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## **Updated Basis Knowledge of Climate Change Summarized from the First part of Thailand's Second Assessment Report on Climate Change**

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### **Abstract**

Recent evidence and key issues on climate change in Thailand have been presented in the first part of Thailand's Second Assessment Report on Climate Change (2<sup>nd</sup> TRAC). The report highlights key findings including 1) a significant country-wide warming of 1.30 °C over the past 48 years (1970-2017); b) significant changes in rainfall patterns at smaller spatial and finer temporal scales; c) significant changes in temperature and rainfall extreme events over the last four-five decades; d) a significant decrease in frequency of tropical cyclones entering Thailand; e) significant rise in sea level in the seas around Thailand at higher rates than the global average; and f) significant projected increases in temperature and rainfall in Thailand by 2100. The first part of the 2<sup>nd</sup> TARC provides a comprehensive and updated analysis of climate change impacts in Thailand that can be used as an authoritative reference for building understanding and awareness, as well as for designing adaptation and mitigation strategies. Moreover, it can serve as a repository for scientific information to support further research related to impact, adaptation and vulnerability to climate change. Regular assessment of national climate change impacts is essential to informing national policy and to allow policymakers to assess priorities and set meaningful targets in line with the country's international obligations under the Climate Change Agreement.

**Keywords:** Thailand's Second Assessment Report on Climate Change; Climate change Scientific knowledge; Thailand

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## Introduction

Our climate is changing rapidly at an accelerating rate. In recent decades, anthropogenically driven climate change has caused widespread impacts on natural and human systems [1]. The best available and the most up-to-date scientific knowledge is fundamentally important if governments and other key stakeholders are to mount an effective, progressive and transformative response to this urgent and in some cases existential threat. A process in which scientists review existing scientific studies and peer-reviewed literatures and assess status and advancement of climate change knowledge is therefore required at both national and sub-national levels [2-5]. This process supports critical analysis of key trends, informs policy choices and fills gaps that can limit effective decision making [4-6].

Over the past two decades, there has been an increasing volume of research devoted to climate change and its impacts in Thailand [7-8]. Previous studies have revealed that Thailand is highly vulnerable to climate change, due to its heavy dependence on climate-sensitive sectors such as agriculture and water resources for socio-economic development and local livelihoods [9-10]. Based on the Climate Risk Index (CRI) developed by Germanwatch, Thailand has been ranked as one of the countries around the world most vulnerable to climate change impacts [11]. Many parts of the country have experienced climate-induced disasters such as floods, drought and extreme weather events that are increasing in both frequency and severity [12]. In early 2011, for example, the worst-ever summer flooding unprecedentedly hit the South, causing severe damage to ten provinces, impacting more than two million people and destroying crops on more than 160,000 hectares of agricultural land [13]. Just a few months later, a 'mega-flood' hit 83 % of

Thailand's provinces, affecting millions of people for several months, and leaving more than 800 people dead [14].

The impacts of climate change on Thailand include prolonged droughts, severe flooding, sea level rise, weather extreme events, decreased agricultural and fishery yields and health-related issues, though already serious, will likely worsen in the coming decades. Thus, research in this area is of fundamental importance to improve understanding of ongoing climate change trends and impacts at national and local levels. This scientific knowledge is important to inform decisions on mitigation and adaptation strategies and actions at national level, and also to contribute to our understanding at regional and global levels.

## Materials and methods

The Thailand Research Fund (TRF) conducted Thailand's First Assessment Report on Climate Change (1<sup>st</sup> TARC) in 2010-2011 [12, 15-16]. The primary goal of the 1<sup>st</sup> TARC was to provide robust updated scientific information to stakeholders and the Intergovernmental Panel on Climate Change (IPCC) on key aspects of climate change in Thailand, including the physical science basis, impacts of and vulnerability to climate change, as well as options for adaptation and mitigation. Assessment methodologies specified by the IPCC [17] were adopted to ensure integrity, balance and clarity of scientific information on the current state of knowledge related to climate change in the context of Thailand, as well as to ensure comparability and coherence with the national assessment exercises conducted in other countries. The assessment comprises independent expert review and synthesis of available extant scientific and technical knowledge relevant to climate change that are essential to inform national policy and support progress towards national targets. The assessment process thus sits at the interface between science and policy, bringing

together scientists, academics and policymakers to contribute to a comprehensive assessment. The reports are publicly available from the TRF website [12, 15-16].

