HOT SPOT OF CLIMATE EXTREME EVENTS (FLOODS AND DROUGHTS) IN THAILAND FOR A CHANGING CLIMATE

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ABSTRACT

Various climate extreme events in Thailand such as more recurrent and more intense floods, droughts, tropical storms, and extreme rainfall events pose increasing threats to environment, water resources, and agricultural production. To assess the occurrence and impacts of extreme climate events, we have investigated the changes of indices characterizing extreme precipitation across the country. Eleven extreme precipitation indices (SWMR, NEMR, SDII, R10mm, R20mm, R95p, R99p, Rx1day, Rx5day, CDD, and CWD were calculated from the station data, then comparisons and projections were made with CMIP5 models. The SWMR displays higher values in the southern and eastern regions than in the northern, northeastern, and central regions, implying high potential flood and drought hazard areas similar to the distributions of precipitation intensity extreme indices. Most GCMs display similar spatial distribution pattern of high intensity of extreme precipitation indices to observations while there is a much greater variety of results between models and observations for the frequency indices. The multi-model ensemble (MME) projects increases in most precipitation extreme indices, indicating stronger precipitation events across the regions notably in the west, central, and south. Overall, the west, central, south, and the northeast of Thailand may encounter with high flood and drought hazards, respectively from extreme climate by the end of 21th century.

Keywords: Extreme precipitation indices, ETCCDI, Multi-Model ensemble (MME), CMIP5

1. INTRODUCTION

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes (IPCC 2013), and can result in unprecedented extreme events. The Fifth Assessment Report (AR5) indicates that near-surface air temperature has approximately increased by 0.78 °C (0.72 to 0.85) on a global scale since 1900, with a larger trend in recent decades. Meehl et al. (2007) indicated that the wet extremes are projected to become more severe in many land areas where the mean precipitation is projected to increase. Therefore, monitoring changes in precipitation has become a critical research focus in recent decades.

Researches on climate extremes have progressed enormously over the last few decades (Nicholls and Alexander, 2007). This has been mainly due to efforts in international cooperation to collate, quality control, analyze variables, and share the data set related to the climate extreme. Thus, resulting in current understanding of possible changes in frequency or intensity of some extreme weather and climate events that will help society to manage the associated risks (Zwiers et al., 2013). One such effort has been led by the Expert Team on Climate Change Detection and Indices (ETCCDI), who have facilitated the calculation of climate extremes indices based on daily temperature and precipitation data.

A big effort by the World Climate Research Programme's Working Group on Climate Models leads to the development of CMIP3 and CMIP5 models. This is one of the leading successful collaboration efforts of several modelling groups around the world who contributed to the climate simulations during the 20th and 21st century (Meehl et al., 2007; Taylor et al., 2012). Recently, models with more sophisticated physics and higher resolution from CMIP5 are available. Significant improvements (More comprehensive set of GCMs, more complexity run at higher spatial resolution, more complete representations of external forcings, more scenario types, and more diagnostic outputs) are included in the CMIP5 in comparison to the CMIP3 models (Knutti and Sedláek, 2013).

The performance of CMIP5 models in simulating climate extremes indices defined by the ETCCDI on a global scale was investigated by Sillmann et al. (2013a). They used four reanalysis data sets (ERA40, ERA-Interim, NCEP/NCAR, and NCEP-DOE) and the CMIP3 ensemble as well as the observation-based set of indices (HadEX2) for comparison. Their end results revealed that models tend to simulate more intense precipitation and fewer consecutive wet days. The projected changes in climate extremes indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) were analysed for different emission scenarios from CMIP3 and CMIP5 multimodel ensembles by Sillmann et al. (2013b). Results generally indicate an intensification with increasing radiative forcing of patterns of change in temperature-based and precipitation-based indices. Projected changes in temperature and precipitation extremes are generally more pronounced in CMIP5 than in CMIP3 simulations with similar amounts of radiative forcing by year 2100.

