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SIMULATION OF MEAN MONTHLY MAXIMUM TEMPERATURE IN SUMMER OF NORTHERN REGION, THAILAND USING INMCM4.0 MODEL

Abstract: Project aims to simulate Mean Monthly Maximum Temperature (Tasmax) in summer of Northern, Thailand (2020-2030) using INMCM4.0 Model. Observation data of historical period were gathered from 14 Meteorological Department of Thailand, used to compare to Simulation data of same period to verify the model. Quantile Mapping (QM) was the best statistical downscaling method to predict future Tasmax with the lowest of %MPAE and MAE at 5.29% and ±1.85 °C. Tasmax values were presented in form of map by kriging method then trend changes were calculated by Mann-Kendall trend test and Sen's slope. The results illustrated that the highest Tasmax was found around left-bottom of the region then fading in the next area to the top. Tasmax was gradually rising from February to May with the most range in hot (35.0 – 39.9 °C) and very hot range (>40 °C). Moreover, trend analysis indicated that the trend of February, March, April, and summer period were fluctuated and obviously increased at +0.111, +0.130, +0.121, and +0.063 °C per year while it was at -0.007 °C per year for May with the lowest and highest Tasmax values at 28.8 and 41.5 °C. This can confirm that the region would have global warming issues in the future.

Key words: mean monthly maximum temperature, climate change, temperature rising, global warming, Thailand

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Introduction

Global warming and climate change issue started wildly to talk since industrial revolution began from the late 1700s (Chen, 2022). Various human activities released a lot of greenhouse gases such as Carbon dioxide which has the most impact to temperature rising, as well as methane, and nitrous oxide. As the reports of Hayhoe et al. (2018) and NOAA (2021a) suggest, carbon dioxide concentrations have been increasing about 40% since before industrial revolution in 2020 (280 ppm to 414 ppm). Moreover, methane and nitrous oxide concentration also increases to about 722 ppb to 1,867 ppb in 2019 and 270 ppb to 332 ppb, respectively (IPCC, 2013; NOAA., 2021b; 2021c). This cause brings global surface temperature rising about 1.0-1.1 degree Celsius by 2020 (National Academy of Sciences, 2020). Moreover, Thailand also gets the temperature rising problem especially in every year's summer. The mean monthly temperature of over Thailand in summer was increasing by 0.0087 degree Celsius per year especially in April (+0.0221 degree Celsius per year) and the highest temperature always found in the behind mountain range area which is far from the sea especially in Northern of Thailand (Phumkokrux & Rukverathum, 2020) As the study of Phumkokrux (2021), the mean annual temperature was increasing from period to period and hit the peak in the late of 21st century around +0.3 degree from previous then this problem also brought agricultural drought and many diseases such as heat stroke, hydrophobia, cholera, etc. to the northern region of Thailand (Phumkokrux et al., 2021), affecting human health and ecology.

Abovementioned reasons brought the authors to monitoring of maximum temperature in summer of future period to plan policy to protect human life and all biological activities. The Institute of Numerical Mathematics Climate Model, version 4.0 (INMCM4.0 Model) has been developed by Russian Academy of Sciences, Institute of Numerical Mathematics, under Coupled Model Intercomparison Project 5 (CMIP5), presenting in IPCC fifth assessment report. INMCM4.0 Model has target to simulate historical climate and future climate in various variables of climate components such as temperature, precipitation, solar radiation, sea-ice, etc. with the resolution of 2°× 1.5 in longitude and latitude (Volodin et al., 2010). Moreover, there are 3 statistical downscaling methods: the Delta, the Quantile Mapping (QM) (Panofsky & Briar, 1968), the Empirical Quantile Mapping (EQM) (Boe et al., 2007) could be used to extract the climate values from the model with less time and low performance of computer, cooperated with Statistical Downscaling of General Circulation Models program (SD GCM V.2.0) which was developed and launched by Agricultural and Meteorological Software. Additionally, raster interpolation maps in Geographic Information System (GIS) can illustrate a spatial distribution of maximum temperature for easily understanding the critical area. Moreover, Mann-Kendall trend test and Sen's slope method also have potential to explain trends and changes of maximum temperature in time series scale.

