

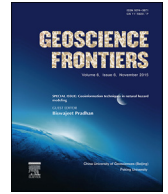
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Research paper

Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia

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ABSTRACT

Global warming and climate change is one of the most extensively researched and discussed topical issues affecting the environment. Although there are enough historical evidence to support the theory that climate change is a natural phenomenon, many research scientists are widely in agreement that the increase in temperature in the 20th century is anthropologically related. The associated effects are the variability of rainfall and cyclonic patterns that are being observed globally. In Southeast Asia the link between global warming and the seasonal atmospheric flow during the monsoon seasons shows varying degree of fuzziness. This study investigates the impact of climate change on the seasonality of monsoon Asia and its effect on the variability of monsoon rainfall in Southeast Asia. The comparison of decadal variation of precipitation and temperature anomalies before the 1970s found general increases which were mostly varying. But beyond the 1970s, global precipitation anomalous showed increases that almost corresponded with increases in global temperature anomalies for the same period. There are frequent changes and a shift westward of the Indian summer monsoon. Although precipitation is observed to be 70% below normal levels, in some areas the topography affects the intensity of rainfall. These shifting phenomenon of other monsoon season in the region are impacting on the variability of rainfall and the onset of monsoons in Southeast Asia and is predicted to delay for 15 days the onset of the monsoon in the future. The variability of monsoon rainfall in the SEA region is observed to be decadal and the frequency and intensity of intermittent flooding of some areas during the monsoon season have serious consequences on the human, financial, infrastructure and food security of the region.

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1. Introduction

The global circulation in terms of precipitation is an important element for the functionality of the Earth's system. It helps to regulate the temperature of the Earth by transporting heat from the tropics to the higher latitudes. However, this system is vulnerable to long-term temperature fluctuations, more commonly termed as climate change. Climate change is currently debated as an anthropologically enhanced phenomenon. Many scientists of today have been trying to quantify climate change and its relation with other

environmental systems. Arguably one of the most heavily dependent upon weather system is the monsoon season of Southeast Asia. While there are many literature available on the interactivity of the monsoon seasons, the impact of climate change in terms of rising temperatures on monsoon rainfall intensities in Southeast Asia has received little attention.

The objective of this study is to establish the link between global warming and precipitation increases and to understand the effects of these climate change trends on the dynamics of Asian monsoon seasons and how it impact rainfall variability in Southeast Asia. Climate change is discussed mainly in references to observed temperature anomalies (°C) from the late 20th century to the early 21st century, while rainfall variability of the East Asian summer monsoon is examined based on the observed seasonal rainfall anomaly. Secondary data on thermometric records over the last century have been analyzed to understand the effects of climate

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change from the overall variation and distribution of temperature and discussed in the context of meteorological records of global precipitation and importantly in the Southeast Asia region. The pattern of South Asian monsoons and other sub seasons are investigated to understand their effect and impact on rainfall distribution and vulnerability during the southeast monsoon season. In recent years, the erratic and unpredictable nature of the monsoons have caused extensive financial loss, damage to lives and property and also the destruction of the environment and farmlands. This consequently leads to food insecurity issues. It has thus, become a priority to predict and understand monsoon rainfall patterns in many Asian countries (Reuter et al., 2012).

2. Climate change and climate variability

Climate change is inevitable and unstoppable in its nature. However, the 20th century global warming has been linked directly with anthropological impacts, such as the burning of fossil fuel, excessive emission of greenhouse gases, and urbanization. Climate variability is concerned with the changeability in 'the mean state and other statistics (such as the standard deviation, extremes, or shape of frequency distribution) of climate elements on all spatial and temporal scales beyond those of individual weather events' (Serreze and Barry, 2010). Climate change on the other hand is variability that continues over a longer period and is statistically significant.

Global temperatures are recorded by combining temperature measurements from around the world. According to NOAA (2012a), due to the variability of methods of the data collection that include mercury thermometers invented in the early eighteen century, temperature records before 1850s are considered unreliable to be used for interpreting climate change. Therefore, temperature anomalies, the deviations from the referenced temperature (NOAA, 2012b), are used as a means to compare the change in temperatures. A positive value indicates a higher temperature and a negative value indicates a lower temperature from the referenced value. These differences are based on a normal, which can be explained as the 'arithmetic average of a climate element (e.g. temperature) over a 30-year period'.

