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TREND ANALYSIS AND FLUCTUATIONS OF AIR TEMPERATURE DURING WINTER: A CASE STUDY OF THE NORTHEAST REGION OF THAILAND

Abstract: This work aims to study and analyze the trend and fluctuations of air temperature during winter in the northeast region of Thailand using the data collected from the weather station of the Thai Meteorological Department (1987-2022). The result from the coefficient of variation data found that the variation of maximum (TMax) and mean (TMean) temperature was similar in all stations and lower than minimum temperature (TMin). Mann-Kendall test and Sen's slope were used to extract the temperature trend, found that almost all stations had a warming trend. The magnitude of the increment of TMean was about 0.035 °C yr^{-1}. The high value of magnitude was found at the northern and western edge of the region as well as the center and southeast areas. The Pettitt test was used to find an abruption change period and found that the most of stations had a changing direction to warming. The summarization of this study indicated that the air temperature during winter in the northeast region of Thailand had an increasing trend which could be evidence of climate change in the area.

Keywords: Mann–Kendall test, Sen′s slope estimator, change-point detection, winter climate variability, long-term temperature monitoring

Introduction

Climate change is widely recognised as one of the most critical global environmental challenges of the twenty-first century, driven by both natural climate variability and anthropogenic activities that modify atmospheric composition and land-surface processes (Cholathat, 2015). Air temperature plays a central role in land–atmosphere energy exchange and strongly regulates ecological dynamics, hydrological cycles, agricultural productivity, and

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human well-being. Observed global warming over recent decades has intensified climate variability, with the mean surface temperature increasing by approximately 0.7 °C during the latter half of the twentieth century (Al-Mutairi et al., 2023). Climate-model simulations further project that additional global warming of 1.5–4 °C will substantially increase the frequency and magnitude of extreme hydro-climatic events—including floods, droughts, and heat waves—although regional responses differ according to geographic and atmospheric conditions (Arnell et al., 2019; IPCC, 2021). Such temperature-driven extremes are increasingly recognised as major risks to environmental sustainability and socio-economic stability worldwide.

At the national scale, multiple long-term observational and modelling studies have confirmed significant warming trends across Thailand. Statistical analyses based on meteorological-station data indicate that national air temperature during 1987–2021 increased at a highly significant level ($p < 0.0001$), with winter and annual warming rates of approximately 0.025 and 0.017 °C yr^{-1}, respectively (Phumkokrux & Trivej, 2024). Furthermore, the decadal warming rate in Thailand (0.174 °C $decade^{-1}$) exceeds the global average (0.126 °C $decade^{-1}$), highlighting the country's heightened sensitivity to climate change (Boonpragob et al., 2011). Climate-projection studies using regional and global circulation models consistently indicate continued increases in annual mean, maximum, and minimum temperatures throughout the twenty-first century under rising greenhouse-gas concentrations (Phumkokrux, 2021; Phumkokrux, 2023). Long-term observations also reveal a significant reduction in the number of cold days and a concurrent rise in hot-day frequency across all regions of Thailand, further confirming ongoing warming (Chinvanno et al., 2008).

Regional-scale investigations provide additional evidence of climate variability and warming sensitivity, particularly in northeastern Thailand. Studies of meteorological drought, precipitation variability, and hydro-climatic extremes demonstrate increasing drought frequency and rainfall irregularity linked to temperature rise and atmospheric-circulation change (Kornkosa et al., 2021; Deb et al., 2018; Supari et al., 2020). Satellite- and model-based analyses further indicate strengthening land-surface heating and evapotranspiration under warmer conditions across mainland Southeast Asia (Wang et al., 2017). These findings collectively suggest that northeastern Thailand represents a climate-sensitive region where temperature variability interacts strongly with hydrological and ecological systems.

The impacts of climate change in Thailand extend across numerous socio-economic sectors. Agricultural productivity and labour capacity are increasingly affected by heat stress and rainfall variability (Noenplab, 2008; Langkulsen & Vichit-Vadakan, 2018). Rising temperatures also influence disease transmission, public-health vulnerability, tourism sustainability, and long-term water-resource availability (Treeputtarat & Wasi, 2011; Romree & Konwai, 2018; Deb et al., 2018). Such multidimensional impacts emphasise the necessity of region-specific climate analyses to support effective adaptation planning.

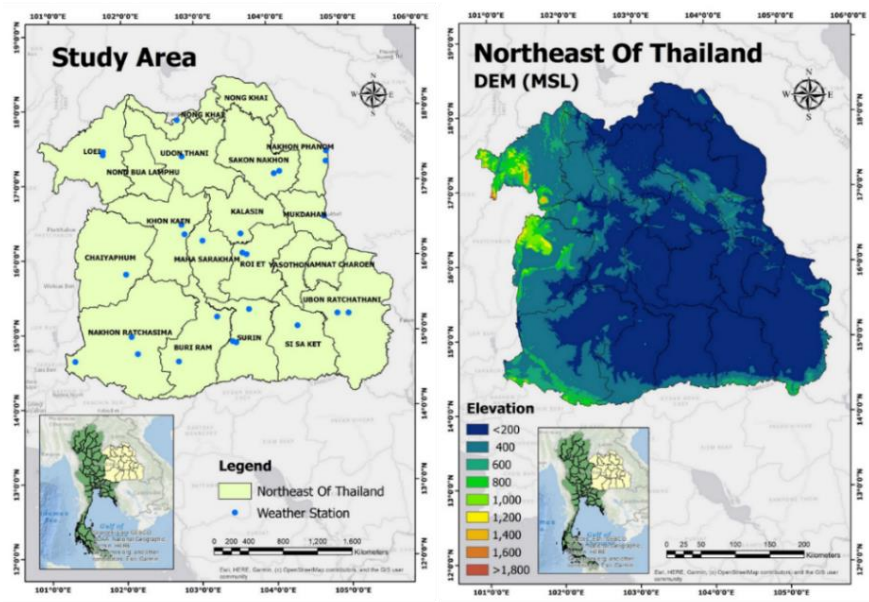
Geographically, the northeastern region of Thailand is characterised by a sandstone plateau with limited maritime influence and surrounding mountain ranges that restrict moisture transport from monsoonal circulation systems. This configuration promotes frequent drought conditions, strong seasonal temperature contrasts, and enhanced sensitivity to atmospheric variability compared with other regions of the country (Department of Mineral Resources, 2014; Limsakul & Singhruck, 2016). Rainfall is strongly dependent on tropical-cyclone activity, which does not always reach the western plateau, resulting in reduced humidity and elevated surface temperatures that affect ecosystems, agriculture, and livelihoods (Kornkosa et al., 2021; Supari et al., 2020). Consequently, winter temperature behaviour in this region represents an important indicator of regional climate change.

Beyond Thailand, numerous studies across different continents report comparable winter-temperature warming trends, suggesting a coherent global signal. In Europe, long-term observational analyses reveal statistically significant increases in both mean and extreme winter temperatures, accompanied by declining cold extremes (Popov et al., 2023; Nikolova & Bárta, 2021). Similar warming tendencies are documented across North Africa and the Middle East, where abrupt temperature shifts and increasing seasonal variability have been detected using non-parametric statistical approaches (Al-Mutairi et al., 2023). Studies in East Asia and China likewise demonstrate rapid winter warming associated with atmospheric-circulation change and anthropogenic forcing (Chen et al., 2019). Collectively, these global-scale findings confirm that winter warming is a widespread manifestation of contemporary climate change rather than a purely localised phenomenon.

Despite growing national and international evidence of temperature change, detailed spatial investigation of winter air-temperature trends and fluctuations in northeastern Thailand remains limited, particularly using integrated statistical and geospatial approaches. Therefore, this study aims to analyse the trend, variability, abrupt change, and spatial distribution of winter air temperature in northeastern Thailand during 1987–2022 using non-parametric statistical techniques, including the Mann–Kendall test, Sen's slope estimator, Pettitt's change-point detection, and cumulative seasonal-mean analysis, combined with GIS-based spatial mapping. Improved understanding of regional winter-temperature dynamics is essential for strengthening climate-adaptation strategies, agricultural planning, environmental management, and long-term sustainability at both regional and broader spatial scales.

Study Area

The northeast region of Thailand as illustrated in Fig. 1(a) and (b) is located in a geographic coordinate system between 14° 14' N and 18° 27' N and 101°15' E and 105°35' E. Wherewith, the northeast region is a plateau consisting of two large basins which are Sakonnakorn basin at the north and Korat basins at the south. The north and eastward are adjacent to the Khong River which separates from Laos. The southward is the location of the Phanom Dong Rak Mountain range which separates from Cambodia. The westward is the location of the Phetchabun and Dong Payayen Mountain range which is separate from the center region of Thailand (Thai Meteorological Department n.d.). The northeast includes 20 provinces covering about 168,854 square kilometres (Mhokprakhon & Chaiyakarm, 2023). According to the Köppen climate classification, Northeastern Thailand is mainly classified as tropical savanna (Aw). The climate is marked by high temperatures year-round, a distinct dry season, and seasonal rainfall associated with the monsoon system (Phumkokrux, 2021).



