



# Projection of the Precipitation Extremes in Thailand Under Climate Change Scenario RCP8.5

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This study explores the predicted extreme precipitation during 2020–2029 in Thailand, using the output of the nested regional climate model (NRCM) with the Representative Concentration Pathway (RCP) 8.5 emission scenario. The research used five different extreme precipitation indices, i.e., annual precipitation total (PRCPTOT), the annual number of rainy days (RD), simple daily intensity index (SDII), consecutive dry days (CDDs), and consecutive wet days (CWD). The PRCPTOT was generally located in eastern Thailand, with significant declining trends, while the increasing trend was found in northern Thailand. The quantity of the PRCPTOT varies marginally from 100 to 200 mm per decade. The annual RD was influenced mostly by the negative trends in Thailand. A remarkable trend is a rising of annual SDII, with major statistical increases ranging from 5 to 20%. A widespread decline in CWD was found in most regions. The statistically significant pattern of CWD has been geographically concentrated in the northern, southern, and eastern regions of Thailand. Southern Thailand continues to decline by –10 to –30%. A drastic decline has been observed in the south of Thailand. Projected interannual precipitation variability shows that December–January–February (DJF) variability will be greater than either annual or June–July–August (JJA) variability in most years, with the exception of 2022, 2025, and 2026, in which the JJA variability will be greater than both the annual variability and the DJF variability.

**Keywords:** precipitation, extreme events, climate change, Thailand, climate extreme

## INTRODUCTION

Precipitation is an important factor in the hydrological cycle. It is one of the most important variables affecting life and human well-being because precipitation change can cause consequences to both the environment and the human society (Pielke and Downton, 2000; Trenberth et al., 2003; Barretta and Santos, 2014; Guan et al., 2014). During the last decades, it has become apparent that, during anthropogenic climate warming, the intensity and the frequency of extreme precipitation events increase, consecutively (Allan and Soden, 2008; Min et al., 2011; Coumou and Rahmstorf, 2012; Donat et al., 2013). Recently, the research focusing on extreme precipitation events has increased in the tropics and subtropics. For example, Endo et al. (2009) expressed that rainfall severity has increased over time. Goswami et al. found that, in the monsoon seasons from 1951 to 2000, the intensity and strength of the extremes in the precipitation events in India increased. An

analysis of daily rainfall data across the Philippines between 1951 and 2010 demonstrated that the frequency and the severity of the extreme rainfall events substantially increased (Cinco et al., 2014). Also, the information from regional workshops shows that the patterns in precipitation extremes vary regionally and are not uniform across Southeast Asia to Arab regions (Choi et al., 2009; Caesar et al., 2011; Donat et al., 2014).

In Southeast Asia, the future of the precipitation extremes was predicted using the output from CORDEX-SEA simulation with 25-km grid spacing under emission scenarios of RCP4.5 and 8.5 at the end of the twenty-first century. Their results indicate that changes in extreme indices are more pronounced and cover a wider area under RCP8.5 than RCP4.5, with the most significant change in consecutive dry days (CDD) (Tangang et al., 2020). However, in order to support decision-making in relation to agriculture, water resources, and disasters in the near future, the study of precipitation extremes, using the fine resolution of climate change output, is required. In this study, we used the output from the simulation of the nested regional climate model (NRCM) with 10-km grid spacing under climate change scenario RCP8.5 for input data in the precipitation extreme indices, including annual precipitation total (PRCPTOT), the annual number of rainy days (RD), simple daily intensity index (SDII), consecutive dry days (CWD), and CDD, for studying the precipitation extremes in Thailand during the period 2020–2029.

## MATERIALS AND METHODS

To analyze the precipitation extreme, the output from the simulation of the NRCM was used as input data in five extreme precipitation indices that were suggested by the World Meteorological Organization (WMO)–Commission for Climatology (WMO–CCI), the World Climate Research Programme (WCRP), The Climate and Ocean: Variability, Predictability and Change (CLIVAR), and The Expert Team on Climate Change Detection and Indices (ETCCDI) projects, namely, annual PRCPTOT, the annual RDs, SDII, CDD, and CWD (Zhang et al., 2011).