For regional and country scales, several works have been dedicated to studying trends in extreme precipitation, e.g. in China (Chen et al., 2012), Europe (van den Besselaar et al., 2012), and North America (Wang and Zhang, 2008). In general, the studies above have shown that precipitation and extreme events have increased at higher latitudes where intensified by the intensity and frequency. Recently, Alexander and Arblaster (2017) expanded previous work of Alexander and Arblaster (2009) by investigating historical and projected trends in temperature and precipitation extremes in Australia. Then, comparisons were made between the CMIP5 multi-model dataset and the multiple observational datasets (AWAP and HadEX2) over a century. Overall, the precipitation extremes over Australia show a much weaker response to future emissions than temperature extremes with much longer dry spells interspersed with more intense precipitation extremes.

However, few studies have examined trends in climate extremes, other than changes in mean values across the southeast Asia. Manton et al. 2001 analysed climate extreme indices for historical period in the Southeast Asia and South Pacific. Regional studies across the Asia–Pacific (Griffiths et al. 2005) have shown significant increases in occurrences of annual number of hot days and warm nights and decreases in occurrences of annual number of cool days and cold nights over the past few decades. The projected changes in precipitation characteristics during the east Asian summer rainy season was investigated by Kitoh et al. (2009). They found an increase in the frequency of heavy precipitation in the near future and by the end of 21st century. Caesar et al. (2011) made an assessment of the changing climate extremes in the Indo-Pacific region using available data from 13 countries between 1971-2005. They found that the warm extremes are increasing and cold extremes are decreasing. Sharma and Babel (2014) made detailed analysis of trends in daily extreme temperature and rainfall from 1961 to 2002 for the western Thailand (Mae Ping and Mae Klong river basins). They found significant increase in the annual number of warm days and warm nights, with corresponding significant decreases in the annual number of cool days and cold nights. There is insignificant decrease in annual total precipitation for nearly all stations. However, little is known about extreme climate trends in different parts across the country.

The goal of this work is to answer one main question, ‘What are the long-term observed trends of the precipitation extremes in different areas of Thailand and how they are likely to change in the near-future, mid-future, and far-future periods?’ This is an initial step required for a decision on what appropriate level of adaptation measures to the impacts of projected climate extreme events.

2. EXTREME PRECIPITATION INDICES AND DATA METHODOLOGY

2.1 Extreme precipitation indices

Regarding the changes in extreme precipitation events using the analysis of climate extreme indices (CEI), we utilize the WMO/WCRP/JCOMM ETCCDI indices (Zhang et al., 2011) that are calculated from daily precipitation and reflect the more “extreme” aspects of climate. Ten precipitation indices (PRCPTOT, SDII, R10mm, R20mm, R95p, R99p, Rx1day, Rx5day, CDD, and CWD) are selected from the 27 ETCCDI recommended indices while 2 indices (SWMR and NEMR) are used to represent the strength of Asian Monsoon (in term of precipitation) as displayed in Table 1.

Table 1. Extreme precipitation indices used in this study

Indices	Definition (Unit)
PRCPTOT	Annual total precipitation from wet days (mm)
SDII	Average precipitation from wet days (mm/day)
R10mm	Number of days per year with precipitation amount > 10 mm (days)
R20mm	Number of days per year with precipitation amount > 20 mm (days)
R95p	Annual total precipitation from wet days > 95th percentile (mm)
R99p	Annual total precipitation from wet days > 99th percentile (mm)
Rx1day	Annual maximum 1-day precipitation (mm)
Rx5day	Annual maximum consecutive 5-day precipitation (mm)
CWD	Annual maximum number of consecutive wet days (days)
CDD	Annual maximum number of consecutive dry days (days)
SWMR	Cumulative 6-month rainfall from May to October (mm)
NEMR	Cumulative 6-month rainfall from November to April (mm)

Table 2. CMIP5 models selected in this study

Model	Institute, Country	Resolution	Historical period	Future period
CNRM-CM5	Centre national de Recherches Meteorologiques, France	256 x 128	1980 - 1999	2010-2099
CSIRO-Mk3.6	CSIRO, Australia	192 x 96	1980 - 1999	2010-2099
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, NOAA, US	144 x 90	1980 - 1999	2010-2099
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, NOAA, US	144 x 90	1980 - 1999	2010-2099
INM-CM4	Institute of Numerical Mathematics, Russia	180 x 120	1980 - 1999	2010-2099
IPSL-CM5A-LR	Institute Pierre Simon Laplace, France	96 x 96	1980 - 1999	2010-2099
MIROC5 (medres)	CCSR/NIES/FRCGC, Japan	256 x 128	1980 - 1999	2010-2099
MRI-CGCM3	Meteorological Research Institute, Japan	320 x 160	1980 - 1999	2010-2099

