year.

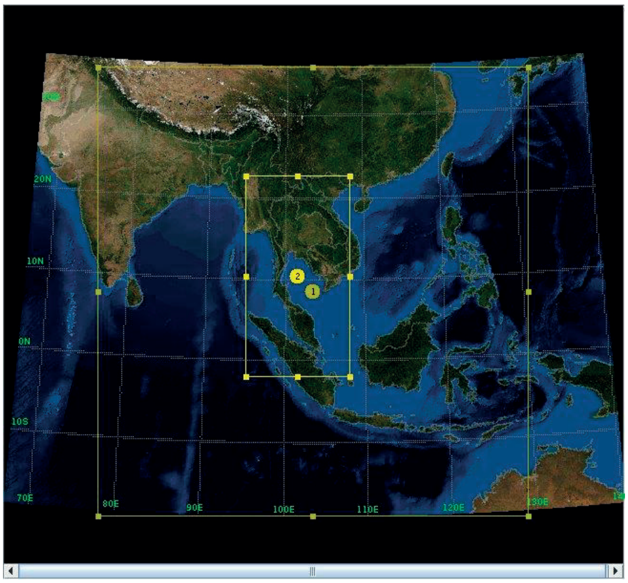

Figure 1. Shows the study domain.

3. Results and Discussion

3.1 Evaluation of the model

3.1.1 Temporal Correlation Coefficient (TCC) between simulation and reanalysis data

Figure 2. shows the temporal correlation coefficient, which is a variable that indicates the temporal relationship between the model results and the reanalysis values in the base year. The model results were correlated with the observational values, with TCC ranging from 0.18–0.9. The climate simulation in upper Thailand yielded consistent results with the reanalysis data, showing TCC values ranging from 0.6 to 0.9. The simulation revealed temporal inconsistency in the model values, particularly in the southern region and certain parts of the eastern region, specifically Chonburi and Rayong province, with low TCC values ranging from 0.18 to 0.5. Temporal inconsistencies in Southern Thailand are not unexpected due to the region's climate, characterized by high temporal and spatial variability, particularly regarding rainfall.

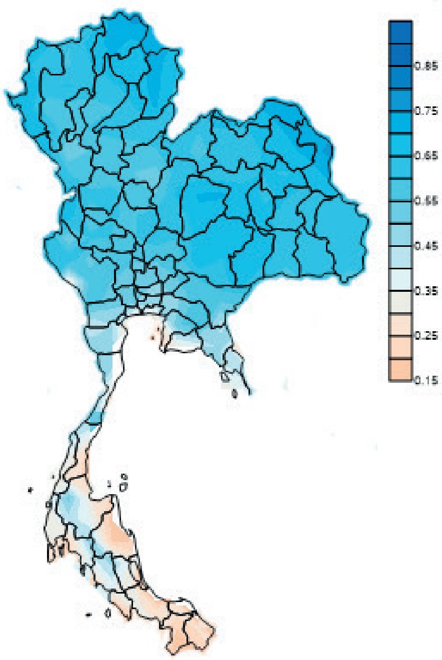

Figure 2. Shows TCC Between simulation and reanalysis data.

3.1.2 Rainfall Distribution from Simulation and Reanalysis Data

Figure 3 shows that the model can simulate high rainfall areas well, especially in the southern, western, and eastern regions of the Northeast. However, the simulated rainfall is significantly lower than the observed values for the entire country, especially in the Southern region.