### General Information of Nested Regional Climate Model Configurations

The data used in the simulation of the NRCM are based on Amnuaylojaroen and Chanvichit, 2019 and Amnuaylojaroen et al., 2021. The output from the NRCM, with resolution of 10-km grid spacing under the RCP8.5 scenario, was used for both time periods of 1990–1999 and 2020–2029. The NRCM is based

on the Weather Research and Forecasting (WRF) model and has been forced by the Community Climate System Model version 4 (CCSM4) for meteorological initial and boundary conditions (Gent et al., 2011; Done et al., 2013; Bruyère et al., 2017). In the model configuration, the interaction between land and ocean estimating oceanic parameters using the Price–Weller–Pinkel (PWP) model (Price et al., 1986). The PWP model is an oceanic mixing layer model that accounts for the oceanic mixing layer convection change and oceanic shear stability. It was created in the HYbrid Coordinate Ocean Model (HYCOM) (Chassignet et al., 2007) model for vertical mixing. Other model configurations were set up similar to the one set up by Amnuaylojaroen et al. (2018). The feedback and the evolution of the aerosol in the atmosphere were carried out through the Rapid Radiative Transfer Model for General Circulation (RRTMG). In this model, feedback is taken from aerosols on meteorological processes under the Thompson scheme (Thompson et al., 2004). Grell-3 and the Noah Land Surface Model were responsible for sub-grid scale calculation and the interaction between land and atmosphere in the model (Chen and Dudhia, 2001). Grid nudging was also applied precisely to provide large-scale meteorology (Stauffer and Seaman, 1990).

### Performance of Nested Regional Climate Model

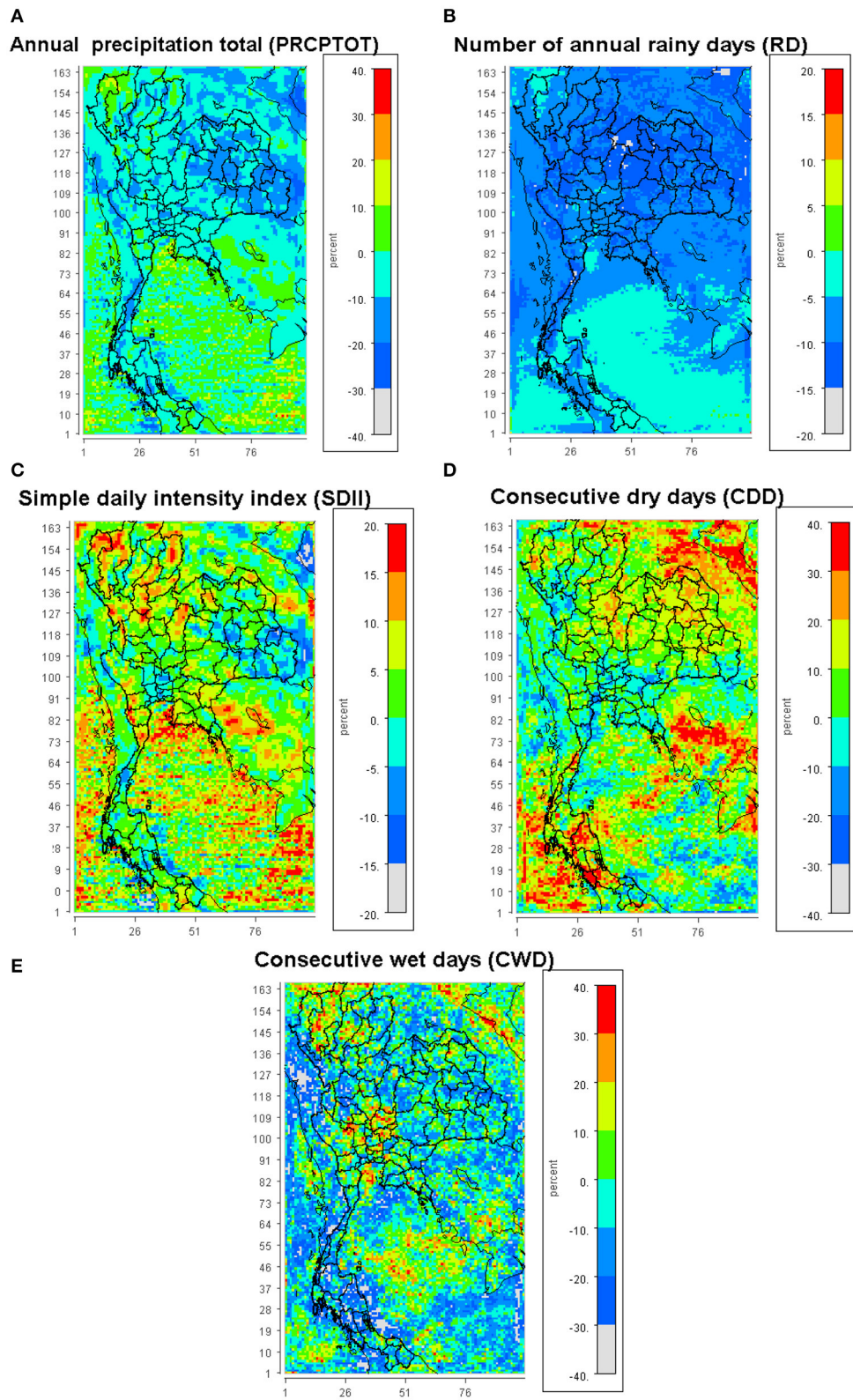
The good performance of the NRCM was shown by statistical analysis, i.e., index of agreement (IOA), mean bias (MB), SD, and R-square ( $R^2$ ), in a study by Amnuaylojaroen and Chanvichit (2019). The statistical calculations between the model data and the observed data (TMD, GPCP, and APHRODITE) are averaged over 1990–1999 from 44 station locations of TMD annually and for the rainy season and the dry season, as shown in **Table 1**. The model has a high ability to capture precipitation that is indicated by R-squared values, ranging from 0.94 to 0.97. Similar to R-squared, IOA values were in the range of 0.60–0.68 in the annual precipitation. In the dry season and in the rainy season, the modeled precipitation was underestimated as compared with observations with an MB ranging from –3 to –2 mm. The SD of the residuals of the model is 2–3.