According to the University of East Anglia's Climatic Research Unit in the UK, there is a distinctive increase in temperature after the last decline from 1945 to 1973 (Brohan et al., 2006). The somewhat exponential increase, shown in Fig. 1, is strongly believed to be anthropologically associated, caused by carbon

emission and urbanization. The impact of rapid urbanization on climate change is the temperature increase caused by buildings and urban activities. This increase in temperature has an immediate effect on the global rainfall distribution. The study NOAA-NCDC (2011) (Fig. 2) shows the total annual amount of global precipitation from 1910 to 2010. The changes in average precipitation over the period since 1910 to 2010 are seen on a baseline which does not change over time and which is also reflected in the global precipitation averages. A further look at the data shows more frequencies of negative precipitation anomalies from the 1950 to 1970. Beyond 1970, the frequent fluctuations between positive and negative precipitation anomalies follow the dramatic increase of global air temperature. Therefore, we can say that there is a relationship between global increase in temperature and precipitation changes beyond the 1970s.

3. Monsoon weather systems

Seasonality is caused by the tilting of the Earth, while the monsoon weather systems are a result of the land-sea temperature differences caused by solar radiation (Huffman et al., 1997). When the Earth rotates and revolves around the Sun, different seasons occur due to the different land masses of the northern and southern hemispheres. To understand this phenomenon, it is useful to note that the land surface area at the northern hemisphere is larger than the southern hemisphere. Therefore, the northern hemisphere is warmed greater. This causes opposing seasons between the northern and southern hemispheres. The two regimes of monsoon are the Southeast Asian summer monsoon (10° – 20° N) and the western North Pacific summer monsoon (10° – 20° N, 130° – 150° E), and are separated by a boundary over the South China Sea (Kripalani and Kulkarni, 1997). This seasonality is important in regulating rain regime. During winter, the tilting of the Earth allows less solar radiation at the northern hemisphere. This results in rapid cooling followed by pressure decrease in the atmosphere. Anti-cyclones develop over Siberia and the cold northeasterly air reaches the coastal waters of China before heading towards Southeast Asia (MMD, 2012). The East Asian winter monsoon (EAWM) is usually dry in Southeast Asia. During summer, the southwest monsoon rainfall is controlled by the warming of the northern hemisphere, where the heated air will rise, and be transported by the monsoon wind towards the southern hemisphere (Wolfson, 2012). East Asian summer monsoon (EASM) seasons are

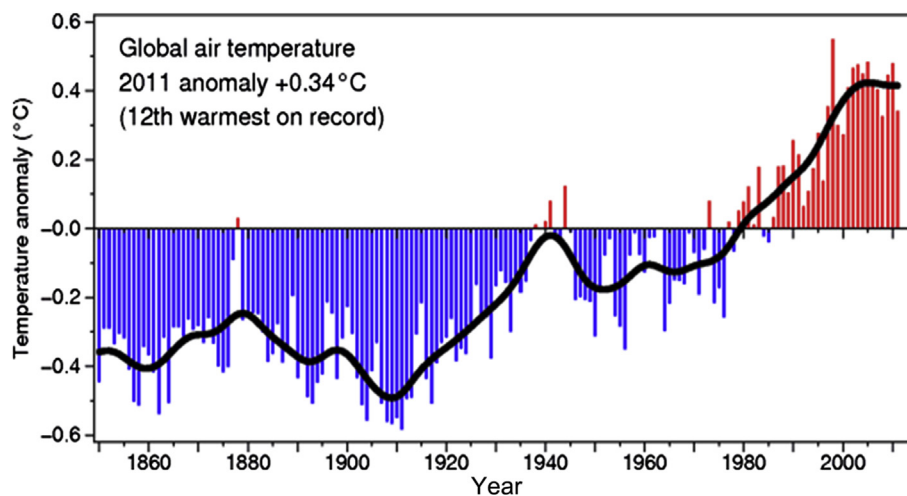


Figure 1. Global temperature anomaly from 1850 to 2010 (Brohan et al., 2006).

