ГЛАСНИК Српског географског друштва 103(1) 65-86
BULLETIN OF THE SERBIAN GEOGRAPHICAL SOCIETY 2023

Original scientific paper UDC 551.583(5)
https://doi.org/10.2298/GSGD2301065P

Received: November 21, 2022
Corrected: December 12, 2022
Accepted: January 09, 2023

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TREND ANALYSIS AND PREDICTION OF TEMPERATURE CHANGE IN THE CONTINENTAL, THAILAND

Abstract: Diurnal Temperature Range (DTR) is one of global warming indicator which using only daily minimum temperature (TMin) and daily maximum temperature (TMax) for calculation. The study aims 1) to analyse trend of TMax, TMin and DTR over the early period of 21st century (1987 – 2020) and 2) to forecast and analyse trend of TMax, TMin and DTR over the mid and late period of 21st century (2021 – 2040 and 2041-2100) using MIROC5 (rcp85) model, cooperated with EQM Statistical downscaling method. TMax, TMin, and and DTR trends of all periods were investigated by Mann Kendall Trend Test and Sen's slope, then presented in the form of spatial maps. The most of TMax and TMin trends for all season and all regions tended to be increasing from year by year with the large increasing of changing in Northern and Northeast region especially in Winter, except for the last period which had a large increasing in Summer. However, DTR trends were quietly fluctuated with the large decreasing of changing in Eastern and Southern part, but the trends become to increase in the last period. A large DTR decreasing of changing usually occurred in Winter and Rainy season. The TMax and TMin of all periods were expanding year by year and leading the DTR decreased in the first and second period, however, a changing of TMax and TMin rate leaded DTR increasing for the last period. It is a good signal for heat transfer performance which can help the earth cooling in night time.

Key words: diurnal temperature range (DTR), climate change, climate variability, climate of Thailand

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Introduction

Climate variability and global warming issues are significant problem which all sectors and authorization were interested (Hansen at al., 2010), including Thailand. Thailand is a part of Southeast Asia which located in low latitude thus, it is normally that sun ray duration is about 10 – 13 hours per day. The sun ray duration period strongly effects to the area and leads Thailand has high temperature through year (Thai Meteorological Department, 2016). Activities in urbanization and deforestation also brings Thailand facing to climate change situation. Moreover, some researchers reported about climate variability in Thailand such as an increasing of mean maximum temperature in Summer of Thailand about 0.0087 degree Celsius (°C) per year (Phumkokrux and Rukveratham, 2020). Moreover, Phumkokrux et al. (2022) simulated mean monthly maximum temperature of Thailand in Summer of 2020-2030 using INMCM4.0 Model (rcp45) then reported that its temperature would increase approximately at +0.063 to +0.130 °C per year through Summer with the highest value at about 41.5 °C. From the situation which mentioned above, this would affect to all organism life if the temperature would be rising more.

Diurnal air temperature range index (DTR) is one of easy universal method which can prove that climate is changed without complex and expensive equipment (Karl et al., 1984). The DTR index is a different value between maximum daily air temperature (TMax) and minimum daily air temperature (TMin) by subtraction at each meteorological station. DTR is susceptible a variety of environmental, effects from nature and human such as water vapor, surface moisture, cloudiness (Trenberth, 2003; Stone and Weaver 2003), urbanization and agricultural development, and all human activities (Kalnay and Cai, 2003). Therefore, DTR can remind all authorities and people about climate change issues (Sun et al., 2006). There are many researchers focusing on studying a change of DTR such as 1) Roy and Balling Jr. (2004) focused on analysis of maximum and minimum air temperature, DTR, and cloud covering in seasonal sector over India by gathering the observation data in 1961 – 1990 period. The data were extracted up to 2002, at 1° x 1° resolution for 285 grid cells from Climate Research Unit. The results presented that maximum and minimum air temperature increased significantly and DTR significantly decreased in Summer. 2) Jhajharia and Singh (2011) studied the trend of temperature, DTR and sunshine duration of Northeast India by gathering the data from 7 stations in terms of season and Annual scale. The results illustrated that DTR decreased in 4 stations with an increasing of sunshine duration, while it increased in other 3 stations. and 3) Qu et al. (2014) studied about DTR changing in the continental United States from 1911 – 2012 period by extraction of maximum, mean, and minimum daily air temperature values from National Climate Data Center's Global Historical Climatology Network Daily. The results presented in yearly, regional, seasonal, and regional in different season sectors, indicated that DTR steadily decreased in all sectors.

As all mentioned above indicated that trend of maximum, minimum air temperature and DTR index can be efficiency evidence, which can prove about the climate change situation and global warming in country scale. Therefore, the objectives of this work focused on 1) to analyse trend of TMax, TMin and DTR over the early period of 21st century (1987 – 2020) and 2) to forecast and analyse trend of TMax, TMin and DTR over the mid and late period of 21st century (2021 – 2040 and 2041-2100) by using MIROC5 (rcp85) model. The author strongly has faith in this work that it can support other future study and remind all sectors about climate variability situation of Thailand.

Study Area

The work was interested in observation and prediction of the DTR changing in country scale of Thailand. The country size is about 518,000 km^2, which is in Southeast Asia at between 5° 37'N - 20° 27'N and 97° 22'E - 105° 37'E (Department of Mineral Resources, 2016). Average annual temperature was in a range of 25-27 °C and the highest annual precipitation can be found in a range of 200 – 1,600 mm per year (Thai Meteorological Department, 2016). The study area was separated by meteorological criterion of Thai Meteorological Department into 5 meteorological regions as illustrated in Fig. 1(A), which are: 1) Northern region covers 15 provinces with many high mountain ranges and small valley as a dominant geographic topography. The top and left side are located next to Myanmar and Laos. The right-side is located next to Northeast region and the bottom side is located next to Central region. The highest point of Thailand is found in this region with the height is about 2,560 metres above mean sea level at Doi Inthanon (a part of the Thanon Thong Chai Range in Chiang Mai province). 2) Northeast region called Isan, has 20 provinces with the Khorat Plateau as a distinctive topography. The top and right-side borders to Laos (Separated by the Mekong River), the left side borders to Northern and Central region (Separated by the Phetchabun and the Dong Phayayen Mountain ranges) and the bottom-side borders to Eastern region (Separated by the Thanon Thong Chai Mountain range and the Sankamphaeng ranges) and the Dângrêk Mountains separates this region from Cambodia. The peak of mountains in this region are about 400 – 1,300 metres above mean sea level which interrupts winds from the nearest sea. 3) Central region consists of 18 provinces with the predominantly flat Chao Phraya River valley as important topography. The top side is next to Northern region, the east side borders to Northeast and Eastern regions (separated by the Dong Phayayen Mountain ranges), the west side borders to Myanmar (separated by the Tanaosri mountain ranges) and the bottom side is next to Southern region and the Gulf of Thailand. The mountains also find with the peak height up to 1,600 metres above mean sea level. 4) Eastern region consists of 8 provinces with undulating plain as an outstanding topography. The top locates next to Northern region, the east side is next to Cambodia (separated by the Cardamom Mountains), the west side borders to Central region and the south side is next to the Gulf of Thailand. Finally, 5) Southern region has 16 provinces, which located next to the Gulf of Thailand at the east side and the Andaman Sea at the west side. Moreover, there are 2 mountain ranges, located from north to south direction (the Nakhon Si Thammarat and the Phuket Mountain ranges). The overall of topography details of Thailand is presented in Fig. 1(B) (Thai Meteorological Department, 2016).

