ANALYSIS AND QUANTIFICATION OF TEMPERATURE TRENDS BY DIFFERENT METHODS IN THE CENTRAL REGION OF SINALOA, MEXICO

ANÁLISIS Y CUANTIFICACIÓN DE TENDENCIAS DE TEMPERATURA POR DIFERENTES MÉTODOS EN LA REGIÓN CENTRAL DE SINALOA, MÉXICO

César Enrique Romero Higareda[1,2]
Orcid: 0000-0002-2794-7363

Gilberto Márquez Salazar[1]
Orcid: 0000-0002-1142-9962

José Saturnino Díaz[1,2]
Orcid: 0000-0001-7494-4002

***Bladimir Salomón Montijo**[1,2]
vladimir.salomon@uas.edu.mx
Orcid: 0000-0002-5053-9691

Jesús Miguel Corrales Sauceda[1]
Orcid: 0000-0003-2520-4547

Facultad de Biología de la Universidad Autónoma de Sinaloa. Ave. Universitarios y Blvd. de las Américas s/n. Ciudad Universitaria, Culiacán Rosales, Sinaloa, México. C.P. 80013.

[2]Posgrado en Ciencias Biológicas. Facultad de Biología, Universidad Autónoma de Sinaloa. Boulevard Universitarios Esquina Avenida Las América. Culiacán, Sinaloa, México. CP 80013.

*Autor de correspondencia

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Abstract

Temperature annual trends have been widely used to describe the impact of climate change. Based on daily temperature data of six stations from central Sinaloa, Mexico, we calculated annual temperature means, number of days within temperature ranges, winter and summer seasons and first and fourth quarter means of the estimated temperature variables. Temperature variation among stations was quantified as well as their temporal trends with the Mann-Kendal method. Multivariate analyses were performed for the quarter data sets. Increasing trends were detected for mean temperatures, number of days with elevated temperatures summer days and decreasing trends were detected for days with low temperatures and winter days. Multivariate analyses depicted the homogenization of urban stations. Frequencies of days within temperature ranges and seasonality were important in the description of temperature trends and variation.

Keywords: Climate change, temperature trends, Sinaloa, quantifying methods

Resumen

Las tendencias anuales de temperatura han sido ampliamente usadas para describir el impacto del cambio climático. Con base en datos diarios de temperatura de seis estaciones del centro de Sinaloa, México, se calcularon promedios anuales de temperatura, número de días con rangos de temperatura, estaciones de invierno y verano; se estimaron promedios de variables del primer y último cuarto de datos. Se cuantificó la variación de temperaturas entre estaciones y sus tendencias con el método Mann-Kendall. Se realizaron análisis multivariados en los cuartos de datos. Se detectaron tendencias positivas de temperaturas medias, días con temperaturas altas y de días de verano, tendencias negativas para reducción de días con temperaturas bajas y de días de invierno. Los análisis multivariados describieron homogeneización de estaciones urbanas. Las frecuencias de días dentro de rangos de temperatura y la estacionalidad son relevantes en la descripción de la variación de temperaturas y sus tendencias.

Palabras Clave: Cambio climático, cuantificación, métodos, Sinaloa, temperatura.

Introduction

According to the Intergovernmental Panel on Climate Change Assessment (IPCC, 2023), recent variations in temperature trends are essentially driven by anthropogenic forced climate change, caused chiefly by CO_2 and other greenhouse gases emissions. The most common approach to analyze temperature trends involve recording daily temperature value: minimum, mean and maximum. From these datum, annual means are calculated (Trewin, 2010). Then, annual means are compared over time using appropriate statistical procedures (Sonali & Kumar, 2013; Mudelsee, 2019). Rising temperatures are widely reported and are one of the main consequences of climate change (Martínez-Austria et al. 2016). In Mexico, climate change by analyzing temperature trends has been reported since the 1950s decade through field data (Wallén, 1955) and has increased steadily incorporating different types of evidence (Metcalfe, 1987) and computer modelling (Liverman & O'Brien, 1991). In northwest Mexico, Gutiérrez-Ruacho et al. (2010) using multivariate analysis found warmer winter conditions; Martínez-Austria et al. (2015) found increasing maximum temperatures for Baja California and southern Sonora.

Another repercussion of climate change is the alteration of seasonality, that is summers lengthening and winters shortening (Wang et al., 2021). In Mexico, Medina-García et al. (2019), reported a decline in typical winter conditions in northwestern

Mexico; Weiss & Overpeck (2005), also documented rising winter temperatures in this region. A common method to quantify seasonal changes is to count the number of days exceeding (or falling below) an arbitrary temperature threshold (Ding et al., 2009; Dong et al., 2009). To date, no such analysis has been done in Mexico.

In Sinaloa, mean temperature differences are more evident along an altitudinal gradient rather than latitudinal. Below 1000 m, annual mean temperatures range from 24°C to 26°C, while above such altitude, means vary between 14 to 22°C. Seasonally, some locations can experience a 10°C differential between summer and winter (Flores-Campaña et al., 2012). This pattern is more pronounced towards the north, where the seasonal temperature differences increase due to an increasing aridity gradient.

Given its geographical position, northwestern Mexico is particularly vulnerable to climate change, which has warmed more rapidly than other regions (Murray-Tortaloro, 2021). Regarding the state of Sinaloa, most studies on climate change have focused on the effects on primary economic activities such as agriculture (Estrada et al., 2022), livestock (Cuevas-Reyes et al., 2024) and shrimp farming (Cota-Durán et al., 2021). Few or none works have examined potential ecosystem responses (Prieto-Torres et al., 2016),

Here, based on the daily data availability of five stations from central Sinaloa, and one from the adjacent state of Durango in Mexico, we estimated the annual trends of the following temperature variables: (1) annual means of minimum, mean and maximum temperatures, (2) quantity of the number of days within an arbitrary temperature rank, (3) length of winter and summer seasons and (4) means of the first and fourth quarter of data sets of the aforementioned variables.

Materials and Methods

Data

Daily temperature data from five meteorological stations of central Sinaloa and eastern Durango in Mexico, was downloaded from the Comisión Nacional del Agua website and processed for its analysis. Selected stations are described in Table 1.

Table 1. Abbreviations, years of data and geographical descriptors of analyzed stations.

Stations	Abbreviation	Years	Latitude (N)	Longitude (W)	Altitude (m)
El Dorado	EDR	1970-1982 1994-1996 2006-2024	24°19’	-107°21’	13
Navolato	NVT	1980, 1983 1999-2024	24°45’	-107°41’	16
Culiacán-CNA	CNA	1961-2024	24°48’	-107°24’	37
Culiacán-UAS	UAS	1995-2000 2002-2024	24°49’	-107°22’	59
Sanalona	SNL	1961-2024	24°48’	-107°08’	154
Tamazula	TMZ	1961-1992 2007, 2010-2024	24°58’	-106°57’	255

The influence of physical environmental features is of paramount relevance for meteorological and climatological variability. Along a transect from the Coastal Plains to the Sierra Foothills, proximity to the coastline can significantly affect temperature regimes via sea-breeze humidity dynamic, which dampens daily temperature oscillation (Zhou et al., 2019). Marine breezes can go inland up to 40 km (Zhou et al., 2021), determining the local climate regime.

Another factor is urbanization, which typically exhibit higher temperatures compared to unmodified (natural) landscapes (Bülüt et al., 2008; Mishra et al., 2015; Chapman et al., 2017). The degree of warming is directly correlated with the spatial extent of the urbanized area such as paved surfaces, built concrete areas and reduced vegetation cover (Liu et al., 2022). Urbanization often reduces the diurnal temperature oscillation by decreasing the difference between daily maximum and nocturnal minimum temperatures (Xu et al., 2013; Tam et al., 2015). This urban-induced warming is particularly relevant in the context of climate change, as it tends to homogenize climatic characteristics across cities (Groffman et al., 2014). For temperature measurements and trend analyses this is significant, the thermal environment surrounding meteorological stations -whether semi-rural or urban- can introduce bias (Zhang et al., 2021).

