REGIONAL MODES OF VARIABILITY OF ANNUAL MEAN AIR TEMPERATURE OVER MEXICO

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ABSTRACT

There are only a few studies that have recently been made assessing regional variability of mean temperature in Mexico. Nevertheless, none of them has fully considered the complex climatic variability of the country. A different approach has been used here with a set of 49 climatological stations containing long-term and high-quality annual Air Surface Mean Temperature (ASMT). Principal Component Analysis (PCA) was applied using an oblique-rotated solution (Promax, kappa=2) to an S-mode configuration. The analysis of the annual gradients of the standardized anomalies of the dataset, has successfully extracted six clear groups of stations that vary coherently through time. The ASMT climatic regionalization show great geographic consistency with the Mexican climatology. The PCA defined climatic regions also highlights the important influence of the orography of Mexico.

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INTRODUCTION

There is now unequivocal evidence from surface temperature observations of a warming of the climate system. Despite remaining uncertainties, it is now clear that the upward trend of global averaged temperatures during the 20th century can be partially attributed to an anthropogenic origin; especially changes in the greenhouse gas concentrations (IPCC, 2007). These climatic variations have been recorded in observations of air and ocean temperatures, ice cores, glaciers, and increasing sea levels. With some geographical variations, all their average conditions testify to geographically widespread increasing temperatures.

Certainly, one of the arguments of the skeptics against global warming is the spatial inhomogeneity of the changes of the parameters that measure climate change across the world, like temperature (Soon et al., 2003). The largest percentage of the meteorological data, comes from mid-latitude developed countries (Vose et al., 2005).There is a real necessity to gather information from developing countries to complete the picture for global surface climate. It is only recently that more extensive climatic information from these regions has been added to the global databases. Among these developing countries there is a great interest in the transition regions between tropical and extra-tropical climatic conditions. Mexico is one of those countries that encompass a rich variety of climatic regions within its territory; being a bridge between tropical and temperate latitudes that reflects a broad distribution of climatic regimes. The advent of new computing technologies opened a number of opportunities in almost every research area; enabling the bulk of the instrumental data (meteorological variables) in Mexico to be digitized (Salas-Flores, 2008).

There are only a few studies in which PCA has been applied to the climate of México. Amongst the many meteorological variables, precipitation has been more consistently explored using Principal Components (Comrie and Glenn, 1998; Englehart and Douglas, 2002; Salas-Flores, 2008) than temperature (Englehart and Douglas, 2004). This situation has been slowly changing for both parameters since the release of digital databases in the early 1990s. Even, for rainfall the studies lack the best possible (in terms of completeness and homogeneity) coverage at both the temporal or spatial scale. Englehart and Douglas (2004) have assessed a network with monthly mean air surface temperature (1941-2001) using PCA with an oblique-rotated solution. Their results show four climatically coherent regions for the entire Mexican territory. They have also observed that monthly persistence is stronger during the warm season of the year compared to the cold season. They have also explored possible ENSO modulation for temperature, but found no clear response except for the southern region of the country. Although, the lack of PCA studies using temperature is being improved due to the recent release of digital climatic databases, the number and spatial coverage of temperature stations is reduced when compared with those available of precipitation. This condition can be explained as result of the Mexican post-revolutionary economic era before the 1980s which was partially linked to agriculture (Liverman and O’Brien, 1991), and therefore the precipitation pattern changes were more important than those for temperature. The meteorological network developed more towards rainfall measurements during the early instrumental periods, instead of developing simultaneously with other climatological variables like temperature.

