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Climate change in NE Mexico: influence of the North Atlantic Oscillation

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Abstract. An exploratory analysis of temperature, precipitation and evaporation records, in five localities of Tamaulipas state (NE Mexico), spanning from about 30s decade of XX century until first years of the XXI, is made by means of multivaried statistical techniques. A change point is detected in 1964. By comparing the period former to this year with the period 1964-2002, a significant decrease of temperature is observed in four out of the five localities, in three ones there is a light increase of precipitation and in the another two it is greater; finally, four of them have an important decrease in evaporation. According to the Köppen´s system of climatic classification adapted to the Mexican Republic, the climate type changed in three out of the studied localities, passing from dry to warm sub-humid. North Atlantic Oscillation (NAO) is analyzed as a possible cause of this behavior. The results suggest that the statistical methodology used is suitable for long term climate studies.

Key words: Climate change, exploratory analysis, multivariate techniques, Tamaulipas, XX century, NAO.

Cambio climático en el NE de México: influencia en la Oscilación del Atlántico Norte

Resumen. Por medio de técnicas estadísticas multivariadas se hace un análisis exploratorio de temperatura, precipitación y evaporación, registradas en cinco localidades del estado de Tamaulipas (en el NE de México), abarcando desde alrededor de la década de los treinta del siglo XX hasta los primeros años del XXI. Se detecta un punto de cambio en 1964. Al comparar el periodo anterior a ese año con el periodo 1964-2002, se observa una disminución significativa de temperatura en cuatro de las cinco localidades, en tres hay un ligero aumento de precipitación y en las otras dos éste es mayor; finalmente, cuatro de ellas tienen un decremento importante de evaporación. De acuerdo con el sistema de clasificación climática de Köppen, adaptado a la República Mexicana, el tipo climático cambió en tres de las localidades estudiadas, pasando de seco a cálido sub-húmedo. Se analiza la Oscilación del Atlántico Norte (NOA, por sus siglas en inglés) como posible causa de este comportamiento. Los resultados sugieren que la metodología estadística usada es adecuada para estudios climáticos de largo plazo.

Palabras clave: Cambio climático, análisis exploratorio, técnicas multivariadas, Tamaulipas, siglo XX, OAN.

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INTRODUCTION

A preliminary analysis of climatic elements in Tamaulipas state, Mexico, suggested a climate change point in the mid-1960s (Sánchez *et al.,* 2002), which could involve changes in the formulas of the Modified Köppen Climatic Classification System (García, 1988). The original Köppen system establishes a relationship between two climatic elements (precipitation and temperature) and the distribution of vegetation of the planet's major biomes worldwide, and was created for large areas of the world (Köppen, 1948). Mexico is characterized by rugged orography, where the physiography changes over short distances and modifies both temperature and rainfall; the author admits that his system has no detail at the regional level neither for the precipitation patterns nor temperature conditions by altitudinal factors. These details are in fact achieved with the Modified Köppen System. For this purpose, García uses the vegetation fenology based on the two species of the genus *Larrea (divaricata* and *tridentata).* She delimited the range of temperature and rainfall along the year; with this criterion, divides the dry climate in three gradients. She also includes the altitude to explain cold climates in low latitudes. Her system follows the Köppen´s statistical criteria for the use of quartiles and, while preserving the capital letters to define the five climate types of the world all represented in Mexico, incorporates a number of additional small letters to quantitatively delimit, to a fine scale, the distribution of both rainfall and temperature by altitude effects.

The Modified System (MS), as it is generically known in Mexico and parts of Central America, uses monthly averages (climatological normals of 30 years) of mean temperature and accumulated precipitation for computing its formulas. The temperature is used to determine the thermal oscillation, the annual march from summer solstice, as well as quantitatively establish the boundaries from hot until very cold climates with all the intermediate gradients. As to volumes of rain, limits are introduced to stablish rainfall regimes: winter or Mediterranean, summer and intermediate (Mexico has the three types), and even with rainfall during all the year; and to assess the proportion of winter rainfall for summer and intermediate regimes, and the intensity of intraestival or midsummer drought (or *canícula*) in those of summer. Most of the country, and particularly the Gulf of Mexico coast receives rain from three origins: east waves and tropical cyclones in summer, and cold fronts in winter (Sánchez and Garduño, 2008).