Study Area

This project focused on studying of 9 provinces in Northern area of Thailand, separated by National Geographic Committee in 1977, which was covered 93,690.85 square kilometres as shown in Figure 1(a) (Office of the Royal Society, 2015; Ministry of Natural Resources and Environment, 2017). The most topography characteristic of the area is high mountain range with the highest peak at Doi Inthanon, Chiang Mai (around 2,590 m.a.s.l.), alternate with small valley and plain with population around 6,350,559 people in this area. The north and west side connected to Myanmar while the north and east side connected to Laos. as shown in Figure 1(b). (Department of Mineral Resource, 2020; Department of Provincial Administration, 2020). Moreover, 14 meteorological stations distributed over the regions which using in this study were illustrated in Figure 1(a).

Data and Methods

This work focused on simulate Mean Monthly Maximum Temperature (Tasmax) of Summer in the period of 2021–2030 over Northern part of Thailand using INMCM4.0 in CMIP5. Firstly, model validation was required by comparison of observation data and simulation data in previous time. Therefore, this project gathered the simulate data of Tasmax from INMCM4.0 (Historical, rcp45), which was performed by the German Climate Computing Center (DKRZ: Deutsches Klimarechenzentrum GmbH) through WDC Climate (https://www.wdc-climate.de/ui/). The historical data of February to May in 2005–2019 were extracted from CMIP5 (cmip5/output1/INM/inmcm4/historical/mon/atmos/Amon/r1i1p1/v20130207/tasmax), cooperated with Statistical Downscaling General Circulation Models (SD-GCM V 2.0) through the Delta, the Quantile Mapping (QM) and the Empirical Quantile Mapping (EQM) downscaling methods (Agricultural and Meteorological Software, 2018). Then, the historical simulation data were compared to historical observation data in the period of 2005–2019 which were collected by 14 meteorological stations over the region to explore the best statistical downscaling method for future mean monthly temperature prediction, through Mean Absolute Percent Error (MAPE) and Mean Absolute Error (MAE) as calculated by equations 1 and 2.

$$\text{MAPE}(\%) = \frac{\Sigma\left(\frac{O_t - P_t}{O_t}\right)}{n} \text{ x } 100 \quad (1)$$

$$\text{MAE} = \frac{1}{N} \times \sum_{i=1}^{n} | O_{t_i} - P_{t_i} | \quad (2)$$

where: O_{tasmax} refers to historical observation data of Mean Monthly temperature in summer which were gathered from 14 meteorological stations over the regions. P_{tasmax} refers to simulation data of Mean Monthly temperature in summer from INMCM4.0 (Historical).