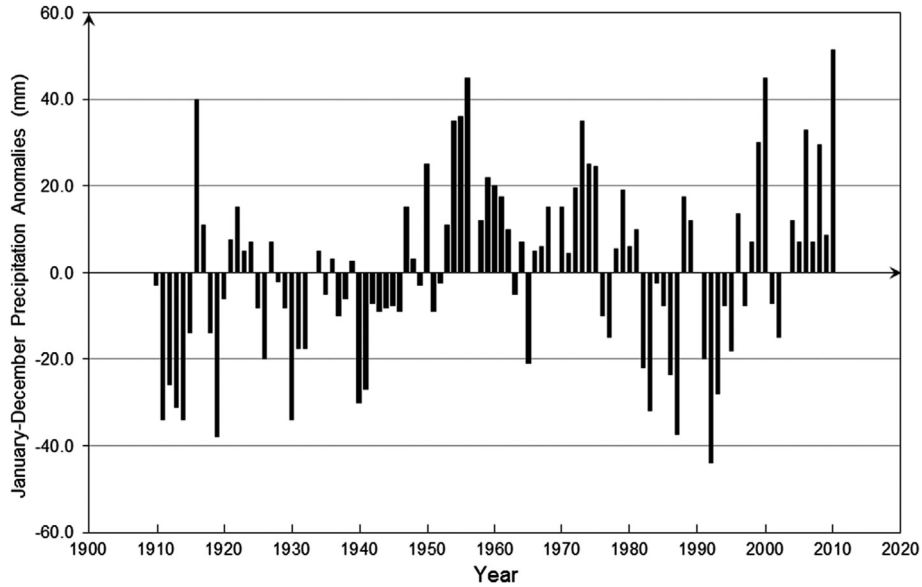


Figure 2. Global precipitation anomalies from 1910 to 2010 (NOAA-NCDC, 2011).

important as a key resource of water in many Southeast Asian countries. Therefore, EASM is discussed more extensively in this paper.

3.1. Monsoon seasons in Southeast Asia and its relation to other weather systems

The Southeast Asian countries include East India, South China, Myanmar, Thailand, Vietnam, Laos, Kampuchea, Malaysia, Singapore, Indonesia, Borneo, the Philippine islands, Portuguese Timor and western New Guinea as illustrated in Fig. 3. These countries are influenced by the monsoon which is a 'large-scale seasonal reversals of the wind regime' (Serreze and Barry, 2010)

and the word is derived from the Arabic word 'mausim' meaning seasonality. Monsoonal areas receive summer rainfall maximums and most of double rainfall maximums. Monsoon not only influences Asian countries, but also breaches beyond the tropical latitudes. Monsoon rainfall can also affect regions that were not originally considered as monsoonal (Serreze and Barry, 2010). The two main monsoon regimes are specifically named the northeast monsoon (winter monsoon) from November to March, and the southwest monsoon (summer monsoon) from late May to September. Furthermore, October is the transition month from the southwest to northeast monsoon seasons (Cruz et al., 2012). The EASM happens when rainfall reaches maximum during the boreal winter, whereas the EAWM happens during boreal summer where



Figure 3. Southeast Asia region (Kripalani and Kulkarni, 1997).

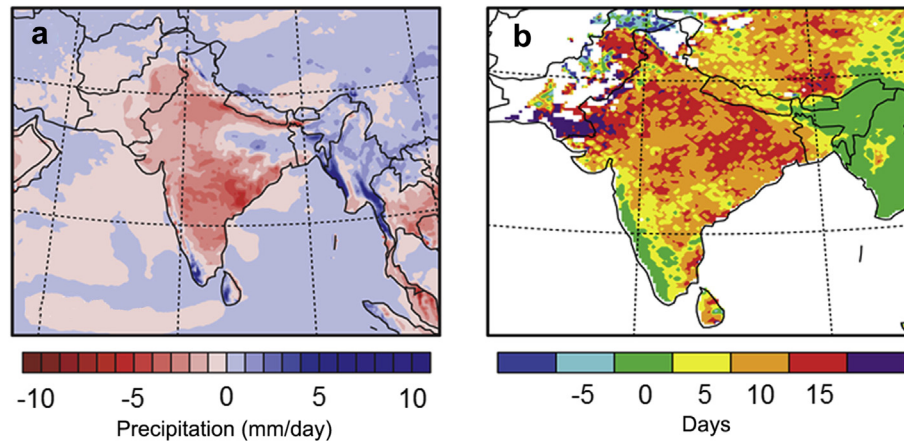


Figure 4. (a) Future change in summer convective precipitation in India and (b) future change in monsoon onset date in India (Ashfaq et al., 2009).

rainfall reaches maximum. The EAWM is an atmospheric flow over Asia and is variable greatly depending on the Siberian High and the Arctic Oscillation (Wang et al., 2012).