## RESULTS AND DISCUSSION

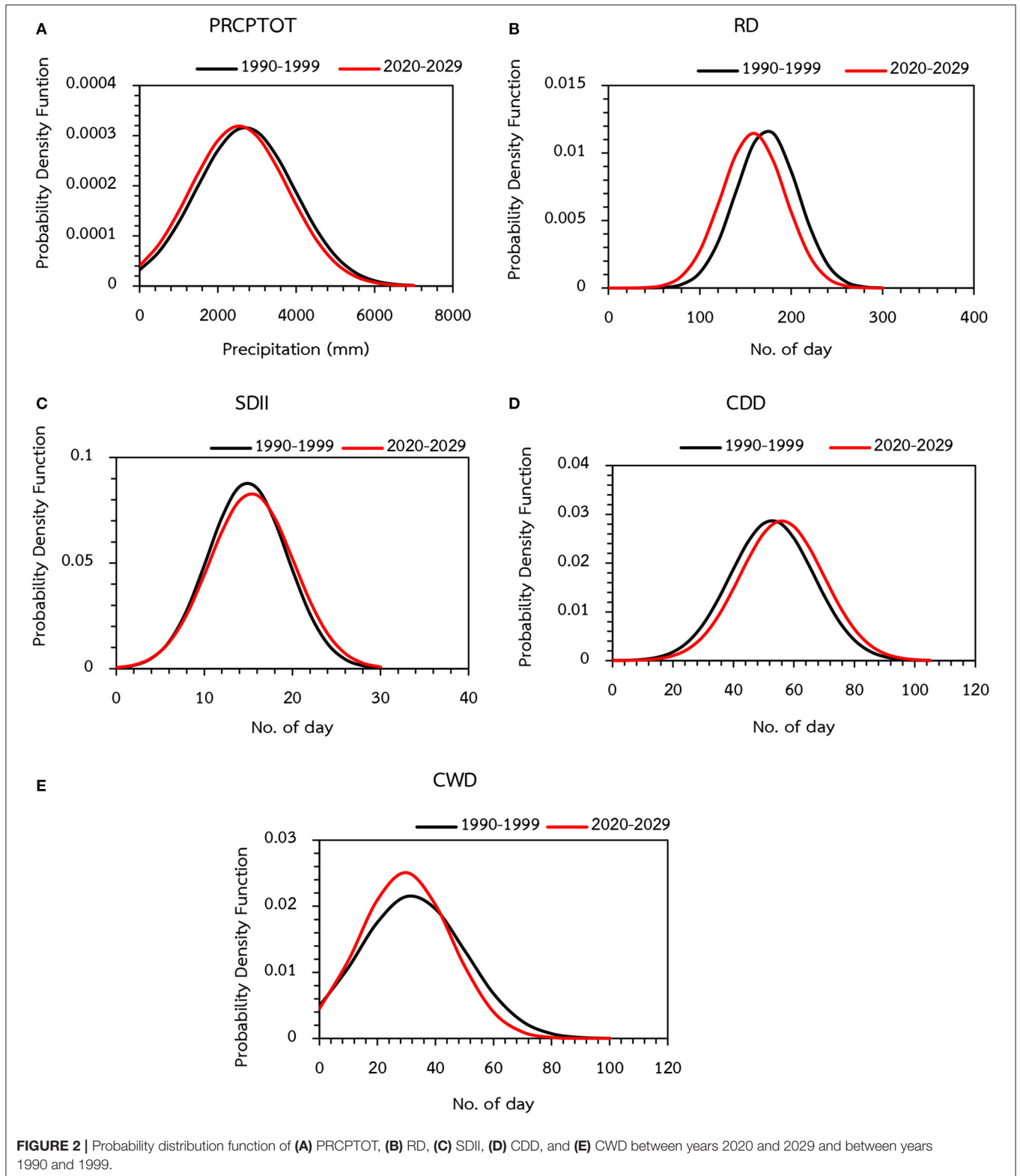
The results of spatial distribution of the yearly PRCPTOT showed that there were both wetting and drying patterns in Thailand during 2020–2029 (**Figure 1A**). The quantity of PRCPTOT slightly changes in the ranges of 100–200 mm per decade, as

**TABLE 1** | Statistics comparing the modeled precipitation and observation [adapted from Amnuaylojaroen and Chanvichit (2019)].

Data	$R^2$			Mean bias			SD			IOA		
	Annual	Rainy	Dry	Annual	Rainy	Dry	Annual	Rainy	Dry	Annual	Rainy	Dry
APHODITE	0.95	0.92	0.97	–1.96	–2.62	–1.30	2.00	2.09	1.40	0.68	0.67	0.92
TMD	0.97	0.96	0.98	–2.68	–3.56	–1.80	2.54	2.76	1.69	0.63	0.50	0.84
GPCP	0.94	0.89	0.99	–3.51	–4.73	–2.27	3.06	3.41	1.85	0.60	0.36	0.77