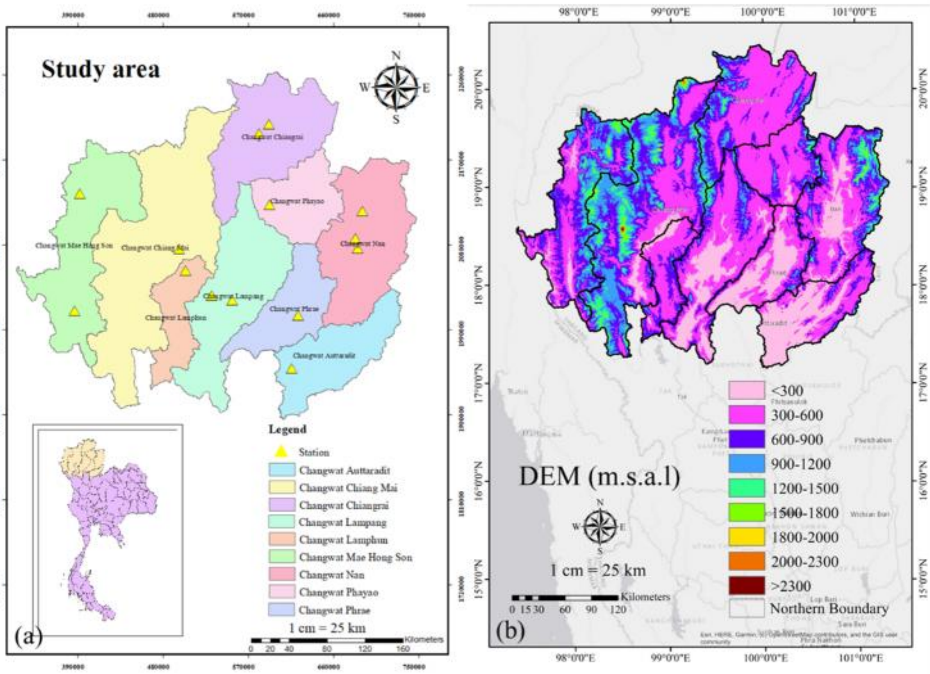

Fig. 1 (a) Northern Thailand, (b) DEM of study area

Secondly, the appropriate statistical downscaling methods was selected by the method which gave the lowest value of MAPE and MAE to predict the mean monthly temperature of Summer in 2020–2030. The simulation data were extracted from INMCM4.0 (rcp45: Representative Concentration Pathway 4.5) which was presented moderate increasing of extreme weather, based on agreement that: 1) temperature rises due to CO_2 rising with high emission, 2) land is warmer slowly than ocean and arctic, 3) the level of radiative forcing by greenhouse gas emissions stabilizing at 4.5 W/m^2 by 2100, 4) technologies and strategies for reducing greenhouse gas emissions are used to reduce global warming (Coastal climate change infographic series, n.d.; National Oceanic and Atmospheric Administration, 2013). The necessary variables was "cmip5/output1/INM/inmcm4/rcp45/mon/atmos/Amon/r1i1p1/v20130207/tasmax", performed through WDC Climate (https://www.wdc-climate.de/ui/), cooperated with SD-GCM V 2.0. Moreover, the spatial future mean monthly temperature distribution of summer in this region were analysed through spatial raster interpolation maps by kriging method, separated by month. Furthermore, the change trends of the mean monthly temperature were calculated by Mann-Kendall trend test (Gilbert, 1987; Kendall, 1975; Salmi et al., 2002; Yusuf et al., 2018) as illustrated in equations 3 – 10.

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} s \quad (x_j - x_k) \tag{3}$$

where:

$$s \quad (x_j - x_k) = +1, ii \ (x_j - x_k) > 0 \tag{4}$$

$$s \quad (x_j - x_k) = 0, ii \ (x_j - x_k) = 0 \tag{5}$$

$$s \quad (x_j - x_k) = -1, ii \ (x_j - x_k) < 0 \tag{6}$$

S gives very high positive value indicates that there is an increasing trend, low very negative value refers to a decreasing trend in contrast. If the sample size is bigger than 8 values and S is equal to 0, S would be calculated by equation 7, and compute a normalized test statistic Z as equations 8 – 10 suggest.

$$v\ (s) = \frac{1}{1}\left[n(n-1)(2n+5) - \sum_{p}^{g} = 1^{t_p(t_p-1)(2t_p-5)}\right] \quad (7)$$

$$Z = \frac{S-1}{\sqrt{v\ (S)}}, i\ S > 0 \quad (8)$$

$$Z = 0, i\ S > 0 \quad (9)$$

$$Z = \frac{S-1}{\sqrt{v\ (S)}}, i\ S < 0 \quad (10)$$

where: n is the sample size
g is number of tied groups
t_p is the sample size in p^{th} group.
Z > 0 an increasing trend and with a significant of 95% and 99%
Z<0 indicates a decreasing trend with a significant of 95% and 99%

Moreover, Linear trend and Sen's Slope can present a change per unit (true slope) in time series by equations 11 – 13 (Drápela & Drápelová, 2011; Sen, 1968).

$$f(t) = Q\ + B \quad (11)$$

$$Q_i = \frac{x_i - x_j}{i-j} \quad i = 1,2,3,\ldots,n; j > k \quad (12)$$

$$Q = \begin{Bmatrix} Q_{n+\left(\frac{1}{2}\right)} & i\ n\ is\ o \\ \frac{1}{2}\left(Q_{n/2} + Q_{n+\left(\frac{1}{2}\right)}\right) & I\ n\ is\ e \end{Bmatrix} \quad (13)$$

where: Q is the true slope. If Q > 0 means an increasing trend while Q < 0 refers to decreasing trend. B is a constant value.