Tab. 1. Meteorological station in Thailand (Meteorological Department of Thailand, 2015)

Meteorological Regions	No. of Provinces	No. of Stations
Northern	15	24
Northeast	20	25
Central	18	16
Eastern	8	13
Southern	16	26
Overall	77	104

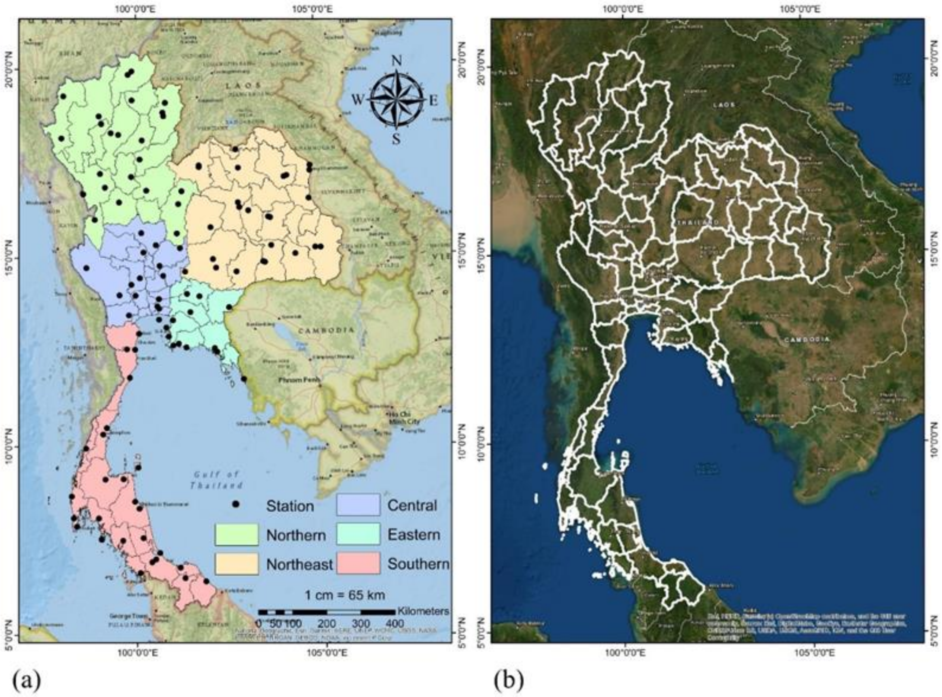

Fig. 1 (a) Study area of Thailand (Source: Developed from National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp., 2021) and (b) Topography of Thailand (Source: Developed from Esri, Maxar, Earthstar Geographics, and the GIS User Community, 2022)

Data, Equipment and Methods

The project collected 2 types of data, which were: first type was observation data about maximum (TMax), and minimum (TMin) daily air temperature of 1987 – 2020 period. The data were gathered from 104 meteorological stations and all stations are located in continental area of Thailand, under Meteorological Department of Thailand responsibility, covered 5 regions of Thailand as presented in Fig. 1(A) and Tab. 1. The second data was prediction data about TMax and TMin daily air temperature of 1987 – 2020 period. The data were obtained from Model for Interdisciplinary Research on Climate Version 5 (MIROC5) with Horizontal Resolution at $\sim 1.4^\circ \times 1.4^\circ$ (Latitude×Longitude) (Xiong, 2021), which were performed in the fifth phase (AR5) of Coupled Model Intercomparison Project Phase 5 (CMIP5) for Intergovernmental Panel on Climate Change (IPCC), developed by Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan. (Watanabe et al., 2010). Therefore, MIROC5 also can be used to forecast TMax and TMin daily air temperature values of 2021 – 2100 period (Golkar Hamzee Yazd et al., 2019), cooperated with Statistical Downscaling of General Circulation Models Version 2.0 (SD GCM V 2.0 software) which can be used to downscale the climate data from all climate models in CMIP5 project (created and developed by Agricultural and Meteorological Software (2018)). The downscaling methods which were performed by the software such as 1) the

Delta, 2) the Quantile Mapping (QM) (Panofsky and Briar, 1968; Gudmundsson, 2012) and 3) the Empirical Quantile Mapping (EQM) (Boe et al., 2007).

MIROC5 provided TMax and TMin dialy air temperature as prediction data with Spatial Coverage at longitude 0 to 358.5938 and latitude -88.9277 to 88.9277. The data of 1987 – 2006 period were conducted by MIROC5 (historical), extracted by "*cmip5 output1 MIROC MIROC5 historical day atmos day r1i1p1 v20120710 tasmax*" for TMax and "*cmip5 output1 MIROC MIROC5 historical day atmos day r1i1p1 v20120710 tasmin*" for TMin. Moreover, the data of 2006 – 2100 period performed by MIROC5 (rcp85), "*cmip5 output1 MIROC MIROC5 rcp85 mon atmos Amon r1i1p1 v20120710 tasmax*" for TMax and "*cmip5 output1 MIROC MIROC5 rcp85 day atmos day r1i1p1 v20120710 tasmin*" for TMin. The dataset of historical and rcp85 provided by The German Climate Computing Center (DKRZ: Deutsches Klimarechenzentrum GmbH) and accessed by https://cera-www.dkrz.de/WDCC/ui/cerasearch/q

Discrepancy of the observation data and the prediction data of 1987 - 2020 were examined by Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Mean Square Error (MSE), Root Mean Square Error (RMSE), Mean Bias Error (MBE), R-squared correlation (R-Sq), Pearson coefficient and Index of Agreement as following the equation (1) – (8) to get the appropriate statistic downscaling method which can be used to forecast the data of 2020 – 2100 period.

$$MAE = \frac{\sum_{i=1}^{n}\left|X_{model,i}-X_{real,i}\right|}{n} \tag{1}$$

$$MPAE = 100\ x\ \frac{1}{n}\sum_{i=1}^{n}\frac{X_{real,i}-X_{model,i}}{X_{real,i}} \tag{2}$$

$$MSE = \frac{\sum_{i=1}^{n}\left|X_{real,i}-X_{model,i}\right|}{n} \tag{3}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{X_{model,i}-X_{real,i}}{X_{real,i}}\right)^2} \tag{4}$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(X_{model,i} - X_{real,i}) \tag{5}$$

$$R - Sq\ =\ 1\ -\ \left(\frac{\sum\left(\mathrm{X}_{\mathrm{real,i}}-X_{model,i}\right)^2}{\sum\left(\mathrm{X}_{\mathrm{real,i}} - \bar{\mathrm{X}}_{\mathrm{real}}\right)^2}\right) \tag*{)6(}$$

$$\rho = \frac{\sum_{i=1}^{n}(X_{model,i}-\bar{X}_{model})(X_{real,i}-\bar{X}_{real})}{\sqrt{\sum_{i=1}^{n}(X_{model,i}-\bar{X}_{model})^2\sum_{i=1}^{n}(X_{real,i}-\bar{X}_{real})^2}} \tag{7}$$

$$d = 1 - \frac{\sum_{i=1}^{n}\left(X_{model,i}-X_{real,i}\right)^2}{\sum_{i=1}^{n}\left(\left|X_{model,i}-\bar{X}_{real}\right|+\left|X_{real,i}-\bar{X}_{real}\right|\right)^2} \tag{8}$$

Notes: $X_{real,i}$ refers to real TMax and TMin value, which is gathered from i meteorological station, $X_{model,i}$ refers to forecasting TMax and TMin, which is extracted from MIROC5 at i meteorological station, ρ is Pearson's correlation coefficient, d is index of agreement. The lowest values of MAE, MAPE, MSE, RMSE, MBE and the highest values of Pearson's correlation coefficient, and Index of Agreement (a range from 0 – 1), represents that real data and prediction data are agreeable.