(a) (b)

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

Data, Equipment and Methods

Monthly Mean (TMean), Maximum (TMax), and Minimun (TMin) air temperatures of the northeast region of Thailand during winter which are October, November, December, and January (consecutive year), were collected between 1987 and 2022 (36 years) from 27 meteorological stations in association with the Thai Meteorological Department located in the northeast region as described in Tab. 1. Procedures were separated into 4 steps as described below.

Homogeneity of the data and abruption change study

Pettitt's test, a non-parametric method (Pettitt, 1979) was used to determine the homogeneity or heterogeneous data which can detect the change point. It depends on detecting the change in the average of the data before and after changing points along with calculating statistically significant values to test the following hypothesis: 1) The null hypothesis is defined as the data is homogenous and no change point is detected. 2) The alternative hypothesis is defined as the data is non-homogeneous and there is an abrupt change occurring at any point in time series data. This work calculated the significant value (P-value) using XLSTAT Statistical Software Premium Version for Students with a 5% confidence level.

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

Station No.	Station Name	Lat. (N)	Long. (E)	Altitude (msl)	Period
48350	Loei Agromet	17.409611	101.729694	260.3	1987-2022
48352	Nong Khai	17.863833	102.750861	173.0	1987-2022
48353	Loei	17.452583	101.730694	253.0	1987-2022
48354	Udon Thani	17.377083	102.809611	177.0	1987-2022
48355	Sakon Nakhon Agromet	17.125028	104.061000	192.0	1987-2022
48356	Sakon Nakhon	17.154861	**104.137028**	171.0	1987-2022
48357	Nakhon Phanom	17.410694	104.782583	140.0	1987-2022
48358	Nakhon Phanom Agromet	17.276417	104.773667	153.1	1987-2022
48381	Khon Kaen	16.461028	102.789611	187.0	1987-2022
48382	Kosumphisai	16.245361	103.069639	153.0	1987-2022
48383	Mukdahan	16.541639	104.729083	138.0	1987-2022
48384	Tha Phra Agromet	16.335444	102.826694	166.0	1987-2022
48390	Kamalasai	16.332028	103.587528	139.0	1998-2022
48403	Chaiyaphum	16.811917	102.029194	182.0	1987-2022
48404	Roi Et Agromet	16.073222	103.608444	153.0	1987-2022
48405	Roi Et	16.051806	103.664389	140.0	1987-2022
48407	Ubon Ratchathani	15.243889	104.874861	122.0	1987-2022
48408	Ubon Ratchathani Agromet	15.239139	105.023500	129.8	1987-2022
48409	Si Saket Agromet	15.085306	104.330639	122.9	1987-2022
48416	Tha Tum	15.316278	103.680361	128.0	1987-2022
48431	Nakhon Ratchasima	14.968306	102.086028	187.0	1987-2022
48432	Surin	14.873944	103.499639	145.0	1987-2022
48433	Surin Agromet	14.890944	103.452472	142.6	1987-2022
48434	Chok Chai	14.737972	102.168111	190.0	1987-2022
48435	Pakchong Agromet	14.642056	101.321500	386.1	1987-2022
48436	Nangrong	14.630972	102.721361	179.0	1987-2022
48437	Buri Ram	15.225750	103.248083	181.0	2001-2022

Variability of the Data Study

This study used the coefficient of variation (CV) to analyze the variability of winter air time series data of 27 stations in the northeast region. The accepted value should not excess of 30% indicating that the data have a small distribution (Jalilibal et al., 2021; Al-Mutairi et al., 2023). The coefficient of variation could be calculated by following the equation (1) (Bran et al., 2022; Pomoim et al., 2022).

$$cv = 100\ x\ \frac{\sigma}{\bar{Y}} \tag{1}$$

where $\bar{Y}$ is the average value of winter air temperature for N year and σ is the standard deviation.

Trend analysis

Many methods were used to determine the trend magnitude of air temperature such as simple linear regression (Panofsky et al., 1958), and Sen's slope method. The most famous method for determining linear trends is regression, but it requires normal distribution data (McBean and Motiee, 2008). The least-squares method is the most popular method for determining regression coefficients. The trend magnitude is determined in C/year using Sen's slope method according to the following equation (2) (Aditya et al., 2021).

$$\beta = Median\left(\frac{y_i - y_j}{i-j}\right); \qquad i < j \tag{2}$$

Where y_i and y_j are winter air temperatures at time i and j. Sen's slope method has an advantage over simple linear regression wherewith it is more tolerant of error in the data.

Mann-Kendall's test (MK) is used to determine the trend that may occur for the winter air temperature and also provide the statistical significance of the trend. MK does not require the assumption about distribution probability and uses the standard normal distribution to assess the trend significantly. The statistic value of MK (S) for time series yi (I = 1, n) could be calculated by the following equation (Mann, 1945).

$$S = \sum_{i=j}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{3}$$

$$sgn(x_j - x_i) = \begin{Bmatrix} +1 & (x_i - x_j) < 0 \\ 0 & (x_i - x_j) = 0 \\ -1 & (x_i - x_j) < 0 \end{Bmatrix} \tag{4}$$

Wherewith the trend of time series which has a higher value of winter air temperature of the present than the past will show as S > 0, and vice versa. When S < 0, it indicates that there is a negative trend and there is a positive trend if S is positive. For testing the monotonic trend with a confidential level of 95%, it is necessary to determine the standard Z value. When the absolute value of Z is greater than $Z_{1-\sigma/2}$ (acquired from Z table) the null hypothesis will be rejected, and the alternative hypothesis will be accepted. Before calculating the standard value, first must be calculated the variation value must be determined with the following equation (5).

$$var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \tag{5}$$

Where t_p is the number of winter air values of group p, and g is the number of groups. The standard value Z could be determined by the following equation (6).

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & , if\ S > 0 \\ 0 & , if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & , if\ S < 0 \end{cases} \quad (6)$$

Kendall's Tau (τ) was used to determine the level of monotonic trend which could be calculated by following the equation (7).

$$\tau = \frac{2S}{n(n-1)} \quad (7)$$

Where τ has a value in a range of -1 and 1, it will be negative if the trend is negative and positive if the trend is positive.

However, trend analysis using the Mann–Kendall trend test and Sen's slope was conducted using the XLSTAT Premium program (Student Version: 2023.2.1413 (64bit). This software was employed to assess the magnitude and direction of temporal trends in the analyzed variables.

The cumulative seasonal means study (CSM)

The cumulative seasonal mean (CSM) (Al-Mutairi et al., 2023) technique was used for detecting the consistency or variation of winter air temperature. This technique (CSM) has an advantage in the study of variation patterns in time series data. CSM of the time series data could be determined by the following equation (8).

$$CSM_j = \frac{1}{j}\sum_{i=1}^{j} Y_i,\ j = 1, 2, 3, \ldots, N \quad (8)$$

where Y_i is the winter air temperature value, and N is the number of years.

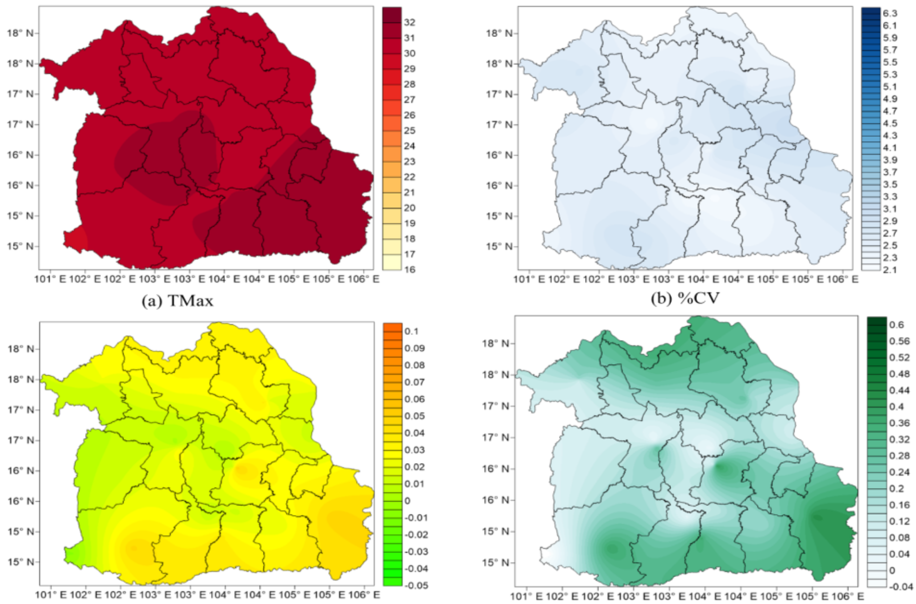
Moreover, the spatial distribution of each air temperature characteristic during the winter was drawn in the form of maps by the GIS analysis program then analysis and discussion were performed.

