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Comparative analysis of average temperature trends in Jalisco, Mexico, based on original and homogenized series to estimate signs of Climate Change

Análisis comparativo de tendencias de temperatura media en Jalisco, México, basado en series originales y homogeneizadas para estimar señales de Cambio Climático

DAVYDOVA-BELITSKAYA, Valentina†, GODÍNEZ-CARVENTE, Andrea Liliana, NAVARRO-RODRÍGUEZ, René and OROZCO-MEDINA, Martha Georgina*

Universidad de Guadalajara. Centro Universitario de Ciencias Biológicas y Agropecuarias
University of Copenhagen. Department of Geosciences and Natural Resource Management

ID 1st Author: *Valentina, Davydova-Belitskaya* / **ORC ID:** 0000-0001-8224-3150, **Researcher ID Thomson:** X-6164-2019, **CVU CONACYT ID:** 20417

ID 1st Coauthor: *Andrea Liliana, Godínez-Carvente* / **ORC ID:** 0000-0001-5272-8915, **CVU CONACYT ID:** 1002439

ID 2nd Coauthor: *René, Navarro-Rodríguez* / **ORC ID:** 0000-0003-1625-2950, **CVU CONACYT ID:** 688898

ID 3st Coauthor: *Martha Georgina, Orozco-Medina* / **ORC ID:** 0000-0002-2619-3408, **Researcher ID Thomson:** T-4562-2018, **CVU CONACYT ID:** 25755

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Abstract

In recent decades, great attempts have been made to create high-quality climatic data sets and spatial resolution on a continental and national scale, as well as the analysis of their variability and change in daily extremes. However, in Mexico there is still no high-resolution database at a national level that complies with quality control, including the review of homogeneity of long series. This paper shows the results of variability analysis and the detection of climate change signs in the state of Jalisco, performed in a high-resolution database developed for the maximum, minimum and average temperature according to the quality control procedures of climatic records. From these two sets, the spatial behavior of annual average temperature estimated for three climatic periods was analyzed. Among the results obtained with stations which have complied with quality control, the presence of annual average temperature increases at 0.31°C in 1971-2000, 0.61°C in 1981-2010 and a very intense increase, 0.81°C for the period 1991-2010. Likewise, it was observed that the Jalisco coasts show an increase of 0.2 to 0.4°C, while the continental region registers an increase up to 0.8°C.

temperature, Quality control, Climate trends, Jalisco

Resumen

En las últimas décadas se dedicó un gran esfuerzo a la creación de conjuntos de datos climáticos de alta calidad y resolución espacial a escala continental y nacional, también al análisis de su variabilidad y cambio en extremos diarios. En México todavía no existe una base de datos de alta resolución a escala nacional que cumpla con un control de calidad incluyendo la revisión de homogeneidad de series largas. En el presente trabajo se muestran los resultados de análisis de variabilidad y la detección de señales de cambio climático en el estado de Jalisco realizado en una base de datos de alta resolución desarrollada para la temperatura máxima, mínima y media de acuerdo a los procedimientos de control de calidad de registros climáticos. A partir de éstos dos conjuntos se analiza el comportamiento espacial de temperatura media anual estimada para tres períodos climáticos. Destaca la presencia de incrementos de temperatura media anual a 0.31°C en 1971-2000, 0.61°C en 1981-2010 y un incremento muy intenso, 0.81°C, para el período de 1991-2010. Asimismo, se observa que las costas de Jalisco muestran un incremento de 0.2 a 0.4°C mientras la región continental registra un incremento hasta 0.8°C.

Temperatura, Control de calidad, Tendencias climáticas, Jalisco

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* Correspondence to Author (email: martha.orozco@academicos.udg.mx)
† Researcher contributing first author.