Results and Discussion

The simulation data of Tasmax in Summer of the area were extracted from INMCM4.0 (Historical of 2005–2019) by SD GCM V 2.0 through Delta, EQM, and QM method then, compared the simulation data to observation data at the same period to confirm that the model can be used in future prediction. The results indicated that QM statistical downscaling method was the appropriate method to downscale the Tasmax data from global scale to regional scale with the lowest %MPAE and MAE at 5.29% and ± 1.85 °C, respectively as presented in Table 1. Therefore, QM was selected to predict the Tasmax data of 2020-2030 in Summer next.

Table 1. Validation of model data and observation data

Statistical downscaling Method	%MAPE	MAE
Delta statistical downscaling)Delta)	12.06	4.26
Empirical Quantile Mapping (EQM) statistical downscaling	5.63	1.97
Quantile Mapping (QM) statistical downscaling	**5.29**	**1.85**

The predicted Tasmax data of 2020 – 2030 were extracted from INMCM4.0 (rcp45) by QM method with SD GCM V2.0 then, the data were illustrated in form of isotherm maps by kriging method, separated by month in summer as presented in Figure 2 (a) – (e) with red colour scale (light red refers to lower Tasmax while dark red means higher Tasmax). The maps illustrated that Tasmax stared to rise from February then hit the peak in May due to north hemisphere pole faces the sun and the sun is perpendicular to Thailand in this period. Moreover, net solar radiation is too much in summer due to the closest distance of earth and the sun, leads the Tasmax is hottest than other seasons (Limhoon & Bualert, 2013). Spatial distribution of Tasmax in overall was hotter in the left-bottom of area, it fading to the next area till the top. In February, Tasmax was about 32-34 ^{o}C at the large area of bottom and it was 30-32 ^{o}C at the top while in March was hotter than February about 34-36 ^{o}C and 32-34 ^{o}C at the bottom and top respectively. For April and May had the same pattern that the hottest Tasmax (38-40 ^{o}C) appeared in this period from the left bottom; however, in May was expanded than April especially in Mae Hong Sorn, Chiang Mai, Lamphun, Lampang and Nan Province. While Tasmax at 36-38 ^{o}C found in the next area to the top. The reason why the northern region had so high temperature can consider as Figure 1(b), is this area located too far from the nearest sea thus it obstructs humidity which can help to reduce the temperature to the area. Moreover, the left side area had higher altitude than right side cause obstructed humidity to the area. The mountain and valley affected to difficult temperature and ventilation process. However, the right side of area had lower slope thus it can easily get humidity from the Pacific Ocean and tropical cyclone (Limsakul et al., 2019), the temperature and ventilation process can be easily to run leading the temperature dropping. Additionally, Chiang Mai-Lamphun basin is the largest basin in the region which had high population living there, leads urbanization activities growing up thus heat dome and high temperature can be appeared there than others (Limsakul et al., 2011; Phumkokrux & Rukverathum; 2020).

Table 2. Trend analysis of Tasmax of summer in Northeast region of 2020–2030 (by Mann-Kendall and Sen's Slope)

	Feb	**Mar**	**Apr**	**May**	**Summer**
Kendall's tau	0.156	0.200	0.333	-0.022	0.200
S	7.000	9.000	15.000	-1.000	9.000
Var(S)	125.000	125.000	125.000	125.000	125.000
p-value (Two-tailed)	0.592	0.474	0.210	1.000	0.474
Alpha	0.050	0.050	0.050	0.050	0.050
Slope	0.111	0.130	0.121	-0.007	0.063
Intercept	-190.970	-227.527	-206.525	51.227	-91.271
Maximum	37.4	38.7	40.3	41.5	39.0
Minimum	28.8	31.1	32.9	33.7	31.7
Mean	34.2	36.1	37.6	38.0	36.5