Results and Discussion

The results were presented about the Homogeneity of the data and abruption change study, the variability of the data study, the trend analysis, and the cumulative seasonal means study (CSM), separated into 3 sections: Maximum temperature (TMax) in the winter of the northeast region of Thailand during 1987-2022 as described in the next sub-session.

Maximum temperature (TMax) in the winter of the northeast region of Thailand (1987-2022)

TMax of 27 stations over the region were collected and calculated for average in the winter during 1987 – 2022. The TMax spatial distribution was illustrated in Fig. 2(a) that the TMax was about 29.7 – 31.8 °C with an average of 30.8 °C. The TMax had not much difference for each station, these were higher in lower latitudes, especially in latitude about 17 ° N and lower (the different values between over and lower 17 ° N latitude was about 1.5 °C while these were lower in the higher latitude due to an influence of the northeast monsoon which covered the area in the winter (Thai Meteorological Department, n.d.). Moreover, plain areas that were < 200 meters of MSL also got high values due to an influence of heat absorption in day time leading high TMax (Tang et al., 2022) while there are mountain ranges on the edge on the right side of the region, leading the temperature to drop more than others due to an influence of adiabatic lapse rate (Badescu, 2024). Furthermore, the area which located next to a large river or large basin also got high temperature due to the heat absorption (day time) and emission (night time) for water which encouraged heat transfers difficultly. (Zhang et al., 2023).



(a) TMax (b) %CV (c) Sen's slope (d) Kendall's Tau

Fig. 2. Spatial distribution of (a) TMax, (b) %CV, (c) Sen's slope, and (d) Kendall's Tau Values

%CV of all stations as shown in the red bar graph of Fig. 3 and the spatial distribution map as in Fig. 2(b) indicated that the %CV was between 3.26% – 6.25% with an average of 4.41% thus the TMax data had a small distribution. The high values of %CV were found near the high mountains and a large river. The cumulative seasonal means study (CSM) results indicated that most stations had TMax values lower than CSM values during 1987-1997 then the TMax values gradually increased over CSM values since 1997 as presented in Fig. 4. Pettitt's statistic test was used to find homogeneity of data and abrupt change. The results indicated that 7 stations had heterogeneous data with abrupt change periods into warming in 1996 (2 stations), 1999 (1 station), and 2001 (4 stations) as presented in Fig. 5 and Tab. 2. The average abrupt change was about 0.92 °C after the point change passing for the region (average values before and after changing point were 30.6 and 31.5 °C, respectively. Moreover, the Mann-Kendall trend test and Sen's slope as reported in Tab. 3, indicated that there was an average rising trend at 0.025 °C per year with 13 stations which had a significant level at >95% (6 stations for 95% and 7 stations for 99%). The spatial distribution of Sen's slope and Kendall's tau values as presented in Fig. 2(c) and (d) illustrated that the high values of both were found in plain areas, especially in the areas that had an altitude lower than < 200 MSL, while the high altitude had lower values. It could be concluded that low-altitude faced higher increasing trends than high-altitude.

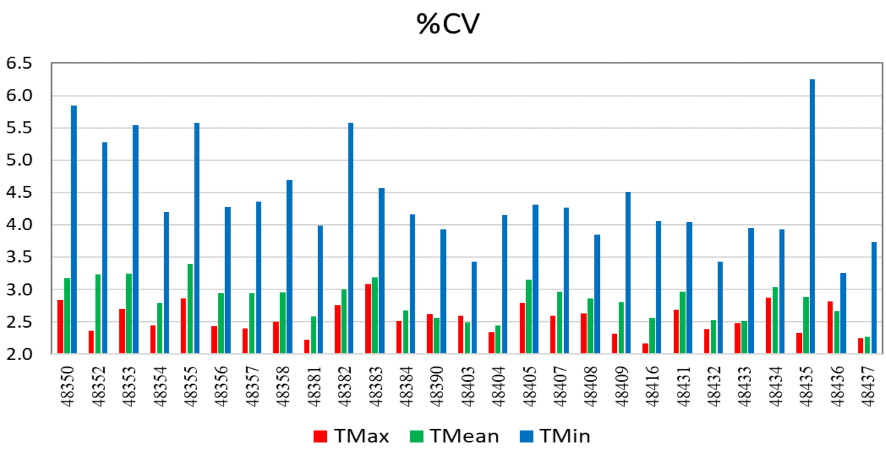


Fig. 3. Coefficient of variation (%CV) of each station in bar chart form with % unit for Tmax (Red), Tmean (Green), and Tmin (Blue)

Table. 2 Description of Pettitt's Test for TMax, TMin, and TMean

Sta. No.	TMax			TMean			TMin		
	Pettitt	Abrupt Change	Point Change	Pettitt	Abrupt Change	Point Change	Pettitt	Abrupt Change	Point Change
48350	0.380	non		0.015	Warming	2011	0.000	Warming	2004
48352	0.007	Warming	1996	0.003	Warming	2008	0.002	Warming	2008
48353	0.338	non		0.020	Warming	1996	0.005	Warming	2009
48354	0.061	non		0.022	Warming	2011	0.024	Warming	2011
48355	0.115	non		0.099	non		0.065	non	
48356	0.183	non		0.061	non		0.040	Warming	1996
48357	0.061	non		0.019	Warming	1996	0.005	Warming	2004
48358	0.540	non		0.352	non		0.592	non	
48381	0.988	non		0.073	non		0.007	Warming	2004
48382	0.057	non		<0.001	Warming	1999	0.000	Warming	2004
48383	0.205	non		0.007	Warming	1996	0.002	Warming	2004
48384	0.076	non		0.087	non		0.090	non	
48390	0.944	non		0.270	non		0.444	non	
48403	0.287	non		0.032	Warming	1996	0.003	Warming	2004
48404	0.717	non		0.203	non		0.037	Warming	2008
48405	0.012	Warming	2001	0.005	Warming	2011	0.005	Warming	2011
48407	0.007	Warming	2001	0.009	Warming	1996	0.003	Warming	2011
48408	0.002	Warming	1999	0.001	Warming	1999	0.005	Warming	1996
48409	0.255	non		0.007	Warming	2009	0.000	Warming	2009

48416	0.492	non		0.084	non		0.043	Warming	2004
48431	0.102	non		0.006	Warming	1996	0.001	Warming	2004
48432	0.041	Warming	2001	0.107	non		0.374	non	
48433	0.006	Warming	2001	0.009	Warming	1999	0.153	non	
48434	0.014	Warming	1996	0.003	Warming	1996	0.002	Warming	2004
48435	0.114	non		0.000	Warming	1999	0.000	Warming	1997
48436	0.067	non		0.039	Warming	1996	0.047	Warming	2009
48437	0.861	non		0.539	non		0.257	non	

Note: Pettitt's test values at <0.05 indicated that the data were heterogeneous while > 0.05 indicated that the data were homogeneous. If the heterogeneous was found, the abrupt change and its point change would be reported.