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1. Introduction

Over the past 30 years, considerable attention was focused on trend analysis in long series of air temperature, focusing on the development of high-quality data sets in order to obtain the highest spatial resolution information for the longest possible periods. Thanks to these efforts, three main databases are available today on a global scale (González-Hidalgo, et al., 2015; Jones & Wigley, 2010): from the Global Historical Climatology Network (GHCN) updated by (Lawrimore, et al., 2011), of the Goddard Institute for Space Studies (GISS) updated by (Hansen, et al., 2010) and the Climate Research Unit, affiliated to the Hadley Center of the Meteorological Office of Great Britain (HadCRUTEM4) updated by (Jones, et al., 2012).

These databases share the same original data and differ in the quality control technique that was applied to them (Feng, et al., 2004; Jones & Wigley, 2010; González-Hidalgo, et al., 2015). Using these updated databases, the Intergovernmental Panel on Climate Change (IPCC, 2013) summarized the global warming processes observed from 1880 to 2010, confirming the results of previous research published in the original research papers (Jones & Moberg, 2003), as well as in the IPCC reports (IPCC, 2007; PICC, 2001). Another great effort has been devoted to the creation of high spatial resolution climatic databases at continental, regional and national levels, as well as to the analysis of their spatial variability and change in daily extremes (Guttman, 1996; NOAA, 1996; Balling Jr. & Idso, 2002; Feng, et al., 2004; Feidas, et al., 2004; Aguilar, et al., 2005; Brunetti, et al., 2006; Brunet, et al., 2006; Brunet, et al., 2007).

In Mexico, the National Institute of Ecology and Climate Change (INECC, in its Spanish acronym) through collaboration with the international group of Experts on Climate Change Detection and Indexes (ETCCDI) and with the purpose of advancing monitoring national climate, it promoted the project “Strengthening of Capacities in Climate Change Detection in Mexico,” sponsored by the Fund of Strategic Programs of the United Kingdom and coordinated at the Universidad Iberoamericana Puebla, and conducted the training course called “Workshop on Detection and Indices of Climate Change in the Mexican Republic” carried out in May 2009.

In this workshop, participants tried to calculate the climate change indices based on the maximum, minimum temperature and precipitation climate information provided by the National Meteorological Service, National Water Commission (Vázquez-Aguirre, 2010).

However, in Mexico there is no high-resolution database (daily climate information) that meets the necessary quality controls aimed at cementing studies of climate variability and trends at national, state and local levels. Therefore, this work shows the results of developing a high-resolution database for the maximum, average and minimum temperature. A comparative analysis of the estimated annual average temperature trends for the periods 1961–1990, 1971–2000 and 1981–2010 in the state of Jalisco is also carried out, based on quality control and the homogeneity review of the long series according to the recommendations of the World Meteorological Organization (WMO, 2010; WMO, 2011; WMO, 2016; WMO, 2017).

It is important to highlight that despite great progress in the development of high-resolution databases at global and regional level, academics continue to review and improve homogenization techniques to optimize the detection of inhomogeneity in climatic data due to man-induced factors, as well as to continue with the rescue of historical climate records (Beaulieu et al., 2008; Domonkos, 2011; Domonkos, 2013; Acquaotta & Fratianni, 2014; Ribeiroa et al., 2015; Killick, 2016; Gubler et al., 2017; Domonkos & Coll, 2017; Termonia et al., 2018).

2. Data and Methodology

2.1. Study Area

The state of Jalisco is in the middle western region of the country, between the following coordinates: 22º 45’ north and 18º 55’ south latitude, east longitude 101º 28’ and west 105º 42’. It has a territorial extension of 77965.88 km² which represents 4% of the national surface. It borders the state of Nayarit to the northwest; Zacatecas and Aguascalientes to the north; Guanajuato and San Luis Potosí to the east; Colima and Michoacán to the south; and towards the west, a coastal strip of 351 km with the Pacific Ocean.