The location, character and spatial dynamics of the sampled stations vary considerably. Tamazula, Durango expanded its urban surface from 0.41 km^2 in the early 1980s to 1.2 km^2 in 2022 (INEGI Durango, 2022). Likewise, Sanalona increased its urban area in the same period from 0.41 km^2 to 0.61 km^2. These two stations are situated in very small towns in the Sierra Foothills of the Sierra Madre Occidental, and are predominantly covered by the tropical dry forest, which in recent years has been severely modified with slash-and-burn practices to settle agave plantations or to develop large rural residential plots.

Navolato and El Dorado, located in the Coastal Plains, also experienced urban growth. Navolato increased its size from 3.3 to 7.3 km^2 and El Dorado from 3.6 to 5.2 km^2. These two stations are surrounded by large crop fields. In contrast, both Culiacán stations (Culiacán-CNA and Culiacán-UAS) are embedded in the urban environment of Culiacán, the largest city of the Sinaloa state, whose area has expanded from 62 to 183 km^2 from the late 1970s through 2022 (INEGI Sinaloa, 2022).

According to INEGI (2022), the stations are located along a west-to-east transect spanning three distinct climate zones. Based on the Köppen classification (Fig. 1), at the western extreme El Dorado and Navolato stations are found within a BS0(h’) climate: very dry, warm, semi-arid regime with irregular summer rainfall. Moving eastward, the Culiacán-CNA and Culiacán-UAS lie within the urban core of Culiacán, which climate is classified as BS1(h’)w, a warm semiarid climate with a summer rainfall regime. Finally, the Sanalona and Tamazula stations situated in the Sierra Foothills, are within an Aw climate area, defined as warm, sub-humid.

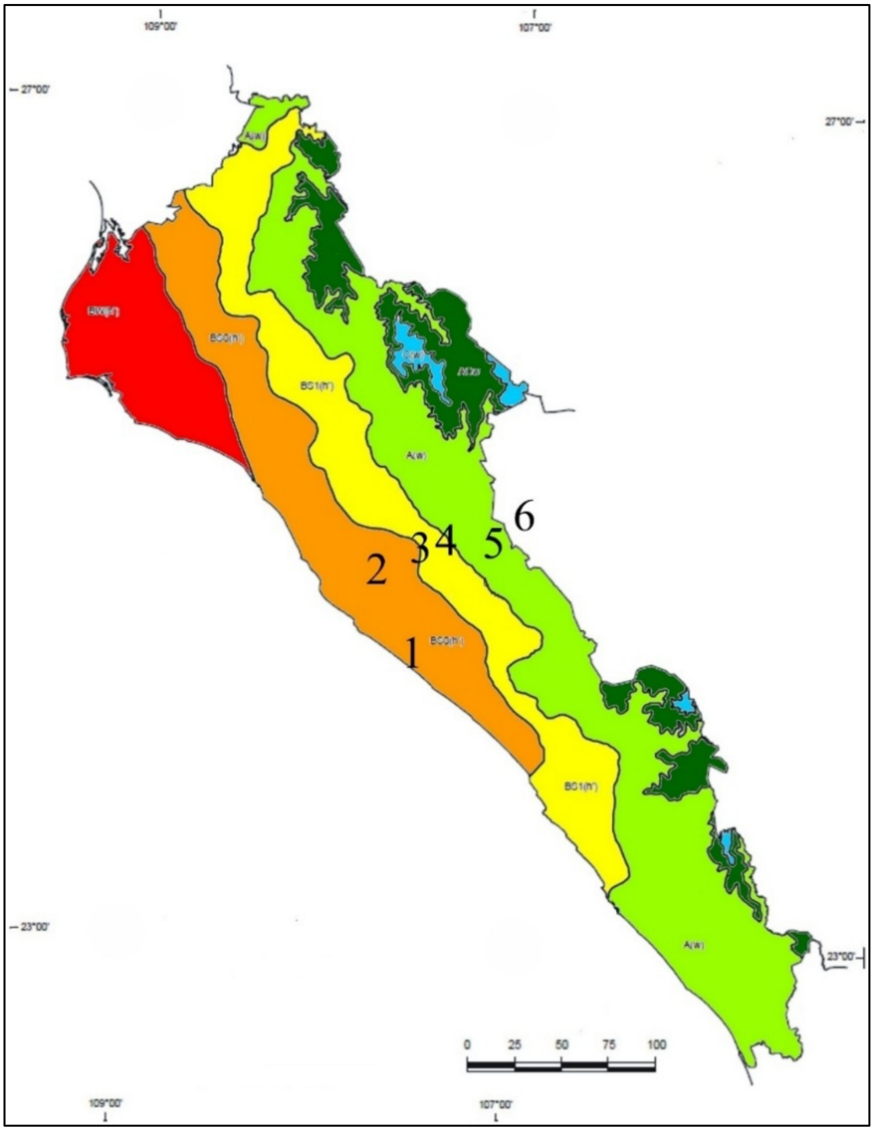

Figure 1. Climate zones of the analyzed stations in central Sinaloa and eastern Durango according to Köppen classification. Colors indicate climate types: dark orange: BS0(h')1; yellow: BS1(h')w; light green: Aw. Station codes: 1= El Dorado, 2 = Navolato, 3 = Culiacán-CNA, 4 = Culiacán-UAS, 5 = Sanalona and 6 = Tamazula.

Annual Means

To analyze temporal changes in annual temperature means, we calculated three basic daily temperature metrics (minimum, mean and maximum) in each station. For minimum temperatures we defined two variables: TMinL the lowest recorded temperature in each year and TMinL as the annual average of daily minimum records. The annual mean temperature was designated as TMean, estimated as the annual average of daily mean records. For maximum temperatures we considered TMax as the annual average of daily records and TMaxH as the maximum temperature of a particular year. The temperature range (TR) was estimated as the annual average of the daily differences between TMax minus TMin.

Number of Days per Year

To quantify the frequencies of days within determined temperature ranges, we classified daily temperature variation into nine intervals measured in °C: <0, 0-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and ≥ 40. For each year of each station, we counted the number of days falling into each bin of minimum (L), mean (M) and maximum (H) temperatures.

Seasonality Dating

To estimate the length of winter and summer seasons, we numbered days of the year sequentially from 1 (January 1st) to 365 (December 31st). Winter End was defined as the last day before summer with a temperature below 10°C; Winter Start was defined as the first day after summer and before December 31st to record a temperature below 10°C.

For summer, we quantified the longest streak of consecutive days with temperatures equal or above 25°C; recognizing that summer heavy rainfall can transiently reduce daily means below this threshold, we required the streak to persist for more than three consecutive days to define season boundaries. The first day was labeled as Summer Start and the last day as Summer End.

Analysis by Data Quarters

As described above, the annual data set is not homogeneous among stations, therefore an alternative approach was adopted to quantify the temporal variation of temperatures *within* each station. To assess the magnitude of change in the proposed variables, for each station the averages of each temperature metric in the first %25 and fourth 25% of its temporal data series were estimated. This approach allowed for direct contrast, since we could compare the magnitude of change in their respective units of measurements: for temperature annual means in °C, in days for frequencies in Number of Days and for seasonality, specific dates for winter and summer. At each station we tested the differences between the first and fourth quarters with a Mann-Whitney *U* test (P<0.05).

Data temporal analysis

First, we estimated temperature mean differences among stations; then, to detect upward or downward trends within temporal variation applying the non-parametric correlation Mann-Kendall test; if a significant trend was detected, then the Sen's slope estimator was computed. To evaluate temperature variation from a wider perspective, we performed multivariate analysis for each quarter of data set.

Results

Annual Means

We detected significant differences for the annual temperature metrics considered among stations. Sanalona exhibited the lowest mean values for TMinL and TMin, while paradoxically displaying the highest values for TMax and TMaxH. The highest minimum temperatures and highest mean temperatures were recorded at Culiacán-UAS station. The largest mean temperature range (TR) occurred at Sanalona, whereas the smallest TR was observed at Culiacán-UAS (Table 2).