Similarly, gradients are established that combine both rainfall and temperature for transition climates found in the ecotones of different ecosystems. The delimitation of the corresponding months of the rainy season, automatically confine the dry months, which in the case of the Gulf of Mexico slope, cover from November to April; however, winter months (November to February) record a volume of rain not always negligible, as a consequence of cold fronts passage (Mosiño, 1988:119-122), northern winds (known locally as *nortes*), and therefore, the dry season occurs in March and April. Since the aim is to establish a link between climatic elements and NAO, event present mostly in winter, this study was divided into three seasons: summer or rainy (May-October), cold fronts or *nortes* (November-February) and dry season (March-April).

In previous seasonality studies for the Gulf of Mexico slope, de la Lanza *et al.* (1998), Sánchez and de la Lanza (2011) report three seasons: rainy (May-October), cold fronts (November-February) and dry (March-April); after observing the same seasonality for Tamaulipas, this study was divided the same.

Tamaulipas was selected for this study because it is an important agricultural state and for that reason it has a very complete and reliable network of agrometeorological stations. Additionally, its contiguity to the Gulf of Mexico gives it maritimeness and its ranges produce outstanding orographic shadow. The NE portion of the state is dry, possibly because in front of its coasts a semipermanent oceanic gyre sinks the warm water, the sea surface slightly cold and the air masses passing over do not get enough moisture (Zavala *et al.,* 2003). Tamaulipas is also interesting due to its location in the transitional zone between tropical and midlatitudes climates.

The temperature and precipitation average over a 30-year period are representative of the climatic features of a particular locality and so define its climate type; the vegetation living in biologically responds to those conditions. For this reason the MS can be used as a tool to evaluate a climate change in terms of temperature and precipitation in a quantitative manner, which eventually becomes manifest as a variation in the abundance and distribution of the vegetation in the local ecosystem.

In this article we first validated the existence of the hypothetical point of change in 1964, then compared the observations of temperature, rainfall and evaporation between the periods before and from this year on (called Periods I and II, respectively). This comparison was made using three multivariate statistical techniques. Finally, the climatic formulas were calculated for each period. The statistical methods were applied to the description of the climatic system, because it satisfies the requirements of being a dissipative system controlled by several physical factors, with nonlinear dynamics involving unstable linear processes, also implicate the response of biota (von Storch and Zwiers, 1999).

While the evaporation is not a variable used in the MS, the climatic variables strongly affect it; the temperature increase, the air dryness and the wind intensity favor evaporation; and the temperature decrease and the salinity of the sea water weaken it. Given that the study region is bordering the Gulf of Mexico and so very influenced by the sea water masses, whilst the inland localities studied belong to a dry climate, it is important to evaluate possible changes in evaporation.

The Anthropocene Era has been defined as "the geological epoch where human influence on the planet is as profound as that of natural forces" (Board on Sustainable Development, National Research Council, 2000) and is also mentioned by Crutzen and Stoermer (2000); Falkowski *et al.* (2000) fixed its onset about the latter part of the XVIII century. With the aim of contributing to regional climate changes studies in the past 150 years, we analyze historical records of five localities in Tamaulipas state covering the last six to eight decades of the XX century, where for the date of climate point of change, we can define two consecutive climatological values, averaged over intervals of about 30 year. All cases greatly exceeded the tolerable minimum of 10 years according to the World Meteorological Organization (WMO, 1966). Of course, climate change in each place is given by the difference between both climates, defined by the respective climatological normals.

Since various statistical tests exist applicable to the same problem and without any precedence in this work, an homogeneity test of data was done to determine its reliability and then applied the three multivariate techniques: analysis of variance of fixed effects (ANOVA), exploratory analysis with diagrams of boxes and whiskers, and Tukey test, also called the truly significant difference (TSD). Subsequently, climates were classified according to MS, to detect changes in their type and, finally, correlations were calculated between the seasons of the year (cold fronts, dry and rainy), with the corresponding index of the NAO, for each locality and for the Periods I and II.