METHODOLODY AND DATABASES

A database of 49 stations containing annual Air Surface Mean Temperature (ASMT) from 1941 to 2001 was prepared. Except for those located across the northern border in the southern USA, all were processed from daily data. In order to perform a data quality analysis, the extracted time-series were compared with the climatological normals calculated by García (1988), basic statistical parameters were also computed and double-mass plots (Cluis, 1983) were prepared with the objective of detecting possible spurious values within the databases. Finally, standardized (based on the overall 1941-2001 period of the records) annual anomalies (Jones and Hulme, 1996) were calculated for each one of the time-series, with the purpose of avoiding contrasting climatic conditions across the country and also the large influence that altitude can exert for some locations in this study. After the above described procedure was ready, time-gradients or annual First Difference (FD) series (Peterson et al., 1998) were computed to the time-series of the standardized anomalies, i.e., the 1941 standardized anomaly was subtracted to the corresponding 1942, then the 1942 value to the 1943 one, and so on. The main underlying hypothesis is that the standardized annual FD preserve important inertial energy changes in comparison with only using the standardized anomalies of the stations in the ASMT.

The aim of applying PCA to this climatological network was to find different groups of stations that vary coherently across time. In the context of PCA simple rotation theory, the S-mode is only one of six different matrix configurations, in which the stations are the columns versus time that are the rows in the array. The principal significant feature of the S-mode is that is the most convenient configuration for regionalization purposes.

In the early developments of PCA, unrotated techniques were the only possible option to reduce the high dimensionality of a dataset. Unrotated solution techniques, as pointed by Richman (1986) are only suitable for application to those cases when weak simple structures are present and the PCs extracted have both positive and negative correlations throughout all the field of study. For this reason, although explored, unrotated techniques were explicitly disregarded in the present research.

Orthogonal rotated solutions used to extract PCs, often allow easier interpretation than the original variables by reducing their dimensionality but conserving the highest possible variance, and therefore their most relevant characteristics. Orthogonal methods try to define “important” components as those with the maximum absolute loadings, and are separated from the lowest ones. Loadings with moderate values (not easy for interpretation) are explicitly avoided.

Orthogonality is sometimes considered as a non-natural approach constraining the solution. Oblique (non-orthogonal) rotated solutions represented an alternative answer to unrotated and orthogonal solutions in PCA. Oblique methods like OBLIMIN or PROMAX try to define clusters and associate them precisely to only one component. This characteristic is frequently linked to the process of clarifying the interpretation when compared with orthogonal rotated solutions. In atmospheric sciences, oblique rotations are sometimes preferred to orthogonal solutions for their advantages in the interpretation of the results (Englehart and Douglas, 2002). DIRECT OBLIMIN has been frequently used amongst oblique rotations. Nevertheless, PROMAX permits clearer results in meteorology when a network with a large number of stations and high grade of complexity are found (Richman, 1986). Therefore, Promax (kappa=2) were used to regionalize the temperature patterns across the country.

