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OBSERVED CHANGES IN DAILY RAINFALL EXTREME ALONG THAILAND'S COASTAL ZONES
การเปลี่ยนแปลงของสภาวะความรุนแรงฝนรายวันบริเวณพื้นที่ชายฝั่งของประเทศไทย

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Abstract

Trends in daily rainfall extreme along Thailand's coastal zones were examined, based on 28 high-quality series of daily rainfall data observed at the stations along the Andaman Sea Coast (ASC), the Gulf of Thailand's western coast (GoTw) and the Gulf of Thailand's eastern coast (GoTe). A set of core climate extreme indices recommended by the WMO-CCL/CLIVAR Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) that measures different aspects of rainfall extreme events such as wetness and dryness conditions, frequency and intensity rainfall events was calculated. Analysis of these indices revealed notable changes in rainfall extreme events along Thailand's coastal zones in the recent decades. On the ASC, significant changes were characterized by an overall decrease in total rainfall amounts accompanied by a coherent reduction of heavy and intensity rainfall events. However, extreme rainfall changes on the GoTw were marked by more intense daily rainfall associated with a significant decrease in the number of rainy days. These changes indicate that GoTw has experienced a wetter condition and increases in magnitude and frequency of more intense rainfall events. For GoTe, changes in extreme rainfall events were relatively mixed with significant positive and negative trends. Additional analyzes of the PDFs for all stations before and after 1990 indicated a significant shift in the distribution towards a decline in dryness conditions. This observed change provides a vital clue of shift in extreme rainfall characteristics along Thailand's coastal zones under an anthropogenic-induced warmer regime and fluctuations of regional climate variability. Our findings suggest that coastal areas of Thailand will be disproportionately 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 social-economic problems on natural resources and environment in the coastal areas of

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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. Such knowledge is important for building sustainable, resilient coastal communities, and effective disaster risk and coastal managements.

Keywords: rainfall extreme, trend, Thailand's coastal zone, vulnerability

บทคัดย่อ

การศึกษานี้ ได้ทำการวิเคราะห์แนวโน้มการเปลี่ยนแปลงของสภาวะความรุนแรงฝนในพื้นที่ชายฝั่งของประเทศไทย จากข้อมูลฝนรายวันคุณภาพสูงที่ตรวจวัดจากสถานีผิวพื้นบริเวณชายฝั่งทะเลอันดามัน ชายฝั่งตะวันออกและตะวันตกของอ่าวไทย ดัชนีหลักสภาวะความรุนแรงฝนที่ถูกพัฒนา โดยทีมผู้เชี่ยวชาญด้านการติดตามตรวจสอบการเปลี่ยนแปลงสภาพภูมิอากาศขององค์การอุตุนิยมวิทยาโลก ถูกคำนวณเพื่อประเมินลักษณะต่าง ๆ ของสภาวะความรุนแรงฝนทั้งในแง่ความแห้งแล้ง สภาวะเปียกกว่าปกติ ความถี่ ความรุนแรงและระยะเวลาของเหตุการณ์ฝน ผลการวิเคราะห์ พบว่า สภาวะความรุนแรงฝนบริเวณพื้นที่ชายฝั่งของประเทศไทยมีการเปลี่ยนแปลงที่ชัดเจนในช่วง 2-3 ทศวรรษที่ผ่านมา โดยบริเวณชายฝั่งทะเลอันดามัน การเปลี่ยนแปลงที่มีนัยสำคัญ ประกอบด้วยการลดลงของปริมาณฝนรายปี และความแรงและความถี่ของเหตุการณ์ฝนตกหนัก ในขณะที่ สภาวะความรุนแรงฝนบริเวณชายฝั่งตะวันตกของอ่าวไทย มีการเปลี่ยนแปลงในลักษณะการเพิ่มขึ้นของความแรงของฝน ซึ่งเกี่ยวโยงกับการลดลงอย่างมีนัยของจำนวนวันฝนตก สำหรับชายฝั่งตะวันออกของอ่าวไทย สภาวะความรุนแรงฝน มีแนวโน้มการเปลี่ยนแปลงที่ค่อนข้างผสมระหว่างการเพิ่มขึ้นและลดลง นอกจากนี้ การวิเคราะห์ Probability Density Functions (PDFs) สำหรับทุกสถานีในช่วงก่อนและหลัง ปี ค.ศ. 1990 ยังพบว่า PDFs ของดัชนีที่บ่งชี้ถึงความแห้งแล้ง มีความแตกต่างอย่างมีนัยสำคัญระหว่างสองช่วงเวลาดังกล่าว โดยการแจกแจงของ PDFs ของดัชนีความแห้งแล้งในช่วงหลัง ปี ค.ศ. 1990 มีค่าลดลง ผลการศึกษานี้ นับเป็นหลักฐานที่แสดงถึงการเปลี่ยนแปลงของลักษณะของสภาวะความรุนแรงฝนบริเวณพื้นที่ชายฝั่งของประเทศไทยภายใต้การเปลี่ยนแปลงสภาพภูมิอากาศที่เกิดจากกิจกรรมของมนุษย์ และความแปรปรวนของภูมิอากาศในภูมิภาค การวิเคราะห์ยังแสดงให้เห็นถึงพื้นที่ชายฝั่งของประเทศไทย จะประสบกับความเสี่ยงของอุบัติภัยจากสภาพภูมิอากาศที่แตกต่างกันในแต่ละพื้นที่ โดยผลกระทบที่อาจเกิดขึ้นประกอบด้วย การเพิ่มขึ้นในแง่ความถี่และความรุนแรงของน้ำท่วมฉับพลันในพื้นที่ชายฝั่ง การกัดเซาะชายฝั่งและขาดแคลนน้ำอุปโภค-บริโภค ซึ่งผลกระทบเหล่านี้จะส่งผลให้ปัญหาการลดลงของทรัพยากรธรรมชาติและความเสื่อมโทรมของสิ่งแวดล้อม รวมทั้งปัญหาเศรษฐกิจและสังคมที่ชุมชนแถบชายฝั่งกำลังประสบอยู่ มีความรุนแรงมากขึ้นในอนาคตอันใกล้ ดังนั้น การประเมินความเสี่ยงและความล่อแหลม จะช่วยให้เข้าใจถึงแนวทางการตั้งรับและปรับตัว ต่อผลกระทบจากการเปลี่ยนแปลงของสภาวะความรุนแรงฝน ทั้งนี้ ความรู้ความเข้าใจดังกล่าว มีความสำคัญต่อการพัฒนาอย่างยั่งยืนของชุมชนแถบชายฝั่ง ตลอดจนการจัดการทรัพยากรน้ำ และการตั้งรับต่อภัยพิบัติทางภูมิภาคอย่างมีประสิทธิภาพ