The Siberian High (SH) refers to the semi-permanent system that accumulates cold, dry air in northeastern Siberia. It reaches its maximum intensity in winter and accounts for the lowest temperatures and the highest pressures in weather systems. The Arctic Oscillation (AO), also known as the Northern Hemisphere annular mode of atmospheric circulation, is categorized into two phases by looking at the characteristics of the wind that circulates the Arctic in an anti-clockwise direction (NOAA, 2012a). When the wind is strong, the circulation remains in the Arctic Circle. This is termed as the positive phase. During the negative phase, the high pressure at the North Pole and lower pressure at mid-latitudes (OSS, 2013) results in wind moving towards the tropics. The weather and climate of the Arctic affects the monsoon seasonality indirectly. The Arctic ice sheets controls the intensity of SH which influences the EAWM – a strong SH results in a strong EAWM. This is also recorded by the methods of measuring the grain size of loess done by many scientists as an indicator of the intensity of EAWM. A stronger wind is able to carry coarser dust (Wang et al., 2012). Chinese loess records showed that there has been an increase in grain size suggesting that the strength of the EAWM has increased during the Holocene (Wang et al., 2012). The increased dust deposition has been associated with drier and cooler EAWM conditions (Porter, 2001).

The EASM however, is dominated by the western Pacific Sub-tropical High (WPSH) (Zhou et al., 2009; SOEST, 2013; Wang et al., 2013). Findings of the study done by Wang et al. (2013) show that positive WPSH–ocean interaction can provide a source of climate predictability and highlight the importance of subtropical dynamics in understanding monsoon and tropical storm predictability. Zhou et al. (2009) stated that the change in atmosphere temperature partly affects the WPSH, which directly influences the EASM. Since the late 1970s, the WPSH had shifted westward for reasons unknown to date. Referring to the study of Zhou et al. (2009), the westward shift of the WPSH from the mean position of the western edge (133.5°E) is 14° during the 1980–1999 (119.5°E). It was suggested that the westward shift of EASM is due to the atmosphere's response to the observed Indian Ocean–western Pacific (IWP) warming (Huang and Yan, 1999; Zhou et al., 2009). Another interesting factor that influences the monsoon rainfall onset dates is the Himalayan uplift, or the Tibetan Plateau (Kilaru et al., 2013). The rate of growth of the Tibetan Plateau is faster than its erosion process possibly (Mishra and Kumar, 2014). The

decrease in rainfall over major parts of the region may account for the slow erosion process. This has been argued as a factor that promoted the monsoon strengthening in Asia (Reuter et al., 2012). The increased convection at high temperatures results in more rainfall at the leeward region. This may also be a contributor of the flooding in Indian regions.

3.2. Temperature increase and seasonal monsoonal changes in Southeast Asia

Schewe and Levermann (2012) predicted the increasing temperature in the late 21st century and early 22nd century will cause frequent changes and shifts to the monsoon precipitation up to 70% below normal levels. Not only will this affect the Indian summer monsoon, but the onset of monsoon over Southeast Asia may also be delayed up to 15 days in the future as indicated by Ashfaq et al. (2009). Fig. 4a and b shows this extent of these distributional changes in the monsoon and of climate change extends to cause less precipitation in summer and a delay on the onset of the EASM. This will be detrimental to the Indian population as 75% of the total annual rainfall of India is from the summer monsoons. On the 24th of July 2004, the scenario was different as northeastern India and Bangladesh received an early monsoon onset and experienced maximum flooding that caused a death toll of approximately 1000 across South Asia (Coenraads, 2006).

