J21.2 ASSESSMENT OF EXTREME WEATHER EVETNS ALONG THE COASTAL AREAS OF THAILAND

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Abstract

Coastal zones are among the most important natural resources, providing human with many essential goods and services. The foundations of prosperity and prominence for most of global cities lie in low-lying areas near coastlines and the mounts of major rivers, which served as conduits for commerce and socio-economic development. As Thailand has an intensive coastline for more than 2,600 km. on the Gulf of Thailand and on the Andaman Sea, enhanced understanding how extreme rainfall events impact this vulnerable system is of paramount importance for country development. In this study, high-quality daily rainfall data from stations located along the coasts during 1965-2006 were analyzed. A set of core extreme indices recommended by the WMO-CCL/CLIVAR Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) were calculated by measuring different aspects of rainfall extreme characteristics such as wetness and dryness conditions, frequency and intensity events. Results indicated notable changes in different patterns of extreme rainfall characteristics in each coastal side of Thailand. Along the Gulf of Thailand coast, changes in extreme rainfall events were characterized by more intense daily rainfall associated with overall increases in very wet day and heavy rainfalls. These changes towards wetter condition and increases in magnitude and frequency of more intense rainfall events were consistent with the prolonged strengthening of the north-east monsoon which governs the region during October to February. While, there were overall decreases in total rainfall accompanied by coherent dryness condition and reduction of heavy rainfall along the Andaman coastal areas. Our findings indicated that both coastal sides of Thailand will be exposed to increasing risks of different extreme rainfall-driven disasters. Anticipated impacts including increases in inland flash flood, more frequent coastal flooding, coastal erosion and severe water shortage would introduce devastating pressures, and intensify other existing stresses to urban, industry, environment and socio-economic development in the coastal areas. Therefore, vulnerability and risk assessment are needed to shed more light how to cope with and adapt to such adverse impacts of current and future changes.

Keywords: Extreme weather events, Coastal areas, Thailand

1. Introduction

Coastal zones are among the most important natural resources, providing human with many essential goods and services. It is also home to over one-third of the world's population (IPCC, 2007). The foundations of prosperity and prominence for most of global mega cities also lie in low-lying areas near the coastlines, which served as conduits for social-economic development and commerce with the rest of the world. As it happens, these locations place coastal communities at greater risk from current and projected climate change and weather extreme events such as cyclones, high winds, flooding and sea-level rise. Annually, about 120 million people are exposed to tropical cyclone hazards, which killed 250,000 people from 1980 to 2000 (IPCC, 2007). The Cyclone Nagis tremendously devastated the low-lying Irrawaddy delta of Myanmar in May 2008 that left more than 80,000 dead with millions homeless and food production severely affected is a recent example of far-reaching catastrophe from such extreme climate-driven disasters (World Bank, 2008).

Thailand, a tropical country lying in the center of mainland Southeast Asia, has an extensive coastline for more than 2,600 km. mainly in the southern region (Sudara, 1999). The coastlines are clearly divided into two parts, namely the Gulf of Thailand and the Andaman Sea. These particular areas are important to the country in terms of society, economy and human settlement. A number of the country's population live along both side of the coastal plains, and most communities depend heavily on local resources for their livelihoods (UNDP, 2006). In recent decades, the coastal zones in Thailand have been subjected the effects of a growing population and economic pressure manifested by a variety of social-economic activities such as industrialization, aquaculture and tourism (Sripen, 2000). Many promising coastal zones with white sandy beaches and colourful coral reefs have been intensively developed to be attractive tourist spots. High-rise buildings such as hotels, condominiums, resorts and restaurants have been widely built along the shorelines. Infrastructures are densely constructed to provide services and easy access. Urbanized coastal cities are also growing in number and size (Sudara, 1999; Sripen, 2000).