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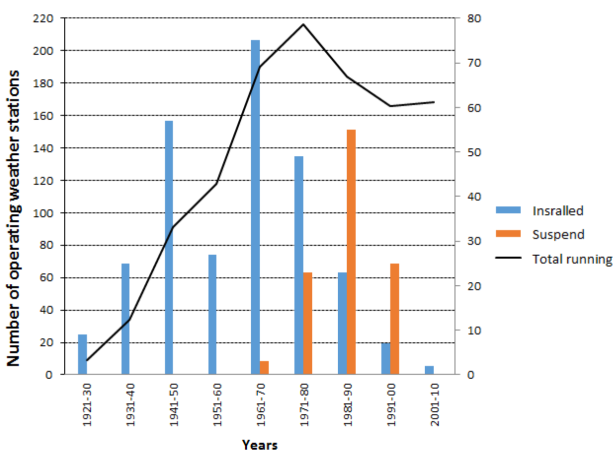
The landscape of Jalisco is characterized by the predominance of mountains, high plateaus and the total absence of extensive plains (INEGI, 2014).

2.2. Data and its source

In order to carry out the study of variability and detect possible signs of climate change in the state of Jalisco, the information of the 274 weather stations in the state of Jalisco was used. As of January 1989, these have been administered by the Management of Surface Water and River Engineering (GASIR, in its Spanish acronym), which is part of the Technical Sub-Directorate of the National Water Commission (CONAGUA, in its Spanish acronym).

However, historical information files that have a daily record of precipitation, as well as maximum and minimum temperatures are under the management of the National Meteorological Service (SMN, in its Spanish acronym). Graph 1 shows the progress of the network of traditional weather stations during the period 1920-2010.



Graph 1 Progress in the development of the network of traditional weather stations in the period from 1921 to 2010. Navarro, 2015

Sources: Based on data from the National Meteorological System of the National Water Commission SMN/CNA

However, the analysis of data density, that is, that each series has at least 80% information, the original set was reduced to a total of 89 stations, 13 of which were suspended in the 1990's. In other words, only 28% of the initial information or 76 stations underwent quality control process.

2.3. Quality Control Analysis

This analysis is extremely important for the calculation of climate change indices, since any erroneous data can have impacts on trends in temperature or precipitation variations. These processes are applied to detect and identify errors which occur during the acquisition, manipulation, format, transmission and filing of data (Aguilar et al., 2003).

An initial monitoring was carried out in the original monthly series, searching for suspicious and inconsistent data, and applying the following criteria:

- $t_{max} < t_{min}$
- Absolute value of t_{max} above 50°C and below -25°C
- Maximum monthly range is greater than 50°C

The RClimdex program implemented in R language and developed by Byron Gleason of the National Climate Data Center (NCDC) of NOAA (National Oceanic and Atmospheric Administration) was applied to analyze the quality of climate data and has been used in multiple workshops on climate indices since 2001 (Zhang & Yang, 2004). In order not to lose records for extreme and atypical events, a threshold of four standard deviations was chosen at the time of running the program.

In addition, temporal and spatial coherence tests were performed (Vincent et al., 2002; 2005; 2012; Wang et al. 2013; Xu et al., 2013). Temporal coherence consists in verifying that the observed variability from one register to the next is within a characteristic limit for the station, i.e., if there was an extreme event or if the information is not justified. The spatial coherence analysis was performed in order to verify whether the behavior of the observations was consistent with those reported at the same time by other stations in similar conditions in a given spatial neighborhood.

The comparative temperature analysis of the stations was then carried out considering that they were complying with a similar altitude pattern using the Digital Elevation Model (INEGI, 2013) and that they were at a relatively short distance from each other, 50 kilometers maximum.

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This is to ensure that the conditions under which the data was compared are as similar to each other as possible and that the data is attributed only to variations in local climatic processes.

