Weather signature of "El Niño" in western Mexico

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RESUMEN

Se investiga la manifestación de la señal de El Niño en los campos de temperatura y precipitación en las estaciones de Guadalajara, Manzanillo, Guanajuato, Mexicali y Ensenada. Tal manifestación es también investigada en el nivel del lago de Chapala. El nivel del lago sirve como un indicador de los procesos integrales en temperatura y precipitación en el territorio de la cuenca Lerma-Chapala. Los espectros normalizados de la fluctuación de la temperatura y precipitación manifiestan claramente picos de densidad espectral con períodos de 0.5 a 22 años, los cuales superan el 90% del nivel de confianza. Dentro de este rango, los períodos de 2 a 7 años se relacionan con El Niño, y los períodos de 9 a 22 años están relacionados con la influencia solar. La investigación de la señal de El Niño 1998 en la Zona Metropolitana de Guadalajara fue realizada con mayor detalle usando los valores horarios de temperatura, humedad relativa, dirección y velocidad del viento. En los años de El Niño el campo de la temperatura y la humedad relativa superó en gran medida el número diario de horas en que la temperatura fue mayor de los 25°C; sin embargo, los valores de la humedad relativa fueron inferiores al 30%. En el campo de temperatura tal efecto es observado con mayor claridad desde principios de marzo de 1998. Para el campo de la humedad relativa el fenómeno se observa desde finales de enero del mismo año. Durante este mismo periodo se registró una estabilidad en la dirección del viento con un rumbo Oeste-Norte-Oeste y un aumento de la velocidad del viento de hasta 9 m/s.

PALABRAS CLAVE: El Niño, temperatura, precipitación, análisis espectral.

ABSTRACT

The study focuses on the signature of "El Niño" on temperature and precipitation in Guadalajara, Manzanillo, Guanajuato, Mexicali and Ensenada, Mexico. The water level of Lake Chapala reflects to some extent the integral processes in temperature and precipitation within the Lerma-Chapala watershed. Hidden periodicities in the monthly time series included peaks of 0.5 to 22 years in the normalized spectra of temperature and precipitation oscillations, with confidence limit above 90%. Within the 2-22 years range, the periods of 2 to 7 years can be related to "El Niño" phenomenon. The periods of 9 to 22 years may be related to solar influence. Hourly measurements of temperature, relative humidity, speed and wind direction were used to study "El Niño" in Guadalajara. During "El Niño" year, there were a large number of hours recording temperatures over 25°C. Higher than normal temperatures were recorded from the beginning of March 1998. Low humidity values, less than 30%, were evident from late January till June of the same year. During this time, the wind showed a West-North-West steady direction, with speeds of up to 9 m/s.

KEY WORDS: "El Niño", temperature, precipitation, spectral analysis.

1. INTRODUCTION

Since the 1982-1983 "El Niño" event, a wide range of ocean/atmosphere effects was recorded at local, regional and global scales (Xiao-Hai, 1997; Shaffer *et al.* 1997; Ambrizzi *et al.* 1998; Magaña *et al.* 1998; Strub *et al.* 2000). Some of "El Niño" studies have been conducted in Mexico by Cavazos *et al.* (1990), Tejeda, (1993), Florescano *et al.* (1995), and Sánchez-Sesma *et al.* (1998). Reports deal with intense droughts in northern Mexico and floods in southern Mexico, both related to "El Niño". Cavazos (1994) also looked at the oscillations of regional climate and "El Niño". Other studies by De la Lanza *et al.* (1989) and by Filonov *et al.* (2000) investigated the signature of "El Niño" in the coastal waters of the Mexican Pacific. Mosiño *et al.* (1998), Cavazos (1994),

Luyando *et al.* (1998), and Magaña *et al.* (1999) studied the interaction between "El Niño" and synoptic systems in Mexico.