Recent evidence has indicated that Thailand coastal zones, where the rapid expansion of socio-economic development taken place, are particularly at

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risks from seismic hazard and also highly prone to hydro-meteorological and environmental disasters (Department of Marine and Coastal Resources, 2005; IPCC, 2007; World Bank, 2008). The Indian Ocean Tsunamis on December 26th, 2004, for instance, caused more than 1000's fatalities, and huge economic losses in the six popular tourist provinces along the Andaman Sea coast of Thailand (Department of Marine and Coastal Resources, 2005). This loss of life and structural damage are probably the worst socio-natural disasters recorded in the Thailand's history. In addition, this region has frequently experienced severe floods associated with monsoon, the El Niño-Southern Oscillation (ENSO), and intense tropical cyclones (Singhratina et al., 2005; Juneng and Tangang, 2005; Lau and Nath, 2003). The high incidence of hydro-meteorological and other disasters affecting Thailand coastal regions are a great challenge to local officials and their communities in being prepared and proactive in addressing increasingly frequent and extreme climate events. In this study, trends in daily rainfall extreme along the southern peninsular of Thailand have been examined. The primary purposes are to identify whether the frequency and/or severity of rainfall extreme events have changed in recent decades and to provide insight into the direction and significance of long-term trends.

2. Data and analysis methods

Daily total rainfall data in the southern peninsular of Thailand used to calculate rainfall extreme indicators were extracted from the archives of the Meteorological Department and the Irrigation Department of the Royal Thai Government. Station records were selected on the basis of record length and data completeness. Each of the selected station records is at least 98% complete. In addition to visual examination of any obvious outliers and potential discontinuities, the extracted data set was subjected to a multi-stage suite of objective quality control and homogeneity tests. Recently developed objective approaches which include spatial and temporal outliers, interpolation and data homogeneity were applied to evaluate the quality of this data set (Feng, et al., 2004; Auger, et al., 2005; Wang, et al., 2007). The most inhomogenous time series were discarded from the analysis. Based on extensive quality control and homogeneity checks, daily rainfall data for a set of 18 high-quality records, which 11 and 7 stations are located along the eastern and western coasts, respectively, were prepared for rainfall extreme indicator calculation and trend analysis (Figure 1). Most of the selected records extend from 1965 to 2006, with a few stations spanning shorter periods ranging from 1973-2006 to 1981-2006.

Five of the 11 core rainfall-related indices recommended by the WMO-CCL/CLIVAR/ETCCDMI were used to assess the changes in extremes for the southern peninsular of Thailand (Alexander et al., 2006). The indices were chosen primarily for assessment of the many aspects of a changing climate which include changes in intensity, frequency and duration of rainfall events. They represent events that occur several times per year giving them more robust statistical properties than measures of extremes which are far enough into the tails of the distribution so as not to be observed during some years. Of the five extreme rainfall indices, four of them relate to 'wetness' [heavy rainfall days (R10), maximum 5-day rainfall total (R5d), simple daily intensity index (SDII) and very wet days (R95)] while one of them relates to 'dryness' [consecutive dry days (CDD)]. R10 is an indicator of the frequency of significant rainfall days for a given year, whereas R95 and R5d represent the magnitude of the more intense rainfall events. In contrast, the SDII is a measure of the average rainfall amount that falls on a wet day in a given year. Last, the CDD index is a measure of the length of the driest part of the year; this indicator may serve as a valuable drought indicator.

Two methods were employed to analyze each of extreme indicator time series. One examines trends in each individual station data, and the other compares empirical probability distribution functions (PDF) for two different time periods. The trend estimator used is the ordinary least square (OLS) method, which is the most widely used and accepted non-parametric trend estimator in the literature (Griffiths and Bradley, 2007). Trend magnitudes are expressed as percentage change relative to long-term means of the entire records and statistical significance is assessed following the non-parametric Kendall's Tau test (Alexander et al., 2006). This method is resistant to outliers in the time series and robust to non-normal data distribution. For the PDF calculation, it was done by fitting the data before and after 1990 intervals with gamma distribution function. To assess whether the probabilities for two periods for each extreme indicator were significantly different or not, a two tail Kolmogorov-Smirnov test was employed. This test has a null hypothesis that two PDFs for two time periods are identical (Griffiths and Bradley, 2007).