Table 2. Means (± SE) of annual temperature from six stations in central Sinaloa. Superscripts letters indicate Tukey *post-hoc* tests (P<0.05). Abbreviations as Table 1.

Station	TMinL	TMin	TMin	TMax	TMaxH	TR
EDR	6.5 ± 0.3^{ab}	18.4 ± 0.1^{a}	25.6 ± 0.1^{b}	32.7 ± 0.2^{c}	39.2 ± 0.3^{d}	14.3 ± 0.2^{cd}
NVT	5.6 ± 0.4^{bc}	17.5 ± 0.1^{c}	25.5 ± 0.1^{b}	33.6 ± 0.1^{ab}	42.1 ± 0.3^{a}	16.1 ± 0.2^{b}
CNA	5.8 ± 0.3^{bc}	17.9 ± 0.2^{bc}	25.3 ± 0.2^{bc}	32.7 ± 0.2^{c}	40.5 ± 0.2^{c}	14.8 ± 0.1^{c}
UAS	7.2 ± 0.4^{a}	19.4 ± 0.2^{a}	26.2 ± 0.1^{a}	33.1 ± 0.1^{bc}	40.8 ± 0.1^{bc}	13.7 ± 0.2^{d}
SNL	2.4 ± 0.2^{d}	15.8 ± 0.1^{e}	24.8 ± 0.1^{c}	33.8 ± 0.1^{a}	41.5 ± 0.2^{ab}	18.0 ± 0.2^{a}
TMZ	4.9 ± 0.3^{c}	16.9 ± 0.1^{d}	25.2 ± 0.1^{bc}	33.6 ± 0.2^{ab}	42.2 ± 0.2^{a}	16.8 ± 0.2^{b}

Number of Days

Days with freezing temperatures L(<0°C) were recorded in Navolato, Sanalona and Tamazula stations. Sanalona and Tamazula registered the highest amounts of cold days L(0-10°C). El Dorado and Culiacán-UAS showed the largest amounts of days in the L(25-30°C) ranks (Table 3, annex A1). Regarding mean temperatures, only Culiacán-CNA and Culiacán-UAS did not record temperatures in the M(0-10°C) category. The categories of M(20-25°C) and M(25-30°C) amassed the largest amounts in the six analyzed stations. Culiacán-UAS and Navolato showed the largest number of days in the M(30-35°C) rank (Table 3, annex A1). For maximum temperatures, El Dorado recorded the highest number of days in the H(30-35°C). In the H(35-340°C) bin, Navolato and Sanalona displayed the highest values. Finally, for extreme heat days H(≥40°C), Navolato and Tamazula were the stations with the highest mean annual counts (Table 3, annex A2).

Table 3. Means (±SE) of number of days per year within temperature ranks (°C) of six stations of central Sinaloa and eastern Durango, Mexico. Superscripts denote Tukey *post-hoc* tests (P<0.05).

Low	**<0°C**	**0-10°C**	**10-15°C**	**15-20°C**	**20-25°C**	**25-30°C**	**30-35°C**	**35-40°C**	**>40°C**
EDR	0	17.3±1.7^{de}	103.2±3.1^{ab}	85.6±14.2^{b}	86.4±4.1^{c}	72.6±4.5^{a}	0.14±0.1	-	-
NVT	0.04±0.1	30.1±2.7^{c}	108.1±2.4^{a}	77.8±2.7^{bc}	110.1±3.6^{b}	39.1±3.6^{b}	0	-	-
CNA	0	26.9±2.6^{cd}	98.3±2.3^{ab}	80.6±2.3^{bc}	113.3±2.2^{b}	46.0±3.3^{b}	0.1±0.1	-	-
UAS	0	7.2±1.2^{e}	70.3 ± 4.4^{c}	108.3±3.4^{a}	11.9 ± 3.4^{b}	67.1±3.7^{a}	0.1 ± 0.1	-	-
SNL	0.1±0.1	78.7±2.9^{a}	94.2±16.3^{b}	55.8±1.6^{d}	120.8±1.5^{ab}	15.7±1.2^{c}	0	-	-
TMZ	0.1±0.1	42.0±2.5^{b}	104.4±2.1^{ab}	74.0±2.2^{c}	130.0±1.6^{a}	14.9±1.8^{c}	0	-	-
Mean	**0°C**	**0-10°C**	**10-15°C**	**15-20°C**	**20-25°C**	**25-30°C**	**30-35°C**	**35-40°C**	**>40°C**
EDR	-	0.1±0.1	1.8±0.4^{b}	38.6±2.7^{c}	125.3±2.2^{a}	116.3±3.3^{c}	82.2±3.8^{abc}	0.2±0.1	-
NVT	-	0.1±0.1	2.0±0.5^{b}	50.6±3.1^{ab}	108.6±2.7^{c}	118.1±3.2^{bc}	85.7±3.6^{ab}	0.3±0.1	-
CNA	-	0	2.2±0.4^{b}	48.7±2.9^{abc}	114.6±2.0^{bc}	130.0±2.9^{b}	69.4±5.0^{bc}	0.3±0.1	-
UAS	-	0	0.3±0.2^{b}	25.3±1.9^{d}	118.8±2.3^{ab}	144.3±2.9^{b}	90.3±3.4^{a}	0.2±0.1	-
SNL	-	0.1±0.2	2.0±0.3^{b}	57.1±1.7^{a}	116.1±1.8^{abc}	144.3±2.2^{a}	45.6±2.3^{d}	0.1±0.1	-
TMZ	-	0.2±0.1	7.1±1.1^{a}	41.0±2.3^{bc}	120.6±2.3^{ab}	128.9±3.5^{bc}	67.2±3.4^{c}	0.4±0.1	-
High	**<0°C**	**0-10°C**	**10-15°C**	**15-20°C**	**20-25°C**	**25-30°C**	**30-35°C**	**35-40°C**	**>40°C**
EDR	-	-	0	0.3±0.1^{b}	5.3±0.8^{c}	65.9±4.8a	174.7±4.1^{a}	117.4±7.4^{b}	1.8±0.6^{c}
NVT	-	-	0.1±0.1	1.3±0.7^{ab}	12.4±2.1^{a}	60.4±4.0a	121.6±4.2^{c}	156.6±6.4^{a}	13.7±1.4^{ab}
CNA	-	-	0.1±0.2	0.1±0.1^{ab}	12.3±0.9^{a}	70.6±2.3a	151.9±4.3^{b}	122.8±5.7^{b}	6.7±1.2^{bc}

UAS	-	-	0.1±0.1	0.2±0.1^{b}	7.9±1.1^{abc}	65.3±1.9a	148.9±3.1^{b}	139.5±3.1^{ab}	3.5±0.5^{c}
SNL	-	-	0	0.4±0.1^{b}	6.6±0.5^{bc}	42.3±2.0b	148.7±3.1^{b}	156.4±3.3^{a}	10.8±2.0^{ab}
MZ	-	-	0	1.9±0.5^{a}	11.8± .9^{ab}	38.9±2.6b	157.5±5.7^{ab}	139.1±6.9^{ab}	15.9±2.0^{a}

Seasonal Dating

Culiacán-UAS station showed the shortest winter, that lasted until February 16th, the earliest summer start (April 20th), the latest summer end (November 17th) and winter Start (December 23rd). On the contrary, Sanalona showed an exactly inverse pattern, by recording the latest Winter End, Summer Start, earliest Summer End and Winter Start (Table 4).

Table 4. Means ± SE of year day for winter and summer seasons. Lower rows = date. Superscripts denote Tukey *post-hoc* tests (P<0.05).