Droughts (some of them severe and decade lasting) have been recurrent in Northern Mexico and several authors have associated them, since the late XIX century, with prevailing atmospheric southern circulation over North America due to the weakening of the Atlantic subtropical (Azores) high pressure cell (Lamb, 1972; Mosiño, 1976; Jáuregui, 1979; Metcalfe, 1987). Supported by this, we pose the hypothesis that decadal climate variability in NE Mexico could be linked to the NAO, defined as a large-scale oscillation between two cells: the Atlantic subtropical high pressure (Azores) located at 38°N and the Arctic polar low (Iceland) at 60°N. This swing has two phases, which are expressed mostly in the cold fronts season; the positive one when the barometric pressure of the Azores is higher than its normal value, while in Iceland is still lower than normal. In the negative phase, the pressure differences between the Azores and Iceland are lesser, the Azores anticyclone is weak, the cyclonic cell of Iceland is strong and both are located more southerly. The alternation between both phases changes the transport of heat and moisture from the Atlantic to America. The recent positive trend in the NAO could be linked to the warming of the tropical ocean, particularly the Pacific and Indian, as a result of rising in greenhouse gases; this trend coincides with the likelihood of chaotic atmospheric processes (Hurrell *et al.,* 2001:603-605; Wanner *et al.,* 2001; Rodríguez *et al.,* 2006).

METHODS

Five climatological stations were selected: Comales, El Barretal, San Fernando, San Gabriel and Tampico, located in the coastal plain, i.e. East (windward) of the Sierra Madre Oriental, at different distances from the sea and spread over the three hydrological regions with littoral in Tamaulipas. Table 1 shows the localization of the stations, the start of the time series of study and the number of years in the Period I (from 1963 backwards) of each station. The five stations have records of different times at the beginning and at the end, the series extends up to 2002, except for Comales (which ends in 1989); therefore, the Period I was variable at the start date and the Period II includes 39 years (1964-2002) for four stations and 26 for Comales. Monthly values were analyzed for mean temperature, accumulated precipitation and evaporation, obtained from the Federal Electricity Commission (1921-2002). The test of homogeneity of data was estimated with the Sved-Eisen-Hart method (Klein, 1982; Wilkis, 1995), because the series is longer than 20 years, resulting in a confidence interval of 95%.

To find the climate point of change, moving (with 1-year leap) averages of each time series available were computed looking for significant differences. We compute the climatic variables for every couple of successive intervals of at least 10 years, in the extremes of the series, and the rest of it, and compare both averages; the valve of the first 10 years of the series vs. the one of the remaining years, the first 11 vs. the remaining ones, and so on until the last 10 vs. the (former) remaining years of the series. In all cases (climatic variables and stations) the greatest difference occurred in the limit 1963-64. Once established the periods with different climatic behavior, the ANOVA was applied for the three climatic variables to corroborate the differences between each one (Bounessah and Atkin, 2003). Subsequently, an exploratory analysis was conducted for the three variables by the method of diagrams of boxes and whiskers (von Storch and Zwiers, 1999); in this case the average was used to determine climate type of each locality (García, 1988). The standard deviation, expressed by the lower and upper box edges, indicates the variability of the data; while the limits of the projected lines from the box (whiskers) represent the extreme values of the confidence interval 95% and, therefore, make possible to verify graphically the homogeneity of data between the periods (when the confidence intervals overlap) or the difference between them (if they do not).