Using the same methodology, the TRF subsequently supported the second assessment process- the 2<sup>nd</sup> TARC (2015-2016) [18]. The objective was to update the 1<sup>st</sup> TARC and to assess the advancement of climate change research in Thailand. The 2<sup>nd</sup> TARC comprises three parts: updated status of climate change in Thailand, risk and climate change adaptation and mitigation of climate change. The first part assesses the latest data on climate change as reported in peer-reviewed literature. The review covered 243 research papers, of which 140 papers were published after the 1<sup>st</sup> TARC during 2011-2016. The full Thai-language version of the 2<sup>nd</sup> TARC report is available for download from the TRF website [18].

This paper summarizes the main findings of the assessment of the first part of the 2<sup>nd</sup> TARC, which gives a description on the issues of 1) key findings of the IPCC Fifth Assessment Report (AR5); 2) surface observation-based evidence of climate change in Thailand; 3) climate change in the coastal zone; 4) projections for future climate change in Thailand; and 5) climate variations in the Southeast Asia (SEA) and projected future changes. Key research questions relating to climate change adaptation and mitigation in Thailand are summarized in the final section of this paper.

## Results and discussion

### 1) The key findings in the AR5

On the basis of the IPCC's AR5, it was evident that the observed globally averaged combined land and ocean surface temperatures for the period 1880 to 2012 showed a warming of 0.85 (0.65 to 1.06) °C (Figure 1). Changes in many extreme weather events were also observed since the second half of the 20<sup>th</sup> century. Over the last two decades, the

Greenland and Antarctic ice sheets and the Arctic sea ice continued to decrease in extent, and glaciers continued to shrink almost worldwide [19]. These changes subsequently resulted in a rise of 0.19 (0.17 to 0.21) m in global sea level over the period 1901 to 2010. Ocean acidification was a further important change observed since the beginning of the industrial era. Hydrogen ion concentration of ocean surface water has increased by 26 % during the same period from 1901 to 2010, corresponding to a 0.1 decrease in pH.