Stations	Winter End	Summer Start	Summer End	Winter Start
El Dorado	61.6 ± 5.3	124.7 ± 1.8	315.8 ± 1.7	352.3 ± 2.1
	(Mar 2nd)^{c}	(May 5th)^{a}	(Nov 12th)^{ab}	(Dec 18th)^{ab}
Navolato	75.5 ± 4.0	121.3 ± 1.9	316.2 ± 2.1	343.4 ± 2.4
	(Mar 17th)^{bc}	(May 1st)^{ab}	(Nov 12th)^{ab}	(Dec 9th)^{cd}
Culiacán-CNA	68.7 ± 3.9	120.3 ± 2.4	312.1 ± 1.4	347.9 ± 1.9
	(Mar 10th)^{bc}	(Apr 30th)^{ab}	(Nov 8th)^{bc}	(Dec 14th)^{bc}
Culiacán-UAS	47.0 ± 5.1	109.6 ± 2.3	321.0 ± 1.7	357.9 ± 1.7
	(Feb 16th)^{d}	(Apr 20th)^{c}	(Nov 17th)^{a}	(Dec 23rd)^{a}
Sanalona	103.8 ± 1.9	123.7 ± 1.0	303.8 ± 1.1	327.8 ± 1.6
	(Apr 14th)^{a}	(May 4th)^{a}	(Oct 1st)^{d}	(Nov 24th)^{e}
Tamazula	80.5 ± 2.7	114.0 ± 2.0	308.2 ± 1.5	338.6 ± 1.8
	(Mar 22nd)^{b}	(Apr 24th)^{b}	(Nov 4th)^{cd}	(Dec 5th)^{d}

Temporal Trends of Annual Means

Two thirds of the stations temperature annual means exhibited increasing trends. Fourteen trends were statistically significant. TMean showed positive increasing trends in all the stations. TR showed decreasing significant trends in Navolato, Culiacán-CNA and

Culiacán-UAS. Sanalona was the only station that displayed an increasing trend for TR (Table 5).

Table 5. Mann-Kendall Sen's slope values of temporal trend analysis of annual temperature means. Abbreviations as in main text and Table 1. $^{+}$(P<0.01), *(P<0.05), **(P<0.01), ***(P<0.001), ns = non-significant, NT = no trend detected.

Station	TMinL	TMin	TMean	TMax	TMaxH	TR
EDR	0.061^{+}	-0.009 ns	0.011 ns	0.038 ns	NT	0.017 ns
NVT	NT	0.035*	0.012 ns	-0.024 ns	NT	-0.068*
CNA	0.075***	0.058***	0.056***	0.054**	0.065***	-0.007^{+}
UAS	0.082 ns	0.052***	0.034***	0.012 ns	NT	-0.040**
SNL	-0.010 ns	-0.018**	0.006*	0.032*	NT	0.049***
TMZ	0.047***	0.035***	0.037***	0.044***	NT	0.010 ns

Temporal Trends of Seasonal Dating

All stations except Sanalona exhibited decreasing trends for Winter End (earlier ending dates). In addition, Winter Start advanced (produced later onset dates) at El Dorado, Culiacán-CNA, Culiacán-UAS and Tamazula. For summer season, El Dorado, Culiacán-CNA, Culiacán-UAS and Tamazula reported trends towards earlier summer onsets and later summer ending (Table 6).

Table 6. Sen's slope values of the Mann-Kendall temporal trend analysis of Seasons Dating variables. *(P<0.05), **(P<0.05), ***(P<0.001), ns = non-significant, NT = no trend detected.

Station	Winter End	Summer Start	Summer End	Winter Start
El Dorado	-1.583*	-0.579***	0.385***	0.333 ns
Navolato	-1.194 ns	-0.167 ns	-0.258 ns	-0.069 ns
Culiacán-CNA	-1.039***	-0.826***	0.457***	0.587***
Culiacán-UAS	-0.575 ns	-0.881***	0.080 ns	0.183*
Sanalona	0.667 ns	0.154 ns	0.333 ns	NT
Tamazula	-0.594***	-0.500***	0.263***	0.267***

Analysis by Data Quarters

Data quarters of annual temperatures

Across all the analyzed stations, the means of TMinL, TMin, TMean, TMax and TMaxL exhibited an overall increase of ≈1.1°C between quarter data sets. The largest average increments detected were observed in TMin (+1.5°C) and TMean (+1.0°C). The comparison of annual temperature metrics between the initial and final quarters within stations revealed that at El Dorado TMinL and TMean showed a significant increase of 2.3 and 0.5°C respectively (annex 1A). In Navolato (annex 1B), TMin increased significantly (+0.63°C). At Culiacán-CNA all the compared variables except TR exhibited significant upward trends: TMinL increased 3.8°C, TMin 3°C, TMean 2.8°C, TMax 2.7°C and TMaxH 3.3°C (annex 1C). For Culiacán-UAS depicted in annex 1D, TMin and TMean increased significantly by 1.1 and 0.72°C respectively, while TR decreased 0.74°C. In Sanalona (annex. 1E), TMin decreased -0.74°C, whereas TMean and TMax increased 0.41°C and 1.6°C. Finally, at Tamazula in annex 1F, TMinL, TMin, TMean and TMax rose significantly 1.6°C, 1.1°C, 1.6°C and 2.1°C respectively, while TR declined 10°C.

Analysis of Number of days by data quarters

For low temperatures, at El Dorado there was a significant increase in the L(20-25°C) rank (+34 days) and a decrease in the L(25-30°C) category (-30 days) (annex 2A). In Navolato, only the L(25-30°C) category showed a significant increase (+26 days) (annex 2B). Culiacán-CNA showed significant decreases in the L(0-10°C) and L(10-15°C) with -43 and -27 days respectively, whilst significant increases in the L(15-20°C) and L(25-30°C) categories (+31 and +49 days) depicted in annex 2C. In Culiacán-UAS, the number of days in the L(0-10°C) rank decreased by 9 days and the L(10-15°C) also decreased (-25 days), but the L(15-20°C) and the L(25-30°C) ranks increased significantly 21 and 26 days respectively (annex 2D). In Sanalona, an increase in the L(0-10°C) rank (+16 days) and significant decreases (-9 days) in L(15-20°C) and L(25-30°C) (annex 2E) was detected. In Tamazula, a decrease in L(0-10°C) and an increase in L(15-20°C) were detected, with -24 and +14 days respectively (annex 2F).

Regarding the ranks for mean temperatures, in El Dorado the M(10-15°C) and M(15-20°C) decreased by -2 and -20 days, whereas M(25-30°C) increased by 27 days (annex 3A). In Navolato, a significant decrease was observed in M(25-30°C) with -27 days, while M(30-35°C) showed an increase of +26 days (annex 3B). At Culiacán-CNA, four significant changes were detected: decreases in M(15-20°C), M(20-25°C), M25-30°C) of -47, -10 and -28 days correspondingly and an increase of +89 days for the M(30-35°C) bin (annex 3C). In Culiacán-UAS there was a significant reduction of -10 days in the M(15-20°C) category and a rise of +23 days for the M(30-35°C) rank (annex 3D). Sanalona showed a positive trend in M(30-35°C) of +15 days (annex 3E). In Tamazula, significant decreases were measured in M(10-15°C) (-6 days), M(15-20°C) (-28 days) and in the M(20-25°C) (-22 days) and increases in the M(25-30°C) and M(30-35°C) with +32 and +25 days per year (annex 3F).

In reference to maximum temperatures, in El Dorado there was a decrease in the H(25-30°C) of -32 days and an increase in extreme heat days H(≥40°C) of +5 days (annex 4A). Navolato did not exhibited any significant change (annex 4B). At Culiacán-CNA significant decreases occurred in the H(20-25°C), H(25-30°C) and H(30-35°C) with -13, -30 and -68 days per year while H(35-40°C) and H(≥40°C) increased by +96 and +16 days respectively (annex 4C). In Culiacán-UAS no significant changes were found (annex 4D). In Sanalona, the number of days decreased in H(20-25°C), H(25-30°C) and H(30-35°C) with -3, -22 and -36 days, yet H(35-40°C) and H(≥40°C) increased by 45 and 16 days per year (annex 4E). In Tamazula, significant declines were observed for H(20-25°C), H(25-30°C) and H(35-40°C) (-6, -23 and -84 days), while H(35-40°C) and H(≥40°C) increased by +103 and +12 days per year (annex 4F).