2.2 Observations and model data

For observations, we use the daily precipitation data from 83 meteorological stations obtained from Thailand Meteorological Department. All of the extreme indices were calculated from the daily precipitation data at each station by using freely available software package : RClimDex (ETCCDI; http://cccma.seos.uvic.ca/ETCCDI/software.htmls). The RClimDex (Running in the R platform) is not only designed to provide a user friendly interface to compute indices of climate extremes, but also includes a simple quality control of the data. Then, the areal precipitation indices were calculated by an Inverse Distance method (Supharatid, 2016) with a resolution of 0.25°.

The Expert Team on Climate Change Detection and Indices (ETCCDI) has defined a set of climate indices that focus on moderate extremes based on daily minimum temperatures, maximum temperatures, and precipitation. We choose CMIP5 model simulations that were available and had been calculated for the studies by Sillmann et al. (2013a, 2013b). The RCP4.5 (a stabilization scenario, in which the total radiative forcing stabilizes to 4.5 W/m^2 shortly after 2100) and RCP8.5 (characterized by increasing greenhouse gas emissions over time leading to a radiative forcing of 8.5 W/m^2 in 2100) scenarios were used in this study. The RCP8.5 is also known as 'business-as-usual' scenario; it does not include any specific climate mitigation target. The extreme precipitation indices of 8 CMIP5 models (Table 2) are available during based line (also available in the observation period, 1980-1999) and target projection years (2010–2099). These extreme indices were downloaded from the ETCCDI archive (available at http://www.cccma.ec.gc.ca/data/climdex). All extreme indices are bi-linearly interpolated into a common grid of 0.25° similar to the observations.

3. OBSERVED TRENDS AND MODEL EVALUATION

As Thailand is located in the Asian-monsoon-dominated region. The monsoon evolution and variability critically influence the livelihood and the socio-economic status of the Thai people. Recent monsoon floods and droughts in Thailand have impacted many people in terms of loss of lives, property damages, agricultural productivity such as the Thailand great flood in 2011 and severe drought in 2015-2016. In this study we concern only the magnitude change in precipitation that will affect the whole country. Therefore, we analyse the strength of the monsoon (only in term of precipitation) by the southwest and northeast monsoon Rainfall (SWMR and NEMR). These 2 indices are calculated from observations to represent one of key indicators in flood and drought events in Thailand. Figure 1 displays the spatial and temporal distributions of these indices averaged across Thailand.

The SWMR varies from 743 mm (Some areas in the north, northeast, central, and the lower south) to 4,183 mm (Southwest and east). Therefore, it is expected high flood hazard occur in those large SWMR areas. However, the central (with limited drainage capacity), where SWMR is larger than 1,200 mm, has also high flood hazard such as a severe flood in the Chao Phraya river basin in 1995, 2006, and 2011. The NEMR varies from 99 mm (North, northeast and central) to 1,434 mm (South). Therefore, during the northeast monsoon, there is also high flood hazard in the south. The time-series of both SWMR and NEMR display small increasing trends but nonsignificant (The Mann-Kendall test statistic Z and Sen's slope are given in the left and right corner, respectively). The severe flood in central Thailand in 1995 can be represented by high SWMR. Two-El Niño events in 1992/1993 and 1997/1998 can also be represented by low SWMR.