3. Results and discussions

In each coast of southern Thailand, a distinction on climatic regimes is remarkable as a result of different influences of monsoon systems. On the Andaman Sea, the wettest period of the year occurs during August-September due to intense south-west monsoon. While the Gulf of Thailand, the wettest period of the year takes place from November to January, resulting from prevailing north-east monsoon. In addition, two coastal areas are differently affected by other climate variability modes such as ENSO and Indian Ocean Dipole (IOD). Such seasonal and regional differences may lead to different patterns of trends in rainfall and associated extreme events. This notation is well supported by the results from this study, revealing coherent spatial changes but different patterns of trends in total annual rainfall amounts (Figure 2). It can be characterized by an overall decrease in the west, whereas a discernable increase is evident in the other side of the peninsular. Significant surplus and deficit in total annual rainfall amounts can be observed at two stations along the east coast and three stations along the Andaman coast, respectively. Changes in total annual rainfall amounts expressed as percentage changes in relation to long-term means among 18 stations varied from -5 to 18% per decade. It should be noted that increases in total annual rainfall amounts along the east coast are coincident with the prolonged strengthening of the north-east monsoon, which is a dominant mode of climate variability mainly governing the eastern coast during rainy season period (Nov.-Jan.). Moreover, a decline in total rainfall amounts along the Andaman coast is in line with the slightly weakening of the Indian monsoon (Goswami et al., 2006) and the shift in the ENSO towards more El Niño events since the late 1970s (Zhang et al., 1997). Previous studies have suggested that shift in the Walker circulation associated with the anomalous sea surface temperature in the eastern Pacific is the dominant mechanism whereby the ENSO events alter the transport and convergence of atmospheric moisture and convective regions in the Indo-Pacific sector, and consequently impact rainfall in the Southeast Asia (Wang et al., 2003; Juneng and Tangang, 2005; Singhrattna et al., 2005). In association with the shift in the ENSO towards more warm events in the recent decades, the Walker circulation has shown a persistent southeastward shift over Thailand-Indonesia region, accompanied by the weakening of southwest monsoon over Thailand (Singhrattna et al., 2005).

Figure 3 reveals a trend toward fewer rainy days (defined as days with at least 1 mm of rain) over most of southern Thailand. Closer examination indicates that 13 stations show noticeable decreases which trend magnitudes range from -1.5 to -6.2% per decade. Significant decreasing trends occurred at 5 stations, of which two stations are located in the west coast and three stations are situated in the east coast. The findings are consistent with the previous study, illustrating that there has been widespread reduction in the number of rainy days in Thailand over the last three decade (Limsakul et al., 2007), and throughout Southeast Asia during 1961-1998 (Manton et al., 2001).

As a result of changes in different magnitudes and signs of rainfall and the number of rain days, a notable west-east difference in trends can be observed in SDII, defined as total annual rainfall per the number of wet days in the year (Figure 4). The significant decrease in SDII is clearly confined along the Andaman coast, with magnitudes in range of -0.59 to -1.46% per decade. A decrease in this index reflects coherent reductions in both the number of rain days and rainfall amounts. On the other hand, all stations in the east coast show trends toward enhanced daily rainfall intensity, of which three stations were statistically significant at the 95% confidence level. It appears that the increasing SDII in the east coast results mainly from a decrease in the number of rain days. Note that SDII changes in the east coast are generally greater in magnitude. Trends in heavy rainfall (R95) show similar pattern as SDII, with spatially-coherent patterns but west-east differences in signs (Figure 5). Trends in heavy rainfall tend to decrease along the Andaman coast, similar to trends in rainfall amounts, the number of rain days and SDII. In contrast, most of stations on the Gulf of Thailand side exhibit discernable increasing trends towards wetter conditions. However, for the 18 stations analyzed, no heavy rainfall trends were statistically significant.

Other two wetness indicators, R10 and R5d, show relatively mixed patterns of changes. There is a mixture of stations exhibiting increasing and decreasing trends for R10 and R5d, with only a few stations in the Gulf of Thailand coast having significant trends (Figures 6 and 7). Exceptionally large changes in multiple heavy rainfall and heavy rainfall days are clearly evident at the stations located in the lower part of the east coast, with trend magnitudes as largest as 45% per decade for R5d and 17% per decade for R10, respectively.