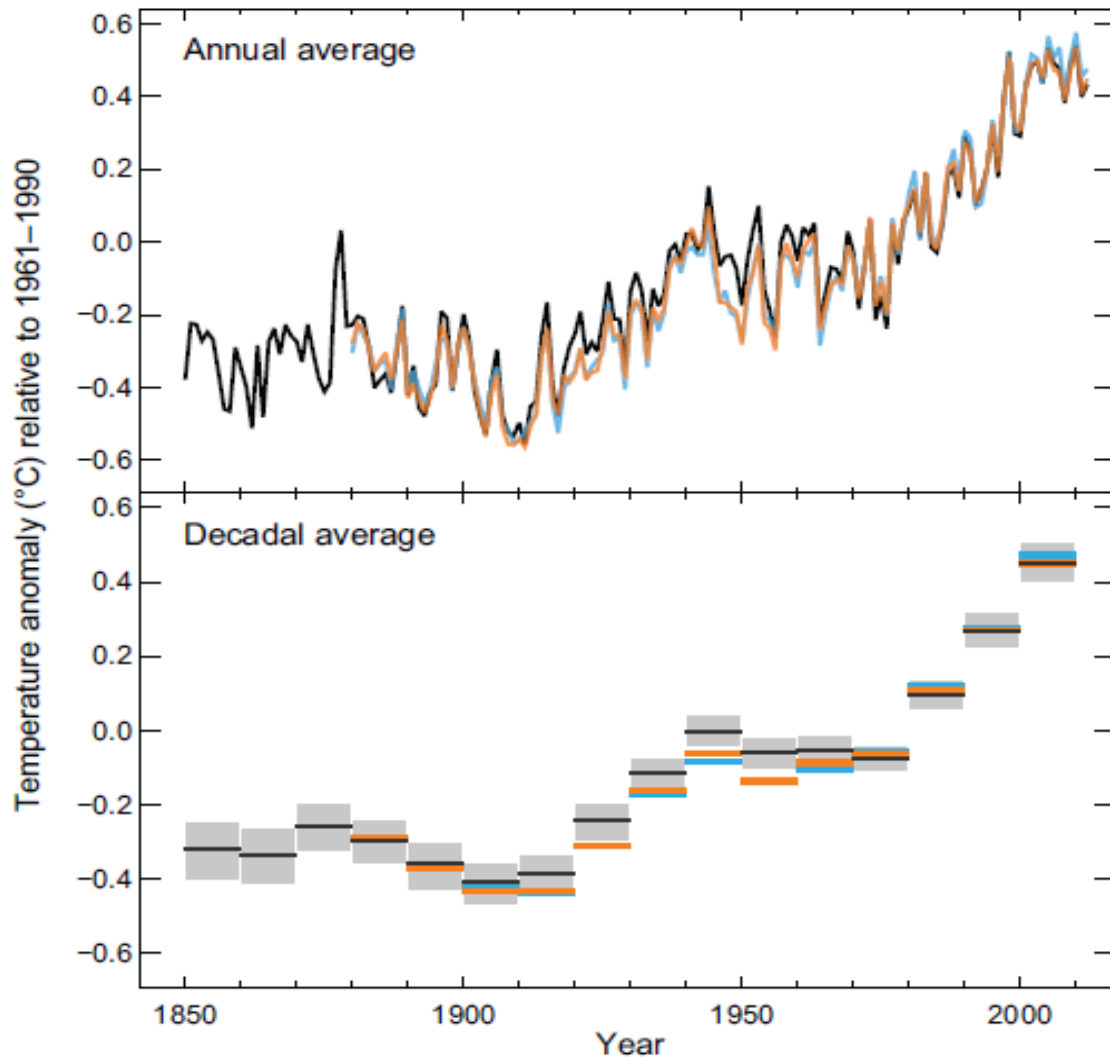
Projected future climate change derived from the concentration-driven Coupled Model Intercomparison Project Phase 5 (CMIP5) based on a set of Representative Concentration Pathway (RCP) scenarios shows that global surface temperatures will increase in range of 0.3-4.8 °C by the end of the 21<sup>st</sup> century [19]. There is an indication that warming over land will be greater than over the ocean, and warming in the Arctic region will happen more rapidly than the global mean. Owing to a pronounced level of projected anthropogenic-induced global warming, the global mean sea level will continue to rise during the 21<sup>st</sup> century. Under all RCP scenarios, sea levels will rise in the range of 0.26-0.82 m, and will exceed the rate observed during 1971 to 2010. This is due to acceleration in ocean warming and loss of mass from glaciers and ice sheets.

### 2) Surface observation-based evidence of climate change in Thailand

Assessment of surface observation-based evidence of climate change in Thailand since the 1<sup>st</sup> TARC consistently showed a significant country-wide warming over the past 40-50 years. For the 40-year period (1970-2009), annual averages of minimum, mean and maximum temperatures in Thailand as a whole increased significantly by 0.96, 0.92 and 1.04 °C, respectively [20]. For a longer period from 1970-2017, our recent analysis of high-quality

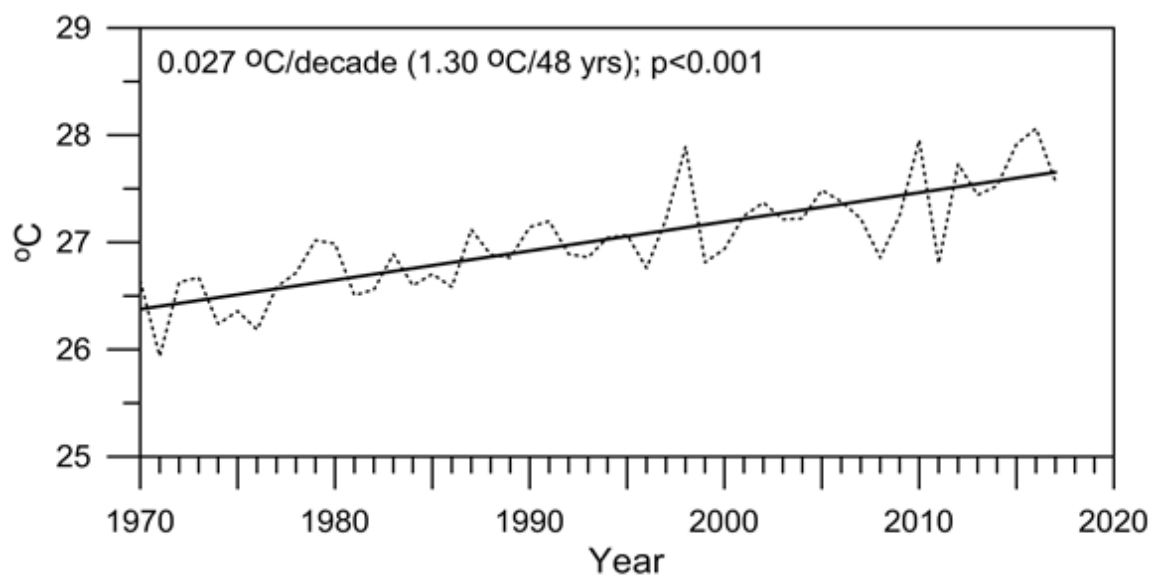
data has shown a higher rate (0.027 °C per decade or 1.30 °C per 48 years) of increase in annual mean temperatures in Thailand (Figure 2). Rainfall studies after the 1<sup>st</sup> TARC have greatly contributed to new evidence indicating significant changes when analyzing at smaller spatial and finer temporal scales. Opposite trends with significant increases and decreases

