Investigation note

## Use of a programming language for punctual detection of climate change for each season in Mexico

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## Abstract

The objective of this manuscript was to study with accuracy the point of change in temperature in each of the country's meteorological stations, if it exists, is extremely important to take the most appropriate mitigation measures. In Mexico there are different studies of changes in temperatures, their trends and their relationship with other variables such as geography, precipitation and vegetation. Among them we can mention those of Pavia *et al.* (2009) and Englehart and Douglas (2004) although in none of them has he used programming to be more exact in this determination.

Keywords: schedule, temperature, weather.

Reception date: October 2020 Acceptance date: November 2020 For the study of climate change, there are various databases with a large amount of information to determine temperature trends, which makes their management difficult. For this reason, in the present study programming using the visual basic high-level language for applications (VBA) was used for the management and analysis of information. Parametric statistical techniques such as Student's t (equal variances) and Student's t modified by Welch reported in Haan (2002) were also used to establish whether the difference of the means between the temperatures (maximum and minimum) of two time periods formed in each season is significant or not.

In the present study, to identify the exact year in which the greatest difference between the two periods occurred (before and after this year), programming in the high-level visual basic language for applications (VBA) that is integrated into Excel was used. Data of daily maximum and minimum temperatures were used from the approximately 5 400 meteorological stations of the National Meteorological Service (SMN) page from 1902 to 2012. Monthly averages of both temperatures were made using only the months that had 25 or more observations.

A database with 12 tables was generated, one for each month, where each record in each table represents a meteorological station and the fields are the monthly average temperature in each of the 110 years analyzed for the respective month. The records were refined using certain quality criteria, selecting only those records (meteorological stations) with a monthly average of at least 14 years. Remaining the 12 tables with a number of stations ranging from 3 800 to 3 900 depending on the month in each of the two types of temperatures (Table 1 and 2).

For each station, an interactive process was carried out to find out if in that particular station the maximum and minimum temperatures had changed. This process was the following for the first interaction of a station: the temperature observations were each divided into two periods, the first period formed by the temperatures of the first 5 years with data and the second with the rest of the data (at least 9). In this way, two representative samples of the temperatures of each of the periods were formed. Subsequently, the statistics necessary to compare both populations (size, mean and variance) to each of the samples were calculated and a test was carried out to find out if both samples came from populations with the same variance.

In the positive case, the Student's t-test methodology was used for populations with equal variances and in the negative case, the Welch methodology was applied, which is the same test, but using equation 1 for the degrees of freedom and equation 2 to get the test statistic ( $t_c$ ). Regardless of the case of both tests, the *p*-value was calculated, saving this value together with the test statistics and the threshold (year of division of the two periods).

For the second interaction, the two samples were formed as follows: the sample from the first period increased with the data from the first year of the sample from the second period, decreasing the size of the sample from the second period by one unit. Thus, formed the samples, the same methodology was applied that was used in the first interaction, again saving the statistics and the p-value. The described process became interactive where the last interaction was when the size of the second sample was five data points, which is the same size of the first sample in the first interaction.

At the end of the interactive process, the interaction with the lowest p-value was selected, which is the interaction in which the populations being compared present a greater significant difference, if there is one. In some stations there were several interactions where there was a significant difference, but the one where the statistical difference is greater between the two populations (lower p-value) was selected.

To find out if the populations are different, the value of the selected p-value was compared with

the level of significance ( $\alpha$ = 0.1); gl=  $\left[\frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\left(\frac{\left(S_1^2/n_1\right)^2}{n_1 - 1} + \frac{\left(S_2^2/n_2\right)^2}{n_2 - 1}\right)}\right]$  1); where: gl= degrees of freedom; S<sup>2</sup><sub>1</sub>= variance of sample 1; S<sup>2</sup><sub>2</sub> = variance of sample 2; n<sub>1</sub>= size of sample 1; n<sub>2</sub>= size of sample 2,