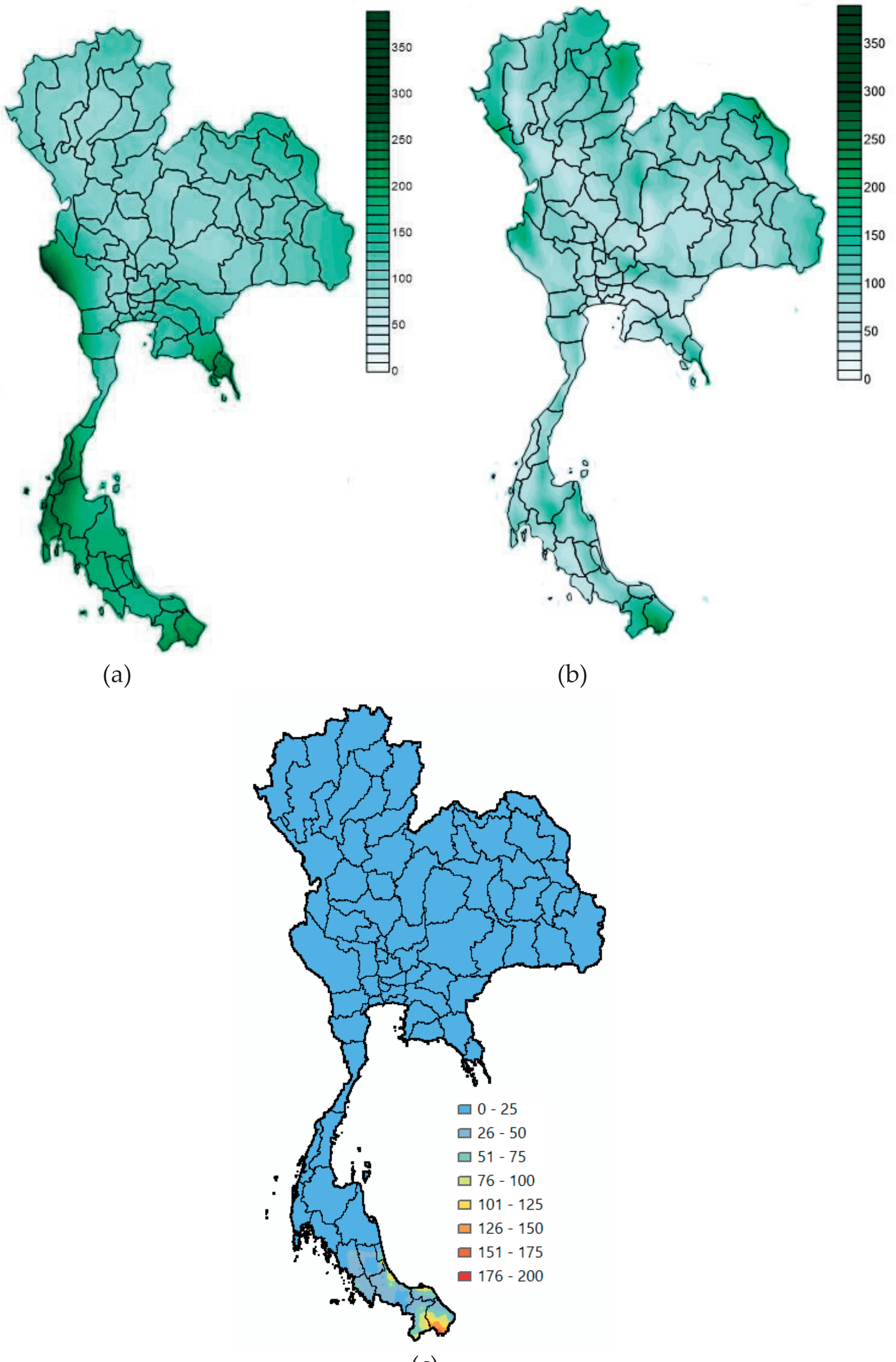

Figure 3. Shows the average annual rainfall (in cm) during the base-year period of 1990–1999, derived from reanalysis data (a) and the output of the WRF simulation (b), and (c) the difference between the two datasets utilizing the IDW technique.

3.2 Projection of Future Rainfall Changes

3.2.1 Projection of changes in the average total annual rainfall.

As shown in Figure 4., more annual rainfall is expected in the lower central, upper West, and eastern regions of the Northeast. Most areas in the Northeast, East, and South may experience a decrease in rainfall. There is an expectation that the northern part of the western region and the western part of the North, which are adjacent to the Thongchai mountain range, will experience an increase in average annual rainfall in the future.

3.2.3 Projection Changes in Rainfall Intensity on a Rainy Day

Figure 5. shows the intensity of rainfall on rainy days. The index is frequently analyzed to assess extreme climate conditions. According to the simulation results, it can be seen that most areas in the upper part of Thailand are likely to experience heavier rainfall. The eastern part of the Northeast and the western and northwestern regions are expected to experience an increase in both total annual rainfall and rainfall intensity. In the future, it is predicted that almost all regions in the south, which currently receive a particularly large amount of rainfall, will experience a decrease in rainfall intensity.