Diurnal air temperature range (DTR) represents the changing of air temperature of Thailand by the different value of TMax and TMin at each meteorological station as specific in the equation (9) (Roy and Balling Jr., 2005; Qu et al., 2014; Pyrgou et al., 2019). The changing of temperature and DTR could be presented in a form of yearly, regional, and seasonal. For the specific detail of season in Thailand, the season is quite different from universal season in north hemisphere. The approximate season defined as Summer is February to May, Rainy is June to September and Winter is October to January. The decreasing of DTR trend indicates that collection of heat increases in the area.

$$DTR = TMax_{dialy,i} - TMin_{dialy,i} \tag{9}$$

Note: DTR means Diurnal air temperature range, $TMax_{dialy,i}$ and $TMin_{dialy,i}$ refer to maximum and minimum daily air temperature, respectively at i meteorological station

GIS process cooperated with administrative boundaries of Thailand territory in shapefile format. The shapefile was retrieved from https://data.humdata.org/dataset/thailand-administrative-boundaries and obtained on 9 November 2019 by Information Technology Outreach Services (ITOS) to collect, analyse, and present the TMax, TMin, and DTR easily in form of maps by raster interpolation method (Kriging) with output cell size at 400 and Number of Point at 12. Moreover, the trend of TMax and TMin, and DTR were performed by Mann-Kendall Trend Test and Sen's slope method in XLSTAT software for student version.

Results and Discussion

Continental Air Temperature Prediction of Mid and Late of 21st Century Period

Maximum and minimum air temperature on continental area of Thailand over mid (2021 – 2060) and late of 21st century periods (2061 – 2100) were predicted by MIROC5 model, cooperated with SD GCM V 2.0 software, and run under Delta, EQM and QM methods. The accuracy of each method was presented that QM method gave the best accuracy in temperature values with MAE, RSME, MSE, MPAE, MBE, R-Squared, Pearson coefficient, and Index of Agreement for TMax prediction at 1.289, 1.690, 2.856, 3.920, -0.050, 0.459, 0.678, and 0.809, respectively. The most accuracy indexes of TMin prediction were agreeable to EQM method with MAE, RSME, MSE, MPAE, MBE, R-Squared, Pearson coefficient, and Index of Agreement at 0.966, 1.458, 2.125, 4.622, -0.020, 0.760, 0.872, and 0.893, respectively; however, the index values were not much different from QM method. Moreover, a comparison of maximum and minimum temperature values in each region illustrated that the best accuracy values were from EQM as presented in Tab. 2. Therefore, EQM method was selected to predict maximum and minimum temperature for mid and late of 21st century period.

Tab. 2. An accuracy of each statistical downscaling method for maximum and minimum temperature prediction

Maximum temperature prediction								
Methods	MAE	RMSE	MSE	MPAE	MBE	R Sq	Pearson	IOA
Delta	1.739	2.241	5.022	5.319	-0.035	0.418	0.647	0.834
EQM	1.273	1.713	2.933	3.861	-0.059	0.448	0.669	0.803
QM	1.289	1.690	2.856	3.920	-0.050	0.459	0.678	0.809
Minimum temperature prediction								
Methods	MAE	RMSE	MSE	MPAE	MBE	R Sq	Pearson	IOA
Delta	1.274	1.749	3.059	5.922	0.041	0.733	0.856	0.908
EQM	0.966	1.458	2.125	4.622	-0.020	0.760	0.872	0.893
QM	0.990	1.462	2.138	4.714	0.002	0.759	0.871	0.893

Average daily maximum temperature (TMax) characteristics, Trends and Spatial analysis

Average daily maximum temperature (TMax) of Thailand over 1987-2020 (Early of 21st century), 2021 – 2040 (Mid of 21st century), and 2061 – 2100 (Late of 21st century) in Annual (black), Summer (red), Rainy (Green), and Winter (Blue) season were illustrated in Fig. 2 (first row). The highest and lowest Tmax were found in Summer and Winter, respectively due to the angle and movement between sun and earth in the Northern hemisphere (Scherrer and Scherrer, 2014); however, the TMax of Rainy season was close to Annual value through over three study period. The TMax usually come from the effect of incoming solar radiation, however; Cumulonimbus and nimbostratus which is expanding over the sky can reduce the radiation thus TMax in Rainy season can be reduce by this reason. (Kumar et al, 2001; Shahid et al., 2012). An average of TMax in Annual, Summer, Rainy, and Winter was 32.8, 34.5, 32.6, and 31.3 °C for early of 21st century, 33.2, 34.5, 33.6, and 31.4 °C for mid of 21st century, and 33.8, 35.1, 34.1, and 32.2 °C for late of 21st century. As the results, the TMax of all seasons tended to increase from period to period. TMax spatial maps of these three periods were displayed by Fig. 3 (a)-(d) for early study period, (e)-(h) for mid study period, and (i)-(l) for late study period with dark red, light red, light grey, and light green colour refers to >35.1, 33.1 – 35.0, 31.1 – 33.0, and 29.1 – 31.0 °C, respectively. The maps of Fig. 3 (a)-(d) were agreeable to Kamworapan et al. (2021), displayed that TMax of all periods were according to line graph that the highest and the lowest TMax appeared in Summer and Winter respectively. Moreover, the hottest area was found in the middle of Thailand then gradually decrease in faraway area, cooler temperature was found especially in upper area of Northern region and upper-east area of Northeast of Thailand for all study periods.

For mid-21st century period, the most area of Thailand had TMax about 33.1-35.0 °C except upper area of Central part and the most area of Northern part had lower of TMax. However, the hottest area in Summer was found in Eastern part while the coldest area in Winter was found in lower part of Northern area and upper area of Central region. The TMax trends of these study periods were calculated by Mann-Kendall trend test and Sen's slope method in XLSTAT Statistical software. The results were presented in tab. 3.

The TMax trends of early-21st century period were increasing in all seasons. The notable TMax increasing trends appeared in Rainy and Winter season for all regions especially in Southern of Thailand; however, it was also gradually increasing in Summer with a significantly at 99%. The TMax increased at a rate of +0.021, +0.015, +0.021, and +0.031 °C per year for Annual, Summer, Rainy, and Winter respectively. For mid-21st century period, TMax trends were increasing in all seasons except in Rainy season with a significantly at 99% and some of it at 95%; however, the trends were not change much comparing to early of 21st period. TMax in Rainy season was decreasing in all regions except in Southern of Thailand. The TMax was expanding around +0.010, +0.014, and +0.017 °C per year for Annual, Summer, and Winter respectively while it was dwindling at -0.005 °C per year for Rainy season.