To confirm the validity of the periods, the Tukey test was applied; this is a method used to test the null hypothesis regarding the equality of all possible pairs of mean values when the samples have the same size. This analysis indicates if the absolute values that exceed the TSD are considered significant (von Storch and Zwiers, 1999). In the case where the periods were not of the same size, the absolute value of the difference between sample means was used (Spjøtcoll and Stoline, cited by Daniel, 1996). The Tukey test, applied after the

Table 1. Localization and period of study of weather stations

Station	Distance to sea (km)	Latitude North	Longitude West	Altitude (amsl)	Beginning of the Period I	Period I length (years)
Comales	168	26°14'00"	98°56'00'	120	1938	26
El Barretal	136	24°05'02"	99°07'37"	220	1940	24
San Fernando	40	24°51'00"	98°56'00"	43	1932	32
San Gabriel	96	23°04'00"	98°47'00"	55	1943	21
Tampico	0	22°13'00"	97°51'00"	13	1921	43

ANOVA, was used to demonstrate significantly different conditions. In this case, given that only two periods are compared, this test is equivalent to the ANOVA.

Climates were classified for each of the two periods and the five studied sites, according to MS, to determine possible differences in their climatic formula. The system uses statistical equations of Gaussian distribution and was designed primarily to define the five types of existing climate in Mexico: tropical rainy (A), dry (B), temperate rainy (C), boreal (D) and cold (E); that result from the behavior of long period of the monthly temperature and precipitation. The first is used to determine the temperature difference between the coldest and warmest month, and the behavior of the annual march (which indicates the date that record the warmest month before the summer solstice, i.e. before June, in the Northern Hemisphere). For the precipitation, volume distribution throughout the year is delimited to characterize it in Mediterranean or cold front regime, monsoonal or summer and intermediate, its fraction of cold front rain, in the case of the summer and intermediate regimes, and finally the intensity of mid summer drought.

The combination of these parameters responds not only to the latitude, but also to the wide variations in altitude and creates very particular conditions in the spatial distribution and behavior of the climatic elements (temperature, precipitation, evaporation, wind direction and intensity, barometric pressure, cloudiness, solar radiation and visibility), especially in long terms. Finally, in order to explain climate change as a result of the influence of the NAO, simple correlation tests were applied between climatic variables (temperature, precipitation and evaporation) and the NAO index; this test was performed for each season (cold fronts, rainy and dry) of every year and period; thereafter the grade and sign of existing association were compared. Note that the NAO index is based on the difference of the normalized value of the barometric pressure at sea level, between Lisbon (Portugal) and Reykjavik (Iceland), (Hurrell, 2009).

RESULTS AND DISCUSSION

The climate change identified in the 60s and specifically in 1964 reflects a change in climatic formulas in three out of the five sites studied. The ANOVA corroborated the difference in the behavior of the three variables during the two periods. Comales locality stands out, which presented the most significant statistical difference in the three variables (p= 0.00000), followed by El Barretal, where the differences in temperature and evaporation were significant, in Tampico and San Fernando only the difference in evaporation was significant (Table 2).

The exploratory analysis of the behavior of temperature, rainfall and evaporation in the five localities, established through the boxes and whiskers test, whose difference was highly significant (p= 0.00000), showed the validity of the transition point in 1964 and clear differences between Periods I and II (Figure 1).

With regard to temperature, in four out of the five localities (Comales, El Barretal, San Fernando and San Gabriel), there was a significant decrease (0.9° C on average) between Periods I and II, while in Tampico increased. The precipitation data showed an increase in El Barretal, San Fernando and Tampico between the two periods (of 3.9 mm on average), and more pronounced in Comales and San Gabriel (35.7 mm on average). On regarding the behavior of the evaporation in the two periods, in the five localities the pattern of decline (20.9 mm on average) was similar and well marked (Figure 1).

As to the variability of annual records between periods, the rainfall has greater variation and opposite signs than the evaporation in the five localities (Table 3), mean differences between the variables were: 1.9° C, 56.6 mm and 47.6 mm, respectively. The estimated results with the Tukey test (Table 4), corroborate those obtained by the ANOVA, 87% of the cases had significant values. Once established Periods I and II, we calculated the monthly temperature and rainfall for each location (Table 5). With these values, climate MS types were computed.

Periods I and II (P I and P II), and their difference (percent, except for temperature and thermal oscillation), in five locations in Tamaulipas.