Table. 3. Description of Mann-Kendall's Trend Test and Sen's slope for TMax, TMin and TMean

Sta. No.	TMax			TMean			TMin		
	Kendall's tau	p-value	Sen's slope	Kendall's tau	p-value	Sen's slope	Kendall's tau	p-value	Sen's slope
48350	0.116	0.327	0.013	0.393	0.001**	0.040	0.527	<0.001**	0.065
48352	0.358	0.002**	0.034	0.436	<0.001**	0.047	0.447	<0.001**	0.060
48353	0.216	0.066	0.024	0.382	0.001**	0.039	0.417	<0.001**	0.054
48354	0.277	0.018*	0.028	0.324	0.006**	0.027	0.258	0.028*	0.030
48355	0.271	0.021*	0.036	0.301	0.010**	0.038	0.293	0.013*	0.034
48356	0.182	0.124	0.019	0.297	0.011*	0.030	0.345	0.003**	0.042
48357	0.242	0.040*	0.027	0.351	0.003**	0.035	0.431	<0.001**	0.048
48358	0.158	0.182	0.018	0.213	0.070	0.021	0.178	0.130	0.021
48381	0.035	0.775	0.004	0.281	0.017*	0.026	0.447	<0.001**	0.046
48382	0.159	0.177	0.019	0.410	<0.001**	0.050	0.537	<0.001**	0.072
48383	0.103	0.383	0.013	0.335	0.004**	0.037	0.502	<0.001**	0.056
48384	0.281	0.017*	0.029	0.308	0.009**	0.030	0.236	0.045*	0.031
48390	0.030	0.852	0.006	0.110	0.455	0.015	0.148	0.314	0.026
48403	0.143	0.225	0.015	0.284	0.015*	0.028	0.398	0.001**	0.039
48404	0.116	0.327	0.014	0.251	0.032*	0.024	0.308	0.009**	0.032
48405	0.402	0.001**	0.047	0.421	<0.001**	0.048	0.415	<0.001**	0.049
48407	0.334	0.004**	0.042	0.407	0.001**	0.040	0.410	<0.001**	0.045
48408	0.427	<0.001**	0.047	0.448	<0.001**	0.042	0.383	0.001**	0.039
48409	0.205	0.081	0.023	0.389	0.001**	0.036	0.490	<0.001**	0.056
48416	0.148	0.210	0.014	0.328	0.005**	0.027	0.349	0.003**	0.037
48431	0.280	0.017*	0.033	0.410	<0.001**	0.044	0.514	<0.001**	0.055
48432	0.322	0.006**	0.035	0.273	0.020*	0.025	0.152	0.200	0.016
48433	0.370	0.002**	0.040	0.378	0.001**	0.037	0.231	0.050*	0.027
48434	0.382	0.001**	0.046	0.467	<0.001**	0.046	0.476	<0.001**	0.049
48435	-0.048	0.693	-0.005	0.464	<0.001**	0.044	0.593	<0.001**	0.095
48436	0.294	0.012*	0.037	0.334	0.004**	0.032	0.329	0.005**	0.026
48437	0.052	0.756	0.013	0.152	0.337	0.024	0.165	0.297	0.028

Note: P-values at <0.05 indicated that there is a trend in the series while P-values at > 0.05 indicated that there is no trend in the series. *,** reported for a significant level at 95% and 99%, respectively.

Mean temperature (TMean) in the winter of the northeast region of Thailand (1987-2022)

TMean of 27 stations over the region were collected and calculated for average in the winter during 1987 – 2022. The TMean spatial distribution was illustrated in Fig. 6(a) that the TMean was about 23.8 – 26.0 ^{o}C with an average of 25.2 ^{o}C. The pattern of TMean spatial distribution was quite similar to the TMax pattern in that the lower latitudes got higher temperatures, especially in the latitudes which lower than 17^{o} N. Moreover, the different temperatures between higher and lower latitudes at 17^{o} N were approximately at 2 ^{o}C. The areas located in latitudes higher 17^{o} N were affected by the northeast monsoon that came by in the winter before lower areas and the adiabatic lapse rate leading to the temperature drop. The CSM results as illustrated in Fig. 7, indicated that most stations had the TMean values lower than CSM values during 1987-2002 then the TMean values gradually increased over CSM values since 2002.

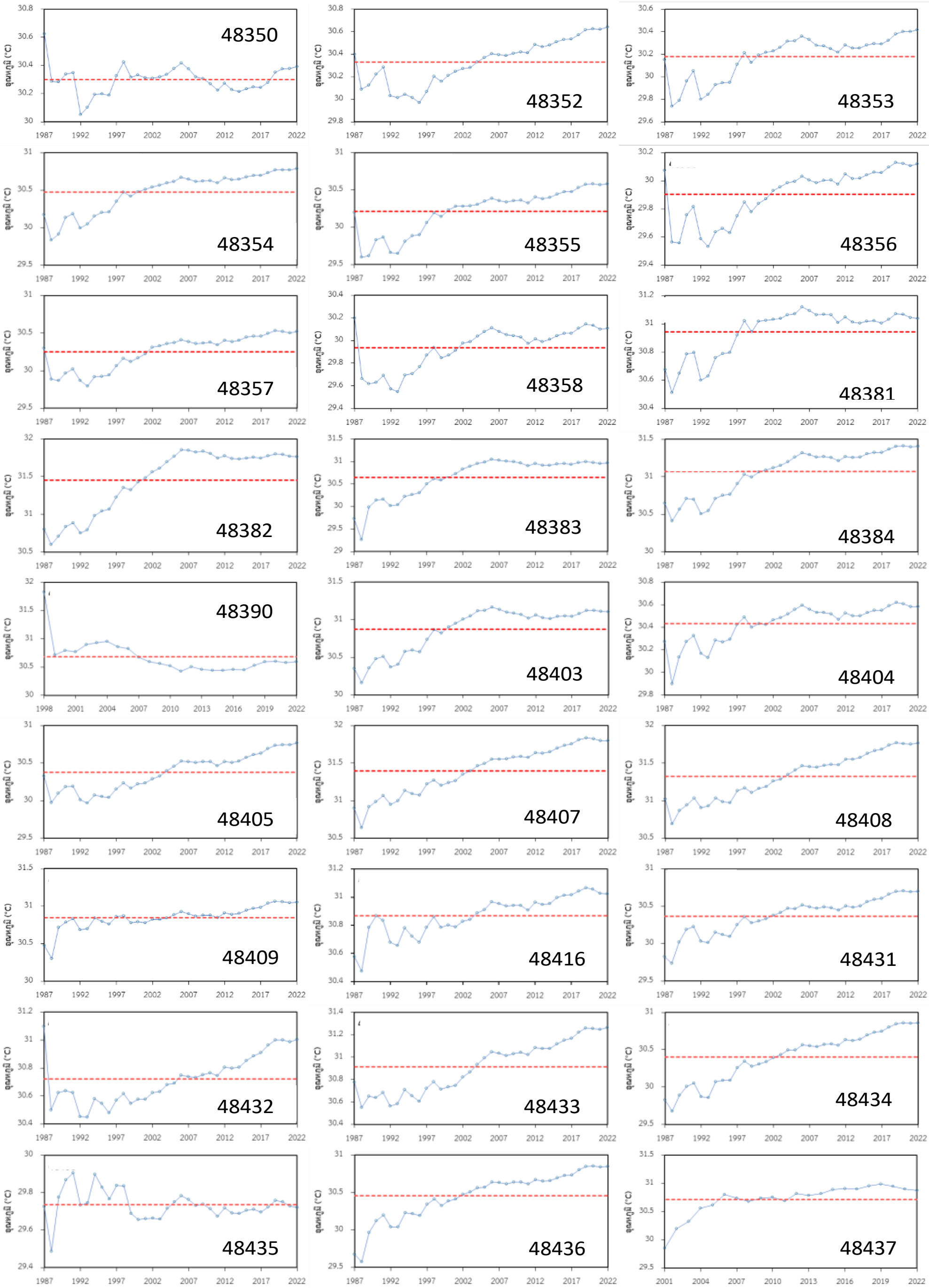


Fig. 4. The cumulative seasonal means study (CSM) of TMax during 1987-2022 (red line)