were observed for annual rainfall totals between the western and eastern parts of southern Thailand for the 60-year period (1955-2014). In contrast, data for rainfall accumulation from November to April in each year revealed a significant upward trend of 64.8 mm over the same period [21].



**Figure 1** Trends in annual and decadal mean values of observed globally averaged mean combined land and ocean surface temperature anomalies from 1850 to 2012 derived from three data sets. Anomalies are relative to the mean of 1961-1990.

Source: Summary for Policymakers of Climate Change 2013 (The Physical Science Basis), Contribution of Working Group I to the AR5 of IPCC.



**Figure 2** Annual series of mean temperature averaged from all 73 stations across Thailand. Each monthly mean temperature series was assessed for homogeneity, based on the penalized t-test and the penalized maximal F-test [22-23] using the RHtestsV4 software developed by the World Meteorological Organization-Commission for Climatology (WMO-CCI)/World Climate Research Program (WCRP)/Climate Variability and Predictability (CLIVAR) project's Expert Team on Climate Change Detection and Indices (ETCCDI). Homogeneity adjustments of artificial shifts occurred around 2005-2006 due to change in the formula for calculating mean daily temperature were made by using the data series in the recent period as the reference to adjust the data in the previous period. The solid line represents a linear trend for 1970-2017, and the significance of the trend is assessed by Kendall's test.

Recent research on changes in weather extreme events in Thailand since the 1<sup>st</sup> TARC has confirmed that temperature extreme events have significantly changed over the last five decades [20]. The findings of recent studies offer a clearer picture of changes in rainfall extreme events in Thailand. There are indications that rainfall across most of Thailand has become more intense even though rainfall events have become less frequent [21]. Evidence also indicates a trend toward wetter conditions as a result of increased magnitude of intense precipitation and a greater fraction of heavy precipitation contributing to annual totals. The year 2011, when Thailand experienced extensive flooding across the country, was marked by exceptionally extreme precipitation events.

Historical data recorded by the Thailand Meteorological Department (TMD) [24], showed that the frequency of tropical cyclones entering Thailand decreased significantly from 1951-2014. However, the number of tropical storms and typhoons increased since 1970 (Figure 3), indicating a greater risk from heavy rainfall events and floods that periodically occur in between longer-lasting droughts.