Analysis of Seasonal Dating by quarters

On average Winter End retreated by 21 days while Winter Start was delayed by 10 days. Summer onset moved earlier by approximately 15 days across all stations and Summer End was extended in average 8 days. In Culiacán-CNA was detected the largest change for Winter End from April 10th to February 12th (-56 days) and Winter Start shifted from December 1st to December 26th (+25 days). Summer Start moved *backwards* from May 21st to April 12th (-40 days) and summer season extended from October 26th to

November 18th (+23 days). The stations of El Dorado, Culiacán-CNA and Tamazula developed the same pattern, with earlier Winter Ends and Summer onsets as well as later Summer Ends and Winter Starts. Culiacán-UAS only showed an earlier significant Summer Start. None of the changes detected in Navolato and Sanalona were statistically significant (Table 7).

Table 7. Seasonal day of the year of the first and fourth quarters of data of six stations of central Sinaloa, Mexico. Asterisks = *U* Mann-Whitney test, **(*P*<0.05), ***(*P*<0.001).

		Winter End		Summer Start		Summer End		Winter First	
		1QT	4QT	1QT	4QT	1QT	4QT	1QT	4QT
EDR	Day	92.7	53.7***	133.2	117.7***	310.6	321.9***	344.7	358.1**
	Date	Apr 3rd	Feb 23rd	May 13th	Apr 27th	Nov 7th	Nov 18th	Dec 11th	Dec 24th
NVT	Day	80.7	82.9	125.3	123.3	319.4	311.9	341.3	344.7
	Date	Mar 22nd	Mar 24th	May 25th	May 3rd	Nov 15th	Nov 8th	Dec 7th	Dec 11th
CNA	Day	99.6	43.3***	141.2	101.6***	299.3	322.0***	335.1	360.4***
	Date	Apr 10th	Feb 12th	May 21st	Apr 12th	Oct 26th	Nov 18th	Dec 1st	Dec 26th
UAS	Day	62.1	56.0	119.4	100.7**	320.0	318.9	352.0	358.6
	Date	Mar 1st	Feb 25th	Apr 29th	Apr 11th	Nov 16th	Nov 19th	Dec 18th	Dec 25th
SNL	Day	109.3	107.8	122.5	126.7	300.3	305.8	326.5	325.8
	Date	Apr 19th	Apr 18th	May 3rd	May 7th	Oct 27th	Nov 2nd	Nov 23rd	Nov 22nd
TMZ	Day	87.4	64.3***	118.5	98.9***	303.9	318.9***	337.1	348.0**
	Date	Mar 28th	Mar 5th	Apr 29th	Apr 9th	Oct 31st	Nov 16th	Dec 3rd	Dec 14th

Multivariate analysis

The principal component analysis (PCA) performed on the first-quarter data set explained almost 70% of the total variation. Principal component 1 (PC1), which accounted 41.9% of variation was positively correlated to TMin, M(30-35°C), L(15-20°C), Winter Start and TMinL, the main negative loadings were: L(0-10°C), M(25-30°C), Winter End, M(15-20°C) and TR. PC2, which explained 26.8% of variation, was built up in its positive side by TMaxH, TMax, H(≥40°C), (H(35-40°C) and TR; on the negative sector, Summer Start, H(25-30°C) M(15-20°C) H(20-25°C) and H(15-20°C) were the main loadings (annex 1).

The PCA of the fourth quarter of data explained over 75% of total variation in their first two principal components. PC1 depicted 53.9% of variation, the main loads were in its positive side: Winter End, L(0-10°C), Summer Start, M(15-20°C) and M(10-15°C); the largest negative loads were: L(15-20°C), TMean, TMin, Winter End and Summer End. For PC2 (23.4% of variation), the positive main loads were: TMax, L(<0°C), M(0-10°C), L(20-25°C) and H(35-40°C), the negative main loadings were: H(25-30°C), L(25-30°C), H(20-25°C), M(30-35°C) and TMin (annex 2).

The bi-plot of *z*-standardized scores for the multivariate analysis (Figure 6), depicts the transition of the stations first quarter data set in blue figures to the fourth quarter data set in red figures. The distribution of the first quarter draws Navolato, UAS and El Dorado associated to variation of TMin, M(30-35°C), L(15-20°C), Winter Start and TMinL. Tamazula, Sanalona and CNA were associated to L(0-10°C), M(25-30°C), Winter End, M(15-20°C) and TR. Also, CNA and El Dorado were clustered in PC2 by Summer Start, H(25-30°C), M(15-20°C), H(20-25°C) and H(15-20°C); Sanalona, Tamazula, Navolato and UAS were correlated in the positive sector to TMaxH, TMax, (H≥40°C), H(35-40°C) and TR.

The fourth quarter *z*-scores depicted in red, congregated Sanalona and Navolato in the positive sector linked to Winter End, L(0-10°C), Summer Start, M(15-20°C) and M(10-15°C); Tamazula, CNA, UAS and El Dorado were clustered by L(15-20°C), TMean, TMin, Winter End and Summer End. PC2 separated Tamazula and Sanalona correlated to TMax, L(<0°C), M(0-10°C), L(20-25°C) and H(35-40°C). CNA, UAS, El Dorado and

Navolato were congregated by Summer Start, H(25-30°C), M(15-20°C), H(20-25°C) and H(15-20°C) (Figure 2).

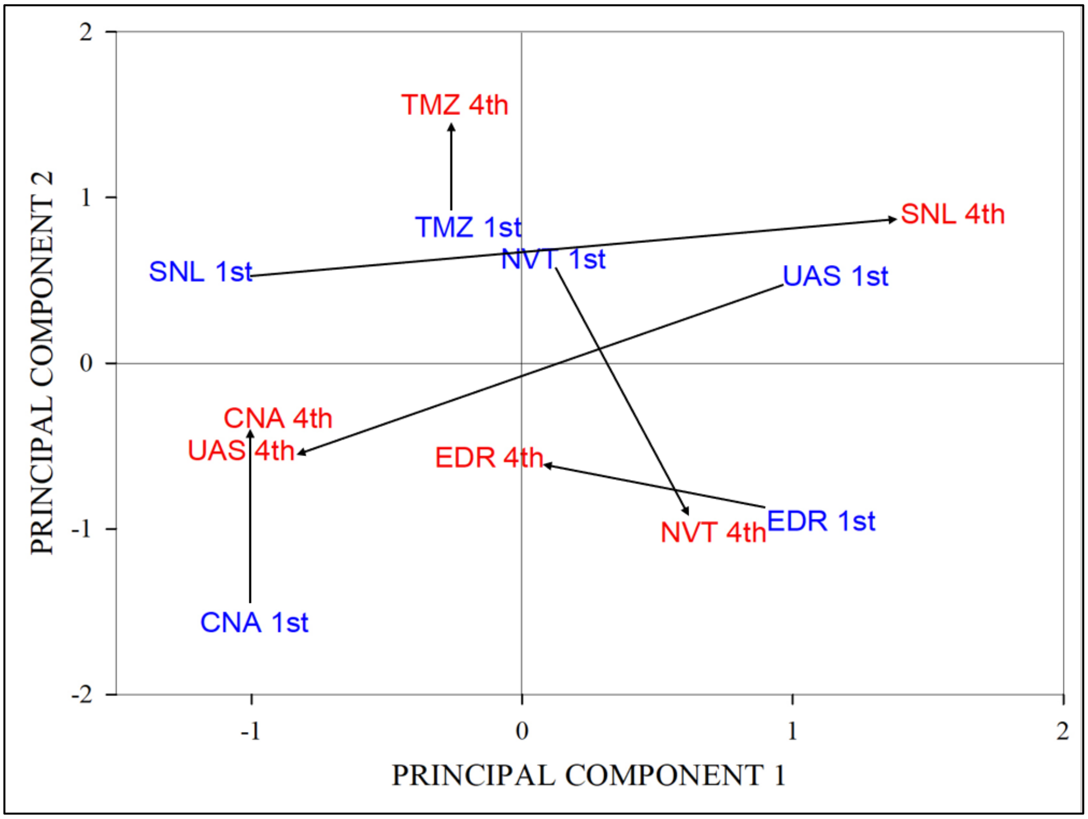

Figure 2. Bi-plot of *z*-scores of first (blue figures) and fourth (red figures) temperature data sets.