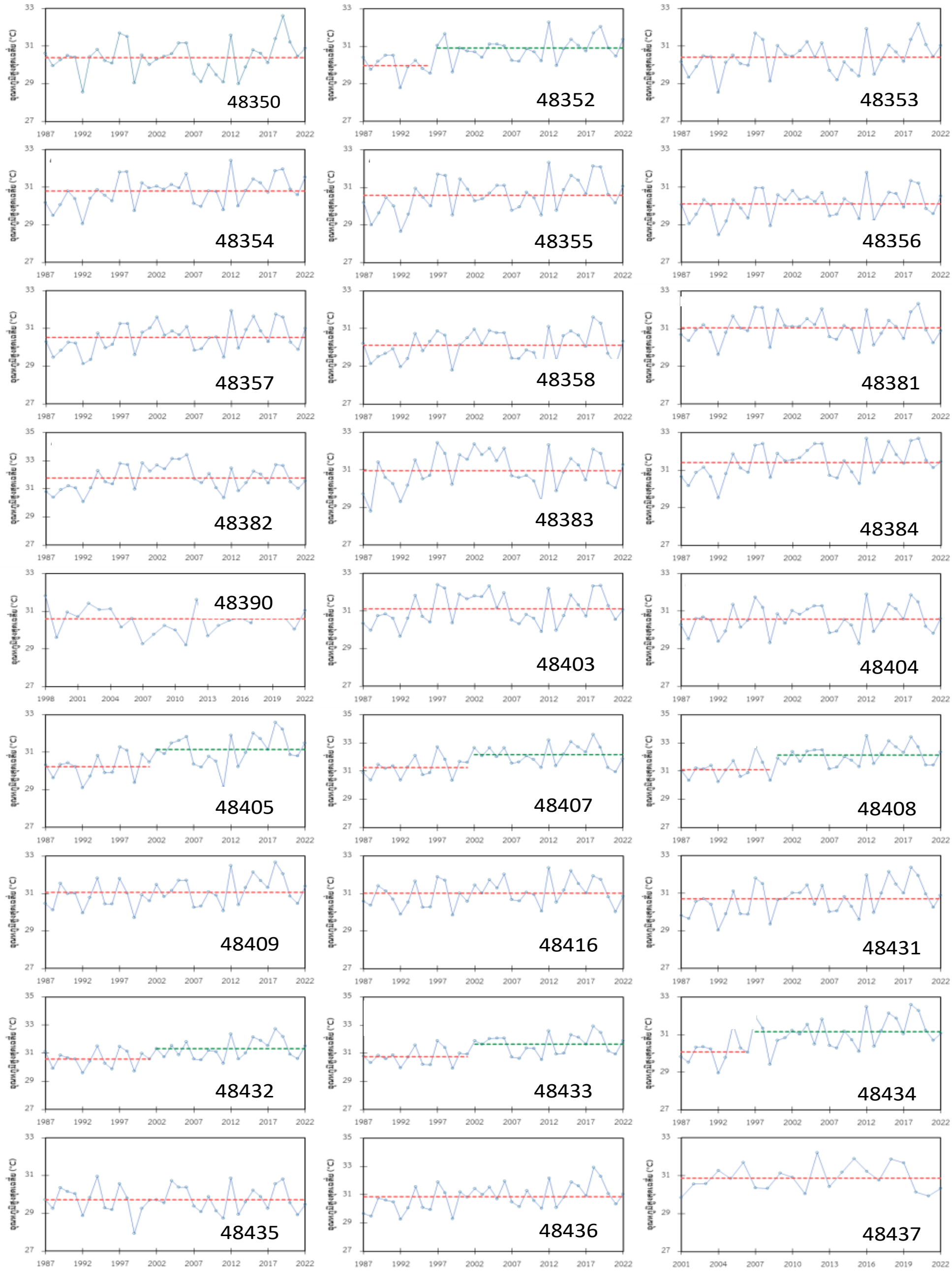


Fig. 5. Pettitt's test analysis for TMax. The red and green line was the average temperature before and after an abrupt change, respectively. The point between the red and green lines reported the point change in the Year form (X started at 27-33 °C, Y was 1987-2022)

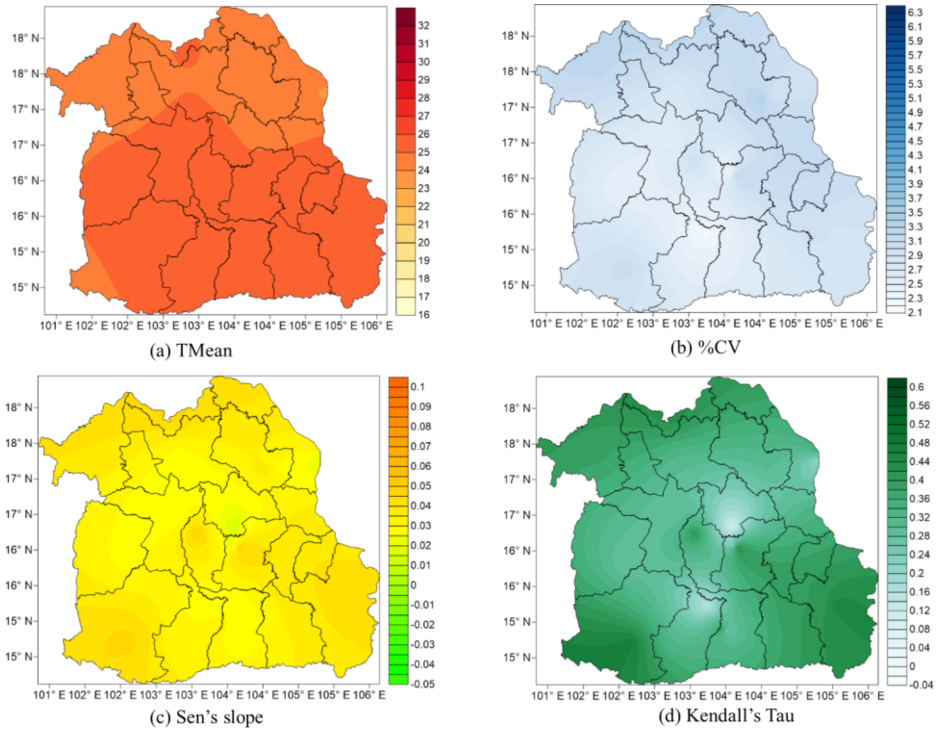


Fig. 6. Spatial distribution of (a) TMean, (b) %CV, (c) Sen's slope, and (d) Kendall's Tau Values

%CV of all stations, as shown in the green bar graph in Fig. 3 and the spatial distribution map in Fig. 6(b), ranged from 2.27% to 3.39% with an average of 2.85%. This indicates that the TMean data exhibited limited variability, similar to the %CV pattern of TMax, though with less pronounced differences. Temperature variability at the topographic high areas may result from the fluctuating strength of the northeast monsoon and westerly wind waves, which generate clouds and rainfall during winter (Weather Forecast Knowledge Management Committee, 2017; Tang et al., 2022). Additionally, monsoon troughs crossing central Thailand and tropical cyclones moving through Cambodia caused further variability from October to December.

Pettitt's test revealed heterogeneous data in 17 stations, with abrupt warming changes occurring in 1996 (8 stations), 1999 (4), 2008 (1), 2009 (1), and 2011 (3) (Fig. 8; Tab. 2). The mean abrupt change was 0.42 °C, with average temperatures before and after the change at 25.6 °C and 26.0 °C, respectively. The Mann–Kendall trend test and Sen's slope (Tab. 3) showed an average warming rate of 0.035 °C yr^{-1}, with 24 stations significant at > 99%. Spatially, Sen's slope and Kendall's tau (Fig. 6(c,d)) were highest along the region's elevated edges, decreasing toward lower interior areas except for the high mountain zone.