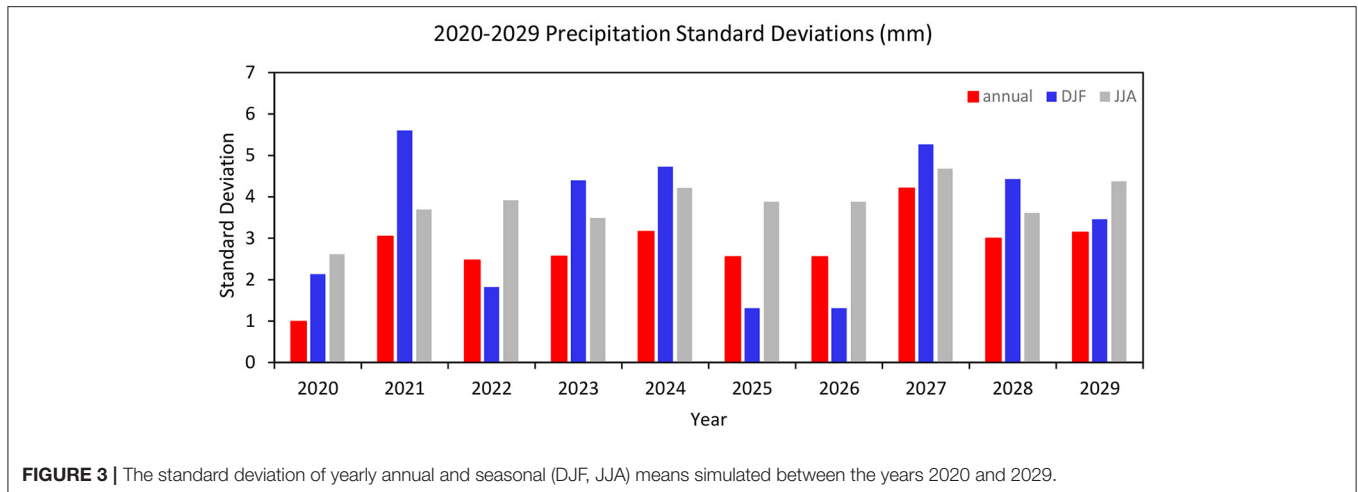


**FIGURE 1 |** Spatial distribution of percentage differences in **(A)** PRCPTOT, **(B)** RD, **(C)** SDII, **(D)** CDD, and **(E)** CWD between years 2020 and 2029 and between years 1990 and 1999 in Thailand.



shown in **Figure 2A**. The annual RD (**Figure 1B**) affected most of Thailand with negative patterns. A remarkable pattern that is noticeable in **Figure 1C** is the domination of increasing annual

SDII in Thailand, with significant statistical rises, ranging from 5 to 20%. The conclusion of this study reasonably indicates that the substantial rise in SDII across most of Thailand



**FIGURE 3** | The standard deviation of yearly annual and seasonal (DJF, JJA) means simulated between the years 2020 and 2029.

represents a decrease in RD instead of an increase in the overall rainfall. Indices of extreme precipitation events were analyzed, using CWD throughout Thailand. The analysis of indices indicates a widespread reduction of CWD in most areas. In the central, southern, and eastern regions of the country, the statistically significant trend of CWD was geographically localized. Southern Thailand continues to decrease by  $-10$  to  $-30\%$ . A dramatic decrease was found in the south of Thailand. Compared to CWD, CDD normally displayed the opposite signal (**Figures 1D,E**). The CDD showed a general drying trend, with statistically significant trends in two areas, including the eastern and southern regions of Thailand. Although the spatial distribution of increasing CDD pattern was robust in most of the country, no statistically significant regional relation was found. During the years 2020–2029, the plot of the probability density function of five indices (**Figures 2A–E**) will, in general, not be significantly different compared to the present day (1990–1999). For example, PRCPTOT, SDII, and CDD had smaller change; in contrast, there were some indices, such as RD (**Figure 2B**) and CWD (**Figure 2E**), that showed great difference compared to the present-day simulation. In **Figure 2B**, the substantial decreasing trends in annual RD varied from 10 to 20 days per decade. The annual RD decreased dramatically by 5–15% when considering the entirety of Thailand, while the CWD generally decreased in ranges of 2–4 days per decade.

The ability of a regional climate model to capture realistic interannual variability in the future is shown in **Figure 3**. We use the SD of yearly annual and seasonal (DJF, JJA) means simulated between the years 2020 and 2029 to show the magnitude of the interannual variability of precipitation of the model. Using the year 2020 as a baseline, we found that only the year 2029 is adequate for capturing the relative magnitude of annual, DJF, and JJA variability. The DJF variability is greater than either the annual or JJA variability in the years 2021, 2023, 2024, 2027, and 2028; whereas, the JJA variability is greater than both the annual variability and the DJF variability in the years 2022, 2025, and 2026.