คำสำคัญ: สภาวะความรุนแรงฝน, แนวโน้มการเปลี่ยนแปลง, พื้นที่ชายฝั่งของประเทศไทย, ความล่อแหลม

Introduction

Coastal zones are one of the important natural resources for mankind. The foundations of prosperity and prominence for most of global mega cities lie in low-lying areas near the coastlines and the mouth of major rivers, which serve as conduits for social-economic development and commerce with the rest of the world [1]. Globally, 1.2 billion people (23% of the world's population) live within 100 km of the coast [2], and 50% are likely to do so by 2030 [3].

As it happens, these locations place coastal societies at greater risk from climate change and weather extremes. Today estimated 10 million people experience coastal flooding each year due to storm surges and landfall typhoons, and 50 million could be at risk by 2080 because of climate change and increasing population densities [2]. The 2008 Cyclone Nagis devastated the low-lying Irrawaddy delta of Myanmar that left more than 80,000 dead with millions home less and food production severely affected is a recent example of such far-reaching catastrophes[4].

Thailand, a tropical country lying in the center of mainland Southeast Asia, has extensive coastlines for more than 2,600 km [5]. The coastlines are divided into two parts - the Gulf of Thailand and the Andaman Sea. These particular areas are crucial for the country in terms of society, economy and human settlement. A number of the country's population live along the coastal plains, and most communities depend heavily on local resources for their livelihoods [6]. Over the past decades, Thailand's coastal zones have come under increasing threat from a growing population and social-economic development manifested by rapid expansion of various activities such as industrialization, aquaculture and tourism [7]. 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 [5, 7].

Recent evidence has indicated that the coastal zones of Thailand are particularly at risks from seismic hazards and also highly prone to hydro-meteorological and environmental disasters [8, 3, 4]. The Indian Ocean Tsunamis on December 26th, 2004, for instance, caused more than 1,000's fatalities and huge economic losses in the six popular tourist provinces along the Andaman Sea coast of Thailand[8]. This loss of life and structural damage is probably the worst socio-natural disasters recorded in the Thailand's history. In addition, Thailand's coastal zones have frequently experienced severe floods associated with monsoon, the El Niño-Southern Oscillation (ENSO), and intense tropical cyclones [9-11]. High incidence of hydro-meteorological and other disasters affecting Thailand's coastal regions poses a great challenge to local officials and their communities in being prepared and proactive in addressing increasingly frequent and extreme climate events. In this paper, trends in several indices of rainfall extreme along the coastal zones of Thailand have been examined. The primary purposes are to identify whether the frequency and/or severity of extreme rainfall events have changed in recent decades, and to evaluate similarities and differences between coastal sub-regions in order to obtain information about spatial coherence of rainfall extreme trends.

Materials and Methods

Data sources

Series of daily rainfall data observed at the stations along the Andaman Sea Coast (ASC), western coast of the Gulf of Thailand (GoTw) and eastern coast of the Gulf of Thailand (GoTe) provided the basis for this study. All series were obtained from archives of the Meteorological Department and the Irrigation Department of the Royal Thai Government. These data were parts of a large historical climate dataset complied and developed for climate change study in Thailand. Station series were selected on the basis of record length and data completeness. Overall, each of selected station records was at least 98% complete.

Data quality control and homogeneity checks

In addition to visual examination of any obvious outliers and discontinuities, all daily rainfall data were subjected to a multi-stage suite of objective quality control and homogeneity tests. The most widely used and accepted objective approaches which include tests of spatial and temporal outliers, data missing interpolation and homogeneity checks were applied to evaluate the quality of data [12-14]. Temporal checks for outliers were performed utilizing the sample distribution of each calendar month separately for each station. Because rainfall data are commonly positively skewed, a standard deviation as traditional quality control technique was applied [15]. Outliers were identified as those values trespassing a threshold of $\pm$15*SD. These thresholds were selected after having tried several other thresholds as a compromise to ensure that the severe errors were captured without including too many correct values in the output records. For spatial outlier checks, a nearby-station technique was employed. This method detects the outliers by comparing the candidate data with neighboring stations by mean of linear regression for each calendar month. Values were flagged as potential outliers if they felt outside $\pm$7*RMSE (root-mean-square-error) of linear regression for all pairs of stations. Those data points that failed both of these tests were removed from data records. The outlier data screened by the two previous checks and missing data were estimated using the method described by two researchers[12, 16].