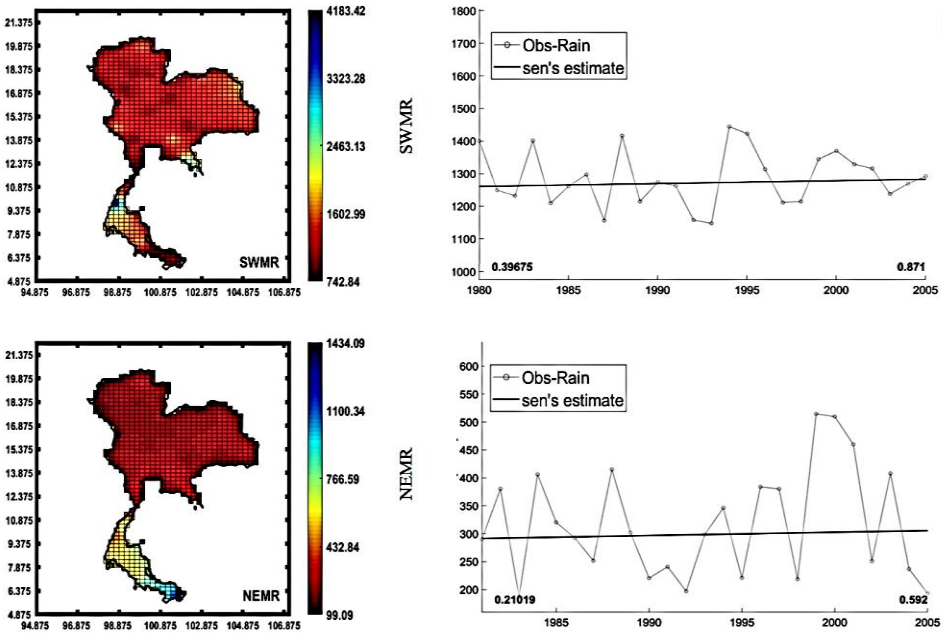

Figure 1. Spatial distribution and trends of SWMR and NEMR over Thailand.

The spatial distribution of precipitation extreme indices climatology is displayed in Figure 2. For the indices representing the intensity, the wet area with an average annual wet-day rainfall (PRCPTOT) of more than 2,000 mm is in the south (Below lat. 11.625) and east, whereas some dry areas with smaller than 1,000 mm are in the north, northeast, and central. The Simple Daily Intensity Index (SDII) show similar spatial distribution to PRCPTOT with the high intensity (>15 mm/day) in the south and east and medium to low intensities (< 15 mm/day) in the other areas. The mean climatology of very wet days (R95p) and extremely wet days (R99p) show high intensities of more than 500 mm (R95p) and 200 mm (R99p) in the south while medium to low intensities of smaller than 500 mm (R95p) and 200 mm (R99p) are found in other areas. A similar distribution pattern is also found for the mean climatology of daily maximum rainfall (RX1day) and 5-day maximum rainfall (RX5day). High intensities of more than 40 mm (Rx1day) and 80 mm (Rx5day) are located on the south and east while medium to low intensities of smaller than 40 mm (Rx1day) and 80 mm (Rx5day) are found in other parts. For the indices representing the frequency, the annual frequency of heavy rainfall day (R10mm) and very heavy rainfall day (R20mm) indices show similar distribution pattern with ranges of 27–99, and 14-68 days each year, respectively. Both the lowest number of heavy rainfall day (27 days) and very heavy rainfall day (14 days) are in the north, while the highest number of heavy rainfall day (99 days) and very heavy rainfall day (68 days) are in the south. The consecutive dry days (CDD) index in Thailand has a range of 27–112 days each year. The areas with large number are located primarily on the northwest, north, northeast, and central, whereas the small numbers are in the south. The spatial pattern of the consecutive wet days (CWD) index has a range of 6–26 days each year. The small numbers are located on the northeast, while the large numbers are in the west and south.

Most GCMs give larger magnitude of intensity (PRCPTOT, R95p) of extreme precipitation indices in the south of Thailand similar to observations (except CSIRO-Mk3-6-0). There is a much greater variety of results between the models and observations for the frequency indices as comparison to the intensity indices. Five models (CNRM-CM5, GFDL-CM3, IPSL-CM5A-LR, MIROC5, and MRI-CGCM3) give reasonable results of R10mm, while 3 models (CSIRO-Mk3-6-0, GFDL-ESM2M, and Inmcm4) give larger values compared to the observations. For CDD, two models (IPSL-CM5A-LR and MIROC5) give reasonable results, while other 2 models (CNRM-CM5 and Inmcm4) and 4 models (CSIRO-Mk3-6-0, GFDL-CM3, GFDL-ESM2M, and MRI-CGCM3) give smaller and larger results, respectively. It is found that the simulated SDII and CWD are too low and too high, respectively (except CSIRO-Mk3-6-0). These significant differences are caused by the fact that there are too many wet days (CWD) in GCMs compared to observations. Therefore, the simulated precipitation intensity (SDII) appears too weak across Thailand. This agrees well with previous studies that have shown this effect in Australia (Alexander and Arblaster, 2017) and in a global scale (Stephens et al., 2010; Herold et al., 2016). Most GCMS also give too low Rx1day due to high simulated CWD.