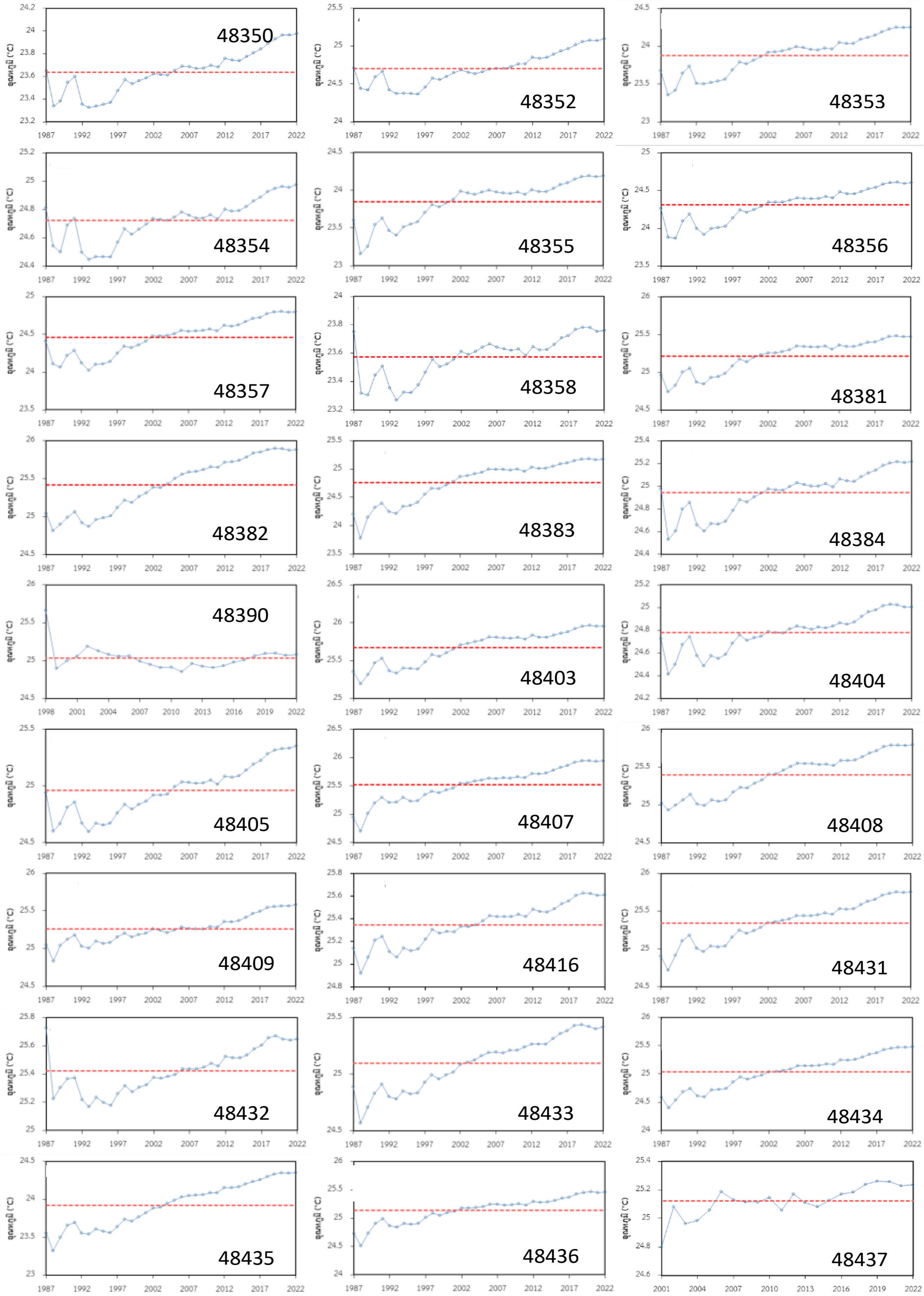


Fig. 7. The cumulative seasonal means study (CSM) of TMean during 1987-2022 (red line)

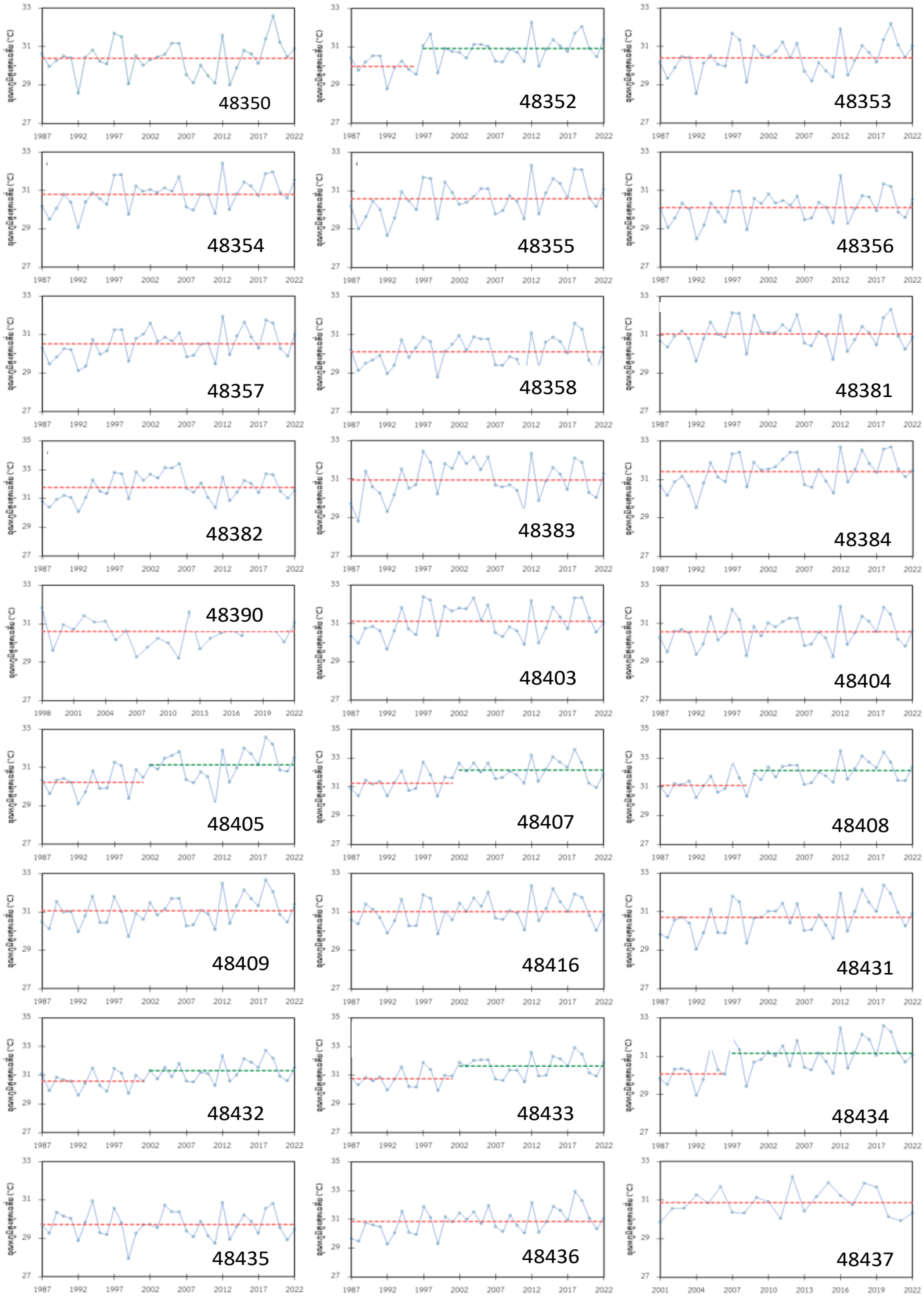


Fig. 8. Pettitt's test analysis for TMean. The red and green line was the average temperature before and after an abrupt change, respectively. The point between the red and green lines reported the point change in the Year form (X started at 27-33 °C, Y was 1987-2022)

Minimum temperature (TMin) in the winter of the northeast region of Thailand (1987-2022)

TMin of 27 stations over the region were collected and calculated for average in the winter during 1987 – 2022. The TMin spatial distribution was illustrated in Fig. 9(a) that the TMin was about 17.4 – 20.8 °C with an average of 19.5 °C. The pattern of TMin spatial distribution and characteristics was quite similar to the TMax and TMean pattern for the same reasons, however; the temperature was dropper than those (the different temperatures between higher and lower latitudes at 17° N were approximately at 2 °C). The CSM results indicated that most stations had the TMin values lower than CSM values during 1987-2002 then the TMin values gradually increased over CSM values since 2002. However, some stations had TMin values higher than CSM values during 1987-1992 and then got lower than CSM values between 1992 – 2015 after that the TMin values turned back to higher than CSM again since 2015 as presented in Fig. 10. %CV of all stations as illustrated in the blue bar graph of Fig. 3 and the spatial distribution map as in Fig. 7(b) indicated that the %CV was between 3.26% – 6.25% with an average of 4.41%. The %CV of TMin was dominantly higher than TMax and TMin particularly in the higher latitude due to the unstable power of the northeast monsoon leading to uncertain cold winds for TMin, especially in the morning before sunrise each day. Moreover, the high %CV was also found at the high altitude and mountain pass on the left side of the area due to the Adiabatic Lapse Rate and unstable cold wind power (Tang et al., 2022) and found near the large river due to the difference between water and land surface leading to the difference in heat absorption and emission which were affected to the difference in temperature especially in the dawn (Zhang et al., 2023).

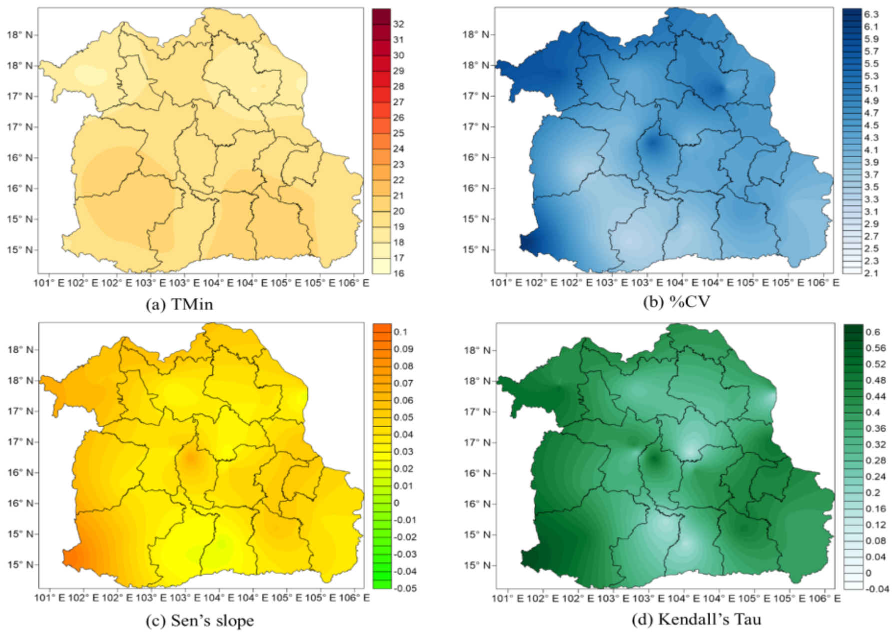


Fig. 9. Spatial distribution of (a) TMin, (b) %CV, (c) Sen's slope, and (d) Kendall's Tau Values