Discussion

The analysis of annual temperature means, depicted that temperature metrics TMinL, TMin, TMaxH and TR, exhibited a spatial pattern. The lowest values of TMinL, TMin and conversely the highest values of TMaxH and TR (except Navolato), were observed at Sanalona and Tamazula stations. This pattern can be attributed to a greater distance from the coast (≈90 and ≈110 km, respectively) to these stations, where an absence of marine humidity and sea breezes result in less thermal moderation. Inversely, stations as El Dorado (≈9km) and Navolato (≈25 km), displayed a scarce oscillation in temperature, most likely due to higher humidity levels associated to coastal proximity as reported by Zhou et al., (2019) and Zhou et al., (2021).

A notable feature is the influence of urban heat-island effect at Culiacán-CNA and Culiacán-UAS stations, which recorded the highest TMin and TMean values. This pattern aligns with the observations of Bülüt et al., (2008), Mishra et al., (2015) and Chapman et al., (2017), as well as the process described by Groffman et al., (2014) and Tam et al., (2015), who reported increased and homogenized temperature variation (i.e. reduced TR).

Although the largest inter-station difference is rather scarce (≈1.4°C) for TMean, this variation is sufficient to divide stations into three distinct groups based solely on this variable. This outcome underscores the importance of interannual variation in TMean at each station, demonstrating its utility for achieving a finer spatial resolution in climatic variation analysis at this scale.

Regarding annual means of Number of Days per Year, in Navolato, Culiacán-CNA, Sanalona and Tamazula stations, a clear pattern was detected in low temperature categorization, where the L(10-15°C) depicted low temperatures of winter days and L(20-25°C) accounted for low records of summer days. The higher number of L(0-10°C) days at Sanalona and Tamazula may be explained by their proximity to the western slopes of the Sierra Madre Occidental. For mean temperatures, the majority of days were in the M(20-25°C) and M(25-30°C) ranks, both accounting for 65.8%% of the year days among stations; however, slight inter-stations differences were detected at El Dorado and Sanalona, where the M(20-25°C) category was more frequent, whereas at Navolato, Culiacán-CNA and Culiacán-UAS the M(25-30°C) category predominated. This pattern might be explained by the influence of greater urbanization, nevertheless data of Tamazula diverge from this pattern and warrant further analysis. As for maximum temperatures, nearly 80% of the accounted Number of Days were classified in the H(30-35°C) and H(35-40°C) ranks. On average, Navolato and Sanalona exhibited a larger proportion of H(35-40°C) days, in the remaining studied stations, the H(30-35°C) ranks proportion was larger.

Seasonality means values illustrated a marked pattern. Based on the temperature-defined dates, Sierra Foothills stations Sanalona and Tamazula showed the longest winters and shorter summers. Coastal stations depicted an inverse pattern: shorter winters and extended summers; within these stations, Culiacán-CNA and Culiacán-UAS showed the earliest summer starts and latest summer ends, this result can be associated to the effect of the large size of Culiacán and its urban heat-island effect, which likely might elevate minimum and mean temperatures and modifies thermal dynamics relative to more rural and less urbanized environments surrounding stations (Bülüt et al., 2008; Mishra et al., 2015; Chapman et al., 2017).

Variables TMin, TMean and TMax exhibited the highest frequency of significant upward trends, corroborating previous findings of Gutiérrez-Ruacho et al., (2010) and Martínez-Austria et al., (2015). Among stations, Culiacán-CNA displayed the greatest number of significant trends, with almost all temperature metrics showing marked increase; its observed decrease in TR indicates that Culiacán climate is becoming warmer, with reduced differences between in temperatures extremes, a clear indication of the effect of urban heat-island effect matching findings of Bülut et al., (2008). In contrast, El Dorado and Navolato, exhibited only slight significant increases in low-temperature metrics, nevertheless these results meet the fading-winter trends described by Weiss & Overpeck (2005) for northwest Mexico.

Shortening of winter and lengthening of summer seasons in El Dorado, Culiacán-CNA, Culiacán-UAS and Tamazula are consistent with trends reported in other regional and global studies (Weiss & Overpeck, 2005; Song et al., 2009; Medina-García et al., 2019; Wang et al., 2019). In contrast, Navolato and Sanalona remained seasonally stable over the time period studied, but their contrasting differences in low and high temperatures indicate a clearcut seasonal change.

By quarters of data, all these observations of mean temperatures are consistent with northwest Mexico warming scenario depicted by Martínez-Austria et al., (2015). Large urbanized areas (Culiacán-CNA, Culiacán-UAS and Navolato) reported increasing temperatures with decreasing TR, a pattern commonly associated to urban heat island-effect, as detailed by Tam et al., (2015). One key driver of this pattern appears to rise nighttime temperatures, reflected here as an increase in TMin. In El Dorado and Navolato stations, the largest intra-quarter temperature differences occurred in minimum temperatures whereas other variables remained largely unchanged. Such behavior is akin to the reports of Weiss & Overpeck (2005).

The three categories of Number of Days per year -Low, Mean and High temperatures- showed a consistent pattern in the quarter comparisons, lower temperature ranks exhibited decreases whilst higher temperature ranks increased in their frequencies across categories; these patterns coincide with the findings of Park et al., (2018), Ding et al., (2009) and Zhu et al., (2022), who documented a decrease in the number of cold days and increases in warm-day frequencies.

In reference to Seasonal dating through data quarters, the analysis also showed substantial changes. With the exceptions of Navolato, all the stations developed similar patterns of shorter winters and longer summers; this is consistent with the results documented by Wang et al., (2021).

In the PCA analysis, Number of Days was most frequent type of variable making-up the principal component of total variation, with over half of the total main loads. For first quarter PC1, variables related to low temperatures were the main source of variation. Contrastingly, in PC2, eight out of ten of the main loadings were related to high temperatures. For the fourth quarter of data, in PC1, Number of Days and Seasonal Dating were the main types of variables. The fourth quarter of data clearly differentiates Coastal from Sierra Foothills stations, here Tamazula and Sanalona were highly correlated to variables depicting extreme temperatures; even further, Culiacán-CNA, Culiacán-UAS and El Dorado were clustered together related to the three types of variables that depicted median conditions of temperature, these results clearly describe the effects of urbanization as stated by Groffman et al. (2014).

Conclusions

Temperature variables that mainly defined spatial variation among stations were TMinL, TMin and TR, due to the moderating influence of sea breezes at coastal sites. Also, is evident that urban heat-island effect exerts a pronounced effect on temperature behavior of both Culiacán stations and has less effect in the remaining stations. In the category of low temperature for Number of Days ranks, it is clear a differentiation of cold winter and cool summer records; in a different way, mean and high temperatures occur concentrated on M(20-25°C), M(25-30°C) and H(30-35°C), H(35-40°C) ranks respectively. Urban heat-island effect reduces winter onset and extends summers in Culiacán stations and its effect decreases gradually heading into less urbanized areas.

There is an overall temperature increasing trend in the studied region, that can be mirrored in mean annual temperatures, decreasing Number of Days with low temperature records, shortening winters and lengthening summers. All of these trends, set for a warning as ecosystem alter their functions, primary economic activities can get disrupted and even human daily activities might get interrupted on a daily and seasonal basis.

The multivariate analysis revealed a clear homogenization among the stations Culiacán-CNA, Culiacán-UAS and El Dorado. This result underscores the urban-heat island effect as a key driver of thermal convergence among urbanized sites. Moreover, the analysis demonstrated that additional temperature metrics beyond traditional mean values -such as Number of Days per year and Seasonality dating- are valuable to characterize temperature variability in a more comprehensive way.