Spatial distribution changing of TMax between Early and Mid-21st century period was displayed by Fig. 3(m – p) that TMax decreased from previous period in central and Eastern part of Thailand while others increased, especially in Rainy and Winter season, founded around -1.00 to 0.5 °C. Even the TMax in Mid-21st century period was cooler than previous, the trend of Mid-21st century period was increasing for annual and all seasons except in Rainy season.

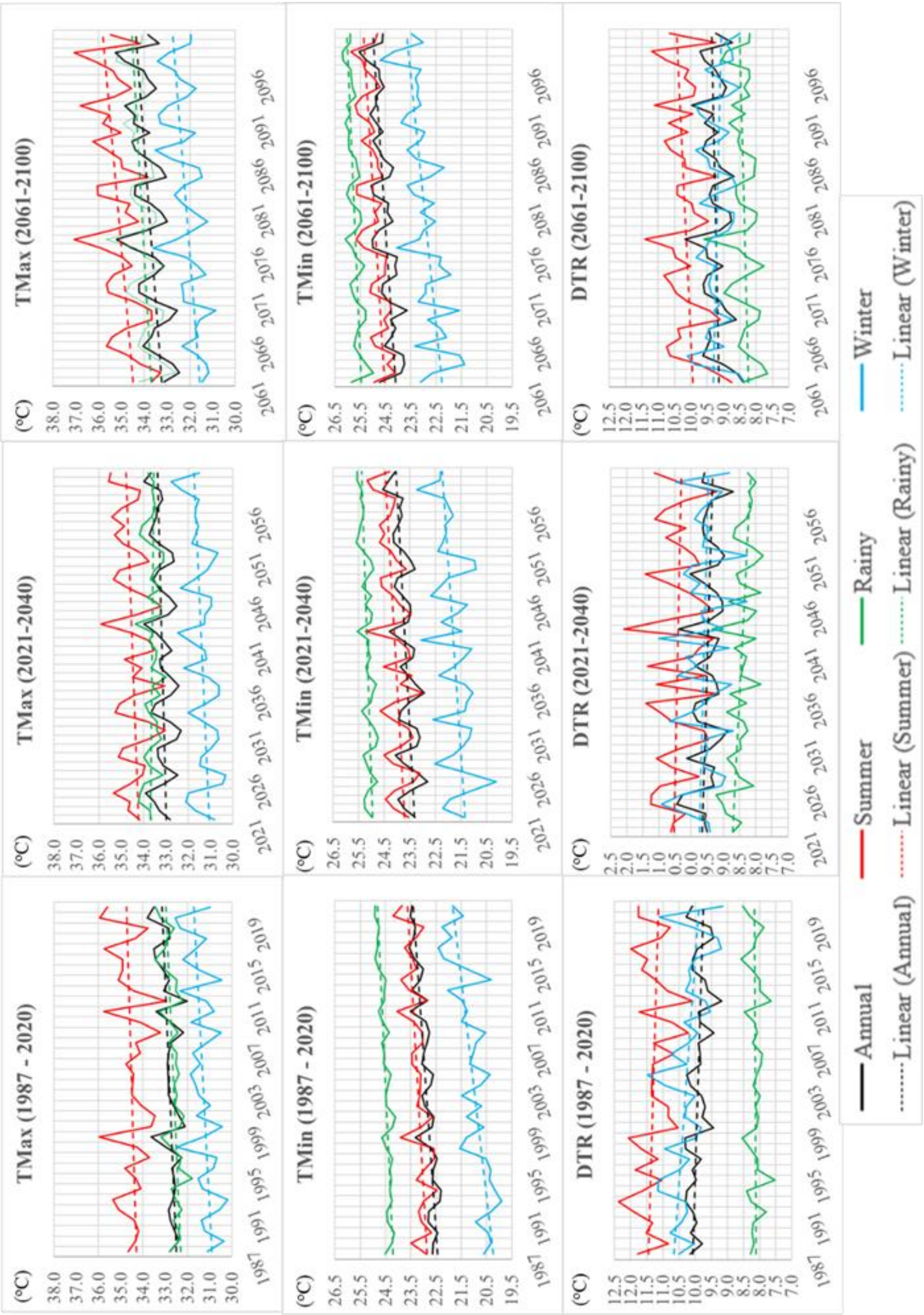

Fig. 2 (First row) TMax, (Second row) TMin, and (Third row) DTR Trends in different season over three study periods

Tab. 3. Average daily maximum temperature (TMax) trends in different regions of Thailand

Region	1987-2020											
	Summer			Rainy			Winter			Annual		
	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope
Thailand	0.133	0.285*	0.015	0.390	0.001	0.021	0.277	0.025	0.031	0.364	0.003	0.021
Northern	0.102	0.412*	0.018	0.307	0.013	0.023	0.277	0.025	0.032	0.337	0.006	0.022
Northeast	0.133	0.285*	0.020	0.383	0.002	0.025	0.280	0.023	0.036	0.413	0.001	0.029
Central	0.127	0.306*	0.012	0.226	0.067*	0.014	0.223	0.070*	0.029	0.273	0.027	0.018
Eastern	0.148	0.233*	0.013	0.345	0.005	0.017	0.242	0.049	0.020	0.307	0.013	0.017
Southern	0.189	0.125*	0.018	0.521	<0.0001	0.021	0.292	0.018	0.021	0.375	0.002	0.020
Region	**2021 - 2060**											
	Summer			**Rainy**			**Winter**			**Annual**		
	Kendall's tau	**p-value**	**Slope**	**Kendall's tau**	**p-value**	**Slope**	**Kendall's tau**	**p-value**	**Slope**	**Kendall's tau**	**p-value**	**Slope**
Thailand	0.152	0.175*	0.014	-0.090	0.425*	-0.005	0.179	0.110*	0.017	0.169	0.134*	0.010
Northern	0.126	0.266*	0.011	-0.007	0.961*	0.000	0.228	0.042	0.015	0.201	0.073*	0.009
Northeast	0.282	0.012	0.026	-0.115	0.310*	-0.006	0.244	0.029	0.020	0.263	0.019	0.015
Central	0.099	0.384*	0.013	-0.193	0.086	-0.012	0.158	0.161*	0.015	0.069	0.545*	0.005
Eastern	0.115	0.310*	0.009	-0.201	0.073	-0.009	0.155	0.168*	0.012	0.074	0.514*	0.004
Southern	0.115	0.310*	0.014	0.069	0.545*	0.004	0.188	0.095*	0.021	0.158	0.161*	0.009
Region	**2061 - 2100**											
	Summer			**Rainy**			**Winter**			**Annual**		
	Kendall's tau	**p-value**	**Slope**	**Kendall's tau**	**p-value**	**Slope**	**Kendall's tau**	**p-value**	**Slope**	**Kendall's tau**	**p-value**	**Slope**
Thailand	0.274	0.015	0.034	0.290	0.010	0.026	0.331	0.003	0.031	0.336	0.003	0.027
Northern	0.255	0.023	0.035	0.347	0.002	0.032	0.417	0.000	0.037	0.358	0.001	0.035
Northeast	0.366	0.001	0.034	0.247	0.028	0.026	0.398	0.000	0.037	0.374	0.001	0.032
Central	0.244	0.029	0.035	0.255	0.023	0.026	0.239	0.033	0.029	0.282	0.012	0.030
Eastern	0.225	0.045	0.019	0.179	0.110*	0.014	0.198	0.077*	0.017	2.242	0.031	0.018
Southern	0.228	0.042	0.027	0.309	0.006	0.025	0.198	0.077*	0.020	0.271	0.016	0.025