Metadata are important in the process of quality control of climate series and in the evaluation of the homogeneity of time series. If sufficient metadata is available, it is easier to determine whether a discontinuity may be caused due to factors outside natural climatic variability, which were already mentioned previously (Aguilar, et al., 2003; Feng, et al., 2004; Vázquez Aguirre, 2010). To develop the metadata files of preselected stations, field research was carried out with Leica GEB121 equipment. It is easy to observe that most stations show a bias regarding their documented positioning in the archives of the National Meteorological Service, National Water Commission (Figure 1).

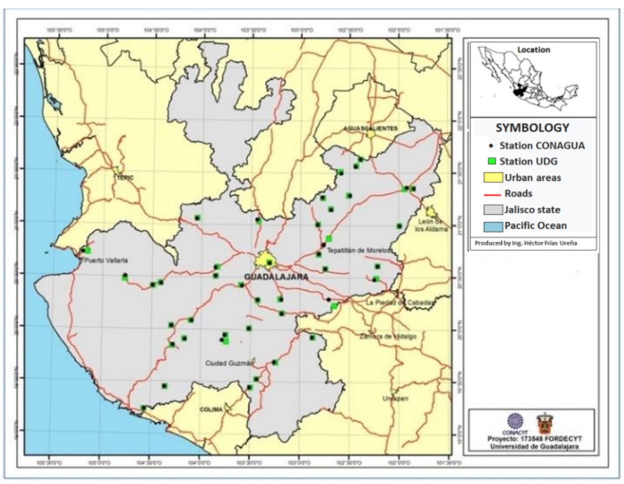


Figure 1 Update of the positioning of the CONAGUA weather stations in the state of Jalisco for the quality control process
Source: Davydova-Belitskaya, 2013

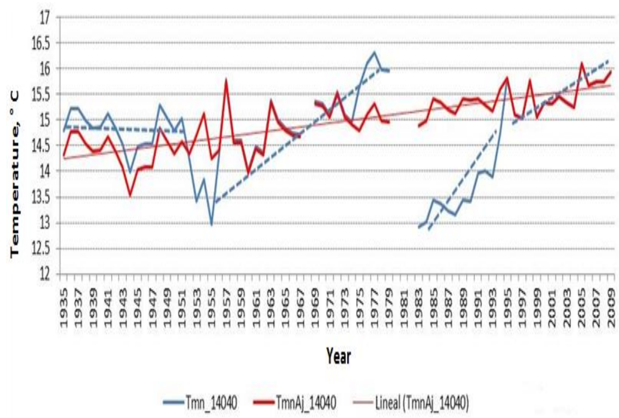
2.4. Homogeneity analysis

The homogeneity of climate data over time directly affects the possibility of calculating and analyzing trends (IPCC, 2007; WMO, 2009).

The tests to demonstrate that a time series of a climatic variable is reasonably homogeneous are intended to ensure that the variations contained in the observations correspond only to climatic processes (WMO, 2009; Wang and Feng, 2013)

For this investigation, we used the methodology of Wang and Feng (2013) based on a two-phase regression model, which applies F and t test functions with penalty (PMT and PMF), capable of detecting displacements in the mean time series of zero tendency, using an empirically constructed penalty function to match the profile of the false alarm rate.

The homogenization of long series of monthly maximum and minimum temperatures in the stations that have complied with the quality control process was executed using the RHtest V4 software. Graph 2 shows the cases of heterogeneous series and after the homogenization process.



Graph 2 The behavior of the original annual average minimum temperature series at station 14040 is shown as a function of time (blue line) and its distribution after the homogenization process (red line)
Source: Navarro, 2015

3. Results

From the quality control and homogenization processes of long series, as well as the available metadata, 22 of the 89 preselected stations were chosen (Fig. 2). It is important to stress that some stations with long series and records since the 1940's were discarded because of the absence of minimum or maximum temperature records, or both in the months of January and December, particularly from the 1990's, that is, during the last two decades.