Table 2. Values of ANOVA fixed effects of temperature, precipitation and evaporation in five localities in Tamaulipas (*value not significant)

Location	Sum of squares effects	Error degrees of freedom	Sum of squares error	Variance (calculated F)	p
Temperature					
Comales	30.584680	50	0.543859	56.236370	0.000000
El Barretal	4.717063	53	0.542237	8.699259	0.004729
San Fernando	4.970902	69	0.526262	9.442372	0.003030
San Gabriel	4.551159	58	0.231740	0.196391	0.000042
Tampico	1.611970	80	0.244643	6.589071	0.012125
Precipitation					
Comales	883427.30	50	30229.47	29.224040	0.000002
El Barretal	25932.40	61	38609.42	0.677650	0.415667*
San Fernando	7630.748	74	34538.66	0.220934	0.639712*
San Gabriel	12627.60	58	28096.11	4.494434	0.038295
Tampico	31162.89	80	89415.10	0.348519	0.556616*
Evaporation					
Comales	12787332.0	50	55472.14	230.51690	0.000000
El Barretal	635977.8	53	20705.55	30.71533	0.000001
San Fernando	1044261.0	69	20803.81	50.19566	0.000000
San Gabriel	185499.4	58	67296.88	2.756433	0.102262
Tampico	610244.8	74	63728.62	9.575678	0.002783

All the cases have 1 degree of freedom effects.

After calculating the climate types for each period and locality (Table 6), it was found that in three of them there was a change in its climate type. Comales, El Barretal and San Gabriel passed from semi-arid (BS1) to semi-hot sub-humid (A) C(w0), and in San Fernando and Tampico there was no change, this could be due to its proximity to the ocean and the effect of thermal stability that it gives; in the case of San Fernando, located on the coastal plain, there are about 40 km away, and Tampico is a port city.

Finally, the correlation between temperature, precipitation and evaporation with the NAO was different for each location, climatic season and period (Table 7). In the case of temperature, the highest coefficients were recorded during the cold fronts season in the Period I and were direct (positive), San Gabriel stands out with r= 0.44. In the Period II there is a slight increase in the coefficients and also sign change, i.e. are reversed (negative); Tampico has the highest with r= -0. 50.

The precipitation correlation coefficients are 50% lower in the three climatic seasons during the Period I with respect to temperature and evaporation ones, in this period highest coefficients occur during the dry and rainy seasons, with r= -0.32 in Comales and r= -0.40 in Tampico. The correlation is comparable in intensity in both periods. The evaporation reaches the highest coefficients in the dry season in both periods, and in the forward direction (positive), San Fernando (r= 0.33), San Gabriel (0.33) and Comales (0.22) stand out; except El Barretal that during the cold fronts season in the Period I recorded an r= 0.44. There is a change in the sign of correlation between the climatic variables and the NAO, and in some cases increase in magnitude of the correlation between Periods I and II in the three climatic seasons. About temperature,