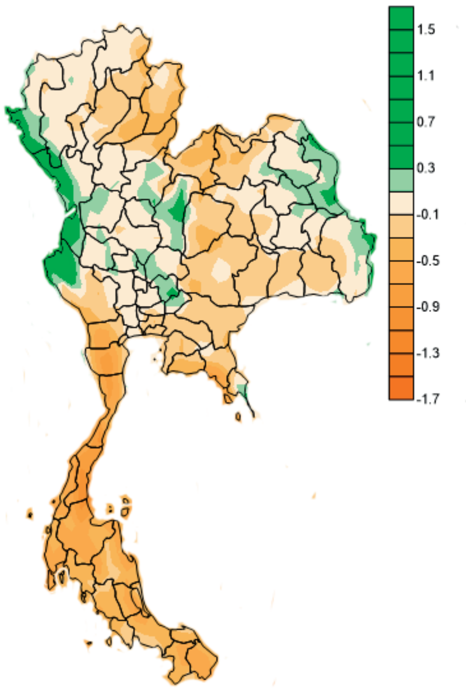

Figure 4. Shows the projected changes in average total annual rainfall in percentage.

As shown in Figure 4, it is evident that most regions in the country are expected to experience decreased precipitation. This could be attributed to the elevated average rainfall during the reference period (1990-1999). There was a noticeable rise in summer rainfall after the mid-1990s. According to the study by Faikrua et al. [37], most of Thailand experienced increased summer precipitation after 1994. The possible causes of this phenomenon are cyclonic anomalies over the Indochina Peninsula in the lower troposphere and the stronger ascending motion of local Hadley circulation over eastern Thailand after 1994.

The increase in rainfall intensity on a rainy day in upper Thailand follows Teerachai's result, in which a remarkable rising trend of annual SDII in 2020–2029 relative to 1990–1999 is observed in the simulation using RCP 8.5 [16].

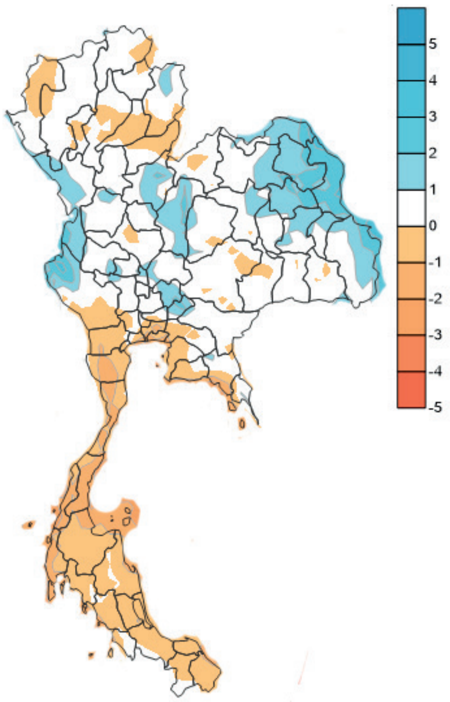

Figure 5. Shows the projected changes in average rainfall intensity on a rainy day in percentage.

3.2.3 Projection changes in the number of days of heavy rain

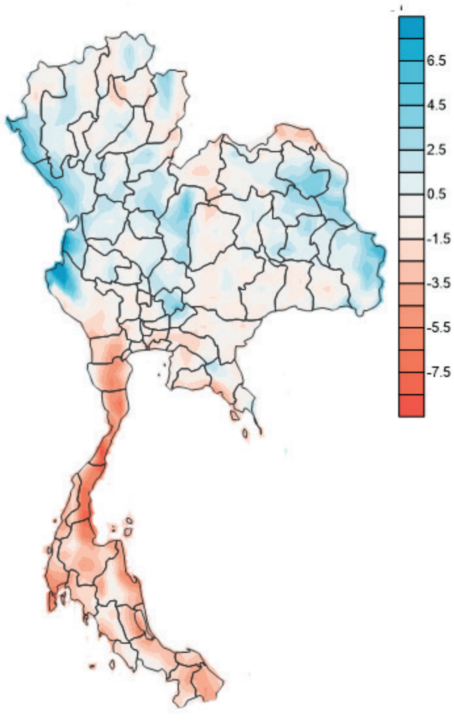

Figure 6. Shows the projected changes in the number of days with heavy rainfall in percentage.