For a dryness indictor, there has been a general reduction in the maximum number of consecutive dry days, with exception in the northern part of the peninsular (Figure 8). Although only 22 % (four stations) have statistically significant trends, the spatial coverage of decreasing trends for CDD is consistent across most of the southern Thailand. Overall, the region has on average 6.8% per decade decrease in CDD. Along the Gulf of Thailand, trends towards fewer CDD are accompanied by increases in wetting conditions and heavy precipitation events.

Regional trends for each of rainfall extreme indicators computed by simply averaging all stations located in each coast are shown in Table 1. On the Andaman coast as a whole, there is evidence of statistically significant decreases in total annual rainfall amounts and the number of rain days during 1965-2006 period. These coherent changes were accompanied by significant reduction of heavy rainfall events. Whereas, the east coast of southern Thailand has experienced a significantly enhanced SDII which increased by about 30% relative to the 1965-2006 mean (Table 1). This pronounced increase results primarily from a significant decrease in the number of rain days.

Figure 9 shows the PDFs of seven annual rainfall extreme indicators before and after 1990 computed from all stations located in both sides of the southern Thailand. From this figure, it is an evident of a marked increase in the wetness index, SDII, decreases in the dryness indicator, CDD, and the number of rain days. There is a reduction in the number of CDD and the number of rain days, accompanied by a pronounced increase in SDII during 1990-2006. For all of these indices, the PDF for the 1990-2006 interval is significantly different from the previous interval. This indicates a shift in the distribution to more intense rainfall, associated with notable declines in dryness condition and the number of rain days in the coastal areas along the southern peninsular of Thailand in recent decades.

4. Conclusions

On the basis of the results derived from the study, there is evidence of notable changes in rainfall extreme during 1965-2006 in the southern peninsular of Thailand. On the Andaman sea, observed significant changes are characterized by an overall decrease in total annual rainfall amounts, accompanied by coherent dryness condition and a reduction of heavy rainfall events. However, changes in extreme rainfall on the Gulf of Thailand revealed a different pattern. Noteworthy changes observed include more intense daily rainfall, associated with significant decreases in the number of rainy days and the dryness conditions. Smaller increases in multiple heavy rainfall and heavy rainfall days are also discernable. These changes indicate the coastal region along the Gulf of Thailand has experienced a wetter condition and increased in magnitude and frequency of more intense rainfall events. It is noticeable that changes observed along the Gulf of Thailand are consistent with prolonged strengthening of the north-east monsoon which is primary climatic forcing the region especially during rainy season (Nov.-Jan.). Additional analyzes of the PDFs for all stations located along both coastal areas of the southern Thailand before and after 1990 further indicated a significant shift in the distribution of more intense rainfall which was associated with a decline in dryness and the number of rainy days. These observed changes are remained with expected changes under greenhouse conditions and fluctuations of regional climate variability in the Indo-Pacific region. Our findings suggest that both coastal areas of Thailand will be exposed to increasing risks of different extreme rainfall-driven disasters. Anticipated impacts including increases in inland flash flood, more frequent coastal flooding, coastal erosion and severe water shortage will introduce devastating pressures, and intensify other existing stresses associated with additional urbanization, industrialization and economic development on natural resources and the environment in the coastal areas of Thailand. Therefore, further assessment on vulnerability and risk is needed to shed more light on how to cope with and adapt to such adverse impacts of current and future changes in the system. It would changes themselves that are particularly important for building sustainable, resilient coastal communities, and effective disaster risk and coastal managements.