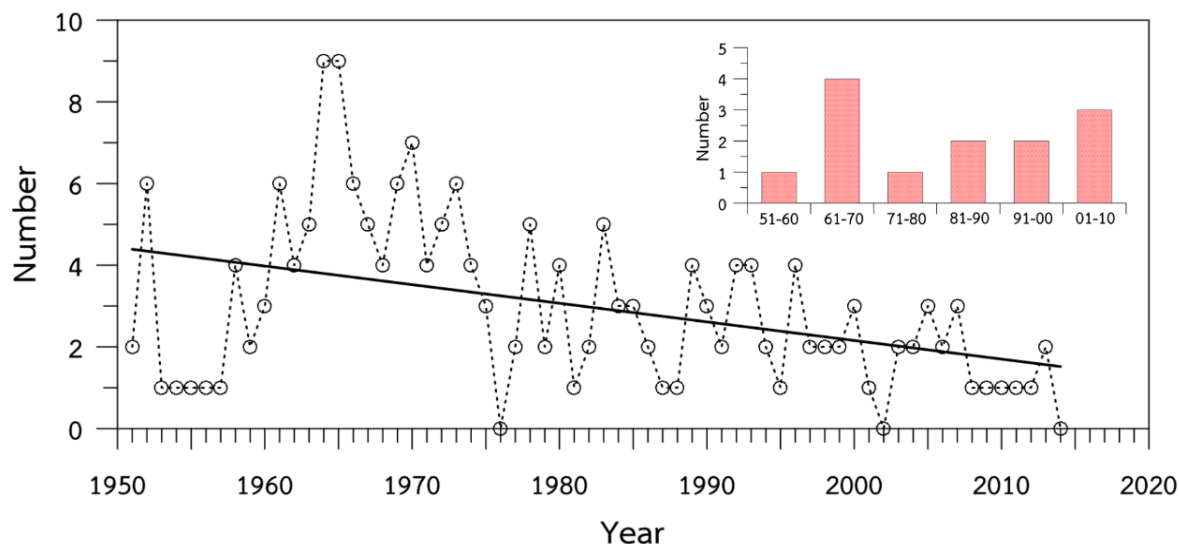
### 3) Climate change in the coastal zone

For coastal zones, sea level rise is clearly a critical issue. Sea levels may change due to increased water volume and mass through hydrological cycles as well as expansion of the ocean as it warms. Change in sea level is tightly coupled with other physical properties of the ocean such as currents and ocean density. As such, a change in sea level at one

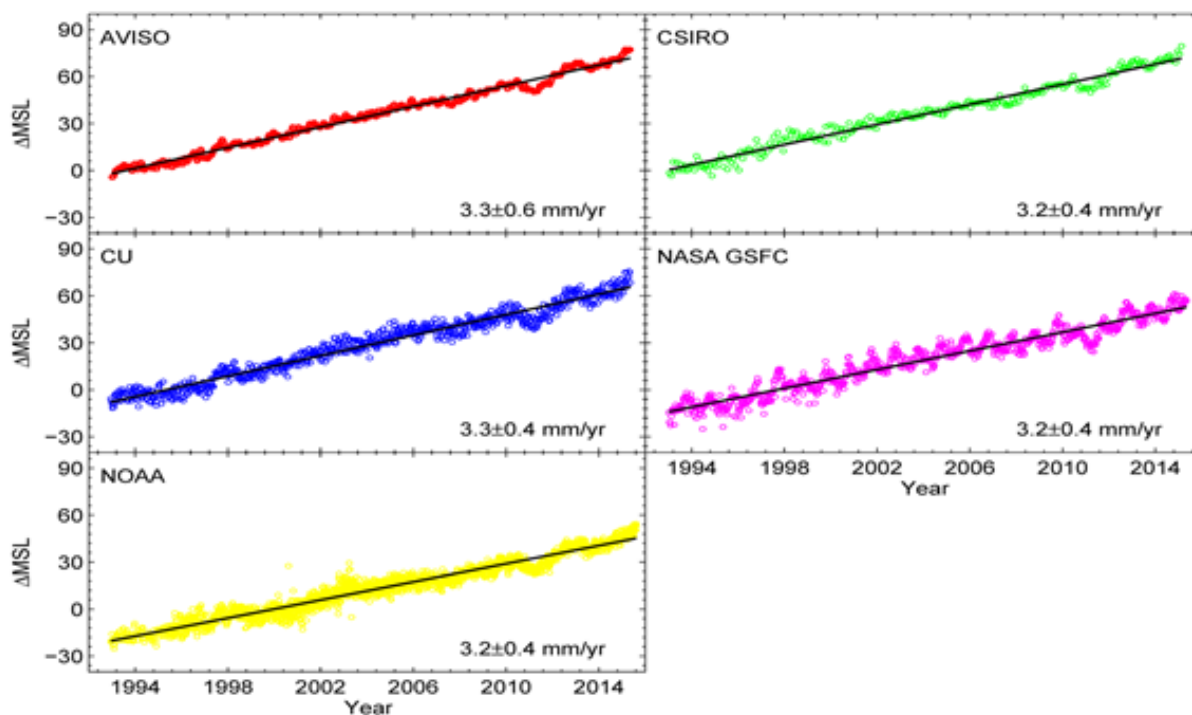
location can influence sea levels far away. Regional and synoptic climate phenomena, especially those related to atmospheric pressure anomalies can also cause sea level to change via atmospheric disturbance and loading [25]. It is increasingly recognized that a number of climate-related processes cause sea level to vary over wider temporal and spatial scales than previously recognized. Waves and storm surges are an example of relatively short-lived events causing sea level change, while those associated with atmospheric and ocean modes of climate variability such as the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are responsible for sustained sea level change over periods covering several decades [26]. However, other non-climate processes also cause changes in sea levels, which are often large enough to confound interpretation of observation records and sea level projections at various spatial scales. Evidence indicates that present-day sea level change is significantly influenced by the ongoing visco-elastic deformation of the Earth and associated changes in ocean floor height and gravity as a result of surface mass transfer from land ice to oceans during the last deglaciation [27]. These processes that are not associated with contemporary climate change are referred to the glacial isostatic adjustment (GIA).