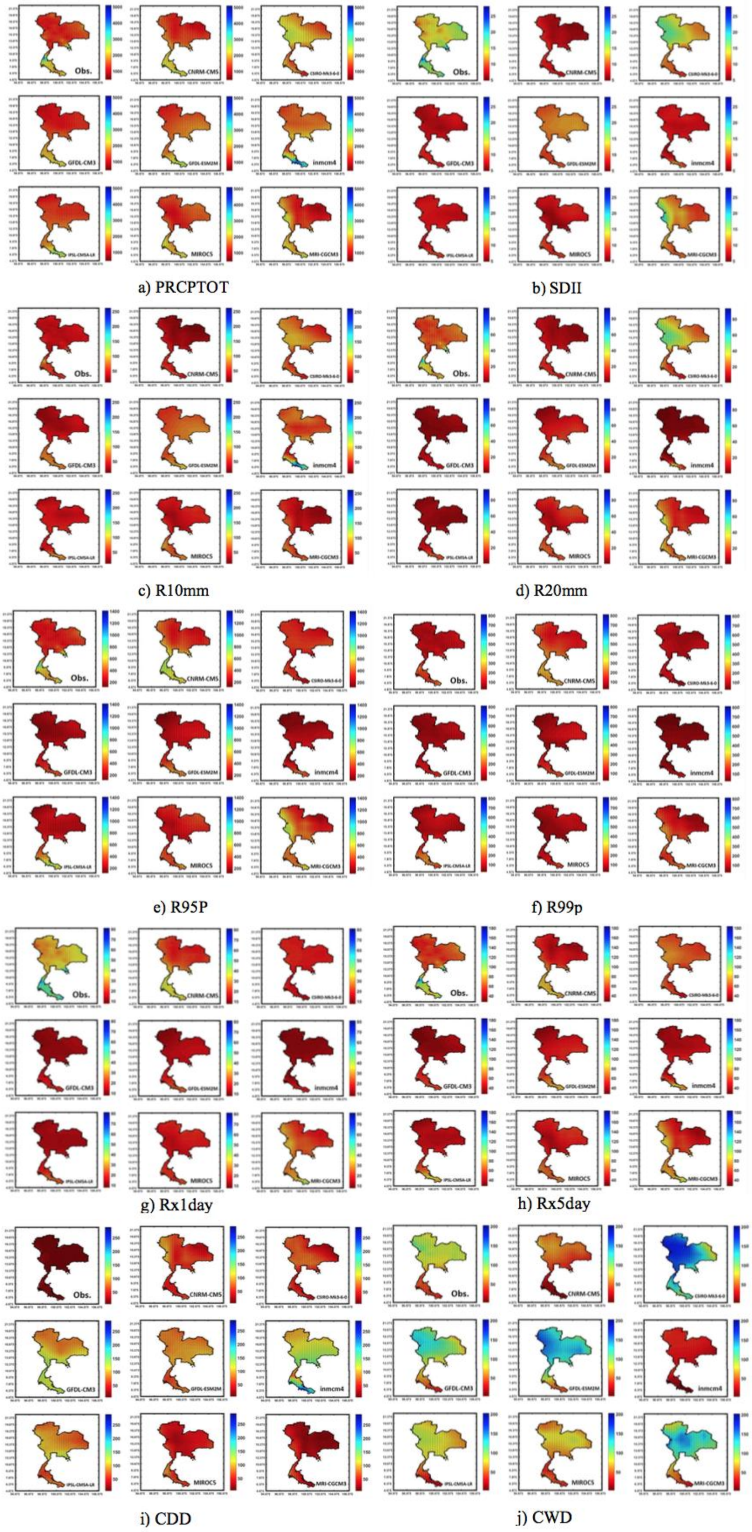

Figure 2. Spatial distribution of precipitation extreme indices climatology.