5. Acknowledgements

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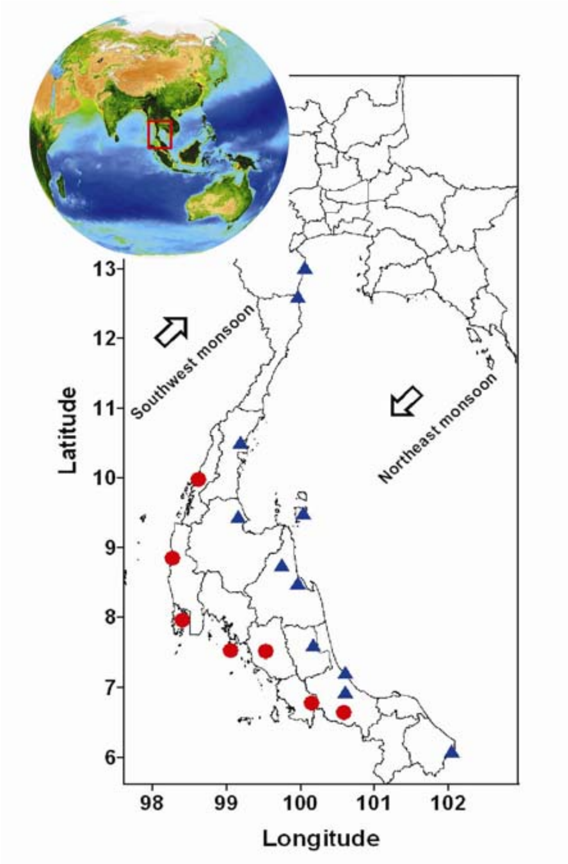

Figure 1. Locations of high-quality meteorological stations used in the rainfall extreme analysis.

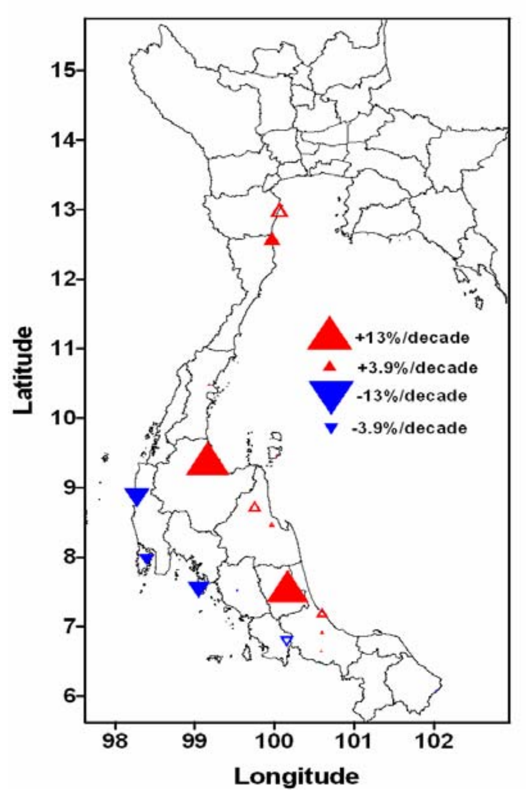

Figure 3. As Figure 2 but for total annual wet days (rainfall greater than 1 mm).

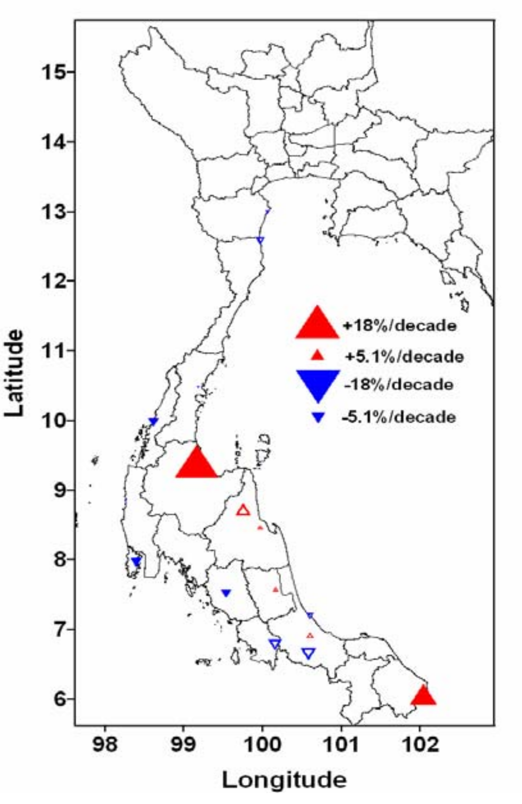

Figure 2. Trends in total annual rainfall amounts expressed as percents relative to long-term means. Filled triangles correspond to trends significant at the 5% level.