Mostly, the result of this study was similar to those of the previous studies in the other regions of Asia (Choi et al., 2009;

Endo et al., 2009; Caesar et al., 2011; Limsakul and Singhruck, 2016). However, compared to the previous regional studies, this study, which is based on the regional climate model, could bring some difference. For example, by comparing the ensemble mean of projected change by the regional climate model, with 25-km grid spacing in Southeast Asia (Supari et al., 2020), their results showed decreasing the PRCPTOT in northern Thailand, but the PRCTOT was generally located in eastern Thailand, with substantial decreasing patterns, while the rising pattern was in northern Thailand in this study. In general, increasing resolution may better capture small-scale processes and features (downscaling effect), but increased GCM resolution may also improve the representation of large-scale atmospheric circulation (upscaling effect) (Iles et al., 2020). Particularly, precipitation extremes are sensitive to resolution over complex orography. In addition, some studies suggest that country-scale higher-resolution precipitation datasets still give heavier precipitation extremes, which may agree best with the  $0.11^\circ$  simulations. For example, Prein et al. (2016) and Torma et al. (2015) found that various aspects (biases, frequency–intensity distributions, spatial patterns) of the mean and extreme precipitation improved in EURO668 CORDEX at  $0.11^\circ$  compared with at  $0.44^\circ$ . Prein et al. (2016) ascribe this mostly to the better representation of orography at higher resolution and the ability to capture the larger scales of convection.

As mentioned in the previous research, (i.e., Caesar et al., 2011; Nguyen et al., 2014; Villafuerte et al., 2014), the El Niño–Southern Oscillation (ENSO) has a strong impact on the year-to-year precipitation variability in Southeast Asia. In addition, Limsakul and Singhruck discussed that the La Niña and El Niño years have more precipitation and less extreme events, and *vice versa*, during the negative years of Pacific Decadal Oscillation (PDO) in Thailand. It is, primarily, warming of the Walker circulation in the eastern Pacific Ocean that has been suggested to influence the moisture and the cell movement in the Indo-Pacific region, hence the incidence of El Niño (Juneng and Tangang, 2005; Singhrattna et al., 2005; Nguyen et al., 2014). The ENSO events were recorded to disrupt the monsoon vertical atmospheric circulation in Thailand and caused decreased

precipitation (Wang et al., 2003; Juneng and Tangang, 2005; Singhrattna et al., 2005). A rise in the formation of tropical cyclones may well be connected to increases in the number of days with heavy precipitation in the area, which is a potential factor in the shift in storm tracks in the east Indian Ocean, and maybe a factor contributing to the increased number of days with tropical cyclones (Caesar et al., 2011). Krishnamurthy and Krishnamurthy (2014) found that the PDO phase is essential for the Walker circulation patterns in the Pacific and Indian Oceans. One of the mechanisms by which PDO influences the monsoon rains is the Hadley circulation in the monsoon region. Changes in the Walker circulation over the Pacific and Indian Oceans also follow the PDO. The PDO, which causes the monsoon rainfall, is being linked to the Hadley circulation; hence, the mechanism by which it impacts the monsoon rainfall is limited to the monsoon region (Krishnamurthy and Krishnamurthy, 2014). However, the limitation of this study is that it is not represented well in terms of climate change. With a 10-year integration period, it is difficult to express the interannual variability, but it is noteworthy that people can do adaptation in the future. To extend the knowledge and better expression of the precipitation variability in Thailand and Southeast Asia, further study of the mechanisms underlying the ENSO and PDO linkage is required. Moreover, climate adaptation, a mitigation plan in the future, a regional climate simulation, and a long-term precipitation-variation analysis should be performed in Thailand.

## CONCLUSION

This study predicts the future extreme precipitation in Thailand during the years 2020 and 2029 relative to the reference period 1990–1999 under the RCP8.5 scenario. The output from the NRCM was used as input into five indices, i.e., PRCPTOT, RD, SDII, CWD, and CDD. The evaluation of the model,

with ground-based measurement and APHRODTE and GCPD data, represents well the precipitation in Thailand. The analysis of the indices expressed that precipitation is becoming less frequent in the entirety of Thailand, and the frequency of the CWD has decreased significantly; precipitation has also become more intensive. The indexes calculating the amount of heavy precipitation caused by wet daytime events and the maximum 1-day precipitation showed a negative trend in wetter conditions. The annual PRCPTOT, RD, SDII, and CWD illustrated spatially consistent patterns with important trends in the regional average annual series.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

## AUTHOR CONTRIBUTIONS

TA: conceived and designed the experiments, performed the experiments, analyzed and interpreted the data, contributed reagents, materials, analysis tools, or data, and wrote the paper.

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**Conflict of Interest:** The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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