The small scale regional circulations are more vulnerable to variations in monsoon rainfall (Rajeevan et al., 2008). Therefore, a general measurement of strength of monsoon systems is not enough to represent the temporal and spatial distributions. Many studies have been done on linking monsoon variability with the El Niño Southern Oscillation (ENSO) (Kripalani and Kulkarni, 1997; Ranatunge et al., 2003). However, the ENSO can only be considered as influential to the Asian monsoon rainfall patterns to an extent of its year-to-year variability. In the study of Turner (2013), it was found that monsoon rainfall in India is likely to increase in the future. The active-break cycles are expected to intensify with the increase of carbon dioxide (CO₂) in the atmosphere.

A study on monsoon rainfall variability in Philippines from 1960 to 2010, found that there is a decreasing trend of EASM rainfall total as well as its rainfall distribution (Cruz et al., 2012). Total rainfall declined gradually (0.016 to 0.075%) every 10 years. On year 1972, the rainfall total is the highest (1702 mm) in Philippines. This happened in synchronization with the Philippine's great flood events in July (Gordon, 1973). Extreme daily rainfall events are due to monsoon depression convection or mid-tropospheric cyclones.

The westward and northward propagating of the EASM is influenced by the fluctuations in convection and circulation of rainfall cycles (May, 2004; Purdue University, 2009).

The evolution of monsoon rainfall in Southeast Asian countries can be understood by the trends of rainfall totals compiled from various sources. From the standardized yearly monsoon rainfall totals in Fig. 5, Kripalani and Kulkarni (1997) investigated the trends of rainfall using the Cramer's *t*-statistics. Decadal mean precipitation is plotted against the overall mean as the zero line for the data period. The decadal means above the overall mean are plotted as positive while means below the overall mean are negative monsoon rainfall anomaly. The monsoon rainfall patterns show decadal variability which is statistically significant according to analysis based on the Cramer's *t*-statistics. In Fig. 6, the summary of the results obtained from Cramer's *t*-statistics shows that the transition is one decade for Malaysia and Singapore, which is closer to the equator; and three decades for the subtropical regions such as Thailand and Philippines.

4. EASM induced flooding in Southeast Asia

The common definition of a flood or inundation is the accumulation of rain water in amounts large enough to submerge the land surface. These floods extend out from rivers and lakes, as well as oceans spreading in-land to cover low-land areas. Floods are said to be most frequent in Asian countries, especially Southeast Asian countries, namely the Philippines, Indonesia, Bangladesh, Thailand, Vietnam, and Cambodia. Most of the floods that occur in Southeast Asia are associated with the EASM down pour. The flooding events, previously accepted by the agriculture-based communities as a positive contribution, had been intensified rapidly by the 20th century global warming. The frequency of floods has not seized to increase since the 1970s (Coenraads, 2006). These flooding events

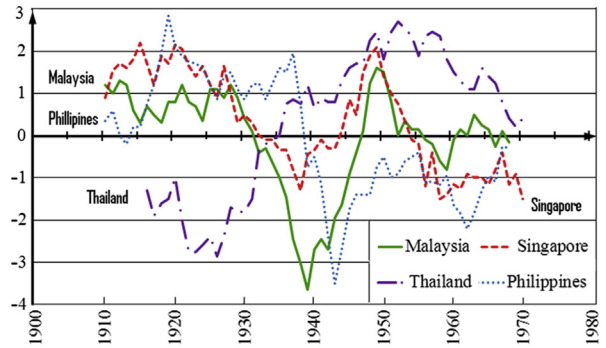


Figure 6. Cramer's *t*-statistics for yearly monsoon rainfall totals in Malaysia, Singapore, Thailand and Philippines (Adapted from Kripalani and Kulkarni, 1997).

in Southeast Asia can be used as evidence that monsoon rainfall is changing.

There is no doubt that precipitation patterns have changed globally in recent. In Malaysia and some Southeast Asian countries, increasing intensities of rainfall during the monsoons are not only a source of major flood but also a triggering cause of major landslide event (Billa et al., 2004). Monsoon flooding in Southeast Asia have impacted many people in terms of loss of lives and property damage. In the Philippines, the recent unusually intense monsoon rainfall (300 mm) in August 2012 had claimed more than 170 lives. While according to the flood watchers, 580,445 people had been evacuated from the flooded capital city, Manila and 3035 houses were reported damaged. The flooding event which had a total return time of 600 years was accumulated from the Typhoon Saola and then the Typhoon Haiqui (WMO, 2013).