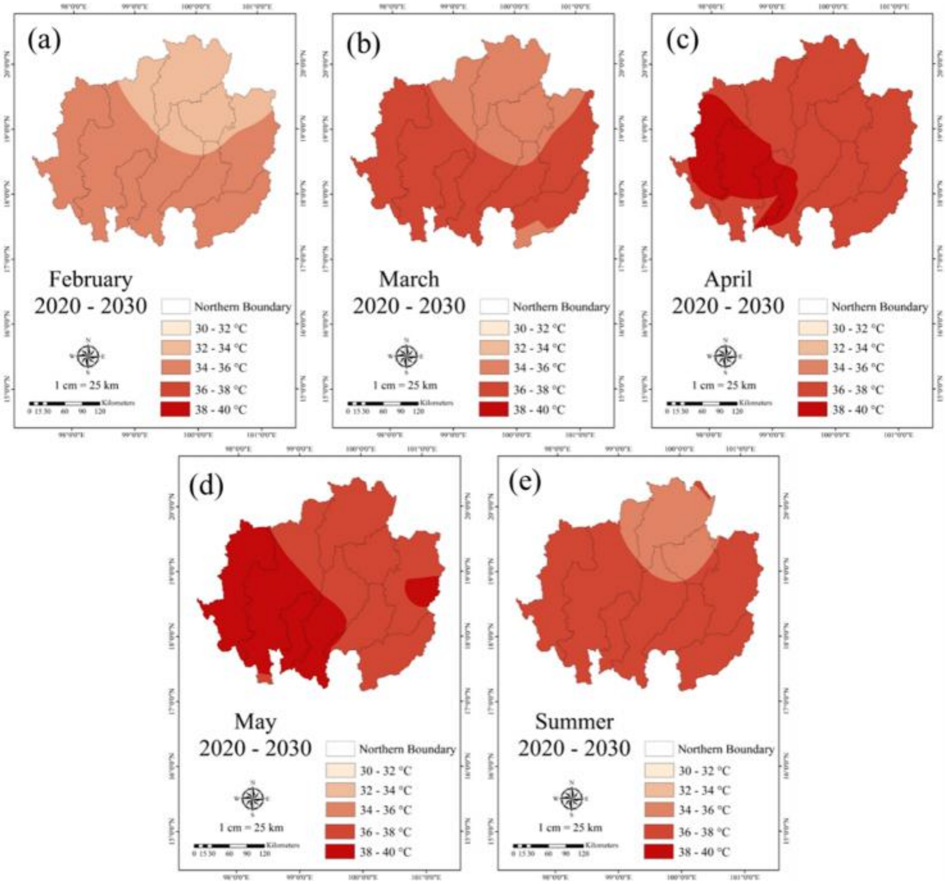

Fig. 2 Spatial distribution maps of Tasmax in Summer of Northern region in 2020–2030 (a) February (b) March (c) April (d) May and (e) Summer

Trend analysis of Tasmax of summer in Northeast region of 2020-2030 was calculated by Mann-Kendall trend test and Sen's Slope method, performed by XLSTAT Premium (Student Version). The most trend tended to be increasing quietly except in May at a significantly of 95%. The trends were about +0.111, +0.130, +0.121, -0.007 °C per year for February, March, April, and May as presented in Fig. 3 and Table 2. The average of Tasmax of 2020–2030 started to rise from February to May at 37.4, 38.7, 40.3, 41.5 for maximum values, 28.8, 31.1, 32.9, 33.7 for minimum values and 34.2, 36.1, 37.6, 38.0 for mean values. From the results in table 2 indicated that Tasmax in April and May of the left-bottom area was classified in very hot range (> 40.0 °C) by Thai Meteorological Department; however, other area was classified in hot range (35.0–39.9 °C) except in February which was classified in normal range (23.0–34.5 °C). As the Figure 3 (a)-(e) shows, the trend lines were fluctuated in every month. The lines dropped down obviously in 2023, 2024, 2027, and 2028 while these lines hit the peak clearly in 2029 and 2030 except in May that it hit the peak at the beginning of the period. For the overall summer, the trend line tended to be growing up at +0.063 °C per year with average maximum, minimum, and mean value at 39.0, 31.7, and 36.5 °C. The fluctuation of Tasmax might be affect from El Niño Southern Oscillation (ENSO) phenomena which alternates between El Niño and La Niña in every 4-

5 years but different intensity (Bureau of Meteorology of Australian Government, 2022). The Tasmax results were in accordance with research of Singhrattna et al. (2005) that decreasing of rainfall leads the temperature rising both of land and atmosphere. Therefore, the northern region might have high Tasmax in El Niño year then drop down in La Niña year. Moreover, urbanization activities and other factors which cannot be controlled might be the reasons for temperature fluctuation also.