Since the early 1990s, sea levels have been routinely measured using high-precision, high-resolution satellite altimetry with global coverage and a revisit time of a few days or weeks. Over the past ~25 years,

several groups worldwide involved in processing the satellite altimetry data regularly provide updates of sea level time series at global and regional scales [28]. A set of satellite altimetry data from various research organizations consistently indicates that global sea level has risen 3.2-3.3 mm a<sup>-1</sup> for the period 1993 to present (Figure 4). When considering at regional scale, changes in sea level may decrease in some regions but increase in other regions depending upon various physical factors. The data used to study sea level change in the coastal zone of Thailand are based mostly on tide gauge records, and calculation is usually reported in terms of apparent sea level, without correction for vertical land motion. Different analytical approaches always generate variable results even for the same stations. Reported sea level rise is higher in the upper part of the Gulf of Thailand where pronounced land subsidence has taken place due to over-abstraction of groundwater. In addition, upward land motion has been found in Thailand after the 2004 Indian Ocean tsunamis that in turn affect the apparent sea level rise [29]. Overall, evidence and confidence of trend in sea level rise in the coastal zone of Thailand based on previous studies were assessed to be at medium level. However, a regional study based on satellite altimetry data shows that sea level in the Andaman Sea, the South China Sea and the seas around Indonesia has increased by 3.6-6.6 mm a<sup>-1</sup> from 1993 to the present day. These rates are comparatively higher than the global average rate [30].



**Figure 3** Frequency of tropical cyclones (depression, tropical storm and typhoon) entering Thailand during 1951-2014. The small picture inserted shows averaged frequency of tropical storm and typhoon occurred every ten year.



**Figure 4** Trends in global average sea level from 1993 to the present, derived from satellite altimetry data of AVISO+, CSIRO Marine and Atmospheric Research (CSIRO), CU Sea Level Research Group (CU), NASA GSFC and NOAA. The calculated global average sea level values have been corrected for inverse barometer effect and glacial isostatic adjustment.

For the next 30 years, sea levels in the Gulf of Thailand are projected to increase about 10 - 20 cm. Based on various scenarios of sea level rise and land subsidence, the Finite Volume Community Ocean Model (FVCOM) predicts that the eastern areas of Bangkok and Samut Prakan and Chachoengsao Provinces will be most seriously affected. Future projections based on the 25-km regional climate model using global driving data from a five-member perturbed physics ensemble highlights that in the second half of the 21<sup>st</sup> century, the number of tropical cycles entering the Gulf of Thailand and causing storm surges during the October-December period will decrease by 20-44 %; however, the number of more intense tropical cycles will increase by 3-9 % [31]. Moreover, sea surface temperatures in the South China Sea including the Gulf of Thailand are projected to increase by 2-4 °C in the second half of the 21<sup>st</sup> century.

#### **4) Future climate change in Thailand**

Simulation of climate change gathered pace in the 1980s. Following progress in our understanding of physical processes within the climate system, models have been continually improved over the past 35 years [32]. Several developments have contributed to enhanced capabilities of modeling approaches in recent years- first and foremost, the rapid increase in horizontal and vertical resolutions. Climate models with a grid spacing of 30 km or better are now available for more regions. Regional-scale climate information can be obtained directly from global models; however, their horizontal resolution is often too low to resolve features that are important at regional scale. Thus, regional climate modeling, especially statistical and dynamical downscaling is often used to generate region-specific climate information at smaller scales.