Besides Philippines, the peninsular Malaysia regions including southern Thailand and northern Malaysia had experienced intense

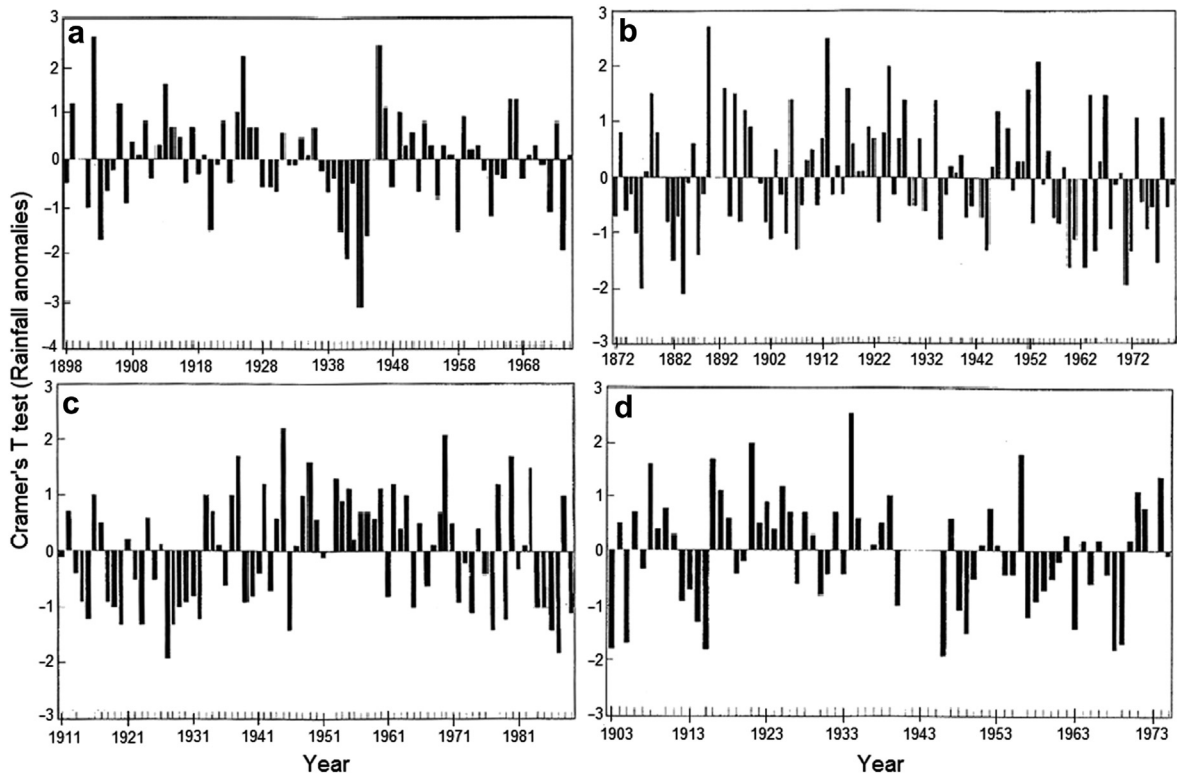


Figure 5. Standardized yearly monsoon rainfall totals in (a) Malaysia, (b) Singapore, (c) Thailand and (d) Philippines (Kripalani and Kulkarni, 1997).