2. DATA

Time series, ranging in length from 49 to 142 years, were obtained from six cities in western Mexico between the latitudes of 19°N to 32°N (Figure 1). The series consist of annual and monthly means of air temperature and precipitation. We also investigated the water level oscillations of Lake Chapala, which are a good indicator of integral processes occurring in the fields of temperature and precipitation within the Lerma-Chapala watershed. In addition, information from the eight ANAM (Automatic Network of
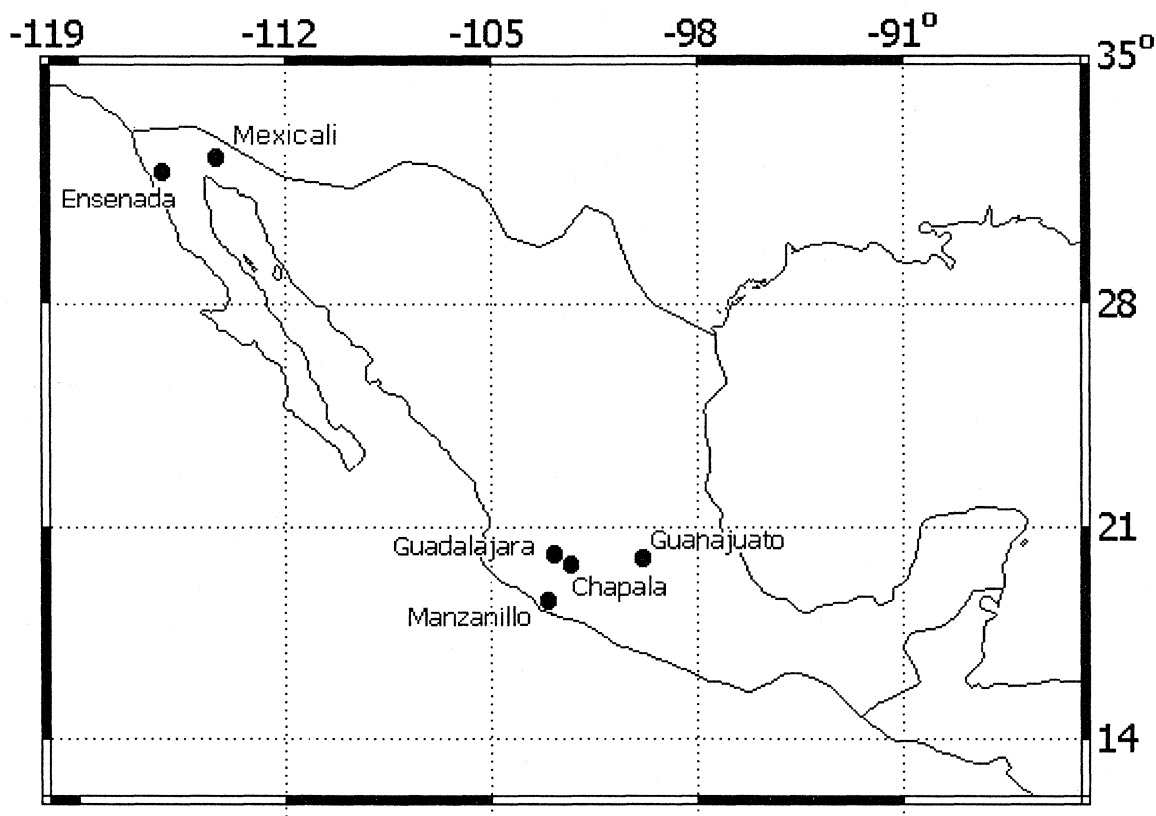
Fig. 1. Location of the meteorological stations.

Atmospheric Monitoring) stations in the city of Guadalajara was also used in the study. The latter belong to the state government and consist of hourly measurements of air temperature, relative humidity, and speed and direction of the wind from January 1996 to December 1998. The monthly curves of meteorological parameters were calculated from such data. The details of the time series used in this study are shown in Table 1.