$$\begin{split} S^{2}_{1} = \text{ variance of sample 1; } S^{2}_{2} = \text{ variance of sample 2; } n_{1} = \text{ size of sample 1; } n_{2} = \text{ size of sample 2, } \\ Tc = \frac{Xm_{1} + Xm_{2}}{\sqrt{\frac{S_{1}^{2}}{n_{1}} + \frac{S_{2}^{2}}{n_{2}}}} \quad 2); \text{ where: } t_{c} = \text{test statistic; } Xm_{1} = \text{ arithmetic mean of sample 1; } Xm_{2} = \text{ arithmetic } n_{1} = 1; \\ Tc = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{1}} + \frac{S_{2}^{2}}{n_{2}}}} \quad 2); \text{ where: } t_{c} = \text{test statistic; } Xm_{1} = \text{ arithmetic mean of sample 1; } Xm_{2} = \text{ arithmetic } n_{2} = 1; \\ Tc = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{1}} + \frac{S_{2}^{2}}{n_{2}}}} \quad 2); \text{ where: } t_{c} = \text{test statistic; } Xm_{1} = \text{ arithmetic mean of sample 1; } Xm_{2} = \text{ arithmetic } n_{2} = 1; \\ Tc = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{1}} + \frac{S_{2}^{2}}{n_{2}}}} \quad 2); \text{ where: } t_{c} = \text{test statistic; } Xm_{1} = \text{ arithmetic mean of sample 1; } Xm_{2} = \text{ arithmetic } n_{2} = 1; \\ Tc = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{1}} + \frac{S_{2}^{2}}{n_{2}}}} \quad 2); \text{ where: } t_{c} = \text{test statistic; } Xm_{1} = \text{ arithmetic mean of sample 1; } Xm_{2} = \text{ arithmetic } n_{2} = 1; \\ Tc = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{1}} + \frac{S_{2}^{2}}{n_{2}}}}} \quad 2 = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{2}} + \frac{S_{2}^{2}}{n_{2}}}} \quad 2 = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{2}} + \frac{S_{2}^{2}}{n_{2}}}} \quad 2 = \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{2}} + \frac{S^{2}}{n_{2}} + \frac{S^{2}}{n_{2}} + \frac{S^{2}}{n_{2}} + \frac{S^{2}}{n_{2}} + \frac{S^{2}}{\sqrt{\frac{S_{1}^{2}}{n_{2}} + \frac{S^{2}}{n_{2}} + \frac{S^{2}}{n_{2}}$$

mean of sample 2;  $S^{2}_{1}$  = already defined;  $S^{2}_{2}$  = already defined.

In Figure 1 it is observed that the first screen of the computer system that was elaborated for the realization of this study has three options in which in its first option <br/>by station> you can see a list of all the almost 3 900 stations to which the mentioned statistical analysis is done. On the right side, you can see four columns. The first two columns would be year and monthly average temperature (of the corresponding month) of the first period compared. In the same way, it's had in the third (year) and fourth (monthly average temperature) columns, but for the second period compared.