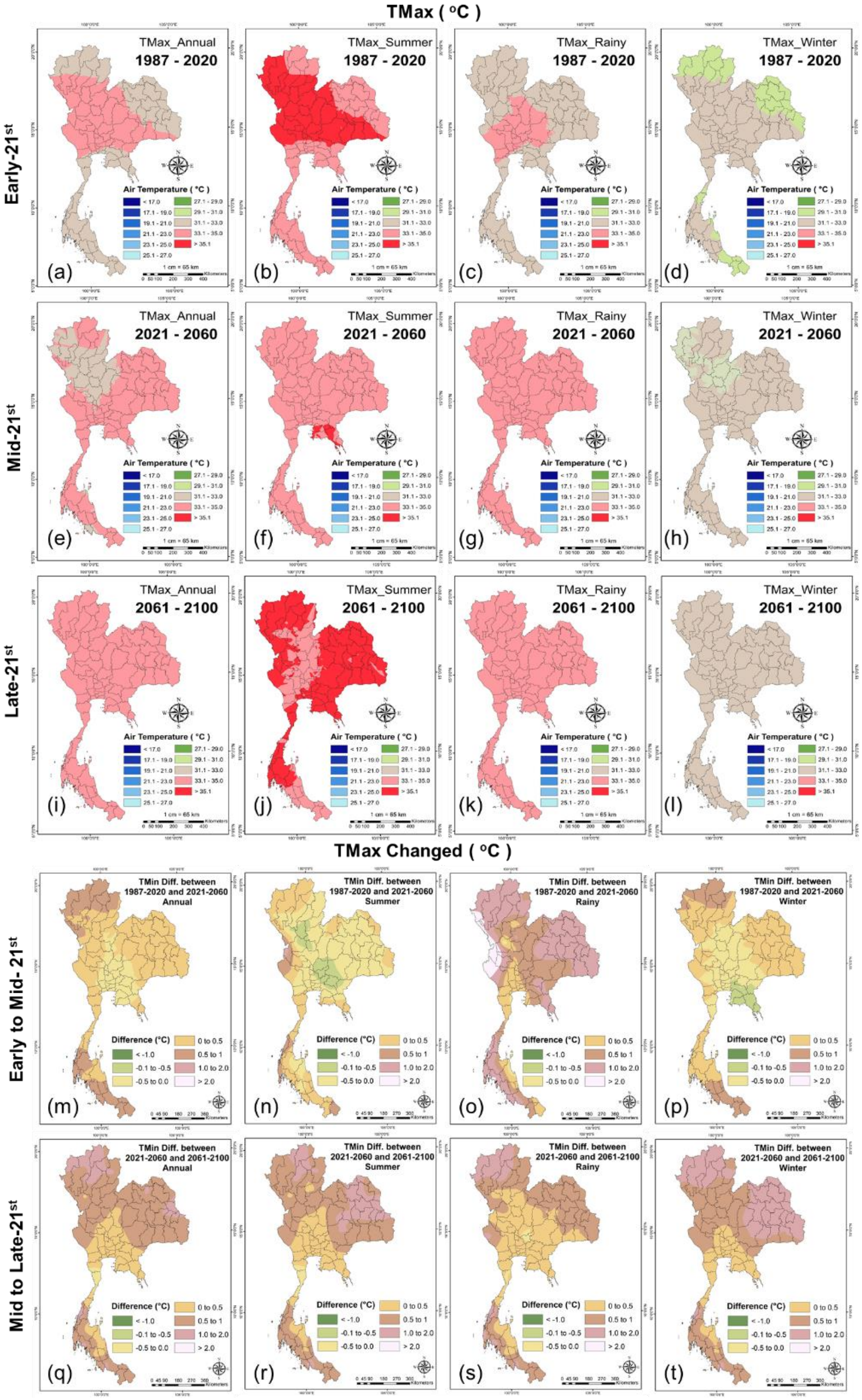

Fig. 3 TMax maps in difference season of (a)-(d) Early-21st century, (e)-(h) Mid-21st century, (i)-(l) Late-21st century and TMax Changed in difference season of (m)-(p) Early to Mid-21st century and (q)-(t) Mid to Late-21st century

In late of 21st century period, TMax in all seasons were notable higher than those previous periods in all regions. The most area of Thailand in Summer faced to the highest temperature except in the most area of Central part, some of lower area of Northern part and some of lower area of Southern part. Whereas TMax of over Thailand was in a range of 33.1 – 35.0 °C for Annual and Rainy season while it was 31.1 – 33.0 °C for Winter. The trends of TMax were also adding in all seasons and all regions with a significantly at 99% at nearby rate around +0.027, +0.034, +0.026, and +0.031 °C per year for Annual, Summer, Rainy, and Winter season respectively. Moreover, the changing rates of this period were higher than those previous periods at all.

Spatial distribution changing of TMax between Mid and Late-21st century period were displayed by Fig. 3(q – t) that TMax increased in the most area then more increasing in the next faraway area from central part (> +0.0 to +2.0 °C).

Average daily minimum temperature (TMin) Characteristics, Trends and Spatial analysis

Average daily minimum temperature (TMin) of Thailand over these three periods were presented in Fig. 2 (second row). The higest TMin appeared in Rainy season due to an effect of outgoing solar radiation performance which can be blocked by thickness of cloud in Rainy season (Kumar et al, 2001; Shahid et al., 2012) while the lowest TMin still found in Winter because of a relationship between earth and sun angular in the Northern hemisphere (Scherrer and Scherrer, 2014). Moreover, TMin in Summer closed to Annual value for all periods because of the effect of low specific heat capacity on land. Even incoming solar radiation can be easily come through the earth so much in daytime of Summer, leading so high temperature; however, the heat can easily emit from land and go back to space in night-time, leading the air temperature drops. Therefore, TMin in Summer would not be so much high in Summer. (Ahrens, 2009; American Meteorological Society, 2009; Archer and Rahmstorf, 2010). An average of Annual, Summer, Rainy, and Winter of TMin for early of 21st century was 22.9, 23.2, 24.5, and 21.0 °C while it was 23.7, 24.1, 25.2, and 21.8 °C for mid of 21st century period and for late of 21st century was about 24.6, 25.0, 25.7, and 23.0 °C., respectively. As the results, an average of TMin values were higher from the beginning to the last study period for all seasons.

TMin spatial maps of these three periods were displayed by Fig. 4 (a)-(d) for early study period, (e)-(h) for mid study period, and (i)-(l) for late study period with dark blue (Cooler) to light blue (Hotter). The maps indicated that the lowest of TMin was found in Winter, following by Summer and Rainy season, respectively in all periods. The lowest of TMin was always found in the upper area of Thailand especially in Northern, upper-Northeast, and upper-Central of Thailand, then gradually increased in lower part of Thailand. From these three periods, TMin tended to be higher from period to period and it tended to hit the highest value in the late of 21st century period.