	STATION NAME	STATE	SMN ID	LONGITUDE	LATITUDE	ALTITUDE*
1	PRESA CALLES	AGS	01018	-102.43	22.13	2025
2	PRESA RODRIGUEZ	BCN	02038	-116.90	32.45	100
3	ENSENADA	BCN	02072	-116.60	31.88	24
4	COMONDú	BCS	03008	-111.85	26.08	260
5	EL PASO DE IRITU	BCS	03012	-111.12	24.77	140
6	LA PURíSIMA	BCS	03029	-112.08	26.18	95
7	SAN BARTOLO	BCS	03050	-109.85	23.73	395
8	SANTA GERTRUDIS	BCS	03060	-110.10	23.48	350
9	SANTA ROSALíA	BCS	03061	-112.28	27.30	17
10	SANTIAGO	BCS	03062	-109.73	23.47	125
11	MANZANILLO	COL	06018	-104.32	19.05	3
12	MOTOZINTLA	CHIAP	07119	-92.25	15.37	1455
13	EL PALMITO	DUR	10021	-104.78	25.52	1540
14	EL SALTO	DUR	10025	-105.37	23.78	2538
15	GUANACEVI	DUR	10029	-105.97	25.93	2200
16	RODEO	DUR	10060	-104.53	25.18	1340
17	SANTIAGO PAPASQUIARO	DUR	10100	-105.42	25.05	1740
18	IRAPUATO	GTO	11028	-101.35	20.68	1725
19	OCAMPO	GTO	11050	-101.48	21.65	2250
20	PERICOS	GTO	11052	-101.10	20.52	1720
21	SALVATIERRA	GTO	11060	-100.87	20.22	1760
22	SALAMANCA	GTO	11096	-101.18	20.57	1723
23	CUITZEO DEL PORVENIR	MICH	16027	-101.15	19.97	1831
24	HUINGO	MICH	16052	-100.83	19.92	1832
25	ZACAPU	MICH	16171	-101.78	19.82	1986
26	AHUACATLAN	NAY	18002	-104.48	21.05	990
27	EL CUCHILLO	NL	19016	-99.25	25.73	145
28	LAMPAZOS	NL	19028	-100.52	27.03	320
29	MATIAS ROMERO	OAX	20068	-95.03	16.88	201
30	SANTO DOMINGO TEHUANTEPEC	OAX	20149	-95.23	16.33	95
31	TEZIUTLAN	PUE	21091	-97.35	19.82	2050
32	MATEHUALA	SLP	24040	-100.63	23.65	1575
33	BADIRAGUATO	SIN	25110	-107.55	25.37	230
34	TRES HERMANOS	SON	26102	-109.20	27.20	100
35	SAN FERNANDO	TAM	28086	-98.15	24.85	43
36	ATZALAN	VER	30012	-97.25	19.80	1842
37	RINCONADA	VER	30141	-96.55	19.35	313
38	LAS VIGAS	VER	30211	-97.10	19.65	37
39	EL SAUZ	ZAC	32018	-103.23	23.18	2100
40	BROWNSVILLE	TX	BWVTX	-97.40	25.80	
41	SAN ANTONIO	TX	SATTX	-98.50	29.50	
42	MIDLAND	TX	MAFTX	-102.20	32.00	
43	EL PASO	TX	ELPTX	-106.40	31.80	
44	TUMBSTONE	US	TSTUS	-110.10	31.70	
45	TUCSON	AZ	TUSAZ	-110.90	32.10	
46	PHOENIX	AZ	PHXAZ	-112.00	33.40	
47	SAN DIEGO	CA	SANCA	-117.20	32.70	
48	CUYAMACA	CA	CYCCA	-116.60	33.00	
49	LOS ANGELES	CA	LAXCA	-118.20	34.10	

Table 1. List of stations with monthly mean temperature. The period of the records for all the stations is from 1941 to 2001. * meters above sea level.

Several studies have assessed the performance of single methods, or contrast the competence of a number of different techniques, but there is no consensus on the best method to determine the most significant number of principal components (Peres-Neto et al., 2005; Al-Kandari et al., 2005). Because of the size and complexities of the datasets, a PCA graphical tool called the Scree Test is used in this study. The component numbers are the abscissa in the plot and their corresponding eigenvalues the ordinates. The plot is seen as a mountain in which the slope is formed by the "true number" of factors containing most of the variance, and the tail by the random components. Therefore, the foot of the mountain or scree straightens closely matching a line at the end of the plot. The aim is to find the last evident break before the variance between components becomes negligible (Cattell, 1966). The low-order PCs before this point of inflexion are then considered as the most relevant and meaningful for the study.

RESULTS

PCA resulting regions show both a geographical and also a climatic consistency. The clusters obtained with this technique are in accordance with the complexity of the mexican climatic regions described by Mosiño and García (1974) and, also, because they are similar, we have adopted the description proposed by Salas-Flores (2008) for the resulting annual precipitation regions (table 2). It was not possible to assign one PC to every station, very likely because of the important influence of the missing data on some of the time-series.