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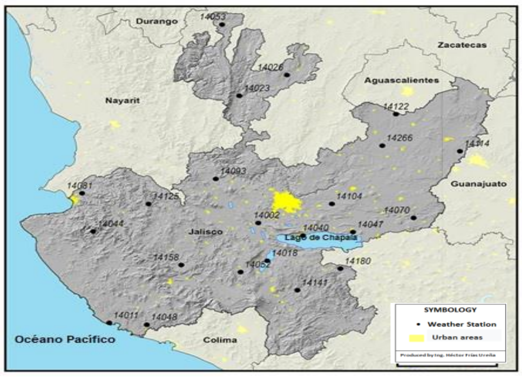

Figure 2 Spatial distribution of the stations that met the quality control and homogenization processes, Jalisco, México
Source: Prepared by the authors

Note that the spatial behavior of the selected stations is balanced, i.e., it covers almost the entire territory, except the southern region and the state's coastline.

The average monthly temperature was calculated from the monthly maximum and minimum temperature records with the arithmetic average of these. Subsequently, the average annual temperature values were estimated for three representative climatic periods, 1961-1990, 1971-2000 and 1981-2010, as well as the average annual temperature for the period 1991-2010 (Table 1).

Code	Name	Municipality	Latitud (N)	Longitude (W)	$t_{med(61-90)}$, °C	$t_{med(71-00)}$, °C	$t_{med(81-10)}$, °C	$t_{med(91-10)}$, °C
14002	Acatlán de Juárez	Acatlán de Juárez	20°25'3	103°35'52"	19.57	20.1	20.57	20.62
14011	Apazulco	La Huerta	19°18'2	104°53'15"	24.5	24.73	24.86	25.01
14018	Atoyac	Atoyac	20°0'37	103°30'55"	20.79	21.1	21.44	21.79
14023	Bolaños	Bolaños	21°49'3	103°47'00"	24.36	24.52	24.62	24.91
14026	Casa Llanta	Colotlán	22°03'3	103°21'43"	17	17.4	17.87	18.18
14040	Chapala	Chapala	20°17'2	103°12'6"	20.66	20.96	21.05	21.11
14044	El Bramador	Talpa de Allende	20°18'3	105°2'59"	24.75	25.09	25.41	25.69
14047	El Fuerte	Ocotlán	20°19'5	102°45'48"	19.45	19.57	19.87	19.87
14048	El Chiflón	Cihuatlán	19°17'3	104°33'10"	24.69	25.11	25.74	25.88
14052	El Nogal	Tapalpa	19°52'5	103°44'49"	15.13	15.41	15.87	16.05
14053	El Pinito	Huejuquilla e Alto	22°36°3	103°56'54"	17.11	17.82	18.37	18.71
14070	Huascato	Degollado	20°29'2	102°13'51"	17.92	18.11	18.4	18.48
14081	La Desembocada	Puerto Vallar	20°43'4	105°9'26"	25.53	25.7	25.97	26.24
14093	Magdalena	Magdalena	20°54'2	103°58'47"	20.28	20.28	20.88	21.05
14104	Palo Verde	Zapotlanejo	20°38'2	102°57'04"	17.89	18.5	18.95	19.13
14114	Presa La Duquesa	Lagos de Moreno	21°13'2	101°49'12"	17.34	17.81	18.26	18.44
14122	San Bernando	Teocaltiche	21°37'5	102°23'22"	17.39	17.75	17.98	18.13
14125	San Gregorio	Gómez Faría	20°37'1	104°34'05"	15.26	15.51	15.78	15.8
14141	Ingenio	Tamazula de Gordiano	19°41'1	103°14'43"	21.2	21.41	21.7	21.85
14158	Unión de Tula	Unión de Tul	19°57'1	104°16'04"	20.42	20.61	20.76	20.83
14180	Quitupan	Quitupan	19°55'3	102°52'16"	19.79	20.11	20.33	20.41
14266	San Gaspar de los Reyes	Jalostotitlán	21°17'0	102°30'35"	16.75	16.94	17.3	17.46

Table 1 Estimated average annual temperature for the periods 1971-2000, 1981-2010 and 1991-2010
Source: Prepared by the authors based on data from SMN/CNA.