Tab. 4. Average daily minimum temperature (TMin) trends in different regions of Thailand

Region	1987-2020											
	Summer			Rainy			Winter			Annual		
	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope
Thailand	0.337	0.006	0.023	0.617	<0.0001	0.021	0.527	<0.0001	0.052	0.585	<0.0001	0.031
Northern	0.375	0.002	0.033	0.568	<0.0001	0.021	0.530	<0.0001	0.074	0.609	<0.0001	0.041
Northeast	0.264	0.032	0.024	0.624	<0.0001	0.023	0.477	0.000	0.060	0.496	<0.0001	0.035
Central	0.389	0.002	0.032	0.598	<0.0001	0.022	0.511	<0.0001	0.054	0.585	<0.0001	0.032
Eastern	0.186	0.133*	0.013	0.430	0.000	0.022	0.508	<0.0001	0.047	0.488	<0.0001	0.026
Southern	0.307	0.013	0.017	0.508	<0.0001	0.015	0.529	<0.0001	0.026	0.565	<0.0001	0.018
Region	**2021 - 2060**											
	Summer			Rainy			Winter			Annual		
	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope
Thailand	0.306	0.006	0.021	0.341	0.002	0.012	0.244	0.029	0.024	0.366	0.001	0.019
Northern	0.279	0.013	0.019	0.402	0.000	0.014	0.288	0.042	0.025	0.358	0.001	0.020
Northeast	0.368	0.001	0.031	0.355	0.002	0.013	0.266	0.018	0.030	0.414	0.000	0.026
Central	0.231	0.040	0.015	0.263	0.019	0.009	0.179	0.110*	0.021	0.269	0.017	0.016
Eastern	0.244	0.029	0.019	0.258	0.022	0.008	0.225	0.045	0.021	0.298	0.008	0.016
Southern	0.242	0.031	0.015	0.352	0.002	0.011	0.298	0.008	0.018	0.296	0.008	0.015
Region	**2061 - 2100**											
	Summer			Rainy			Winter			Annual		
	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope
Thailand	0.412	0.000	0.025	0.493	<0.0001	0.016	0.436	<0.0001	0.038	0.460	<0.0001	0.025
Northern	0.429	0.000	0.030	0.533	<0.0001	0.019	0.433	0.000	0.054	0.498	<0.0001	0.034
Northeast	0.377	0.001	0.024	0.455	<0.0001	0.013	0.438	<0.0001	0.046	0.482	<0.0001	0.028
Central	0.363	0.001	0.024	0.457	<0.0001	0.017	0.401	0.000	0.036	0.406	0.000	0.025
Eastern	0.367	0.001	0.019	0.452	<0.0001	0.013	0.422	0.000	0.032	0.430	0.000	0.021
Southern	0.390	0.000	0.021	0.478	<0.0001	0.017	0.414	0.000	0.021	0.428	0.000	0.019

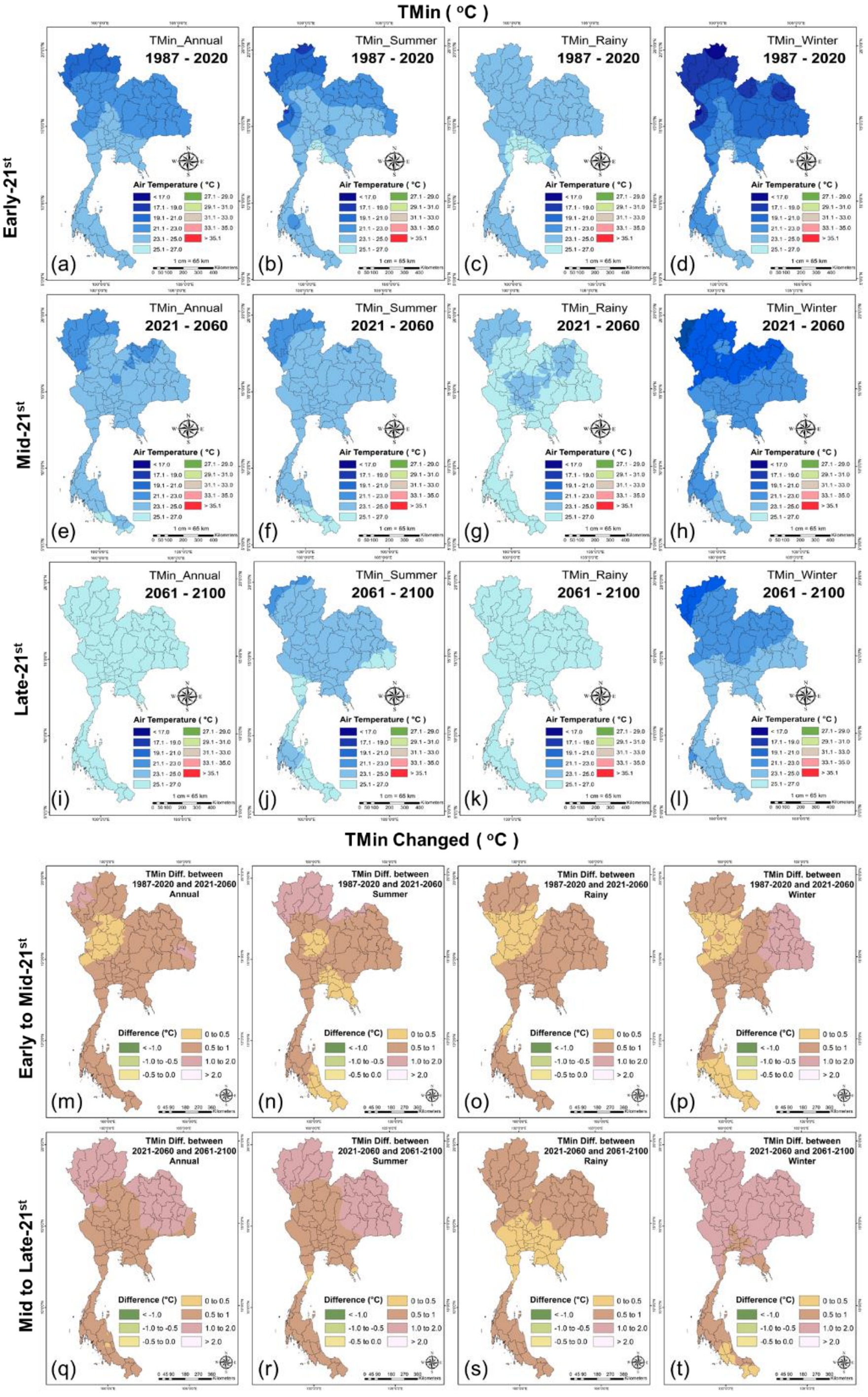

Fig. 4 TMin maps in diference season of (a)-(d) Early-21st century, (e)-(h) Mid-21st century, (i)-(l) Late-21st century and TMin Changed in diference season of (m)-(p) Early to Mid-21st century and (q)-(t) Mid to Late-21st century

According to the TMin trends of these study periods were calculated by Mann-Kendall trend test and Sen's slope method as presented in tab. 4. The TMin trends of all periods tended to increase in all seasons especially in winter for all regions with the most significantly at 99%. The TMin trends of the early-21st century period were increasing at a rate of +0.031, +0.023, +0.021, and +0.052 °C per year for Annual, Summer, Rainy, and Winter period, respectively same as a study of Zhang et al. (2021) that the near area of Thailand had the increasing TMin values about 0 – 0.06 °C per decade. Moreover, the trends also increased at a rate of +0.019, +0.021, +0.012, and +0.024 °C per year for the mid-21st century period of Annual, Summer, Rainy, and Winter period, respectively. For the last period, the trends also tended to increase at a rate of +0.025, +0.025, +0.016, and +0.038 °C per year for Annual, Summer, Rainy, and Winter period, respectively. Moreover, the changing rates of the last period was higher than those previous periods. Furthermore, the changing of TMin spatial distribution of all seasons indicated that TMin were obviously increasing from period to period especially in top and right side of Thailand with changing rate at +0 to +2.0 °C as presented in Fig. 4 (m-t).