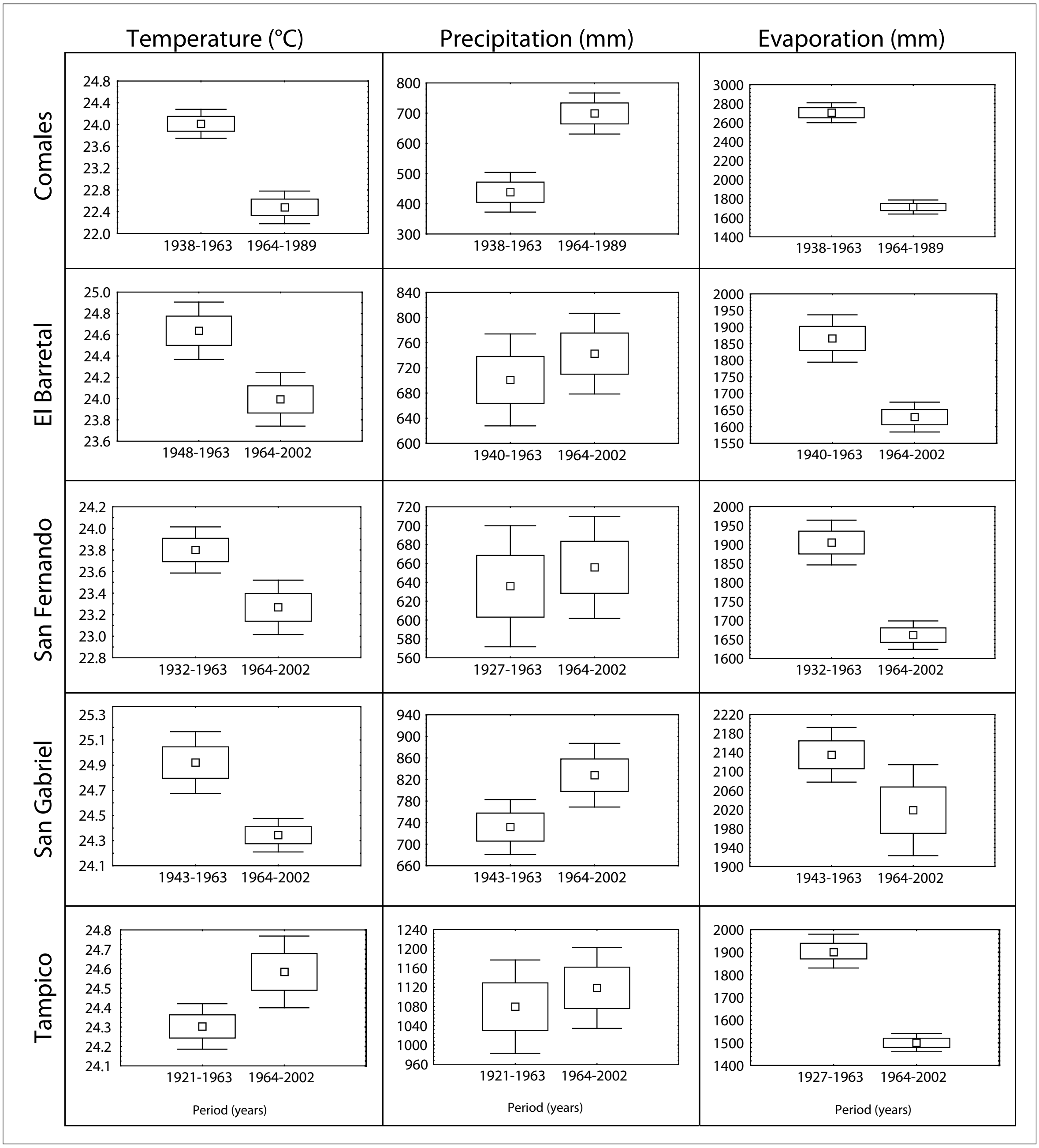

Figure 1. Behavior of temperature, precipitation and evaporation for the Periods I and II, in five locations of Tamaulipas (± 1.96 std. error; ± 1.00 std. error; average).

Table 3. Annual values of climatic variables during

Location	Temperature °C			Precipitation mm			Evaporation mm		
	P I	P II	Dif. °C	P I	P II	Dif. %	P I	P II	Dif. %
Comales	24.0	22.4	-1.6	438.3	700.7	59.9	2705.4	1713.3	-36.7
El Barretal	24.6	23.9	-0.7	700.8	738.7	5.4	1865.7	1628.9	-12.7
San Fernando	23.8	23.2	-0.6	635.8	655.9	3.2	1909.4	1661.5	-13.0
San Gabriel	24.9	24.3	-0.6	731.7	827.9	3.2	2135.2	2367.8	10.9
Tampico	24.2	24.5	0.3	1079.7	1119.9	3.7	1909.5	1505.4	-21.2
Location	Midsummer drought %			Cold fronts precipitation %			Thermal oscillation °C		
	P I	P II	Dif. %	P I	P II	Dif. %	P I	P II	Dif. °C
Comales	25.8	13.5	-47.7	11.9	14.4	21.0	17.4	14.3	-3.1
El Barretal	26.4	20.5	-22.4	8.2	8.3	1.2	13.2	13.3	0.1
San Fernando	18.7	13.0	-30.5	11.2	9.7	-13.4	13.3	13.9	0.6
San Gabriel	8.4	6.2	-26.2	3.7	5.2	40.5	10.7	11.4	0.7
Tampico	18.6	17.0	-8.6	6.2	5.4	-12.9	9.5	9.7	0.2