3. METHODOLOGY

Spectral analysis was used to identify periodicities hidden in the analysed time series, including possible oscillations due to "El Niño". All time series checked to find data discontinuities or outliers using the procedure of Jones *et al.* (1985). The spectra of the amplitudes were estimated for all time periods (Jenkins *et al.* 1969; Konyaev, 1990) as follows:

$$C_x(\omega) = \int_0^{T_r} x(t) \cdot \exp(-i2\pi\omega t)dt, \qquad (1)$$

where x (t) is the time series; T is the total length of the series; ω is the frequency; t is the time and $i = \sqrt{-1}$. The

autospectral density function S_{xx} (ω) and the cross-spectral density function S_{xy} (ω) are defined as

$$S_{xx}(\omega) = \frac{1}{T}C_x(\omega) \cdot C_x^*(\omega), \qquad (2)$$

$$S_{xy}(\omega) = \frac{1}{T}C_x(\omega) \cdot C_y^*(\omega) = P_{xy}(\omega) - iQ_{xy}(\omega). \qquad (3)$$

Here P_{xy} (ω), Qxy(ω) are the real and imaginary parts of the cross-spectral density function; (*) is the complex conjugate. Spectral estimates were obtained by smoothing the spectral functions (2) and (3) over frequency:

$$\hat{S}_{xx}(\omega) = \int_{-\Delta\omega/2}^{+\Delta\omega/2} S_{xx}(\omega')Z(\omega-\omega')d\omega', \qquad (4)$$

where $Z(\omega)$ is a smoothing function and $\Delta\omega$ is the width of the smoothing band.

Coherence function estimates for pairs of time series were calculated as

Table 1

The characteristics of the data

NAME OF THE	COORDENATES		AIR TEMPERATURE (°C)		PRECIPITATION (mm)		RELATIVE HUMIDITY (%)		WIND SPEED(m/s) and DIRECTION (grad)		LAKE LEVEL (M)	
STATION	Latitude N	Longitude W	Years	Discretization	Years	Discretization	Years	Discretization	Years	Discretization	Years	Discretization
MEXICALI	32° 40'	115° 27'	1921-988	Monthly[1]	x	x	x	x	x	x	x	x
ENSENADA	31° 50'	116° 38'	x	x	1894-1994	Monthly[1]	x	x	x	x	x	x
GUANAJUATO	21° 01'	101°15'	x	x	1864-1996	Annual[1]	x	x	x	x	x	x
GUADALAJARA (IAM)	20° 41'	103° 23'	1900-1998	Monthly[2]	1904 -1998	Monthly[2]	x	x	x	x	x	x
GUADALAJARA (ANAM)	20° 41'	103° 23'	1996-1998	Hourly[3]	x	x	1996-1998	Hourly[3]	1996-1998	Hourly[3]	x	x
LAKE CHAPALA (CENTER)	20° 20'	102° 50'	1934-1998	Monthly[1]	1934-1998	Monthly[1]	x	x	x	x	1900-1998	Monthly[1]
MANZANILLO	19°05'	104°20	1941-1990	Monthly[1]	x	x	x	x	x	x		

[1] National Commission of Water.
[2] Institute of Astronomy and Meteorology of the University of Guadalajara.
[3] Jalisco State's Secretariat of Environment and Sustainable Development.

$$C^2_{^\circ xy}(\omega) = \frac{\left|\hat{S}_{xy}(\omega)\right|^2}{\hat{S}_{xx}(\omega) \cdot \hat{S}_{yy}(\omega)} \qquad (5)$$

and their phase difference as

$$\Delta\varphi_{xy}(\omega) = arctg\left(\hat{Q}_{xy}(\omega)/\hat{P}_{xy}(\omega)\right) \qquad (6)$$

From the values of the spectral density, the mean square amplitudes of the harmonics of the dominant peaks in the spectra were found.

4. RESULTS AND DISCUSSION

Spectra of temperature and precipitation of all stations show peaks at 0.5 to 11 years with a confidence limit of 90% (Figure 2, 3 and 4). Annual and semi-annual periods peaks of spectral density as well as high frequency overtones, are clearly shown in the figures. High spectral density peaks relate to "El Niño" variations, i.e. period of 2 to 7 years; and to periods of solar activity, i.e. 11 years. In the literature, the oscillations with periods of 8-11 years are known as half the Haley cycle and are related to the magnetic polar activity of solar spots. According to some authors, such variation of periodicity can differ strongly from the mean value of 11.2 years, within 8 to 14 years (Monin, 1980).