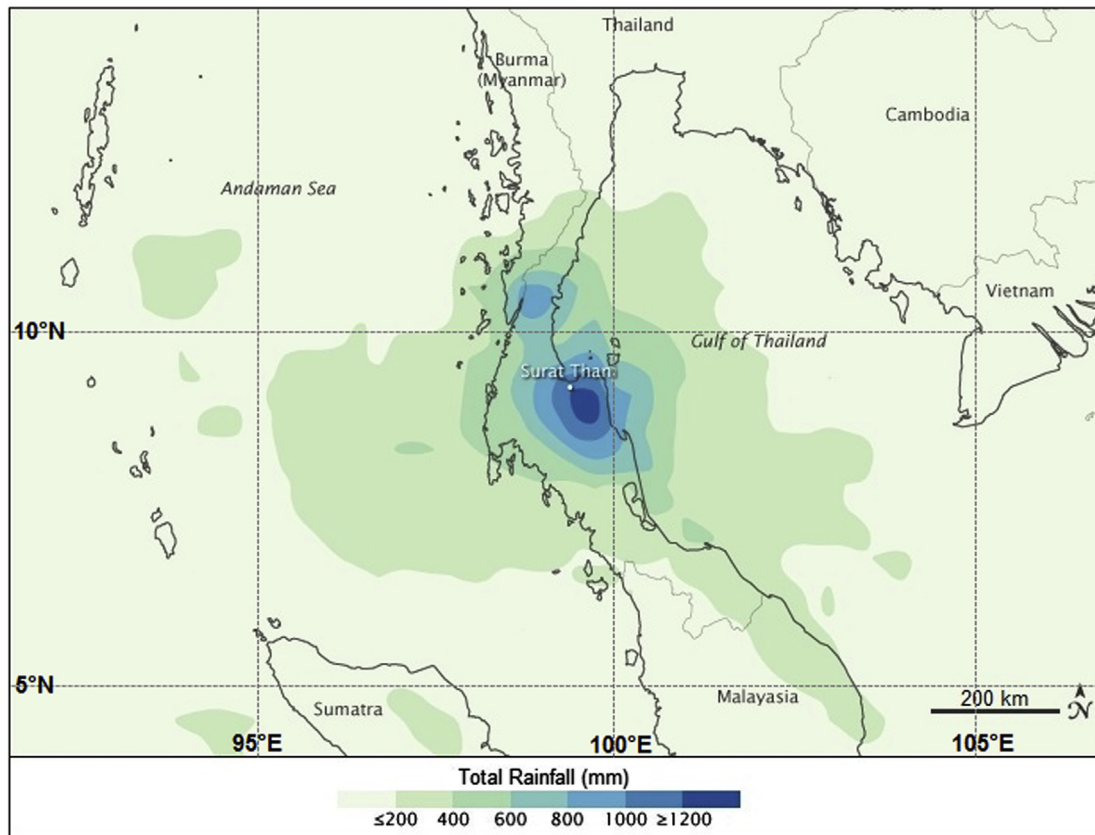


Figure 7. Rainfall totals of March 23–30, 2011 in Thailand, resulting a maximum flooding event (Adapted from [NASA-Earth Observation, 2011](#)).

EAWM rainfall (300 mm) during mid-December 2005 ([NOAA, 2012c](#)). [Fig. 7](#) shows an example of the intensity of rainfall during an EAWM. Thailand is considered one of the ten worst flood affected countries of the world as experienced in the September and October 1980 and the recent March and April 2011 monsoon flooding that inundated most of southern Thailand ([NASA-Earth Observation, 2011](#)). The severity of the Monsoon flood in 2011 continued until the end of July triggered by the landfall of Tropical Storm Nock-ten. The flooding spread through the northern and central provinces of Thailand where in the month of October floodwaters reached and inundated parts of the capital city of Bangkok. The resulting consequence of the flood was 13.6 million people affected and about 815 deaths. Over 20,000 km² of farmland was damaged. This had a profound impact on food security for the entire SEA region as Thailand is a leading exporter of rice, which is a staple for the region. The [World Bank \(2011\)](#) estimated the economic damages and losses due to the flooding, to be US\$ 45.7 Billion. According to [Coenraads \(2006\)](#) these broad-scale floods covering large areas and caused by monsoon rains are also mostly common in India and Bangladesh. Northeastern India and Bangladesh, however, receive their yearly monsoon rainfall during the wet season from June to end of September.

5. Conclusion

This study has given some insights on the connections between global warming and monsoon rainfall. It is evident that the distribution of monsoon rainfall is greatly influenced by a number of weather systems, such as the Arctic Oscillation, Siberian High and Western Pacific Subtropical High, as well as the complex Asian topography, i.e. the Tibetan Plateau. The EAWM is regulated by the

Arctic ice which influences the SH weather system. The EASM is affected by the westward shift of the WPSH and consequently impacting on the distribution and variability of monsoon precipitation. Excessive monsoon flooding which has become frequent in recent years in parts of Southeast Asia remain an issue to be overcome. Understanding the shift and predicting changing trends of monsoon may be central to managing the floods that impact on millions of people, damage to lives and property, destruction of ecology and farmlands and the long term effect on food security.

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