Table 4. Values of significance in the Tukey test for Periods I and II in five locations of Tamaulipas

Location	Tukey (Periods I vs II)		
	Temperature	Precipitation	Evaporation
Comales	0.000115	0.000117	0.000115
El Barretal	0.004863	0.415815*	0.000114
San Fernando	0.003170	0.639834*	0.000111
San Gabriel	0.000149	0.038385	0.102381
Tampico	0.012235	0.556733*	0.002930

(*value not significant).

in 93% of the cases the correlation was positive (Period I) and became negative in 66.6% (Period II). In the rain there was an increase in the number of cases of negative correlation (46.6 to 60%). The evaporation also increased the number of cases of positive one (66.6 to 73.3%).

CONCLUSIONS

A climate change is confirmed in the 60s, reflected in a change in the type of three out of the five locations analyzed. In these, the type of semi-arid BS1 climate passed to semi-hot sub-humid (A)C, which implies a marked increase in the volume of precipitation. This change in three localities indicates the possibility that the intensity and position of the Bermuda-Azores anti-cyclonic cell presents inter-seasonal, inter-annual and biennial to decadal scale fluctuations, due to the difference generated between this and the Arctic cells, characterized by the NAO; which changes the amount and type of cold fronts (Mosiño, 1988:119-122), the frequency and intensity of cyclones, and the intensity of trade winds (Hurrell *et al.*, 2001:603-605; Wanner *et al.*, 2001).

Seemingly the temperature decrease found in Tamaulipas contradicts warming; however, it is well known that, within this general increase in temperature over one and a half century, there are periods of the order of decades in which coolings are recorded; in addition, the global warming includes large areas, mainly in North America and the Northern Atlantic and Pacific oceans, where a sharp drop in temperature is reported, especially between 1946 and 1975 (IPCC, 2001:116) and no warming, between 1901 and 2005, in middle and eastern USA and NE Mexico, and the surrounding Gulf of Mexico and Atlantic Ocean (IPCC,

Table 5. Monthly values used to estimate the climate types in five locations of Tamaulipas, in Periods I and II (P I and P II) (T = average temperature in °C and R = accumulated precipitation in mm)