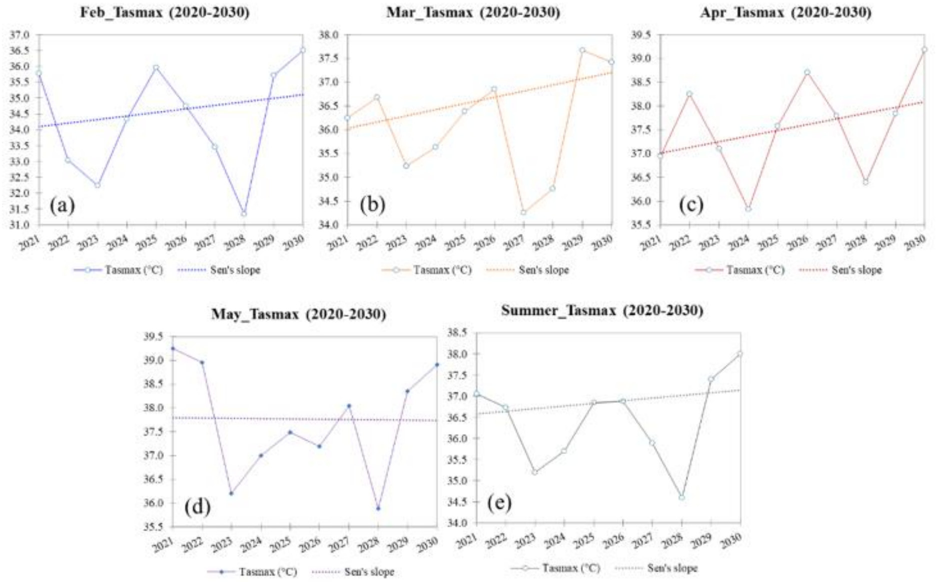

Fig. 3 Line trend of Tasmax of summer in Northeast region of 2020-2030 (a) February (b) March (c) April (d) May and (e) Summer

Conclusion

Simulation of Mean Monthly Maximum Temperature (Tasmax) in Summer of Northern of Thailand in 2020-2030 was performed by INMCM4.0 Model (rcp45), cooperated by SD CGM V.2.0. The best statistical downscaling method was Quantile Mapping (QM) statistical downscaling method with the lowest of Mean Absolute Percent Error (MAPE) and Mean Absolute Error (MAE) at 5.29% and ±1.85 °C. The Tasmax values of February to May were extracted then illustrated in form of maps (by Kriging method) and the trend changes were analyzed by Mann-Kendall trend test and Sen's Slope. The results indicated that the Tasmax was classified in hot (35.0–39.9 °C) and very hot range (> 40 °C) especially in left-bottom of region then faded in the next area to the top, except in February. The Tasmax started to rise from February to May with increasing trends at +0.111, +0.130, +0.121, and +0.063 °C per year for February, March, April, and All summer, respectively while decreasing trend found at -0.007 °C per year for May with a significantly of 95%. This result gave awareness that global warming and climate change being an important issue which impact to all activities in Thailand such as biodiversity changes, human health, economical activities, and social activities. Therefore, planning policy to reduce climate change problems is necessary.

However, this work used only INMCM4.0 Model with QM method to predict the Tasmax of future period, there were so many studies which using other models and versions thus trying to study with others might get the lower error between simulation and observation data to get the most accuracy values for the best climate understanding. Additionally, simulation of other variables such as precipitation, relative humidity, and wind speeds which are affected to air temperature, will be useful to understand the climate in the area for planning efficiency policy to protect human and all life (IPCC, 2022).

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