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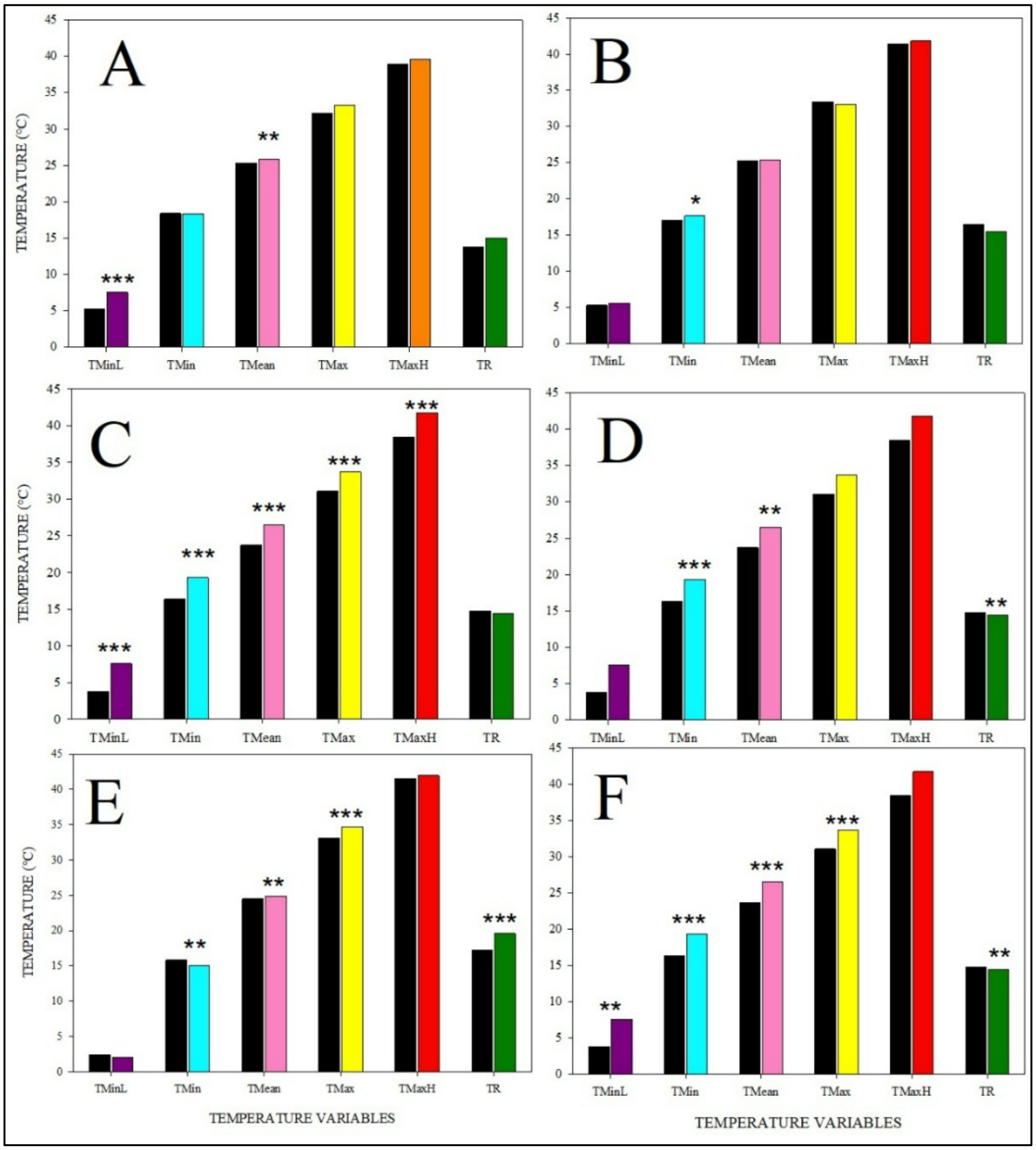
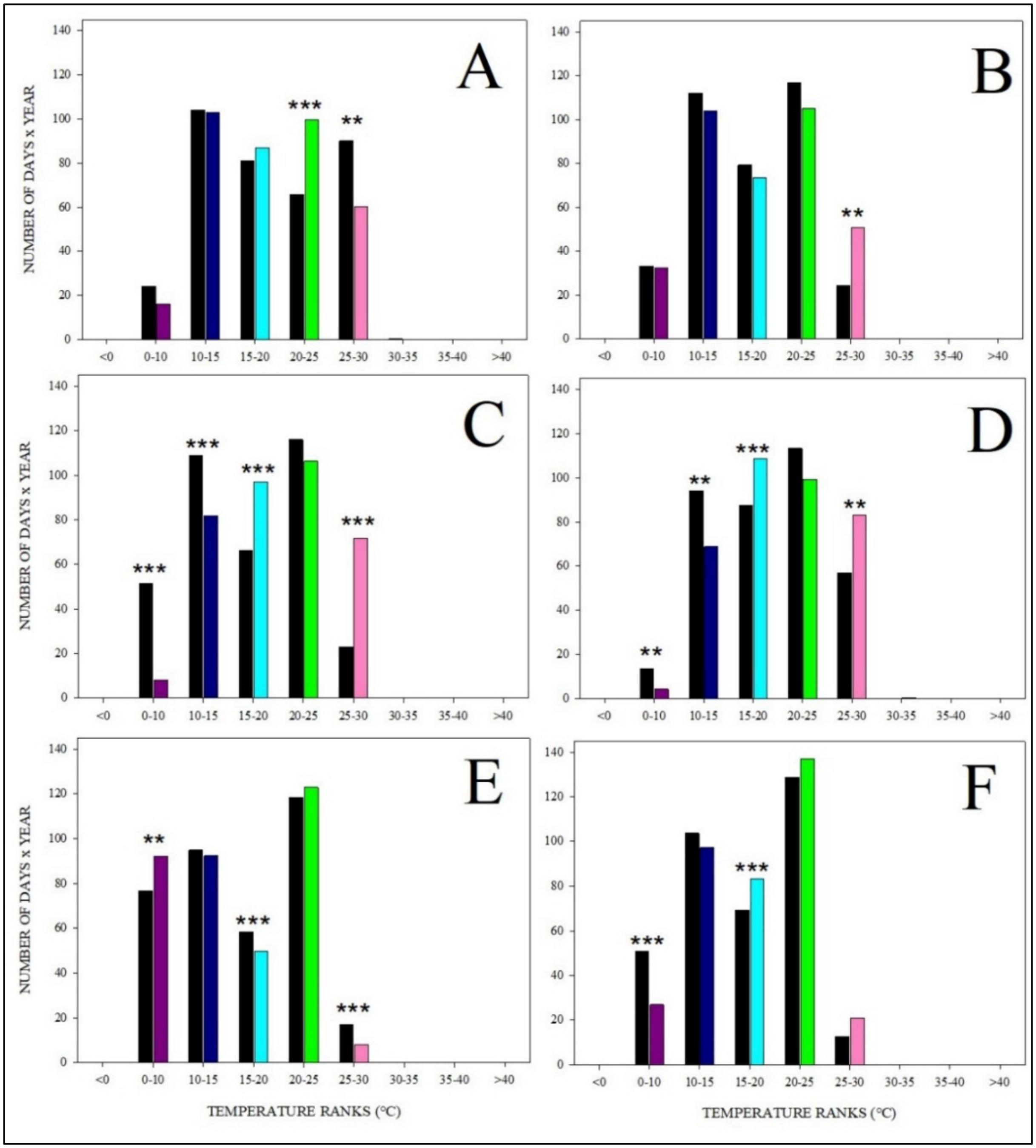
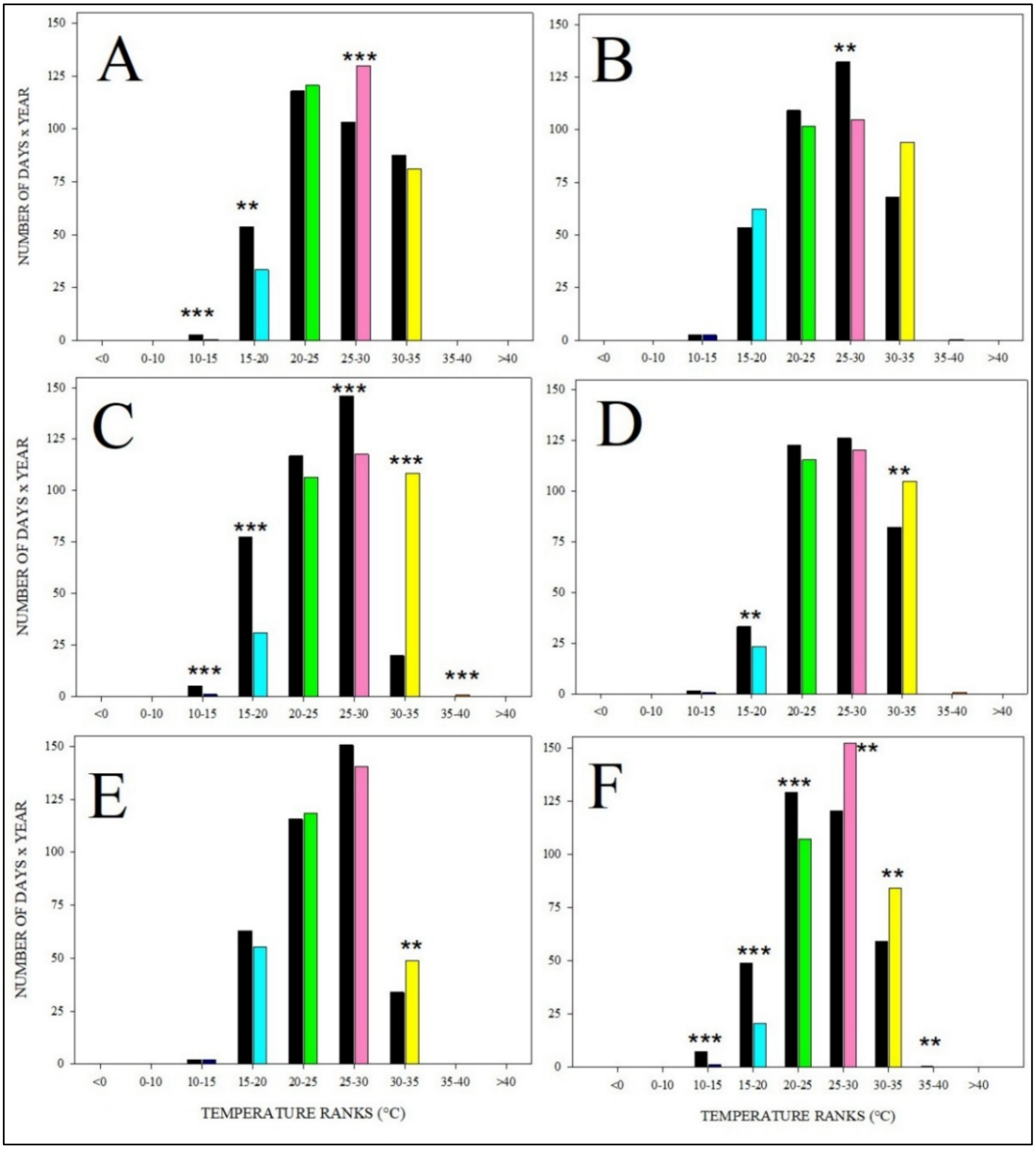
Annexes