DTR characteristics, Trends and Spatial analysis

Average diurnal temperature range (DTR) of Thailand over these three study periods, separated by seasons and annual report, were illustrated in Fig. 2 (Third row). The highest values were found in Summer due to the effect of heat capacity and heat transfer on land in Summer (Ahrens, 2009; American Meteorological Society, 2009; Archer and Rahmstorf, 2010) and the lowest DTR values found in Rainy season due to the relationship between a thickness of cloud and solar radiation performance in Rainy season (Kumar et al, 2001; Shahid et al., 2012), respectively. However, the DTR values of Winter was closing to Annual DTR values for through periods. An average of Annual, Summer, Rainy, and Winter of DTR for early 21st century period was 9.9, 11.3, 8.1, and 10.3 °C, respectively. For mid of 21st century period was 11.2, 10.4, 8.4, and 9.6 °C while it was 9.2, 10.2, 8.4, and 9.2 °C respectively for late of 21st century period. The results indicated that most of DTR in the late period were lower than those in previous.

DTR spatial maps of these three periods were displayed by Fig. 5 (a)-(d) for early study period, (e)-(h) for mid study period, and (i)-(l) for late study period with rainbow colour (Red to Purple refers to the lowest to the highest DTR values). For the overview, upper of Thailand had higher DTR values than lower part for over three periods. Moreover, DTR values tended to be lower from period to period and the late of 21st century had the lowest values. Furthermore, the highest DTR values appeared in Summer, following by Winter; however, Rainy season had the lowest DTR values. The reason for this phenomenon is a relationship between cloud over the sky during Rainy season especially for low-level of cloud can overshadow and reflect sunlight which can reduce the TMax in afternoon (Geerts, 2003, Shahid et al., 2012). Moreover, clouds also drop a long-wave radiation performance thus TMin values would increase and cause DTR values drop down (Karl et al., 1993, Dai et al., 1997, Dai et al., 1999, Travis et al., 2004, Zhou et al., 2009, Rai et al., 2012, Shahid et al., 2012, Xue et al., 2019).

The trends which were calculated from Mann-Kendall trend test and Sen's slope method as presented in tab. 5. The results indicated that the most trends of DTR of early and mid-period of 21st century decreased in all seasons except in Rainy season of first period with the most significantly at 99% and 95% for first and mid period, respectively. In the first period, the trends were agreeable to Sun et al. (2019) that the trends were decreasing for all regions especially in Winter; however, the Rainy trends decreased only in Central and Eastern part. The changing rates for all regions were at -0.011, -0.008, +0.001, and -0.024 °C per year for Annual, Summer, Rainy, and Winter season, respectively. For the mid of 21st century period, the most trends in all regions decreased especially in Rainy season with the most significantly at 95%, except in Summer and Winter of Southern part with the most significantly at 99%. The changing rates for all regions in the mid period were at -0.008, -0.004, -0.014, and -0.008 °C per year for Annual, Summer, Rainy, and Winter season, respectively.

However, the DTR trends for the last period tended to increase in all seasons with the most significantly at 95% especially in summer trend, which its trend tended to increase in all regions. Moreover, the Rainy trend was increasing in all regions except in Eastern part. Nevertheless, only the Winter trend was decreasing in all regions except in Eastern part. The changing rates for all regions were at +0.002, +0.007, +0.009, and -0.011 °C per year for Annual, Summer, Rainy, and Winter season, respectively.

Focusing on the changing of DTR compared with previous period as presented in Fig. 5 (m - t), indicated that the DTR values tended to decrease in annual, summer, and rainy season with the more decreasing started from the upper-southern part then expanded to the north area of Thailand. However, the changing rate of DTR values in Rainy season of all periods was not changed much comparing with other season. Moreover, the more decreasing values were founded in the central area due to the high population density and urbanization activities cause urban heat island (UHI) there which can increase TMin, and cooperate to thick of cloud to reduce a long-wave radiation performance leading the DTR values drop same as a study of Pyrgou et al. (2019) in China.

Tab. 5. Diurnal temperature range (DTR) trends in different regions of Thailand

Region	1987-2020											
	Summer			Rainy			Winter			Annual		
	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope
Thailand	-0.076	0.546*	-0.008	0.034	0.792*	0.001	-0.322	0.009	-0.024	-0.198	0.116*	-0.011
Northern	-0.068	0.588*	-0.012	0.072	0.566*	0.003	-0.443	0.000	-0.045	-0.250	0.046	-0.021
Northeast	-0.064	0.609*	-0.006	0.004	0.988*	0.000	-0.235	0.057*	-0.027	-0.165	0.189*	-0.011
Central	-0.123	0.321*	-0.016	-0.091	0.466*	-0.005	-0.284	0.021	-0.030	-0.254	0.043	-0.015
Eastern	-0.133	0.285*	-0.006	-0.083	0.505*	-0.004	-0.307	0.013	-0.024	-0.298	0.017	-0.011
Southern	-0.015	0.914*	0.001	0.239	0.053*	0.007	-0.117	0.345*	-0.005	-0.032	0.808*	-0.001

Region	2021 - 2060											
	Summer			Rainy			Winter			Annual		
	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope
Thailand	-0.031	0.790*	-0.004	-0.309	0.006	-0.014	-0.066	0.561*	-0.008	-0.107	0.345*	-0.008
Northern	-0.096	0.397*	-0.012	-0.215	0.056*	-0.012	-0.058	0.611*	-0.009	-0.117	0.298*	-0.008
Northeast	-0.036	0.753*	-0.004	-0.298	0.008	-0.020	-0.074	0.514*	-0.008	-0.163	0.147*	-0.010
Central	-0.007	0.961*	-0.001	-0.341	0.002	-0.021	-0.088	0.439*	-0.010	-0.161	0.153*	-0.010
Eastern	-0.120	0.287*	-0.008	-0.339	0.002	-0.017	-0.123	0.276*	-0.012	-0.252	0.024	-0.011
Southern	0.009	0.942*	0.003	-0.136	0.226*	-0.008	0.009	0.942*	0.001	-0.001	1.000*	0.000

Region	2061 - 2100											
	Summer			Rainy			Winter			Annual		
	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope	Kendall's tau	p-value	Slope
Thailand	0.096	0.397*	0.007	0.155	0.168*	0.009	-0.163	0.147*	-0.011	0.050	0.663*	0.002
Northern	0.020	0.866*	0.004	0.242	0.031	0.014	-0.196	0.082*	-0.018	-0.007	0.961*	-0.001
Northeast	0.139	0.217*	0.010	0.144	0.200*	0.010	-0.128	0.255*	-0.009	0.082	0.468*	0.003
Central	0.093	0.411*	0.008	0.126	0.266*	0.008	-0.123	0.276*	-0.012	0.072	0.529*	0.005
Eastern	0.058	0.611*	0.003	-0.004	0.981*	0.000	0.247	0.028	-0.015	-0.096	0.397*	-0.003
Southern	0.109	0.333*	0.011	0.177	0.116*	0.009	-0.047	0.681*	-0.003	0.112	0.321*	0.008