Data homogeneity was assessed using an R-based program, RH test, developed at the Climate Research Branch of Meteorological Service of Canada [14]. This program is capable of identifying multiple step changes based on a two-phase regression model with a linear trend for the entire base series [17]. Detailed discussion about this model can be found in the work of Wang [17]. Significant in-homogenous series were discarded for further analysis. Based on extensive quality control and homogeneity checks, daily rainfall data for a set of 28 high-quality records, which 7, 11 and 10 stations are located along ASC, GoTw and

GoTe, respectively, were prepared for rainfall extreme indicator calculation and trend analysis (Figure 1). Most of high-quality rainfall records extend from 1965 to 2006, with a few stations spanning shorter periods ranging from 1969-2006 to 1981-2006.

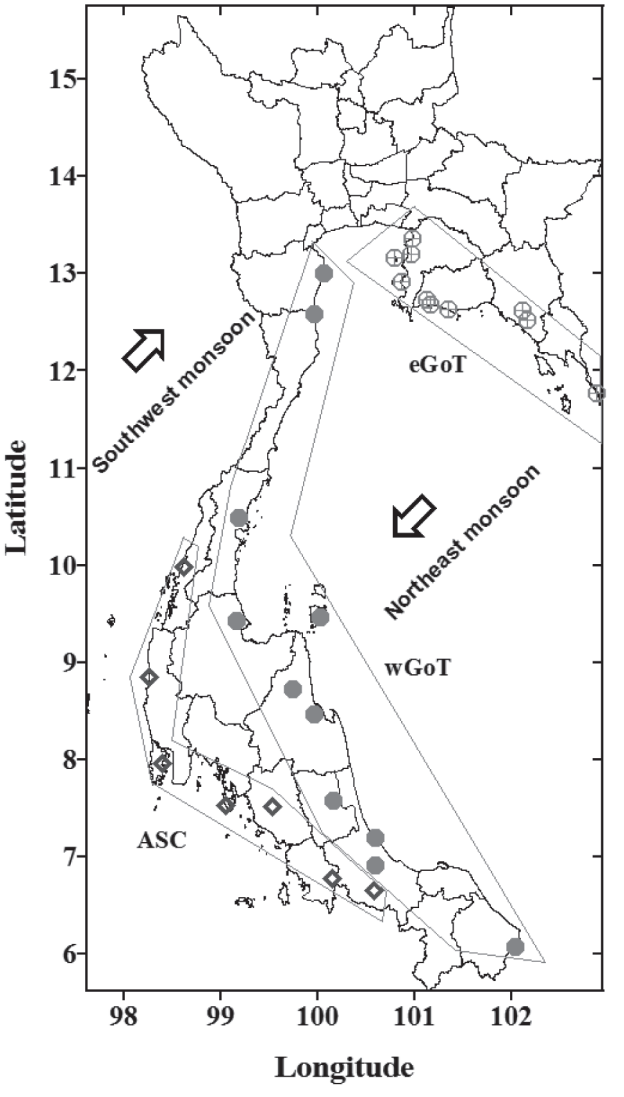

Figure 1 Locations of high-quality daily rainfall stations used in the extreme indicator analysis.

The indices

Five of the 11 core rainfall-related indices recommended by WMO [18] were used to assess changes in rainfall extreme [19, 20]. The indices were chosen primarily for assessment of many aspects 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 d 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 more intense rainfall events. In contrast, SDII is a measure of the average rainfall amount that falls on a wet day in a given year. Last, CDD index is a measure of the length of the driest part of the year; this indicator may serve as a valuable drought indicator.

Trend calculation

A linear trend was computed from the index series using the ordinary least square (OLS) method, which is the most widely used and accepted non-parametric trend estimator in hydro-meteorological series (e.g. the work carried out in Canada[21], Northern Hemisphere oceans[22] and Northeast United States[23]). This estimator is resistant to the effect of outliers and robust to non-normal data distribution. Trend magnitudes were expressed as a percentage change relative to long-term means of the entire records and statistical significance was assessed following the non-parametric Kendall's Tau test[20]. To evaluate changes in each coastal sub-region, rainfall extreme indices for ASC, GoTw and GoTe were computed by simply averaging all stations located in those sub-regions. In addition, to provide an overall picture of changes in the recent decades, empirical probability distribution functions (PDFs) for all stations before and after 1990 time periods were calculated by fitting two data intervals with gamma distribution function, which shape (α) and scale (β) parameters had been estimated by Maximum Likelihood method [24, 25]. To assess whether the probabilities for two periods for each extreme indicator were significantly different or not, a 2-tailed Kolmogorov-Smimov test was employed. This test has a null hypothesis that two PDFs for two time periods are identical [20, 23].

Results and discussions

In each coast of Thailand, a distinction of climate conditions is remarkable as a result of differential influences by the Asian monsoon systems as a primary external driving forcing of the regions. They are parts of the annual reversal of the steady wind regimes associated