All stations show spectral peaks of low frequency. However, for some of them the confidence limit is close to 90%. Peaks of good significant level are at 11 years and the ones from 5.2 to 2.7 years. These can be related to solar activity and to "El Niño", as mentioned before.

Such findings suggest that at the coast, temperature oscillations of short period are more significant than seasonal variations. However, the energy density of "El Niño" spectrum in Mexicali is almost one order of magnitude smaller than the one from Manzanillo, indicating a possible buffering effect due to latitude.

The records of 142 years of precipitation in Guanajuato (Figure 4), revealed ever lower frequency oscillations (22 and 45 years). Periods of 11, 22 and 45 years suggest a relationship between the meteorological parameters and solar activity. It might also be that the interaction between two oscillatory structures, such as "El Niño" and solar activity variations, modifies the large-scale circulation and enhances the development of strong climatic anomalies in the fields of temperature and precipitation. Similar results are described by Pérez-Enríquez (1998).

Spectra of temperature, precipitation, and water level at Lake Chapala (Figure 5) are very similar to the ones previously described. Peaks of spectral density as well as high frequency overtones correspond to annual, semi-annual periods and the low frequency variations with periods 2-5 and 11 years.
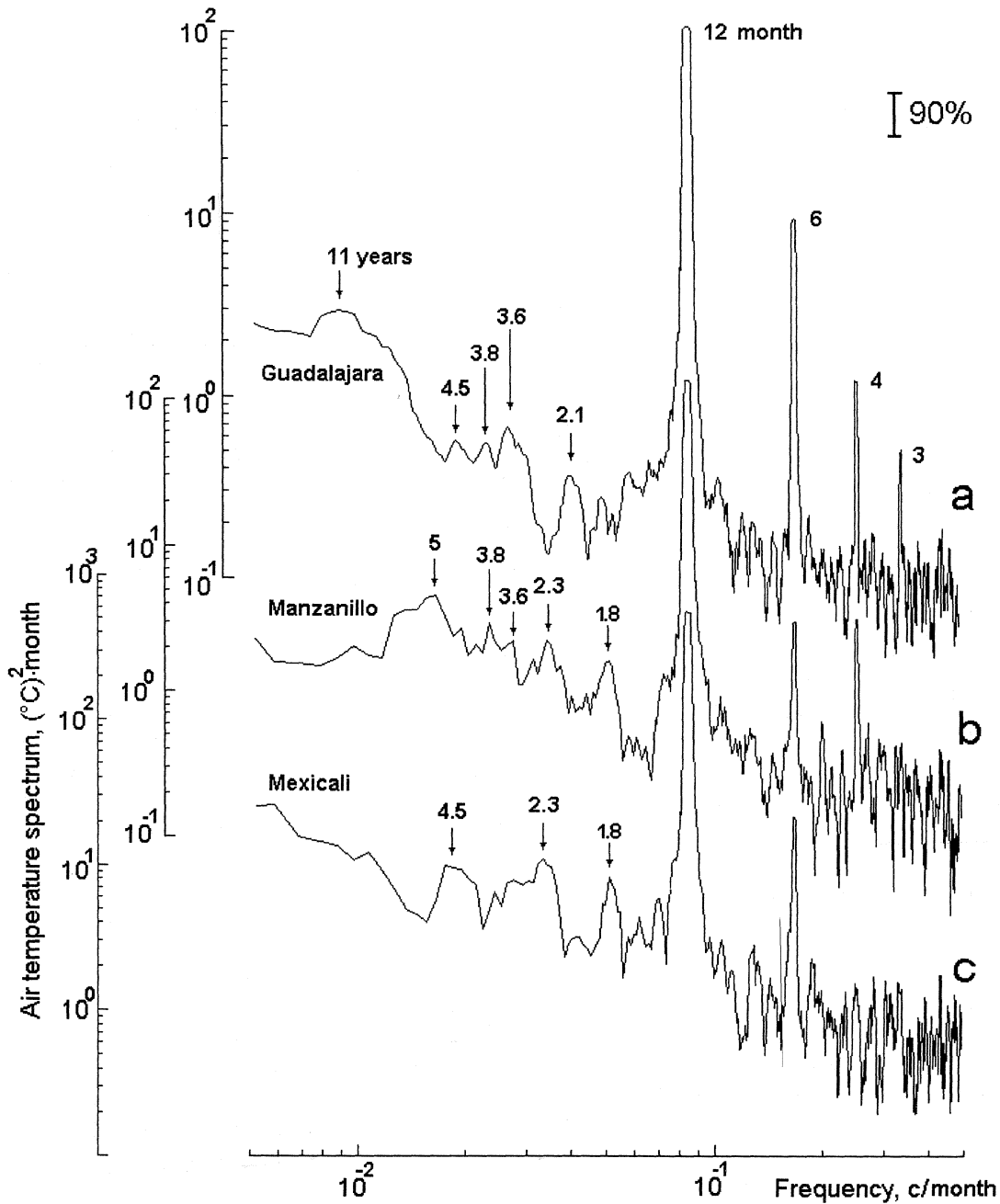
Fig. 2. The spectra of the temperature fluctuations in (a) Guadalajara, (b) Manzanillo and (c) Mexicali. The vertical line indicates the 90% confidence interval.