Code Stati	ion.	State	Lonaitud	Latitud	Altitud	Clima	NumClima	Tit 🔺	Primer P	eriodo	Se		Periodo
	VILLO (SMN)	Ads.	-102.719		1640	SemiSecoSemiCalido(17)	17		Año	Temperatura	Añ	0	Temperatura
	ADA HONDA	Ags.	-102.198			SemiSecoTemplado(18)	18	ne	1932	25,381	<b>•</b>	1977	28,258
1005 PRE	SA EL NIAGARA	Ags.	-102.441			SemiSecoTemplado(18)	18	po	1933	27,613		1978	24,871
006 EL T	ULE (SMN)	Aqs.	-102.091	22.082	1960	SemiSecoTemplado(18)	18	po	1934	26,984		1979	26,532
	JS MÀRIA (SMN)	Ags.	-102.345			SemiSecoSemiCalido(17)	17	ne	1935	24,694		1980	27,694
	RTO DE LA CONCEPCION		-102.134			SemiSecoTemplado(18)	18	po	1936	25,919		1981	28,468
1010 LAT	ALANT	Ags.	-102.55€	22.165	2425	TempladoSubHumedo(20)	20	ne	1937	23,726		1982	24,371
011 MAL	PASO	Ags.	-102.663			SemiSecoSemiCalido(17)	17	po	1938	25,113		1983	27,468
012 PRE	SA MEDIA LUNA	Aqs.	-102.802			SemiSecoSemiCalido(17)	17	ne	1939	25,113		1984	28,806
013 MES	ILLAS	Ags.	-102.168	22.315	1990	SemiSecoTemplado(18)	18	po	1940	25,419		1985	26,581
014 PABE	ELLON CAMPO EXPERIMEN	N Ags.	-102.292	22.163	1900	SemiSecoTemplado(18)	18	ne	1941	24,452		1986	26,484
015 PALC	O ALTO	Aqs.	-101.969	21.916	2020	SemiSecoTemplado(18)	18	po	1942	26,935		1987	27,355
016 GAN	ADERIA PEÃ'UELAS	Ags.	-102.282	21.711	1850	SemiSecoSemiCalido(17)	17	ne	1943	24,435		1988	28,952
017 PRE	SA POTRERILLO	Ags.	-102.416	22.231	2110	SemiSecoTemplado(18)	18	ne	1944	25,177			
018 PRE	SA PLUTARCO ELIAS CAL		-102.416	22.142	2050	SemiSecoTemplado(18)	18	po	1945	26,855			
019 PRE	SA JOCOQUI	Ags.	-102.354	22.121	2030	SemiSecoTemplado(18)	18	po	1946	25,306			
1020 PRES	SA LA CODORNIZ	Ags.	-102.675	21.996	1820	SemiSecoTemplado(18)	18	po	1947	24,274			
021 RAN	CHO VIEJO	Ags.	-102.513	22.125	2110	SemiSecoTemplado(18)	18	po	1948	28,339			
1022 SAN	BARTOLO	Ags.	-102.184	21.739	1970	SemiSecoSemiCalido(17)	17	ne .	1949	27,177			
1023 CAL\	VILLO (DGE)	Ags.	-102.719	21.846	1640	SemiSecoSemiCalido(17)	17	ne 🔻	1954	26,726			
	. ,	5						•	1955 1956	26,5 26,29			
	CALVILLO (SMN)								1957 1958	27,032 23,742			
	CALVILLO (SMN)								1959 1961	25,403 25,265			
		Periodo 1	Periodo 2		ESTA	DÍSTICAS			1962 1963 1964	25,229 23,177 24,139			
	n	38	12	•	TOTAL	DE DATOS	50	<b></b>	1966	24,6			
	Media	25.55	27.15			E MEDIAS(P2-P1)	1.61		1967	25,687			
									1969	25,903			
	Varianza	1.52	2.13		VALOR	DE Tc	3.77		1970	25			
	DESV. EST.	1.23	1.46	-	GRADO	OS DE LIBERTAD	48		1971	25,619			
	0101.101.	1.20	1.10		P-VAL		.00045		1972	27,919			

**Figure 1. First screen of the computer program developed for the present study.** The stations of the two periods compared and some statistics for each of them are presented. In addition, the statistics of the test with a lower *p*-value.

In the lower left corner a table is presented in which some statistics of the average temperature data are presented in the selected station of the two periods that are being compared, such as n (number of observations), mean, variance, standard deviation of each of the periods compared. The last table of this screen shows the statistics of the test used in the comparison, such as the total data, DIF of means (P2-P1) (difference of means between the two periods, value of tc (the value of the test statistic), degrees of freedom, *p*-value, year of change (exactly the year in which the change occurs where the means present the greatest statistical difference).

The program also presents the option to analyze the temperatures of the stations grouped by state (Figure 2). In the menu on the right of Figure 2, the list of states that make up Mexico is presented, from which any of them can be selected. When selecting the system, it presents the list of weather stations that the state has that can be seen in the middle box.