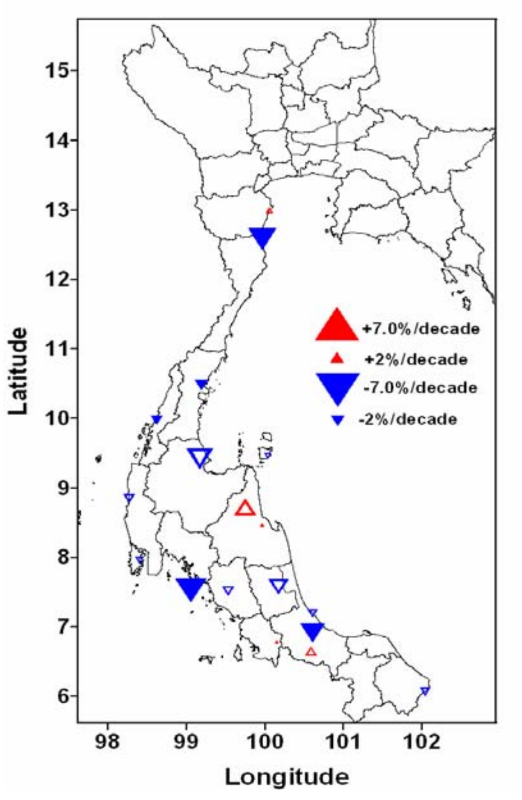

Figure 4. As Figure 2 but for simple daily intensity index (SDII).

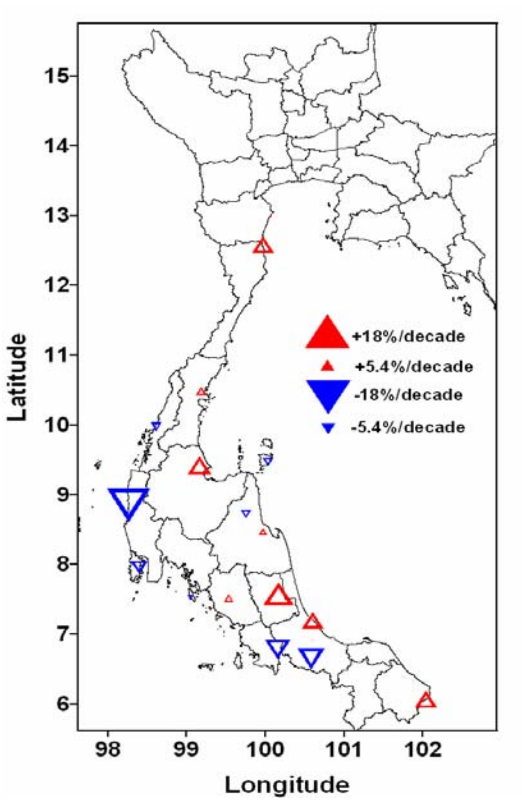

Figure 5. As Figure 2 but for R95.