Concerning the influence of "El Niño" upon the oscillations of temperature, relative humidity, speed and wind direction in the Metropolitan Zone of Guadalajara (MZG) we discuss the results at station "Center" of the ANAM which is typical of the other seven stations.

The station is located in downtown Guadalajara where traffic and buildings have an important effect. A three-year database of meteorological parameters was used in this investigation. Three years are not enough to explain the variation of meteorological parameters studied here, but these are the only data available at present since the ANAM started functioning at the end of 1995.

Nineteen ninety-six was taken as a reference year in order to compare with "El Niño 1997-1998" episode. According to the Monthly Ocean Report (1998), the SST anomalies in the equatorial zone of the Pacific ocean were close to
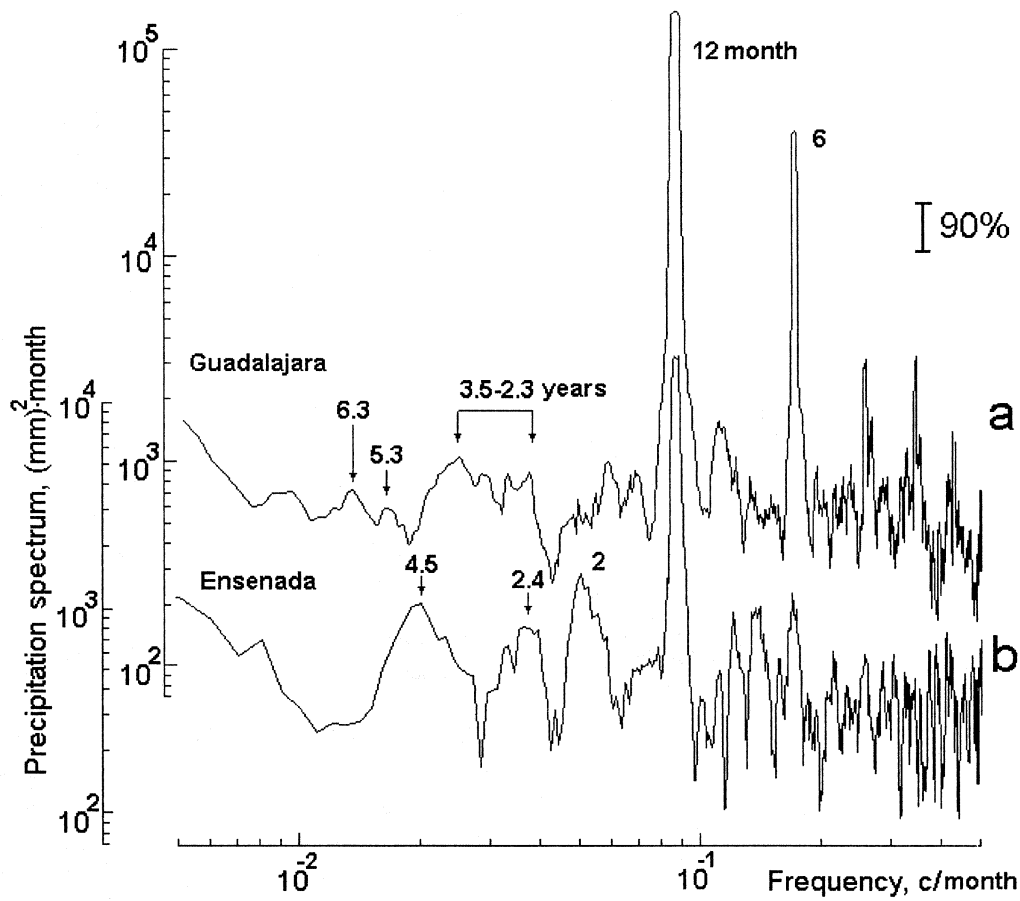
Fig. 3. The spectra of the precipitation fluctuations in (a) Guadalajara, (b) Ensenada.
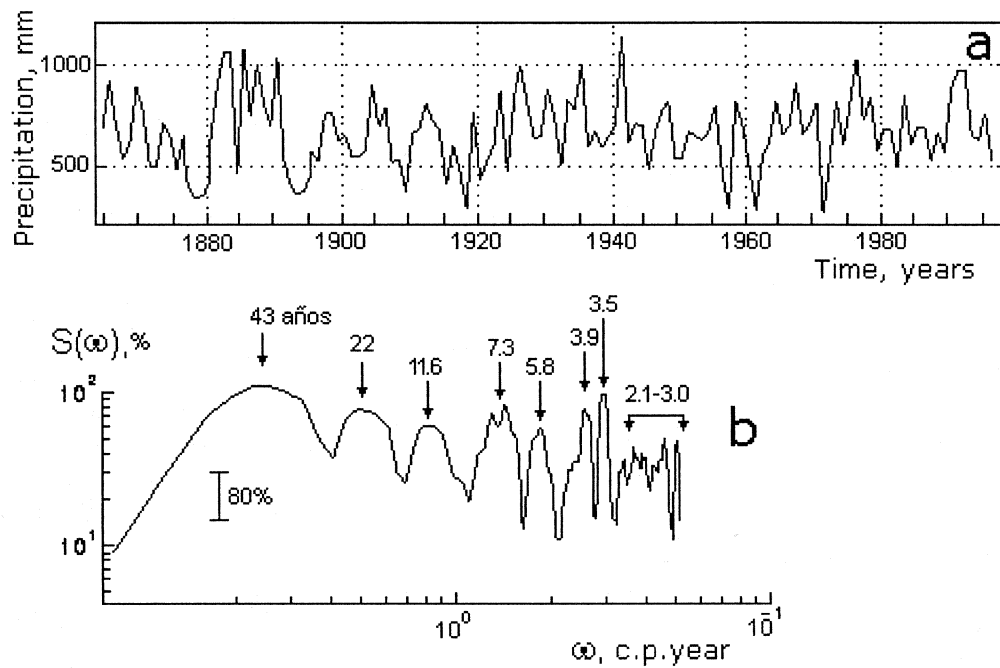