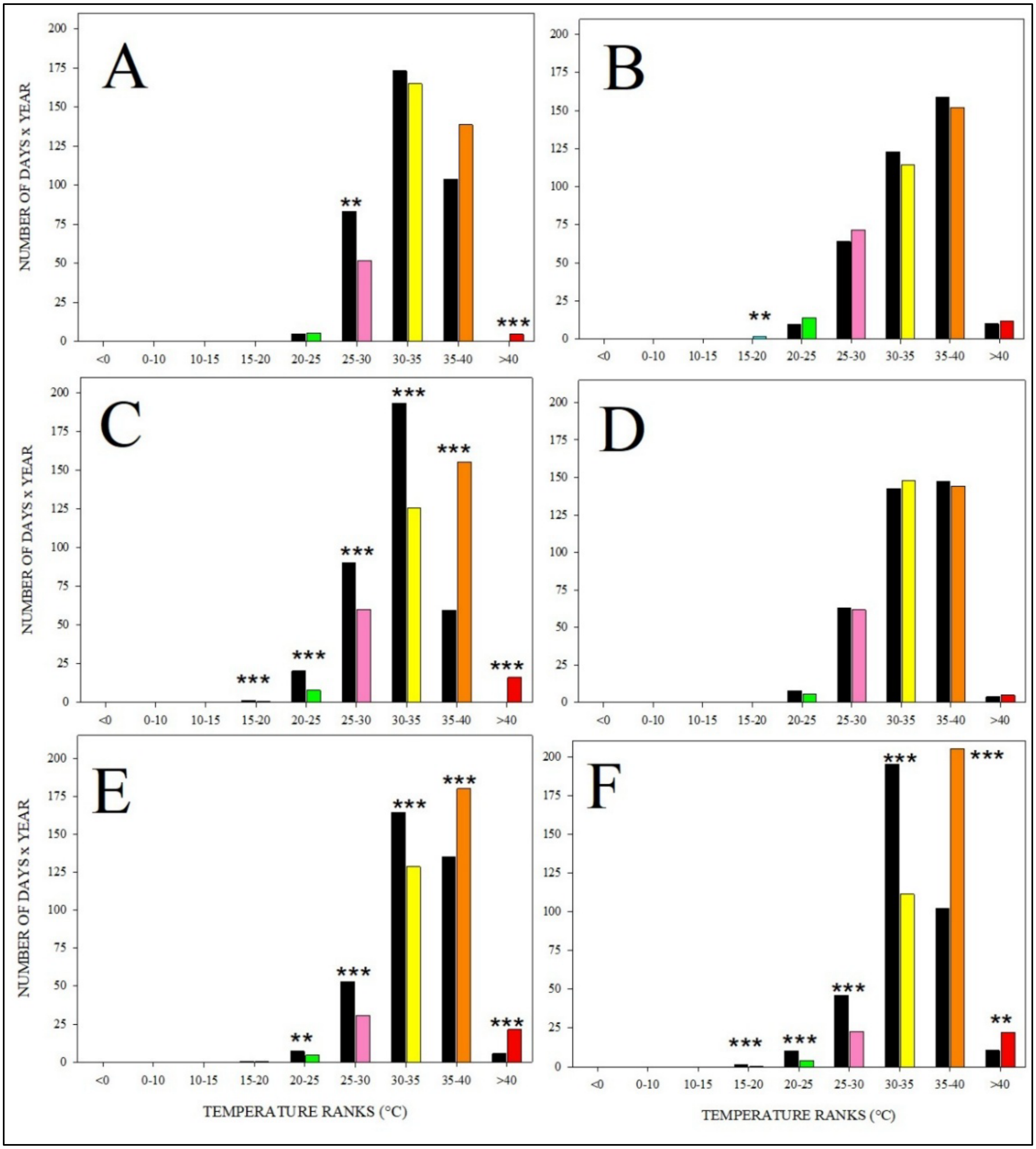
Annex 1. Temperature annual means of first quarter data set (black bars) and annual mean of fourth quarter data set (colored bars) of temperature variables. Asterisks above bars describe *U* Mann-Whitney tests statistical analysis (*P<0.05, **P<0.01).



Annex 2. Number of days per year annual means of first quarter data set (black bars) and annual means of fourth quarter data set (colored bars) of low temperatures. Asterisks above bars denote statistical differences for a *U* Mann-Whitney test *(*P*<0.05), **(*P*<0.01), ***(*P*<0.001).



Annex 3. Number of days per year annual means of first quarter data set (black bars) and annual means of fourth quarter data set (colored bars) of mean temperatures. Asterisks above bars denote statistical differences for a *U* Mann-Whitney test *(P<0.05), **(P<0.01), ***(P<0.001).



Annex 4. Number of days per year annual means of first quarter data set (black bars) and annual means of fourth quarter data set (colored bars) of high temperatures. Asterisks above bars denote statistical differences for a *U* Mann-Whitney test *(*P*<0.05), **(*P*<0.01), ***(*P*<0.001).