Over the past decade, Thailand has continued to conduct research on regional

climate downscaling, employing statistical and dynamical methods. At present, the research framework for regional climate downscaling has been expanded through collaboration among ASEAN member countries under the SEA Regional Climate Downscaling (SEACLID)/ Coordinated Regional Climate Downscaling Experiment (CORDEX) SEA Project (<http://www.ukm.edu.my/seaclid-cordex/>). Based on a recent study of regional climate modeling in Thailand with a spatial resolution of 10 km x 10 km downscaled from the outputs of three global climate models under three RCP scenarios, RCP4.5, RCP6.0 and RCP8.5, maximum, mean and minimum temperatures and rainfall amounts in Thailand as a whole are projected to significantly increase for all models and scenarios by the end of the 21<sup>st</sup> century. The average annual temperature under RCP8.5 for three models is higher than the long-term mean of about 1.67 °C, 3.98 °C and 4.82 °C, respectively [33].

#### **5) Climate variations in the SEA and their future changes**

The world's climate varies greatly, depending on geographic settings and responses to the influence of regional and global climate variations. As the power and capabilities of climate models have continued to advance, scientists are increasingly able to use simulation to better understand natural fluctuations including climate phenomena, and increase the accuracy of future projections of climate change at regional scale. Based on the assessment of multi-model simulations on major climate phenomena linked to future climate change under a warmer world, the majority of global climate models consistently show that the global monsoon is likely to strengthen in the 21<sup>st</sup> century with increases in its area and intensity, while the monsoon circulation weakens [34]. These multi-models further predict that monsoon onset dates will



tend to stay constant or advance slightly, while monsoon withdrawal dates are likely to be postponed, extending the monsoon rainy season in many regions. Future increases in monsoon-related inter-annual precipitation variability are also projected by some climate models. The SEA is likely to experience an increase in precipitation extremes related to the monsoon under these model projections.

A set of climate models that can produce general features of the Indian Ocean Dipole projects the tropical Indian Ocean is likely to become a zonal (east-west) pattern of change in the future [35]. Projections indicate that warming and precipitation will increase in the west of the Indian Ocean, and fall in the east. Changes in the future features of the tropical Indian Ocean directly influence SEA precipitation. There is high confidence resulting from increased climate models' ability in simulating ENSO and its ongoing variability that ENSO remains as the dominant mode of inter-annual variability in the future [36]. On the regional scale, ENSO-associated precipitation variability is expected to intensify as a result of increased moisture availability. Furthermore, projections derived from a set of coupled atmosphere-ocean general circulation (AOGCMs) show that the SEA winter rainfall will increase under all RCP scenarios. The highest increase has been observed in the RCP8.5 scenario. Northward and southward expansion of the Intertropical Convergence Zone is a possible manifestation of the observed increment that is characterized by a zonal band of positive anomalies located at  $\sim 10^{\circ}\text{N}$  and  $\sim 5^{\circ}\text{S}$  [37].

## Conclusions

Recent scientific evidence and new findings on key issues relating to the status of climate change and its impacts in Thailand have been analyzed and presented in the first part of the 2<sup>nd</sup> TRAC. Key findings are as follows:

- 1) A significant country-wide warming of  $1.30^{\circ}\text{C}$  over the past 48 years (1970-2017).
- 2) Significant changes in rainfall at smaller spatial and finer temporal scales.
- 3) Significant changes in temperature and rainfall extreme events over the last four-five decades, with more intense rainfall events across most of the country over this period.
- 4) Decreasing frequency of tropical cyclones entering Thailand.
- 5) A rise in sea levels above the global average.
- 6) Rising temperatures and rainfall are projected for Thailand by the end of 21<sup>st</sup> century.

The first part of the 2<sup>nd</sup> TARC provides a comprehensive overview of the current status of climate changes and its consequences in Thailand, as well as projections for the future. The assessment report represents the most current and authoritative sources of climate change knowledge for Thailand. It can serve as a recognized reference and benchmark for further work, as well as to support decision making and planning for future climate actions related to vulnerability, impact and adaptation. The methodologies and protocols adopted throughout the assessment process follows guidelines set by IPCC, enabling cross-country comparisons for all relevant themes covered. The assessment is conducted periodically, aligned with the IPCC assessment cycle.

For Thailand, climate change research including high-resolution simulation modeling will be crucial to setting effective policy and implementation plans, and should be strongly supported in the long term by governmental agencies and the scientific community in the context of the Paris Agreement and the AR6 of the IPCC.

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