with changes in large-scale atmospheric circulation in the Indo-Pacific sector and north-south migration of tropical convergence zone[26, 27]. On the ASC and GoTe, the wettest period of the year occurs during June-September due to intense summer south-west monsoon. Whereas, the GoTw especially the lower part, the wettest period of the year takes place from November to January resulting from prevailing winter north-east monsoon. In addition, each coastal sub-region of Thailand is disproportionately affected by other regional and global climate variability modes such as ENSO and Indian Ocean Dipole (IOD). Such seasonal and regional differences may manifest in distinctive patterns of trends in rainfall and associated extreme events. This notation is supported by the results from this study, revealing coherent spatial changes but different patterns of trends in total rainfall amounts (Figure 2). Trends in total rainfall amounts can be characterized by an overall decrease on the ASC, while a discernable increase was evident on the GoTw. For the GoTe, there was a mixed pattern showing both decreasing and increasing trends (Figure 2). Significant surplus and deficit in total rainfall amounts can be observed at two stations on the GoTw, three stations on the GoTe and five stations along the ASC, respectively. Trends in total rainfall amounts expressed as percentage changes in relation to long-term means among 28 stations varied from -7.5 to 17.3%/decade. It should be noted that an increase in total rainfall amounts along the GoTw was coincident with the prolonged strengthening of the winter north-east monsoon, as evident from an abrupt shift in winter-time (Oct.-Feb.) wind speed at station in the middle of the GoTw (Figure 3). Moreover, a decline in total rainfall amounts along the ASC was in line with the slightly weakening of the Indian monsoon [28]. Webster and Yang Index, as circulation index measuring variability of the broad-scale Asian Summer Monsoon defined by a time-mean zonal wind (U) shear between 850 and 200 hPa, U850-U200, averaged over south Asia from the equator to 20° N and from 40° to 110° E [29], showed a progressive weakening over the past decades (Figure 4). Decreased total rainfall amounts on the ASC were also consistent with a decadal shift in the ENSO towards more El Niño events since the late 1970s[30, 31]. Previous studies have illustrated 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 [32, 10, 9]. In association with the a recent shift in the ENSO towards more warm events, the Walker circulation has shown a persistent southeastward shift over Thailand-Indonesia region accompanied by the weakening of southwest monsoon over Thailand [9].

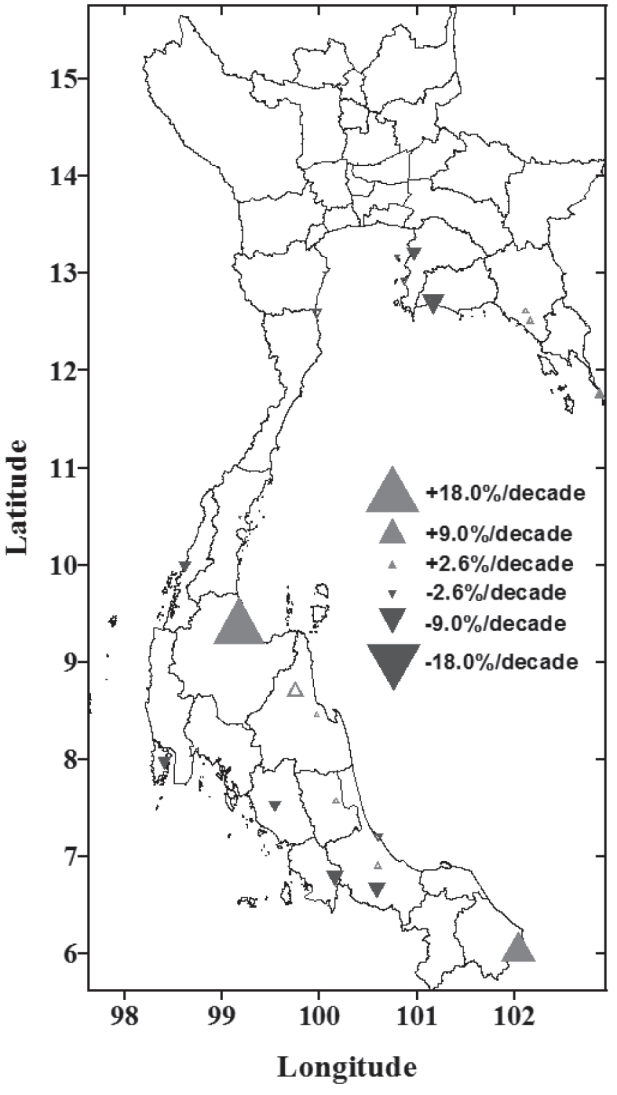

Figure 2 Trends in total rainfall amounts expressed as percents relative to long-term means. Filled triangle (down) and triangle (up) correspond to trends significant at the 5% level.

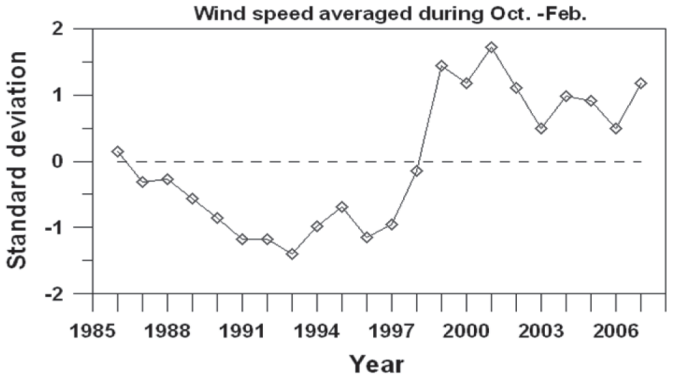

Figure 3 Wind speed averaged during Oct.-Feb. at Nakhon Si Thommarat Station.

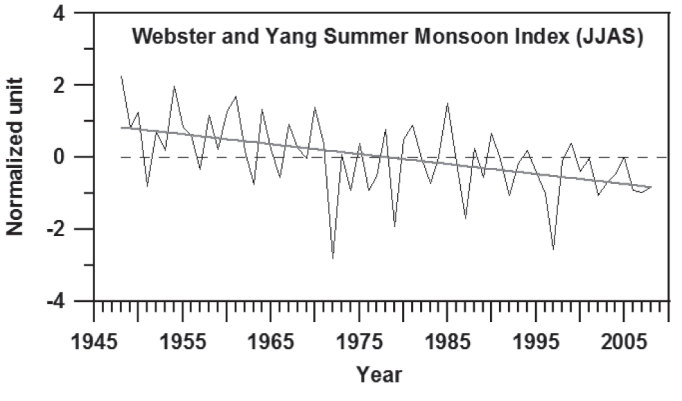

Figure 4 Webster and Yang Summer Monsoon Index for Jun.-Sep period. It is defined by a time-mean zonal wind (U) shear between 850 and 200 hPa, U850-U200, averaged over south Asia from the equator to 20° N and from 40° to 110° E.