To estimate the temperature change in the last decades in Jalisco, values of $\Delta t_{md71-00}$, $\Delta t_{md81-10}$ and $\Delta t_{md91-10}$ are calculated considering the reference 1961-1990 climate period (Table 2). It is important to emphasize that in all the stations, in the three analysis periods, there was a positive change or increase in average annual temperature.

Code	Name	Municipality	Latitude (N)	Longitude (W)	Altitude	Δt_{md} 71-00	Δt_{md} 81-10	Δt_{md} 91-10
14002	Acatlán de Juárez	Acatlán de Juárez	20°25'34"	103°35'52"	1344 .51	0.53	1	1.05
14011	Apazulco	La Huerta	19°18'23"	104°53'15"	5	0.23	0.36	0.52
14018	Atoyac	Atoyac	20°0'37"	103°30'55"	1341 .26	0.31	0.65	1
14023	Bolaños	Bolaños	21°49'30"	103°47'00"	963	0.16	0.26	0.56
14026	Casa Llanta	Colotlán	22°03'32"	103°21'43"	1730	0.4	0.86	1.17
14040	Chapala	Chapala	20°17'25"	103°12'6"	1510 .26	0.3	0.39	0.45
14044	El Bramador	Talpa de Allende	20°18'36"	105°2'59"	1704	0.34	0.66	0.94
14047	El Fuerte	Ocotlán	20°19'51"	102°45'48"	1540	0.12	0.42	0.41
14048	El Chiflón	Cihuatlán	19°17'30"	104°33'10"	360	0.42	1.05	1.19
14052	El Nogal	Tapalpa	19°52'59"	103°44'49"	1963.29	0.28	0.73	0.92
14053	El Pinito	Huejuquilla el Alto	22°36°33'	103°56'54"	1684	0.71	0.55	1.6
14070	Huascato	Degollado	20°29'23"	102°13'51"	1658.16	0.19	0.48	0.56
14081	La Desembocada	Puerto Vallarta	20°43'40"	105°9'26"	10.42	0.17	0.44	0.71
14093	Magdalena	Magdalena	20°54'23"	103°58'47"	1380	0.18	0.59	0.76
14104	Palo Verde	Zapotlanejo	20°38'25"	102°57'04"	1730	0.61	1.06	1.24
14114	Presa La Duquesa	Lagos de Moreno	21°13'28"	101°49'12"	1950	0.46	0.91	1.1
14122	San Bernando	Teocaltiche	21°37'54"	102°23'22"	1796.87	0.36	0.59	0.74
14125	San Gregorio	Gómez Farías	20°37'15"	104°34'05"	1640	0.25	0.52	0.54
14141	Ingenio	Tamazula de Gordiano	19°41'13"	103°14'43"	1450	0.21	0.5	0.64
14158	Unión de Tula	Unión de Tula	19°57'16"	104°16'04"	1340	0.19	0.34	0.41
14180	Quitupan	Quitupan	19°55'38"	102°52'16"	1593	0.32	0.53	0.61
14266	San Gaspar de los Reyes	Jalostotitlán	21°17'05"	102°30'35"	1657.35	0.19	0.55	0.71

Table 2 Estimated average annual temperature change for the periods 1971-2000, 1981-2010 and 1991-2010
Source: Prepared by the authors from data from the SMN / CNA

The spatial behavior of the average temperature trend is shown on the maps constructed with the ESRI ArcGIS 10.1 computational tool for the three periods (Fig. 3-5). It is important to mention that a higher temperature increase is observed in the temperature trend map of the homogenized data compared to the original information. However, in both cases and in all stations, positive trends are recorded, while in the periods 1981-2010 (Fig. 4 ab) and 1991-2010 (Fig. 5 ab) the estimated trend behavior with original data or without homogenization shows both negative and positive trends.