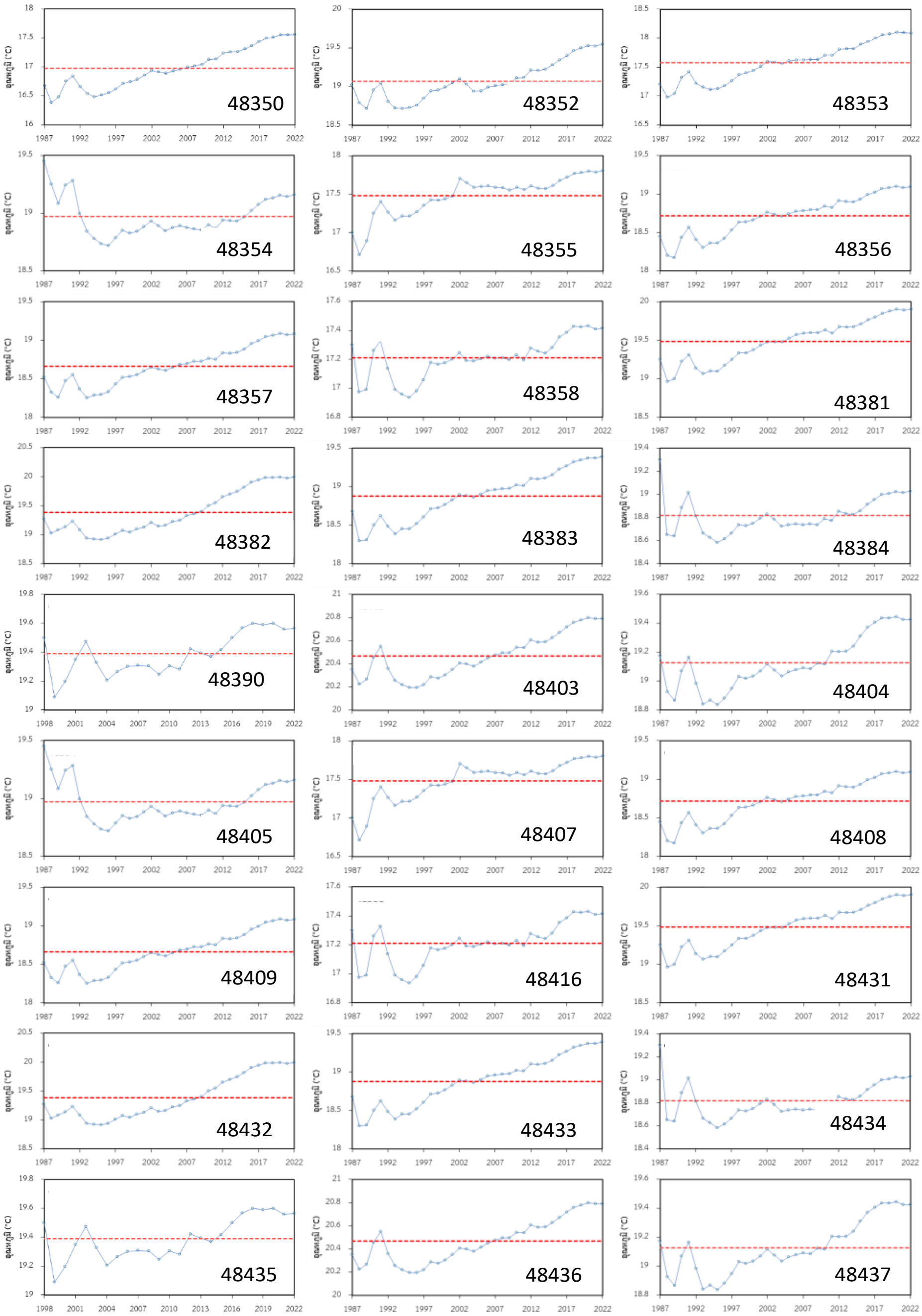


Fig. 10. The cumulative seasonal means study (CSM) of TMin during 1987-2022 (red line) (Source: the authors)

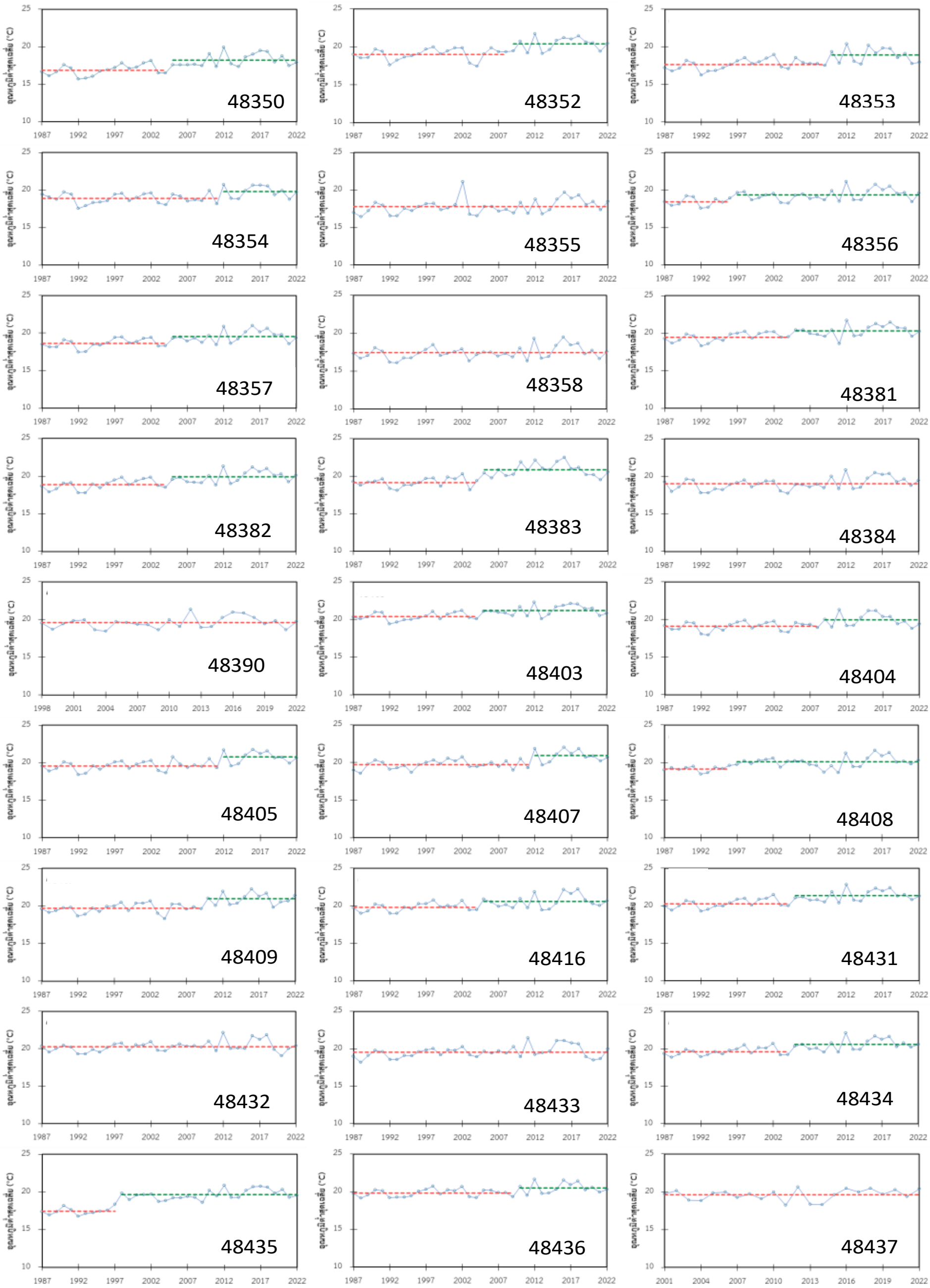


Fig. 11. Pettitt's test analysis for TMin. The red and green lines were the average temperature before and after an abrupt change, respectively. The point between the red and green lines reported the point change in the Year form (X started at 10-25 °C, Y was 1987-2022) (Source: the authors)

Pettitt's statistic results indicated that 20 stations had heterogeneous data with all abrupt change periods into warming in 1996 (2 stations), 1997 (1 station), 2004 (9 stations), 2008 (2 stations), 2009 (3 station), and 2011 (3 stations) as presented in Fig. 11

and Tab. 2. The average abrupt change was about 0.69 °C after the point change passing for the region (average values before and after changing point were 19.8 and 20.5 °C, respectively). Sen's slope and Mann-Kendall trend test as reported in Table 2 and the spatial distribution as presented in Fig. 9(c) and (d) illustrated that the pattern of Sen's slope and Mann-Kendall values were similar to both Sen'slope and Mann-Kendall values for TMean pattern in Fig.6(c) and (d), however; the displayed values were noticeably higher than those TMean. There was an average increasing trend into the warming situation at 0.044 °C per year with 4 and 23 stations which had a significant level at >95% and 99%, respectively. The high trend changes were found at the edge of the region, especially in the high altitude then gradually decreased into the plain basin.