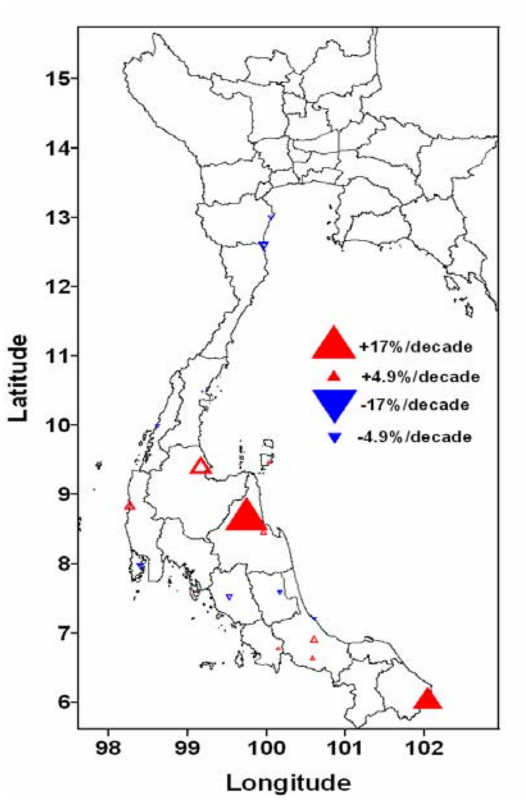

Figure 6. As Figure 2 but for R10.

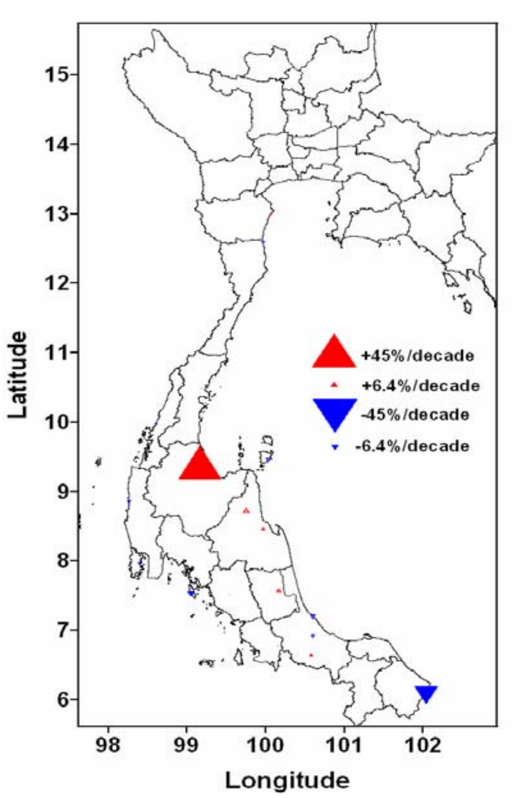

Figure 7. As Figure 2 but for R5d.

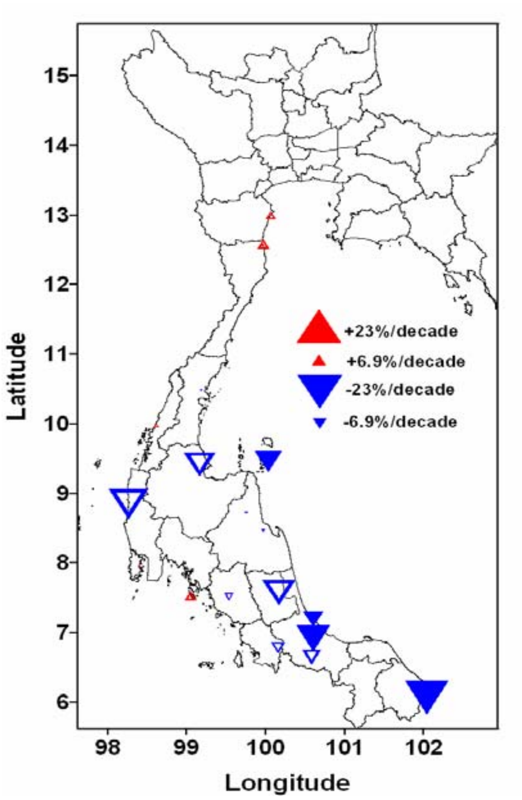

Figure 8. As Figure 2 but for CDD.

Table 1. Trends in regionally averaged rainfall extreme indices expressed as percentage changes relative to 1965-2006 means.

Extreme indices	Trends in the Andaman Sea coast (%/decade)	Trends in the Gulf of Thailand coast (%/decade)
Total rainfall amounts	-4.63*	-0.14
Number of rain days	-1.19	-2.73*
SDII	-1.95*	30.4*
R10	-2.13	0.73
R95	-5.30*	1.34
R5d	-2.63	-2.23
CDD	-0.75	0.24

* significant trends exceed the 95% confidence level in the Kendall-Tau test.