NÚMERO	ESTADOS	Abreviacion		Code	Station	State	Longitud 🔺	CAMPTO		DODOCHITAN
1	Aguascalentes	Ags.		1003	CALVILLO (SMN)	Ags.	-102.719	CAMBIO	NUM	PORCENTAJ
2	Baja California	B.C.		1004	CAÃ'ADA HONDA		-102.198	SE CALENTARON	32	50.79
3	Baja California Sur	B.C.S.		1005	PRESA EL NIAGAF		-102.441	SE ENFRIARON	18	28.57
4	Campeche	Camp.		1006	EL TULE (SMN)	Ags.	-102.091			
5	Chiapas	Chs.		1007	JESUS MARIA (SM		-102.345	PERMANECIERON IGUAL	13	20.63
6	Chihuahua	Chih.		1008	PUERTO DE LA CI	Ags.	-102.134	TOTAL	63	100.00
7	Ciudad de México	D.F.		1010	LA TINAJA	Ags.	-102.556	1		
8	Coahuila de Zaragoza	Coah.		1011	MALPASO	Ags.	-102.663			
9	Colima	Col.		1012	PRESA MEDIA LUI	Ags.	-102.802			
10	Durango	Dgo.		1013	MESILLAS	Ags.	-102.168			
11	Estado de México	México		1014	PABELLON CAMP(	Ags.	-102.292			
12	Guanajuato	Gto.		1015	PALO ALTO	Ags.	-101.969			
13	Guerrero	Gro.		1016	GANADERIA PEÃ`I	Ags.	-102.282			
14	Hidalgo	Hgo.		1017	PRESA POTRERIL		-102.416			
15	Jalisco	Jal.		1018	PRESA PLUTARCO	Ags.	-102.416			
16	Michoacán de Ocampo	Mich.		1019	PRESA JOCOQUI	Ags.	-102.354			
17	Morelos	Mor.		1020	PRESA LA CODOF	Ags.	-102.675			
18	Nayarit	Nay.		1021	RANCHO VIEJO	Ags.	-102.513			
19	Nuevo León	N.L.		1022	SAN BARTOLO	Ags.	-102.184			
20	Oaxaca	Oax.		1023	CALVILLO (DGE)	Ags.	-102.719			
21	Puebla	Pue.		1024	SAN ISIDRO	Ags.	-102.158			
22	Querétaro	Qro.		1025	SAN FRANCISCO	Ags.	-102.271			
23	Quintana Roo	Q.R.		1026	TEPEZALA	Ags.	-102.169			
24	San Luis Potosí	S.L.P.		1027	VENADERO (DGE)	Ags.	-102.46			
25	Sinaloa	Sin.		1028	VILLA JUAREZ	Ags.	-102.067			
26	Sonora	Son.		1029	ASIENTOS	Ags.	-102.089			
27	Tabasco	Tab.		1030	AGUASCALIENTES	Ags.	-102.31			
28	Tamaulipas	Tamps.		1031	EL NOVILLO	Ags.	-101.999			
29	Tlaxcala	Tlax.		1032	LAS FRAGUAS	Ags.	-101.894			
30	Veracruz de Ignacio de la	Ver.	-	1033	LOS CONOS	Ags.	-102	1		
	-			1034	SANDOVALES	Ags.	-102.341	Terminar		
				1041	PABELLON DE AR	Ags.	-102.283			
				1045	EL TULE (DGE)	Ags.	-102.093			
				1046	LA LABOR (DGE)	Ags.	-102.693 🔻			
				4		-	•			

**Figure 2. Second screen of the computer program developed for the present study.** A menu of the list of states that make up the country Mexico is presented, from which any of them can be selected and it presents the list of stations of the selected state (list in the middle) and the number and percentage of stations that were heated, cooled and they remained the same, in addition to the totals.

In the table on the right, you can see the most important statistics of all the stations, such as how many stations were heated and their percentage, how many cooled and their percentage and how many remained the same and their percentage, as well as the total of each one of them. the above. It was found that the two states where there is a higher percentage of stations that warmed up are Michoacán de Ocampo (60.45%) and Quintana Roo (60.53%). In the two states where there is a higher percentage of stations that cooled down are Durango (46.9%) and Quintana Roo (47.62%).

In addition, you have the option of analyzing the temperatures of the stations for each one of the existing climatological zones in Mexico (Figure 3). Choosing one of the zones in the menu on the left of Figure 3 displays the list of stations that belong to that zone (in the middle box). In the table on the right you can see the statistics that have already been explained for Figure 2 but by climatological zone.