Discussion

The observed winter TMax pattern across northeastern Thailand indicates a modest but spatially coherent warming signal, characterised by limited inter-station variability and stronger increases in low-latitude, low-elevation plains. Such behaviour suggests dominant control from regional-scale atmospheric forcing rather than local microclimatic effects.

Comparable spatial homogeneity in winter daytime temperature has been reported in subtropical continental interiors of South and East Asia, where synoptic circulation and surface radiation balance regulate seasonal thermal structure (Li et al., 2022). The stronger warming detected in plains below 200 m above mean sea level is also consistent with recent findings that low-elevation agricultural basins experience amplified daytime heating due to reduced evaporative cooling and enhanced land-surface energy absorption (Phumkokrux et al., 2022; Sun et al., 2023). The detected abrupt warming during the mid-1990s to early-2000s corresponds with climate-regime transitions identified across monsoon-influenced regions. Recent analyses in the Indo-China Peninsula and South Asian dry-season climate reveal statistically significant winter temperature shifts beginning in the late twentieth century, attributed to greenhouse-gas forcing combined with circulation weakening of cold-air advection (Rahman et al., 2022). Similarly, continental-scale assessments in East Asia show accelerated winter daytime warming after the 1990s, particularly in regions distant from maritime moderation (You et al., 2021). These temporal consistencies support interpretation of the northeastern Thailand signal as part of a broader regional climate transition rather than an isolated local change. The mean warming rate of approximately 0.025 °C yr^{-1} aligns with recent multi-regional estimates of winter maximum temperature increase across subtropical Asia, typically ranging between 0.02 and 0.05 °C yr^{-1} under contemporary climate change (Sun et al., 2023; Li et al., 2022). Although weaker than minimum-temperature amplification reported globally, sustained daytime warming may intensify evapotranspiration demand, drought stress, and agricultural heat exposure in plateau environments. Therefore, continued regional monitoring integrating statistical trend detection and spatial analysis remains essential for anticipating future winter thermal extremes and supporting adaptive land-use and climate-resilience planning.

Winter mean temperature (TMean) in northeastern Thailand shows a clear and highly significant warming signal (average Sen's slope ≈ 0.035 °C yr^{-1}, with most stations significant at >99%), while the low %CV (≈ 2.85%) indicates that the winter thermal regime is largely controlled by regional-scale forcing rather than localized noise. This strong and spatially coherent warming agrees with recent nationwide evidence that Thailand's temperature has generally increased across regions when assessed using Mann–Kendall-type approaches, although the magnitude and seasonal expression vary regionally (Kliengchuay et al., 2024). Likewise, recent regional analyses and forecasting-oriented assessments also report warming in the northeastern region and decreasing temperature variability, consistent with the low dispersion observed here (Waqas et al., 2024). The CSM results suggest that many stations transitioned from predominantly below-average conditions (relative to CSM) before ~2002 to persistently above-average conditions thereafter, while Pettitt's test indicates widespread step-like warming—especially clustered around 1996 and 1999—with a mean shift of about 0.42 °C. Such clustered changepoints are comparable to findings from other monsoon-influenced, topographically complex regions where change-point detection reveals "regime shifts" in temperature series linked to large-scale circulation changes and land-surface feedbacks (Kumar et al., 2023). Spatially, the highest Sen's slope and Kendall's tau values occur along the elevated margins of the region (with lower trends over interior lowlands, except the high mountain zone). This "edge-amplified" pattern is consistent with recent geospatial temperature work in northeastern Thailand highlighting the role of elevation/topographic setting in shaping temperature extremes and spatial gradients (Senapeng et al., 2022). The results imply that winter TMean warming in northeastern Thailand is not only robust over time but also structured by monsoon–topography interactions, producing stronger trend signals along highland boundaries where airflow, cloudiness, and radiative balance can differ from the interior plains.

The winter minimum temperature (TMin) in northeastern Thailand exhibits the strongest warming signal among the three temperature indicators, with an average increase of approximately 0.044 °C yr^{-1} and statistically significant trends at most stations. This dominance of nighttime warming over daytime warming is consistent with recent global and regional evidence indicating that minimum temperature responds more sensitively to greenhouse forcing, cloud-radiative feedbacks, and boundary-layer stability than maximum temperature (Dunn et al., 2020; Liu et al., 2025). The relatively higher coefficient of variation in TMin, particularly in high-latitude and high-elevation zones, further reflects the influence of cold-air advection variability and nocturnal radiative cooling, processes widely reported in continental monsoon margins and plateau environments (Zhao et al., 2022). The detected abrupt warming periods—clustered around the late 1990s and early 2000s—are temporally comparable with regime-shift behaviour observed across other subtropical and semi-arid regions. Recent studies in the Mekong Basin and inland Southeast Asia demonstrate rapid increases in nighttime temperature beginning near the turn of the century, associated with weakened cold-season monsoon flow and enhanced atmospheric moisture retention (Hoang et al., 2022). Similarly, warming of winter minimum temperature has been documented across subtropical highlands of South China and northern Indochina, where elevation-dependent amplification produces stronger trends along mountainous boundaries than in interior plains (Liu et al., 2023). This spatial correspondence closely mirrors the edge-intensified warming pattern identified in northeastern Thailand. The magnitude of TMin warming found here also aligns with recent multi-regional assessments reporting nighttime winter warming rates of roughly 0.03–0.06 °C yr^{-1} across tropical and subtropical Asia under ongoing climate change (Park et al., 2021; Liu et al., 2023). Such accelerated nocturnal warming has important implications for evapotranspiration balance, crop phenology, and ecosystem respiration, particularly in drought-prone plateau environments where thermal stress accumulates during the dry season. Consequently, the pronounced increase in winter TMin identified in this study provides strong regional evidence of climate-change amplification and highlights the need for continued high-resolution monitoring and adaptive climate-risk management in northeastern Thailand.

Conclusion

This study investigated the spatial distribution, variability, abrupt change, and long-term trends of winter air temperature in the northeastern region of Thailand during 1987–2022 using non-parametric statistical analyses and geospatial interpretation. The results consistently demonstrate a regional warming signal across all temperature indicators, confirming that winter climate conditions in the northeastern region of Thailand have shifted toward a warmer regime over recent decades.

Spatially, maximum, mean, and minimum winter temperatures exhibit similar geographic patterns, with higher values concentrated in lower latitudes and low-elevation plains and lower temperatures occurring in higher-latitude and mountainous areas influenced by cold-season monsoon circulation. Topographic controls, land–surface energy balance, and proximity to major river basins contribute to this spatial structure. Despite these similarities, the magnitude and variability of warming differ among temperature indices, indicating distinct physical responses of daytime and nighttime thermal processes.

Temporal analyses based on cumulative seasonal means, change-point detection, and trend estimation reveal coherent warming transitions beginning in the late 1990s to early 2000s. Abrupt warming signals occur across a substantial number of stations, followed by persistent increases in winter temperature thereafter. Trend magnitudes indicate widespread warming across the region, with the strongest and most statistically significant increases observed in minimum temperature, followed by mean temperature, while maximum temperature shows weaker but still predominantly positive trends. This asymmetric warming behaviour highlights the dominant role of nighttime temperature increase in shaping regional winter climate change.

Spatial trend patterns further indicate that enhanced warming frequently occurs along elevated margins and transitional topographic zones, whereas interior plains exhibit comparatively lower trend magnitudes for daytime temperature. Such structure suggests an interaction between regional atmospheric circulation, elevation-dependent processes, and land-surface feedbacks in controlling winter thermal evolution across the plateau environment of northeastern Thailand.

Overall, the consistent increase in winter temperature—particularly the pronounced rise in minimum temperature—provides strong regional-scale evidence of ongoing climate change. These findings imply growing risks related to drought stress, agricultural heat exposure, ecosystem respiration, and water-resource sustainability during the dry season.
Consequently, continued long-term monitoring, high-resolution spatial analysis, and in-

tegration with climate-adaptation planning are essential to support environmental management and socio-economic resilience in northeastern Thailand and comparable monsoon-influenced plateau regions.

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