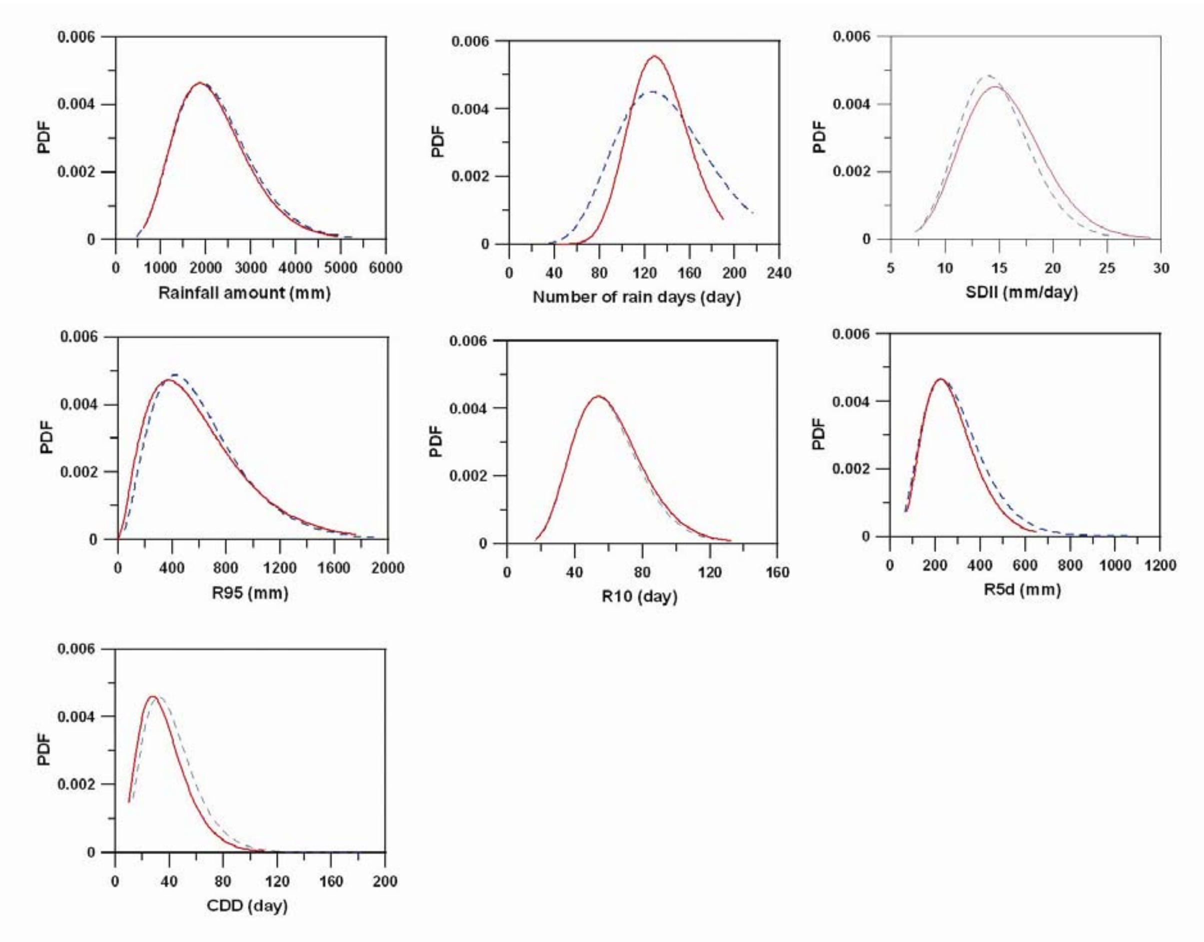

Figure 9. Annual probability distribution functions of rainfall extreme indices, estimated by gamma distribution. Blue dash lines/red solid lines are the data before and after 1990, respectively. Two-tailed Kolmogorov-Smirnov test was used to assess different significance for the data of two periods. CDD, SDII and the number of rain days are significantly different at 95% confidence level.