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This behavior is physically unlikely and, based on metadata information, is explained by the modification of the minimum and maximum average temperatures due to the relocation of thermopluviometric stations during the 1980's and the beginning of the 1990's. Nonetheless, the maps with the homogenized series show a growing tendency for the period 1981-2010, as well as 1991-2010, where the last 20 years (1991-2010) show an increase of 0.81°C or 0.2°C greater than the 1981-2010 period.

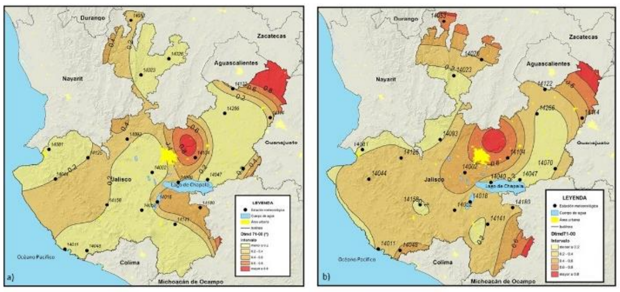

Figure 3 Spatial behavior of the estimated temperature trend for the 1971-2000 period with data from a) original series and b)homogenized series
Source: Prepared by the authors based on data from SMN/CNA

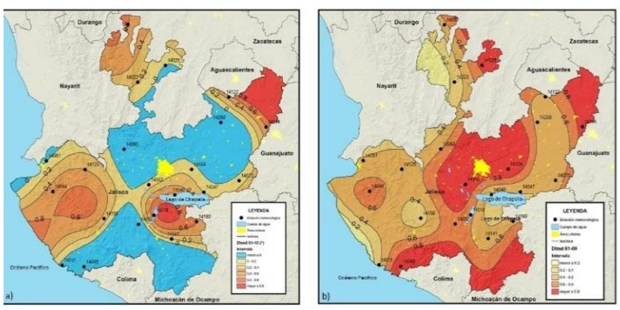

Figure 4 Spatial behavior of the estimated temperature trend for the 1981-2010 period with data from a) original series and b)homogenized series
Source: Prepared by the authors based on data from SMN/CNA

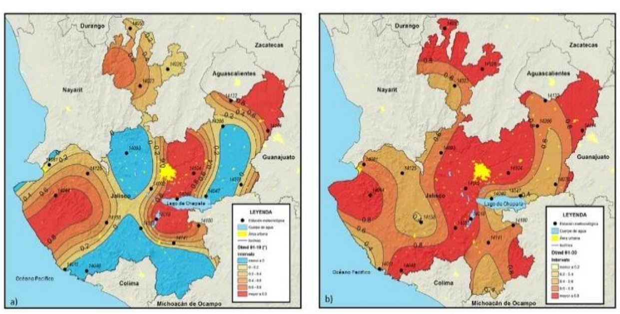

Figure 5 Spatial behavior of the estimated temperature trend for the 1991-2010 period with data from a) original series and b)homogenized series
Source: Prepared by the authors based on data from SMN/CNA

It is interesting to note that along the coast and around Lake Chapala the temperature increase is milder compared to the continental region of the state, which can be explained by the abundant presence of water vapor or high humidity levels. (Fig. 4b - 5b).

The comparison of three different periods makes it possible to locate the most vulnerable areas regarding climate change impact, particularly intense annual average temperature increase: central, south, south-west regions, as well as the east zone in the north and the Los Altos de Jalisco region.

From the information generated, the following stands out:

It is the first research work carried out for the state of Jalisco that applied a quality control of climatological series as well as its homogenization, which allowed to visualize true temperature trends, their oscillations and anomalies. It also established the development of the thesis "Study of the Variability and Trends of Climate Change in the state of Jalisco during the Period 1961-2010" (Navarro, 2015).