Figure 6 shows that the number of heavy rainfall days is generally increasing in most parts of the upper country, especially in the northern, northeastern, and central regions. On the contrary, the southern region is expected to experience a decreasing trend in the number of days with heavy rainfall. The change in the number of heavy rain days ranges from -8 to 7 percent.

3.2.4 Changes in Seasonal Rainfall

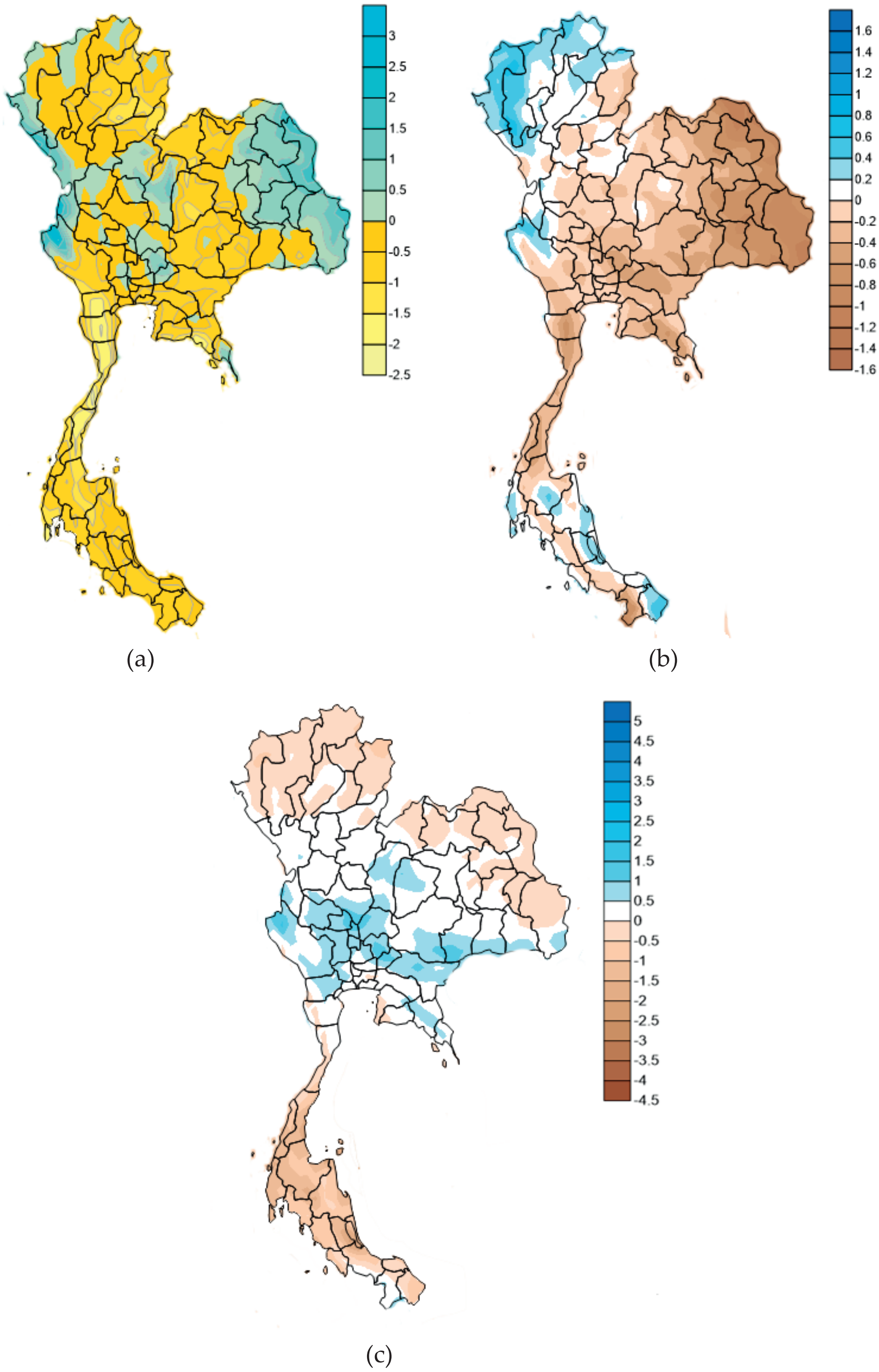

Figure 7. Shows the projected changes in seasonal rainfall in percentage during (a) the rainy season (June to September), (b) summer (March to May), and (c) winter (October to February).