Figure 5 reveals a trend toward fewer rainy days (defined as days with at least 1 mm of rain) over most of southern Thailand. However, a significant increase superimposed on a non-significant decrease in rainy days was confined on the GoTe. A closer examination indicated that 20 stations showed noticeable decreases with trend magnitudes ranging from -0.2 to -4.4%/decade. Significant decreasing trends occurred at 4 stations of southern peninsular of Thailand. The findings are consistent with the previous studies, illustrating that there has been widespread reduction in the number of rainy days in Thailand over the last three decades [33] and throughout the Southeast Asia during 1961-1998 [34].

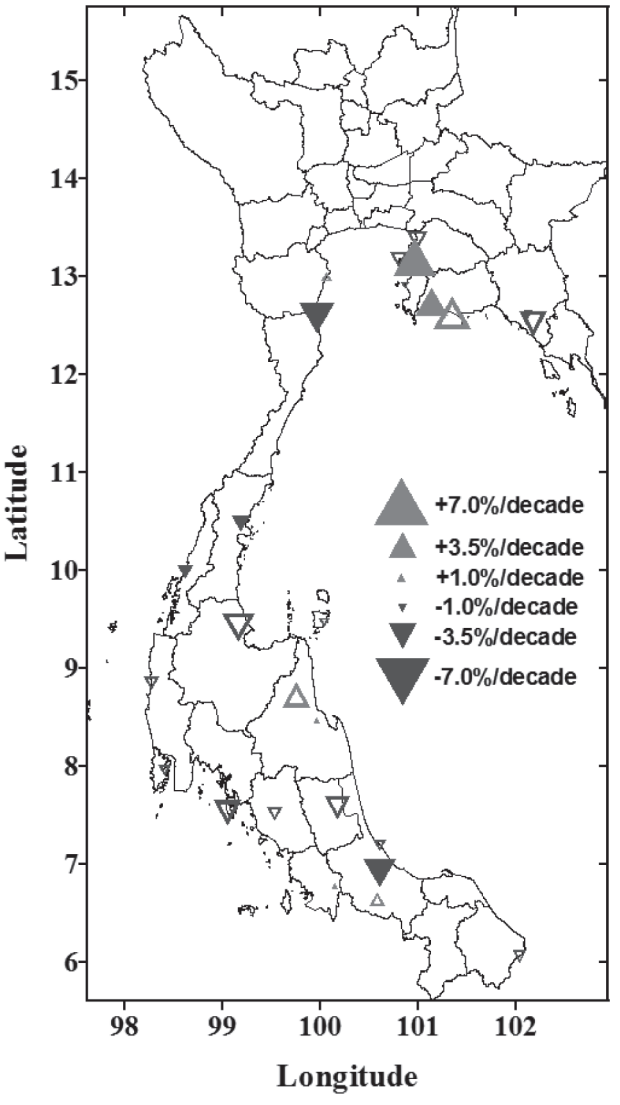

Figure 5 As Figure 2 but for the number of rainy days (rainfall greater than 1 mm).

As a result of changes in different magnitudes and signs of rainfall and the number of rainy days, notable regional differences in trends can be observed in SDII defined as total rainfall amounts per the number of rainy days in the year (Figure 6). A significant decrease in SDII was clearly confined on the ASC and GoTe, with magnitudes in range of -4.2 to -7.5% /decade. A decrease in this index reflects coherent reduction in both the number of rainy days and total rainfall amounts. On the other hand, all stations on the GoTw showed trends toward enhanced daily rainfall intensity, of which three stations were statistically significant at the 95%

confidence level. It appears that an increasing SDII on the GoTw results mainly from a decrease in the number of rainy days. Note that SDII changes on the GoTw were generally greater in magnitude. Trends in heavy rainfall (R95) showed similar pattern as SDII, with spatially coherent patterns but regional differences in signs (Figure 7). Trends in heavy rainfall tended to decrease along the ASC, similar to trends in total rainfall amounts, the number of rainy days and SDII. In contrast, most of stations on the GoTw exhibited discernable trends toward wetter conditions. However, for the stations analyzed, no heavy rainfall trends in the southern peninsular were statistically significant (Figure 7). For the GoTe, there was relatively a mixed pattern, which both significant increase and decrease could be observed (Figure 7).