The collection, processing and management of climate data showed insufficient quality for direct use in the inferential analysis of climate variability and change in the region. Therefore, a detailed review and modification of climatological data was conducted applying the techniques and procedures established by the World Meteorological Organization (WMO, 2010, WMO, 2011, WMO, 2016).

The average of the mean temperature calculated for stations that have complied with quality control shows an increase for the three study periods (Graph 3). The growing annual average temperature trends at regional level were also recorded in recent studies from Brazil, Peru and Romania (Acquaotta & Fratianni, 2014; Dumitrescu, Bojariu, Birsan, Marin, & Manea, 2015; Gubler, and others, 2017).

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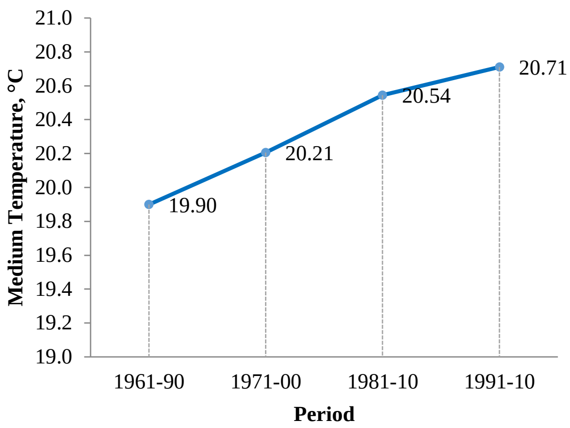
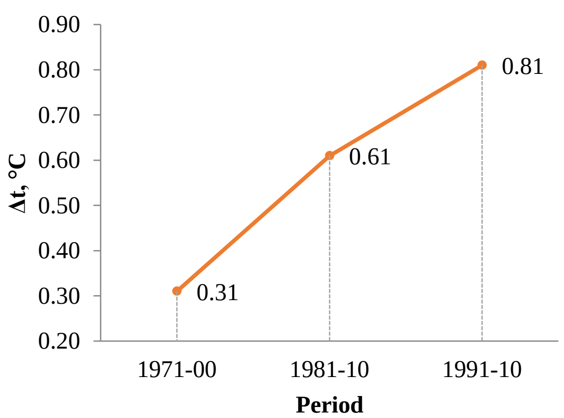


Graph 3 Average annual mean temperature distribution from 1961 to 2010
Source: Prepared by the authors

The calculation of the average annual mean temperature trend shows a behavior similar to that reported for global climate change (Graph 4).



Graph 4 Temporal behavior of the average annual mean temperature increase from 1961 to 2010
Source: Prepared by the authors

4. Acknowledgments

CONACYT's support for the research carried out through the project "Regional strategy to reduce vulnerability and improve the capacity to adapt to climate change in the western region of Mexico", FORDECYT-2011-01, is gratefully acknowledged.

5. Conclusions

In summary, signs of climate change are observed from the analysis carried out in the state of Jalisco.

In addition, the magnitude of this change is greater than the one showed by some previous studies performed and published by the Secretary of the Environment and Territorial Development of the state of Jalisco (Autonomous University of Guadalajara, 2014), so it is recommended to update these studies observing the quality control guidelines of climatic data, particularly the development of metadata files and homogenization of its long series.

The comparative analysis in this study demonstrates the importance of continuing quality control of climatic data, including the homogenization of long series, a process that will allow to eliminate the variations induced by human activity: relocation of station, change of observation equipment, emergent constructions near climatic stations, etc.

By excluding non-climatic factors, a positive trend of the estimated annual average temperature for three climatic periods was detected: 1971-2000, 1981-2010 and 1991-2010. It is important to mention that the growing trend of the average annual temperature is lower along the coast of the state of Jalisco and in the Lake Chapala basin, while the most vulnerable areas to intense increase in average annual temperature are the center, south, and south-west regions, as well as the east zone in the north and the Los Altos de Jalisco region.

6. References

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