The average rainfall pattern during the rainy season is similar to yearly rainfall. This season's rainfall increase is expected in some parts of the North, West, Central, and Northeast regions. Figure 7(b) shows that most areas will receive less summer rainfall, especially in the Northeast and east. An increase in summer rainfall is also observed in some parts of the northern, western, and southern regions. A projected change in winter rainfall in most areas in the upper part of the country ranges from -0.5 to 1 percent. The southern part of the country has experienced a more significant decrease in rainfall than other regions.

Some of the findings from this study are consistent with the research conducted from the ensemble means of projected changes in rainfall for RCP4.5 and RCP8.5 by Tangang et al. [18]. The results show a distinct contrast between the northern-central-eastern parts and the southern parts of Thailand, with generally wetter and drier conditions, respectively (during dry months), while generally drier conditions are projected during the wet season (June to September) throughout the country.

In general, there is a decrease in rainfall across most regions of Thailand. This finding may differ from the results in earlier research. For example, according to Arpornrat et al. [33], the average southwest monsoon rainfall in Thailand is expected to increase by the end of the century. Chotamonsak et al. [29] suggested that there will be overall increases in precipitation, with some local decreases during the dry season. Additionally, Chinvanno et al. [14] stated that precipitation will likely fluctuate in the first half of the century, with higher rainfall expected across the region in the latter half. However, the experiments are climate simulations under different conditions (models, periods, RCP, etc.). The decrease in rainfall has also been published in several studies. For example, an annual precipitation total decline (PRCPTOT index) has been observed in eastern Thailand in WRF simulation under RCP 8.5 [16]. Additionally, CORDEX-SEA simulations at 25 km spatial resolution under RCP4.5 and 8.5 have shown a decrease in annual precipitation over most of the SEA region by the end of the 21st century [18]. According to Manomaiphiboon et al. [38], while there are no substantial changes in average precipitation in the upper sub-regions, less rain is expected for the South in most seasons in the mid-21st century years simulation under IPCC A2, A1B, and B1 scenarios.

4. Conclusions

Climate change is a phenomenon that affects many different fields and has been investigated for decades. Many studies have found that this phenomenon affects rainfall characteristics in various regions. This research analyzed the response of rainfall to climate change in Thailand. The results of the CESM model with RCP 6.0 emission assumptions were used. The output from the CESM model was dynamically downscaled using the WRF regional climate model to increase the resolution. Two periods were selected for simulation to study the changes in rainfall: the base year (1990-1999) and the future years (2020-2029). Results from the simulation in the base year are evaluated by comparing them to the reanalysis data, which represents the observed data. The evaluation found that the simulation of the climate in upper Thailand was consistent with the reanalysis values. The TCC values indicate low temporal consistency with the reanalysis, ranging from 0.18 to 0.5 in the South, a region characterized by high rainfall variability. WRF can simulate rainy areas well, but the amount of rainfall is underestimated compared to the observed value. However, lower values may not impact the projected changes in rainfall because the simulated changes are based on comparing two data sets, both of which have underestimated values.

The projections indicate that some parts of the upper and most parts of the south of the country will probably experience a decrease in rainfall annually and seasonally, particularly during the summer. There are indications that rainfall will increase in both average and extreme conditions, such as total annual rainfall, rainfall intensity, and the number of days with heavy rainfall, in some regions, including the eastern region of the Northeast, the western side of the North, and the upper part of the West. These regions receive more rainfall than other parts of the country, and there will likely be an increase in both the frequency and intensity of rainfall. The area of interest is the southern part of the country, where the overall rainfall indices are expected to decrease annually and seasonally, except for some areas where summer rain is expected to increase. However, considering the evaluation, confidence in the simulations in this area is low.

The results from this simulation are quite different from those of our previous research [15]. This difference may be attributed to the utilization of different models and options. Multiple studies indicate that in the future, rainfall in Thailand is likely to fluctuate, with both increases and decreases. The results depend on the simulation conditions, the model used, the different model options, and the study period. The numerous factors that affect rainfall simulation make it really challenging to obtain accurate simulation values. To utilize the simulation data, users must be aware that the output of simulations inevitably contains discrepancies. The application of simulation results should be studied through extensive research and requires prior knowledge and understanding before implementation.

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