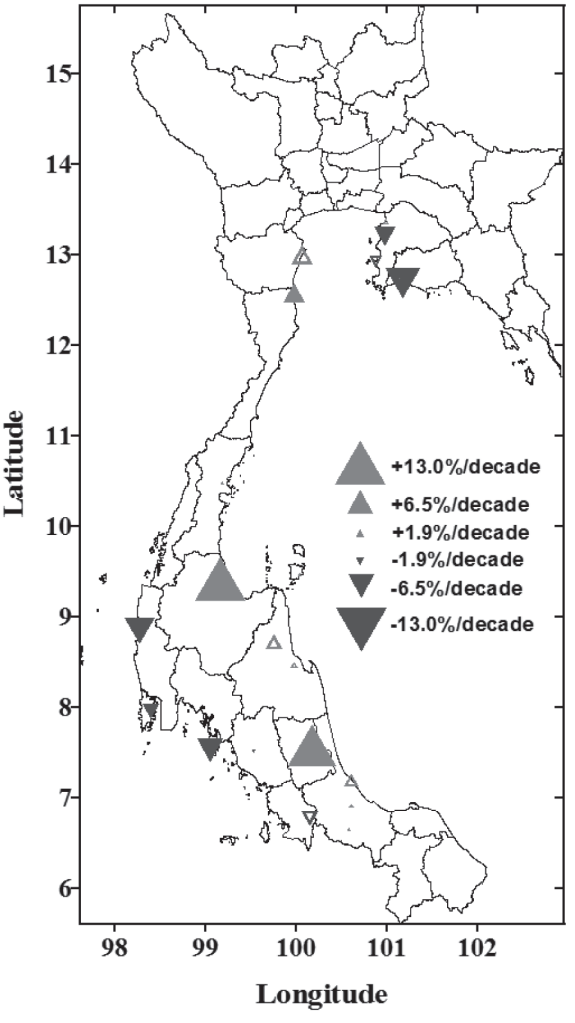

Figure 6 As Figure 2 but for simple daily intensity index (SDII).

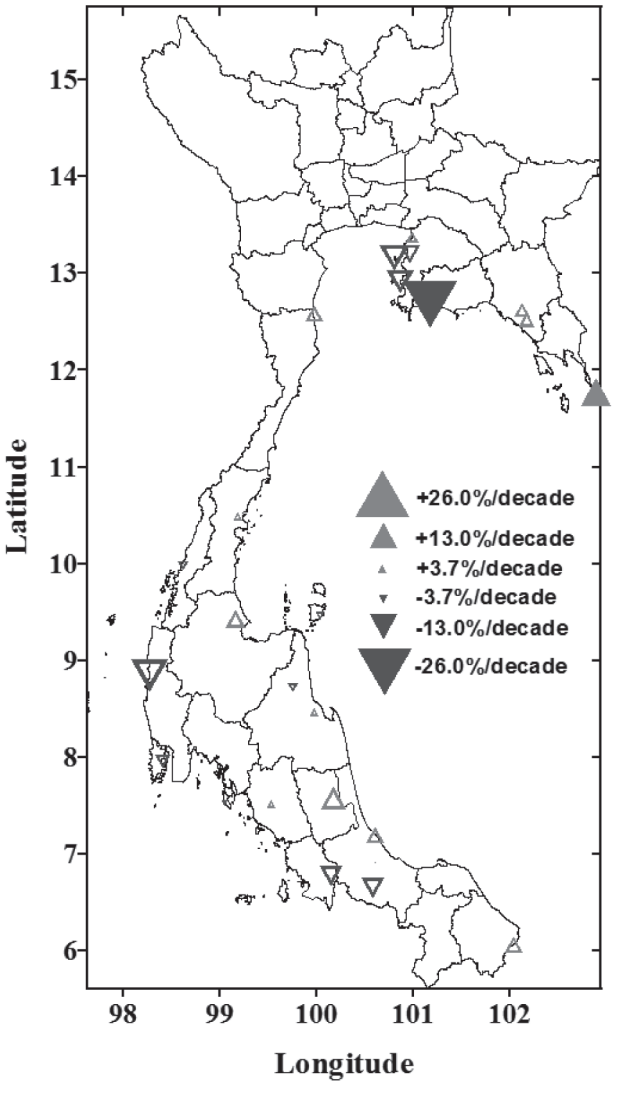

Figure 7 As Figure 2 but for very wet days (R95).

Other two wetness indicators, R10 and R5d, showed relatively mixed patterns of changes. There was a mixture of stations exhibiting increasing and decreasing trends of R10 and R5d, with a few stations in the GoT having significant trends (Figures 8 and 9). Exceptionally large changes in multiple heavy rainfall and heavy rainfall days were clearly evident at the stations located in the lower part of the GoTw, with trend magnitudes as largest as 45%/decade for R5d and 17%/decade for R10, respectively.

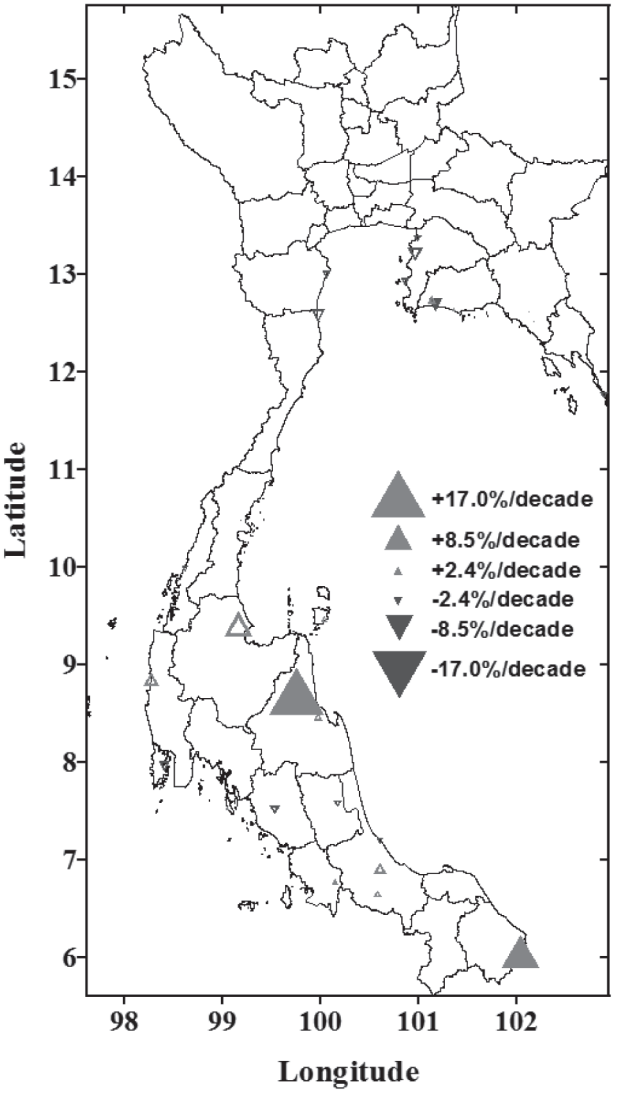

Figure 8 As Figure 2 but for heavy rainfall days (R10).