Por Estado Por Zona Climatológica					
NUMERO ZONAS CLIMATOLÓGICAS	Code 4024	Station State PALIZADA Camp.	L( ▲	CAMBIO	NUM PORCENTAJE
2         Cald/dSubHumedo(2)           3         Frio(3)           4         MuySecoCaldo(4)           5         MuySecoCaldo(4)           6         MuySecoCaldo(5)           6         MuySecoCaldo(6)           7         MuySecoCaldo(6)           8         SecoCaldo(8)           9         SecoCaldo(8)           10         SecoSemiCaldo(10)           11         SecoSemiCaldo(10)           12         SemiCaldoHumedo(12)	4024 4056 4079 7004 7005 7014 7017 7018 7020 7020 7022 7029 7038	PALZAUM MCLINO CHUMPA Camp. VISTA ALEGRE Camp. AGUA AZUL Chs. ALMANDRO (CFC; Chs. BELISARD DOMIT Chs. BONAMPAK Chs. CACHOATAN Chs. VERTEDOR 1-2-3 Chs. PLAYAS DE CATA Chs. CHAJUL Chs. DESPOBLADO Chs.	-9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -9 -	SE CALENTARON SE ENFRIARON PERMANECIERON IGUAL TOTAL	114 50.89 60 26.79 50 22.32 224 100.00
13         SemicaldoSubHumedo(13)           14         SemirloSubHumedo(14)           15         SemiSecoCaldo(15)           16         SemiSecoMuyCaldo(16)           17         SemiSecoOm(addo(17))           18         SemiSecoTemplado(18)           19         TempladoHumedo(19)           20         TempladoSubHumedo(20)           21         Otras(21)	7043 7044 7046 7047 7048 7052 7053 7056 7056 7058	EL CEDRO Chs. EL COLORADO (C Chs. EL EUSEBA (OFE) Chs. EL JABALI (CFE) Chs. FINCA EL TRUINF Chs. EL ZAPOTAL (CFE Chs. ESCUINTA (DGE Chs. FINCA CHIRIPA Chs. EL PERU Chs.	-9 -9 -9 -9 -9 -9 -9 -9 -9		
	7064 7071 7072 7077 7079 7081 7084 7085 7089 7105	FINCA MORELIA Chs. GUAQUITEPEC Chs. HACTENDA LAS M Chs. HULXTLA Chs. ROSARIO IZAPA (Chs. D/CAN Chs. JESUS CHIAPAS Chs. PALENQUE (DGE) Chs. LA CATARATA (CI Chs. LAS NUBES Chs.	-9 -9 -9 -9 -9 -9 -9 -9 -9 -9		Terminar
	7106	LAS PEÄTTAS Chs.	-9 <b>v</b>		

**Figure 3. Third screen of the computer program developed for the present study.** A menu of the list of climatological zones that make up the country Mexico is presented, from which any of them can be selected and it presents the list of stations in the selected area (list in the middle) and the number and percentage of stations that were heated, cooled and they remained the same, in addition to the totals (list to the right).

It was found that the two climatological zones where there is a higher percentage of stations that warmed up are the cold zone (66.67%) although there are only three seasons in this zone and the temperate subhumid zone (53.65%). And the two areas where there is a higher percentage of stations that cooled down are very dry, very warm (100%), although there is only one station in this area and very warm semi-dry Quintana (47.27%).

Referring to global statistics, 80% of the stations analyzed throughout Mexico (between 3 800 and 3 900 depending on the month) there was a significant change in both the maximum and minimum temperatures. In the analysis of maximum temperatures, in all months there was a marked predominance of the stations where there was a significant increase over those that had a decrease. In the analysis of the minimum temperatures, the opposite occurred. In almost all months (with the exception of January and February) the seasons where there was a significant decrease in temperatures predominated (Table 1).

	Ν	Maximum tem	peratures		Minimum temperatures					
Month	Increase	Decrement	Without changes	Total	Increase	Decrement	Without changes	Total		
January	1 805	1 229	792	3826	1 579	1 576	724	3879		
February	1 952	1 120	804	3876	1 665	1 367	842	3874		
March	1 954	1 167	764	3885	1 529	1 564	792	3885		
April	1 895	1 182	805	3882	1 372	1 730	778	3880		
May	2 048	1 093	740	3881	1 491	1 710	681	3882		
June	2 0 2 5	1 071	786	3882	1 488	1 713	682	3883		
July	2 157	1 143	587	3887	1 539	1 664	682	3885		
August	2 098	1 163	622	3883	1 609	1 651	623	3883		
September	1 962	1 170	758	3890	1 521	1 658	708	3887		
October	1 975	1 180	718	3873	1 443	1 551	881	3875		
November	1 843	1 253	757	3853	1 273	1 687	890	3850		
December	1 805	1 229	792	3826	1 142	1 888	794	3824		

 Table 1. Number of total stations for each month where there was an increase, a decrease and where there was no significant change in the maximum and minimum temperatures.

## Conclusions

A significant change in temperatures (maximum and minimum) was identified in approximately 80% of the more than 3 800 stations analyzed. At maximum temperatures, more seasons have a significant increase than those with a decrease, in all months of the year. For the minimum temperatures there was a contrary trend, since in almost every month (with the exception of January and February) there were more stations that suffered a decrease in temperature.

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