4. PROJECTION OF PRECIPITATION EXTREME INDICES

The projection of temporal evolution of precipitation extreme indices is shown in Figure 3. In general, we certainly confirm that the observations are within the model spread except for SDII and CWD. The model simulations display very high CWD, therefore, underestimating SDII, Rx1day, and Rx5day. These findings agree well with previous studies on a global scale (Sillmann et al., 2013a) and in Australia (Alexander & Arblaster, 2017). Model projects increases in most precipitation extreme indices for both emission scenarios except CDD that does not show any significant variations. The increase trends of extreme indices for RCP8.5 are more than those for RCP4.5, especially for the far-future period (2070-2099).

Overall, the differences in magnitude between these 2 RCPs are larger for indices that represent the extreme intensity (R95p, R99p, Rx1day, Rx5day) than for indices represent the extreme frequency (R10mm, R20mm). The latter also show little change over the century with a large spread across the model. These results indicate generally that extreme precipitation events will be more frequent and more intense than at present under both RCP scenarios, especially the RCP8.5 scenario, by the end of the 21th century.

5. SUMMARY AND CONCLUSION

In this paper, ten precipitation extreme indices are calculated from the daily precipitation by using freely available software package: RClimDex. The monsoon strength in term of the precipitation is also investigated by the southwest and northeast monsoon rainfall (SWMR and NEMR). The extreme precipitation indices of 8-selected CMIP5 models were downloaded from the ETCCDI archive.

The SWMR displays high values in the south and east, implying high potential flood hazard areas. However, with medium value of SWMR but limited drainage capacity, the central has also experienced big flood events such as the floods in the Chao Phraya river basin in 1995, 2006, and 2011. During the northeast monsoon season, there is also high flood hazard in the south. The time-series of both SWMR and NEMR display small increasing trends and can reproduce well the 1995 flood and the two-El Niño events in 1992/1993 and 1997/1998.