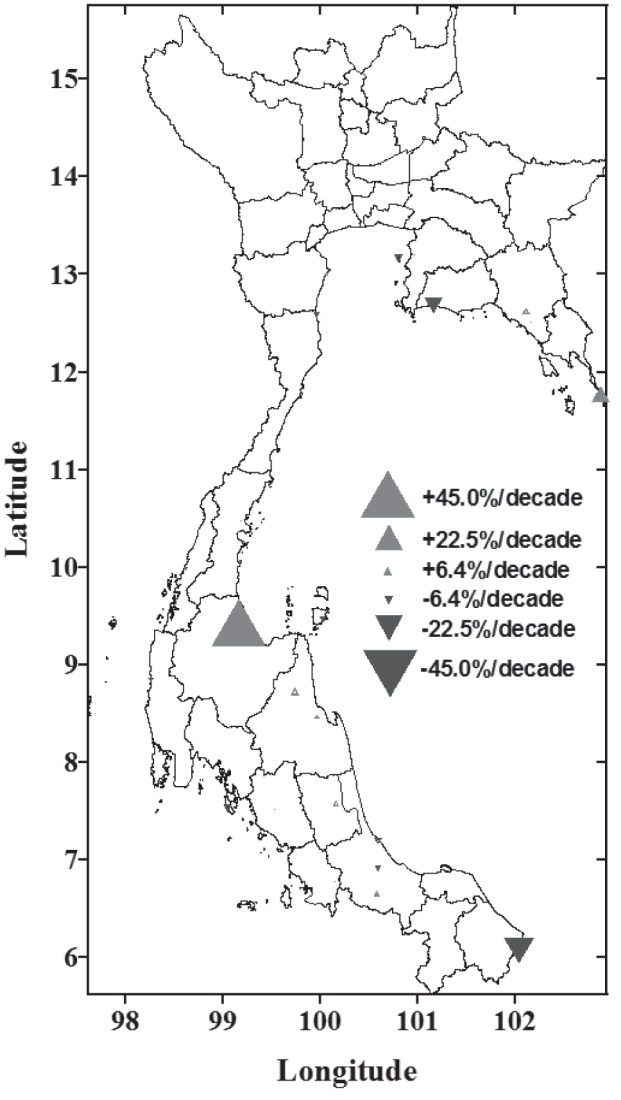

Figure 9 As Figure 2 but for maximum 5 d rainfall total (R5d).

For a dryness indicator, there was a general reduction in the maximum number of consecutive dry days, with exception in the northern part of the peninsular and the eGoT (Figure 10). Although only 14% (four stations) had statistically significant trends, spatial coverage of decreasing trends of CDD was consistent across most of the southern Thailand. Overall, the region has on an average 5%/decade decrease in CDD. Along the wGoT, trends toward fewer CDD were accompanied by increases in wetting conditions and heavy rainfall events.

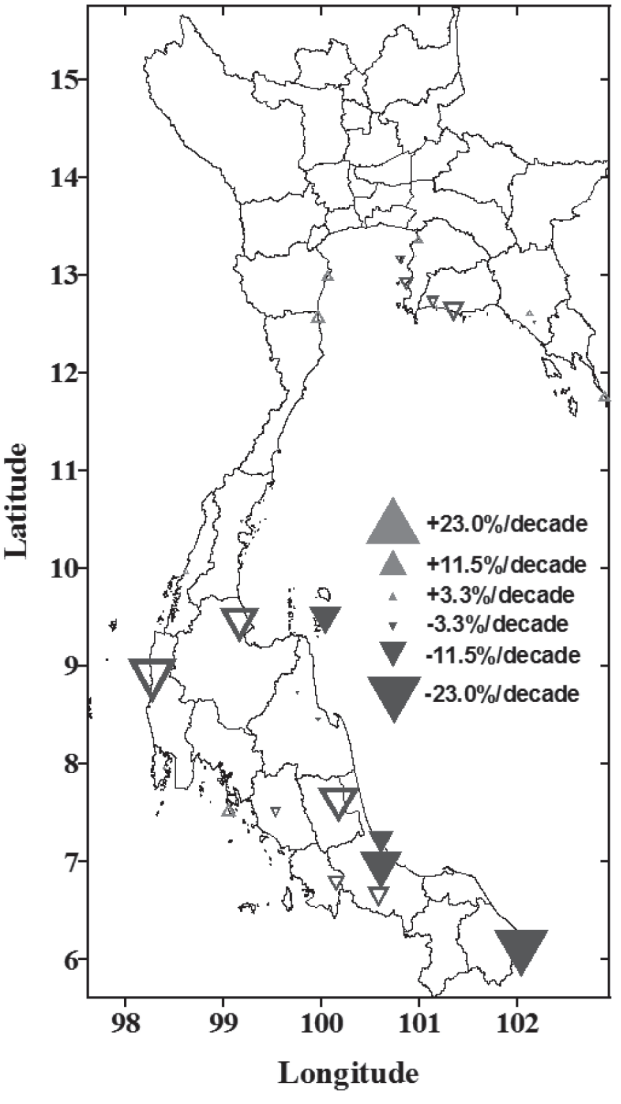

Figure 10 As Figure 2 but for consecutive dry days (CDD).