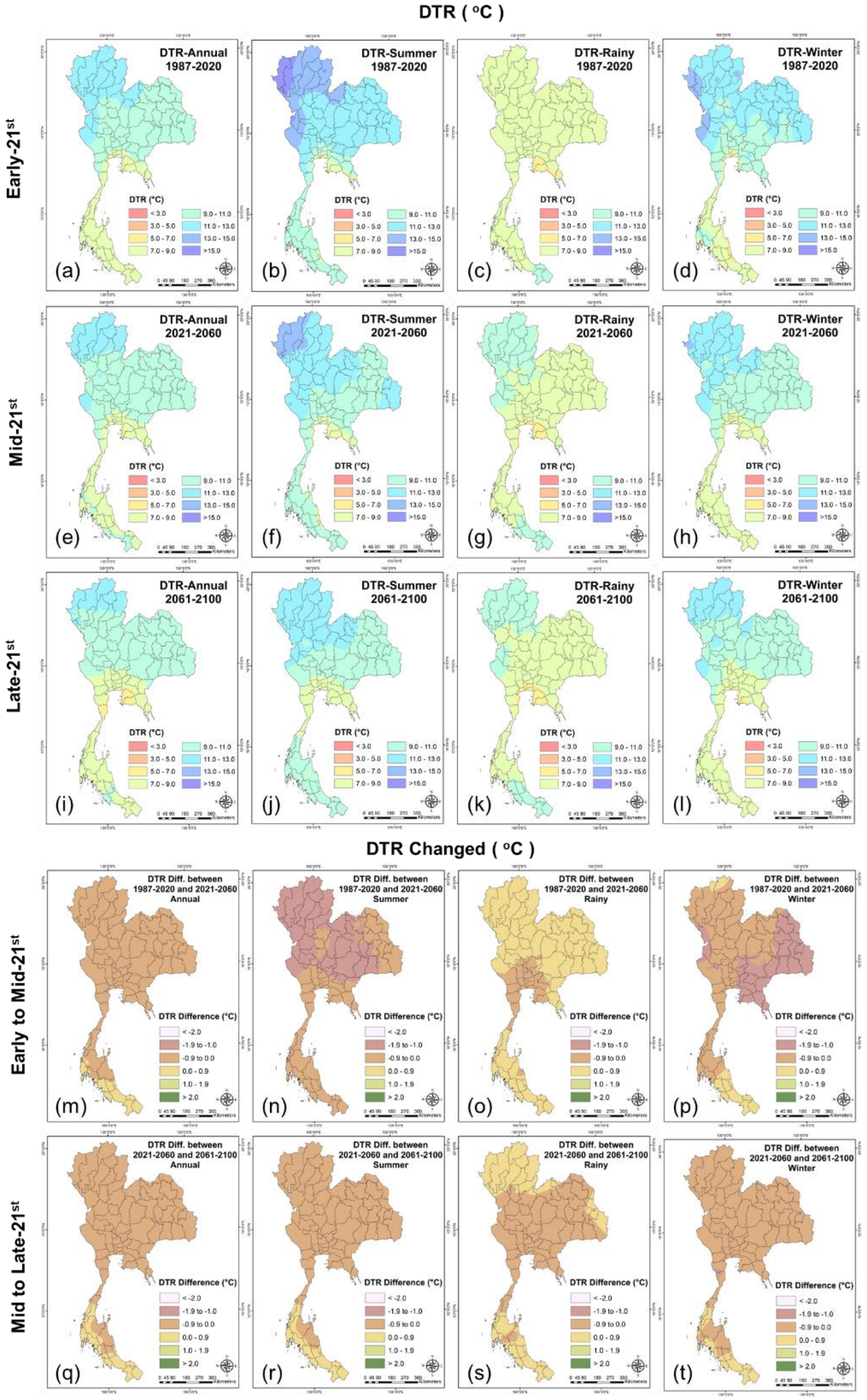

Fig. 5 DTR maps in diference season of (a)-(d) Early-21st century, (e)-(h) Mid-21st century, (i)-(l) Late-21st century and DTR Changed in diference season of (m)-(p) Early to Mid-21st century and (q)-(t) Mid to Late-21st century

Conclusion

Average daily minimum temperature (TMin), Average daily maximum temperature (TMax) of early-21st century period (1987-2020), mid-21st century period (2021-2060) and late-21st century period were modelled by MIROC5 (rcp85) model which can represent the meteorological component without any adaptation from human to project the extremely situation, cooperated with EQM Statistical downscaling method. TMax, TMin, and Diurnal temperature range (DTR) trends of Thailand in each region and each season for early, mid, and late of 21st century period were investigated by Mann Kendall Trend Test and Sen's slope, then presented in the form of spatial maps by GIS programme with Kriging method. The most TMax and TMin trends for all season and all regions tended to be increasing year by year with the large increasing changed in Northern and Northeast region, especially in Winter, except for the last period which had a large increasing in Summer.

However, DTR is one of global warming indicator which using only air temperature to calculate. The DTR trends were quietly fluctuated with the large decreasing in Eastern and Southern part, but the trends become to increase in the last period. A large DTR decreasing usually occurred in Winter and Rainy season. The TMax and TMin of all periods were expanding year by year and leading the DTR to decrease in the first and second period. However, even the TMax and Tmin tended to be increasing and making Thailand to be hot and hotter for the last period, the DTR trend tended to be increasing also. This can indicate that it would be a good sign for heat transfer performance in the atmosphere, even so much incoming solar radiation come but outgoing solar radiation also go out so much and help the earth cooling in night time.

Park et al. (2019) reported that low daily temperature and ± 3°C of DTR changing leaded more an influenza incidence risk. Wang et al. (2020) and Zheng et al. (2020) reported that high DTR values changing leaded more chronic respiratory diseases and increasing blood pressure. Therefore, large fluctuation of TMax, TMin, and DTR values effected to human life so much in negative way. Moreover, big trees could be easily growing up in lower DTR values area, more cloud which covered the sky can reduce the growth obstacle from severe drought problem due to a little change of TMax and TMin in same day. This statement indicated that lower DTR values effected to plant life in positive way, presented by Zhang et al. (2022). Therefore, difference of each specie responded to different TMax, TMin and DTR values. The changing of all those values needed to be study to plan policies, find appropriate and adaptation ways for all life's activities, leads economic and social mobility.

However, even this study can be a global warming alarms, only air temperature changing might not be enough to project the impact of climate change, thus other meteorological variables would be used to examine in future study.

Acknowledgement: This manuscript was operated under a research topic of Trend Analysis and Prediction of Temperature Change in the Continental, Thailand with personal fund. Author would like to say thank you to Meteorological Department of Thailand to support all air temperature data which were important for this work. Moreover, the author is appreciating to the Human Subject Research Ethics Sub-Committee of Ramkhamhaeng University to give research advices and approve this study.

Approval of Documents Related to Study Protocol: The Human Subject Research Ethics Sub-Committee of Ramkhamhaeng University, Thailand, has approved this study. Study Code: RU-HRE 63/0005, Approval Date: 21/08/20 and Expiry Date: 20/08/21

Conflicts of Interest: The author declares no conflict of interest.

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