	J	F	M	A	M	J	J	A	S	O	N	D
Comales (P I)												
T	14.3	17.2	20.8	25.3	28.3	30.8	31.7	31.5	28.7	25.0	19.1	15.5
R	19.6	16.6	16.1	37.6	47.5	43.9	22.2	60.2	91.4	52.4	16.3	14.5
Comales (P II)												
T	14.3	15.7	19.9	23.6	25.7	27.8	28.6	28.0	27.0	23.6	19.6	16.0
R	50.4	31.3	19.6	45.6	71.4	76.0	69.0	76.1	135.4	62.4	33.3	30.2
El Barretal (P I)												
T	17.3	19.7	22.5	26.1	28.1	30.2	30.2	30.5	28.5	24.9	11.9	17.4
R	7.5	21.0	29.4	60.4	111.3	67.7	43.1	111.3	133.2	81.3	23.4	11.2
El Barretal (P II)												
T	16.2	18.4	22.1	25.7	27.9	29.3	29.4	29.5	27.6	24.3	20.4	17.1
R	20.7	15.3	25.4	46.9	111.0	109.8	76.0	80.6	148.8	69.1	19.1	17.0
San Fernando (P I)												
T	16.3	18.6	21.4	24.8	27.3	28.8	29.3	29.6	27.8	24.6	19.9	17.2
R	27.9	21.4	22.1	43.7	72.7	88.8	39.2	83.7	123.5	69.8	22.4	20.6
San Fernando (P II)												
T	15.3	17.2	20.9	24.6	27.2	28.8	29.2	29.1	27.4	23.7	19.6	16.1
R	29.3	18.3	16.3	35.0	60.4	85.6	64.1	89.2	132.7	68.9	29.9	26.2
San Gabriel (P I)												
T	18.5	21.1	24.0	26.7	29.0	29.1	28.6	29.2	27.5	25.0	21.6	18.8
R	8.2	8.8	10.2	34.9	53.1	173.7	98.6	131.9	120.8	66.0	14.8	10.7
San Gabriel (P II)												
T	17.6	19.6	23.1	26.4	28.5	29.0	28.1	28.3	27.0	24.4	21.5	18.6
R	19.0	7.7	16.5	34.7	69.3	142.7	157.3	125.3	154.2	66.0	18.0	16.6
Tampico (P I)												
T	18.8	20.3	22.0	24.7	26.8	27.9	27.9	28.3	27.3	25.6	22.2	19.7
R	37.1	17.9	12.9	19.1	51.0	151.6	147.3	125.1	290.5	146.5	48.5	32.2
Tampico (P II)												
T	18.8	19.7	22.9	25.2	27.3	28.3	28.3	28.5	27.6	25.8	22.8	19.8
R	26.7	19.4	14.9	23.1	50.4	179.7	136.8	162.1	281.3	138.8	42.0	44.7

Table 6. Climate types per period at five locations in Tamaulipas

Location	Period I (before 1964)	Period II * (1964-2002)
Comales	BS1w(h')h(e')w"	(A)C(w0)(x')a(e')w"
El Barretal	BS1w(h')h(e)w"	(A)C(w0)a(e)w"
San Fernando	BS1w(h')h(e)w"	BS1w(h')h(e)w"
San Gabriel	BS1w(h')(e)w"	(A)C(w0)a(e)w"
Tampico	Aw1(e)w"	Aw1(e)w"

* Comales ends in 1989.

2007:250). The change of land use in much of the state from the 60s went from the natural vegetation to agricultural use, changing the river flows, since in many cases they were dammed.

Even though the growth of the human settlements causes a temperature increase, the shrinkage of the natural vegetation causes a decrease of available water; therefore the evaporation rather diminishes, as can be seen in the results: with the exception of San Gabriel, where there was a light increase, in the remaining localities the evaporation significantly decreases.

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Table 7. Correlation coefficients (r) per period and location between climatic variables (temperature, precipitation and evaporation) and the NAO index

Location	Period I (before 1964)			Period II * (1964-2002)		
	Cold fronts	Dry	Rainy	Cold fronts	Dry	Rainy
	Temperature vs. NAO					
Comales	0.36	0.13	0.21	0.00	0.19	-0.07
El Barretal	0.05	-0.16	0.05	-0.30	-0.26	-0.30
San Fernando	0.27	0.23	0.14	0.22	-0.12	-0.40
San Gabriel	0.44	0.09	0.10	0.18	-0.20	-0.07
Tampico	0.10	0.22	0.20	0.10	-0.10	-0.50
	Precipitation vs NAO					
Comales	-0.13	-0.06	-0.08	-0.25	-0.32	0.20
El Barretal	0.13	0.21	-0.25	-0.04	0.14	0.24
San Fernando	-0.03	-0.16	0.06	0.17	0.11	0.07
San Gabriel	0.08	0.09	-0.02	0.11	0.29	-0.16
Tampico	0.23	0.03	-0.14	0.05	-0.21	-0.40
	Evaporation vs. NAO					
Comales	0.24	0.22	-0.01	-0.20	0.32	0.24
El Barretal	0.44	-0.14	0.06	0.19	0.30	0.13
San Fernando	0.14	0.33	-0.06	-0.01	0.31	-0.11
San Gabriel	0.11	0.33	-0.09	0.05	0.13	-0.27
Tampico	0.18	0.16	-0.02	0.05	0.28	0.12

* Comales ends in 1989.

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