Overall trends for each of rainfall extreme indicators computed by simply averaging all stations located in the ASC, GoTw and GoTe were shown in Table 1. On the ASC as a whole, there was evidence of statistically significant decreases in total rainfall amounts and the number of rainy days in the recent decades. These coherent changes were accompanied by a significant reduction of heavy rainfall events. Whereas, the GoTw has experienced a signifi cantly enhanced SDII which increased by about 3%/decade relative to the long-term

mean (Table 1). This pronounced increase results primarily from a significant decrease in the number of rainy days. For the GoTe, no significant changes were found (Table 1).

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

Extreme indices	ASC (%/decade)	GoTw (%/decade)	GoTe (%/decade)
Total rainfall amounts	-4.63*	-0.14	-1.53
Number of rain days	-1.19	-2.73*	-2.15
SDII	-1.95*	3.0?	-0.19
R10	-2.13	0.73	-2.79
R95	-5.30*	1.34	0.71
R5d	-2.63	-2.23	0.58
CDD	-0.75	0.24	0.89

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

Figure 11 shows the PDFs of seven rainfall extreme indicators before and after 1990 computed from all stations located along Thailand's coastal zones and fitted by gamma distribution function. From this figure, it is only evidence of a significant decrease in the dryness indicator, CDD. Based on a 2-tailed Kolmogorov-Smimov test, the PDF of CDD for the 1990-2006 intervals was significantly different from the previous interval, indicating a shift in the distribution towards declines in dryness condition. For the other indices such as SDII, R95 and the number of rainy days, there was no evidence of a significant difference between two intervals. Changes in comparable magnitudes but different signs in each sub-region may cancel out overall significant signals of PDFs.

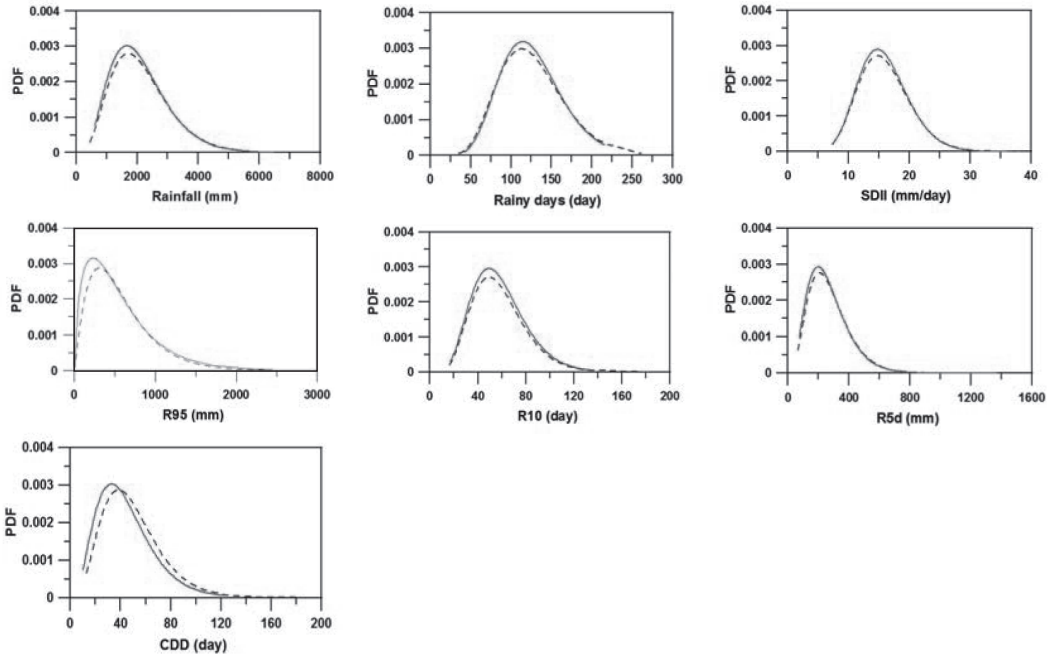

Figure 11 Annual probability distribution functions of rainfall extreme indices. Dash lines/solid lines are the data before and after 1990, respectively. Only CDD was significantly different at 95% confident level based on a 2-tailed Kolmogorov-Smirnov test.

Conclusions

On the basis of the results derived from this study, there has been evidence of notable changes in rainfall extreme events along Thailand's coastal zones in the recent decades. On the ASC, observed significant changes were characterized by an overall decrease in total rainfall amounts accompanied by a coherent reduction of heavy and intensity rainfall events. However, changes in extreme rainfall on the GoTw revealed different patterns. A noteworthy change observed included more intense daily rainfall associated with a significant decrease in the number of rainy days. A smaller increase in heavy rainfall events was also discernable. These changes indicated that GoTw has experienced a wetter condition and increases in magnitude and frequency of more intense rainfall events. It was noticeable that changes observed along the GoTw were consistent with prolonged strengthening of the north-east winter monsoon as primary climatic forcing of the region especially during rainy season (Nov.-Jan.). For GoTe, changes in extreme rainfall events were relatively mixed with significant positive and negative trends. Additional analyzes

of the PDFs for all stations located along Thailand's coastal zones before and after 1990 indicated a significant shift in the distribution towards a decline in dryness conditions. This observed change provides a vital clue of shift in extreme rainfall characteristics along Thailand's coastal zones toward a wetter condition under an anthropogenic-induced warmer regime and fluctuations of regional climate variability in the Indo-Pacific region. Our findings suggest that coastal areas of Thailand will be disproportionately 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 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 climate-related disaster risk and coastal managements.

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