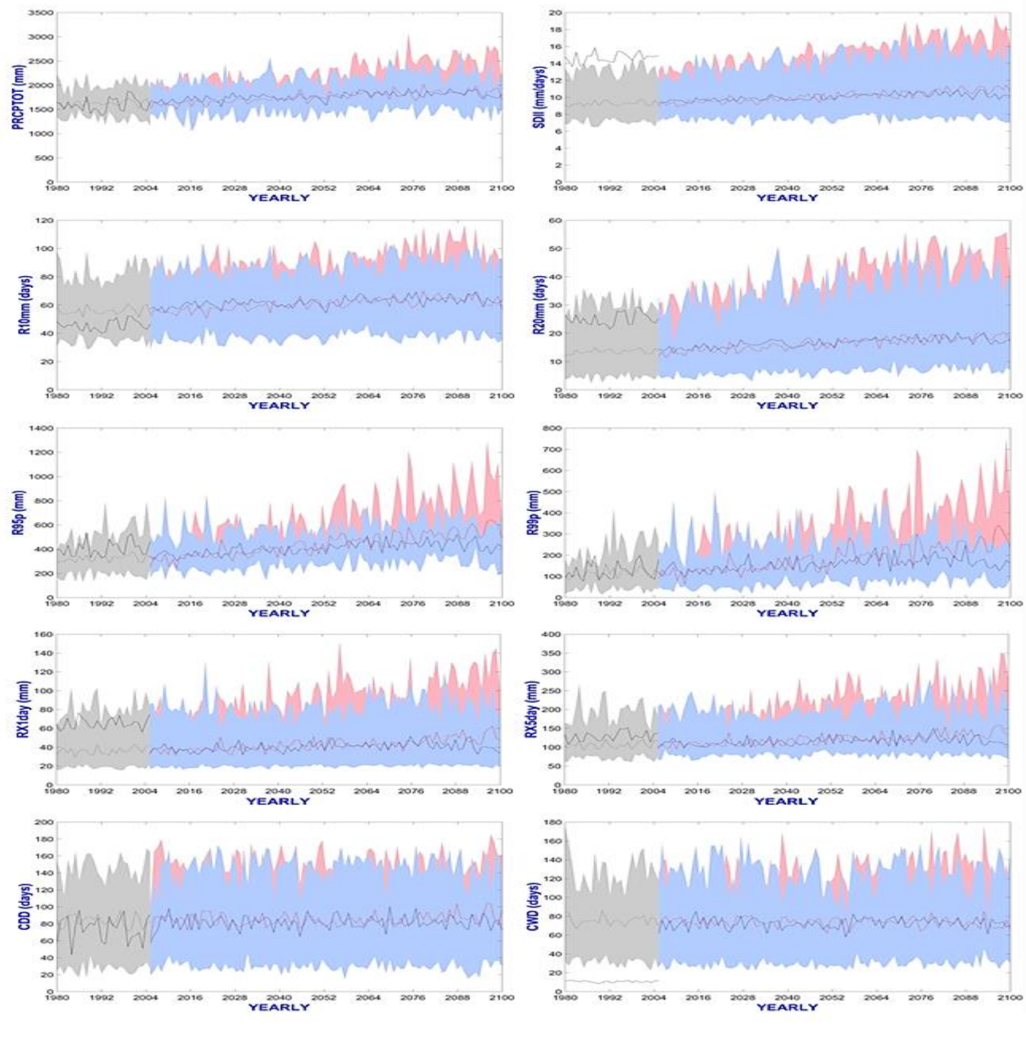

Figure 3. Temporal evolution projection of precipitation extreme index.

In general, the extreme intensity indices represented by PRCPTOT, SDII, R95p, R99p, Rx1day, and Rx5day show similar spatial variability with larger values in the south and east than other areas. The frequency indices represented by R10mm, R20mm display larger values in the south. The areas with large number of consecutive dry days (CDD) are primarily in the north, northeast, and central whereas the small numbers are in the south. While the spatial pattern of the consecutive wet days (CWD) show small numbers in the northeast, but large numbers in the west and south. There is a tendency towards wetter conditions across the country.

Most GCMs in this study give larger magnitude of precipitation extreme in the south of Thailand similar to observations. Agreements for the frequency indices are not so good as the intensity indices. The simulated SDII and CWD are found too low and too high, respectively, compared to the observations. These significant differences are caused by the fact that there are too many wet days (CWD) in GCMs, indicating too weak SDII across Thailand. These behaviors agree well with previous studies in a global scale (Stephens et al., 2010; Herold et al., 2016) and in Australia (Alexander and Arblaster, 2017). The temporal distribution of observations is found to lie within the model spread with similar variability except SDII and CWD. Most GCMs simulate too low Rx1day compared to observations similar to Asadieh and Krakauer (2015).

The projection of temporal evolution of precipitation extreme indices confirms that the observations be within the model spread (except for SDII and CWD). The model simulations display too high CWD, therefore, underestimating SDII, Rx1day, and Rx5day. These findings agree well with previous studies on a global scale (Sillmann et al., 2013a) and in Australia (Alexander & Arblaster, 2017). Model projects increases in most precipitation extreme indices with some evidence of scaling with emission scenarios (except CDD). The increase trends of extreme indices for the RCP8.5 are more than those for the RCP4.5, especially for the far-future period (2070-2099). The differences in magnitude between these 2 RCPs are larger for indices that represent the extreme intensity (R95p, R99p, Rx1day, Rx5day) than for indices represent the extreme frequency (R10mm, R20mm). The latter also show small changes over the century with a large spread across the model. These results indicate generally that extreme precipitation events will be more frequent and more intense than at present under both RCPs, especially the RCP8.5, by the end of the 21th century.

Overall, the west, central, south and northeast of Thailand may encounter with high flood and drought hazards, respectively in the future. All these findings imply that the country may have more hydrological extreme flood and drought hazards in different areas. In general, we can understand the recent behaviour of climate extremes over Thailand. However, further analysis using the longer dataset (Covering the year of recent flood, 2011 and drought, 2016) is still required to extend our understanding on the changes in the past climate extreme events.

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