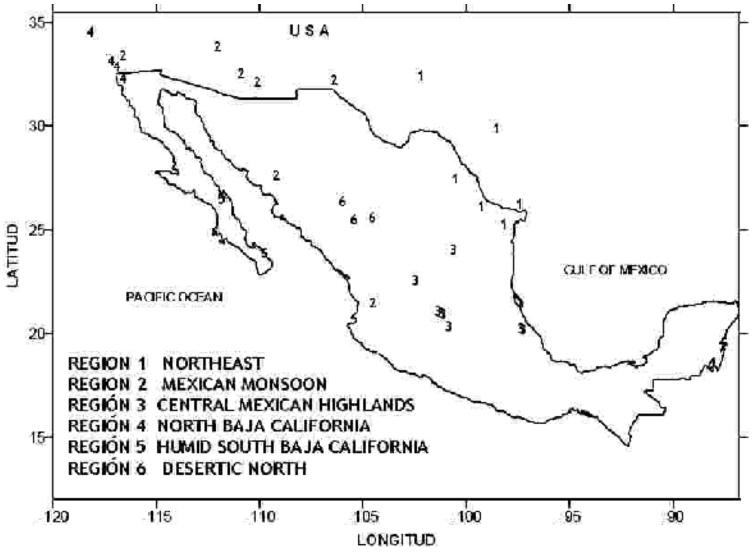

Figure 1. Climatic regionalization applied to a set of 49 stations containing annual mean temperature using Principal Component Analysis (PCA, Promax, kappa=2).

The limited spatial density of the temperature records has led to a concentration of the results on central and northern of Mexico, due to the small number of southern stations included in this study, because of their large percentage of missing data; but the stations on the USA side have help in the clarification of three interesting climatic regions -in accordance with those obtained by Salas-Flores (2008) for the annual precipitation- that are: the Northeast, the Mexican Monsoon, and the north Baja California regions. The PCA resulting region on the Central Mexican Highlands, show us that, despite trying to avoid it explicitly, the orography factor (all the stations are located at a considerable altitude) plays a main role in large regions of the Mexican Republic.

Component	Associated region	Climatic characteristics
Region one (RA1)	Central Mexican Highlands	Trends in summer, monsoon from the Pacific, summer rainfall, two temperature maxima
Region two (RA2)	Gulf of Mexico coast	Trends in summer, hurricanes in summer and autumn, polar fronts in winter, two temperature maxima.
Region three (RA3)	Northeast	Trends in summer, polar fronts in winter, hurricanes in summer and autumn, one temperature maximum.
Region four (RA4)	Desertic north, New Mexico and Texas	Little moisture sources, arid regions, one temperature maximum
Region one (RA5)	Humid south Baja California	Summer monsoon, hurricanes y summer and autumn.
Region six (RA6)	North Baja California	Westerlies, winter precipitation, one temperature maximum.
Region seven (RA7)	La Huasteca	Summer precipitation, hurricanes in summer and autumn, polar fronts.
Region eight (RA8)	Desertic south Baja California	Westerlies, one temperature maximum
Region nine (RA9)	Southeast rainforest	InterTropical Convergence Zone (ITCZ), southeastern trades, hurricanes in summer and autumn, two temperature maxima.
Region ten (RA10)	South Pacific coast	InterTropical Convergence Zone (ITCZ), southeastern trades, hurricanes in summer and autumn, low winter precipitation, two temperature maxima.
Region eleven (RA11)	Mexican Monsoon	Summer rainfalll, westerlies, hurricanes in summer and autumn, one temperature maximum.

Table 2. PCA resulting climatic regions for annual total precipitation (tabla taken from Salas-Flores, 2008) using Principal Component Analysis, in accordance with the resulting regions for the annual for annual Air Surface Mean Temperature.

CONCLUSIONS

The PCA resulting climatic regionalization for the annual First Difference (FD) series (Peterson et al., 1998) of the standardized anomalies of the Air Surface Mean Temperature, shows great consistency with the Mexican climatology (Mosiño and García, 1974; García, 1988). The six climatic regions successfully extracted using PCA, have a clear geographic correspondence with the complex climatic variability of the country.

The groups of stations that vary coherently also have a great correspondence with their large-scale atmospheric controls, such as the ENSO for the north Baja California or hurricanes for the humid south of Baja California. Another important outcome of this study is the important influence of the orography on the climate of Mexico, being one interesting case the Mexican Central Highlands (Region 1 in Table 2). Improvement of the spatial density of the network of instrumental data is necessary for future research, and to explore other seasonal alternatives on mean temperature too. Finally, this study has led to an important advance for a meteorological parameter on which, until today, had been difficult to obtain clear climatic results.

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