Fig. 4. (a) Annual mean precipitation in Guanajuato (Mexico) from 1864 to 1996. (b) The normalized spectrum (in relation to the % of the maximum value).
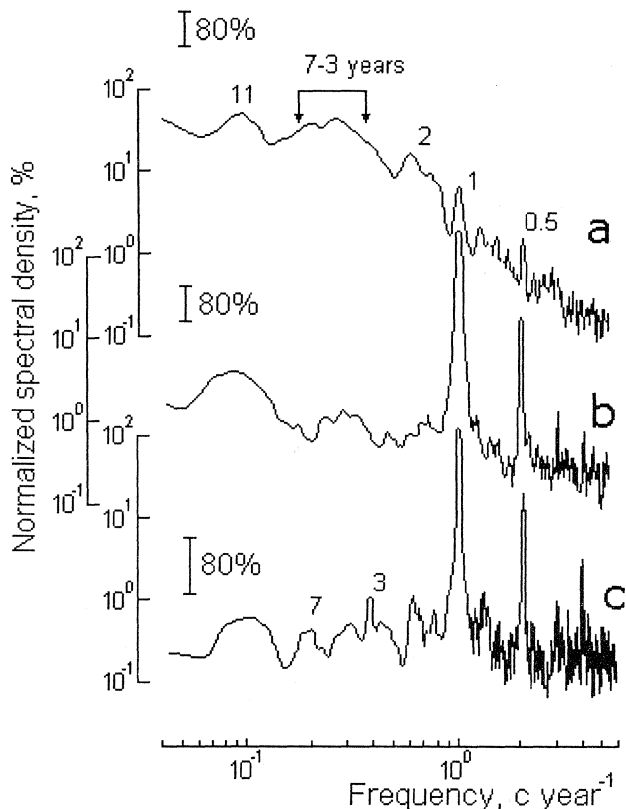
Fig. 5. The normalized spectra (in relation to the % of the maximum value) of the: (a) water level oscillations ,(b) temperature and (c) precipitation of Lake Chapala.

zero in 1996. Thus in the tropical zone of the Pacific ocean, the climatic deviations from the norm were small in the atmosphere and the ocean.

Figure 6 shows the distribution of the monthly average of hourly data in the MZG station "Center" for temperature, relative humidity, wind speed and wind direction from 1996 to 1998.

There are significant differences in the daily variations of the meteorological parameters between 1996 and the 1997-1998 period. For example, the maximum temperatures occurred between the 14:00 and 19:00 hours of Local Time (LT) from April to May in 1996. In 1997 the temperature maxima occurred at the same time, but their values were lower. However, in 1998 the temperatures were registered from 13:00 to 21:00 LT beginning from March to July. Therefore the maximum temperatures in 1997 (start of "El Niño"), were 2 °C lower than in 1996. In 1998 (end of "El Niño") temperatures were registered one month before and after (with values more than 30 °C), and lasted 3 hours longer than in 1996. Daily minimum temperatures (10°C and lower) in 1996 and 1997 were registered between 6:00 and 9:00 LT; and in

1998 this occurred between 5:00 and 9:00 LT from January to March.

The daily relative humidity was different in 1998 as compared to 1996 1997. Lower values (<30%) of relative humidity were registered at noon. In particular, during the period 1996-1997 these values were constant from 13:00 to 19:00 LT, and from 11:00 to 23:00 LT in 1998. Values higher than 70% were recorded at night and early morning. By comparing the relative humidity between the three years (Figure 6b), it can be noticed that higher values were registered in 1997, and that the lowest values were recorded in 1998, in comparison with the two previous years. Finally, in the second half of 1998, the temperature and relative humidity began to return to the reference values of 1996.

The wind speed and direction showed clearly a daily and annual course (Figures 6c and 6d). Weak winds (1-3 m/s) of unstable direction were registered during the night for the 1996-1998 periods, and during the day for 1996. The highest wind speeds for 1997 and 1998 were registered at noon with values of 5 m/s and 9 m/s. In the period 1997-1998 the wind speed, which was recorded in the day, was higher than the one registered in 1996. During this time the winds from the NE were dominant, but towards the end of 1998 the direction of the wind changed to SE.

5. CONCLUSIONS

The quantitative features obtained by the analysis show the existence of well-defined periodicities in the time series of air temperature, precipitation, and Lake Chapala level oscillations, which correspond to "El Niño" and solar activity periods. It is very important to study the type of spectral density and the frequency of "El Niño" as a function of the altitude and the longitude of space distributed points. A general picture of the appearance of "El Niño" in Mexico is not yet completely clear.

Results of MZG meteorological parameters show daily and annual differences between the reference year (1996) and the "El Niño" (1997-1998) years. Future investigations should consider data from the ANAM stations as well as remote sensing data, and satellite images of high resolution. An investigation of this kind will be valuable for understanding the conditions of the urban climate and will advance the knowledge of forecasting.
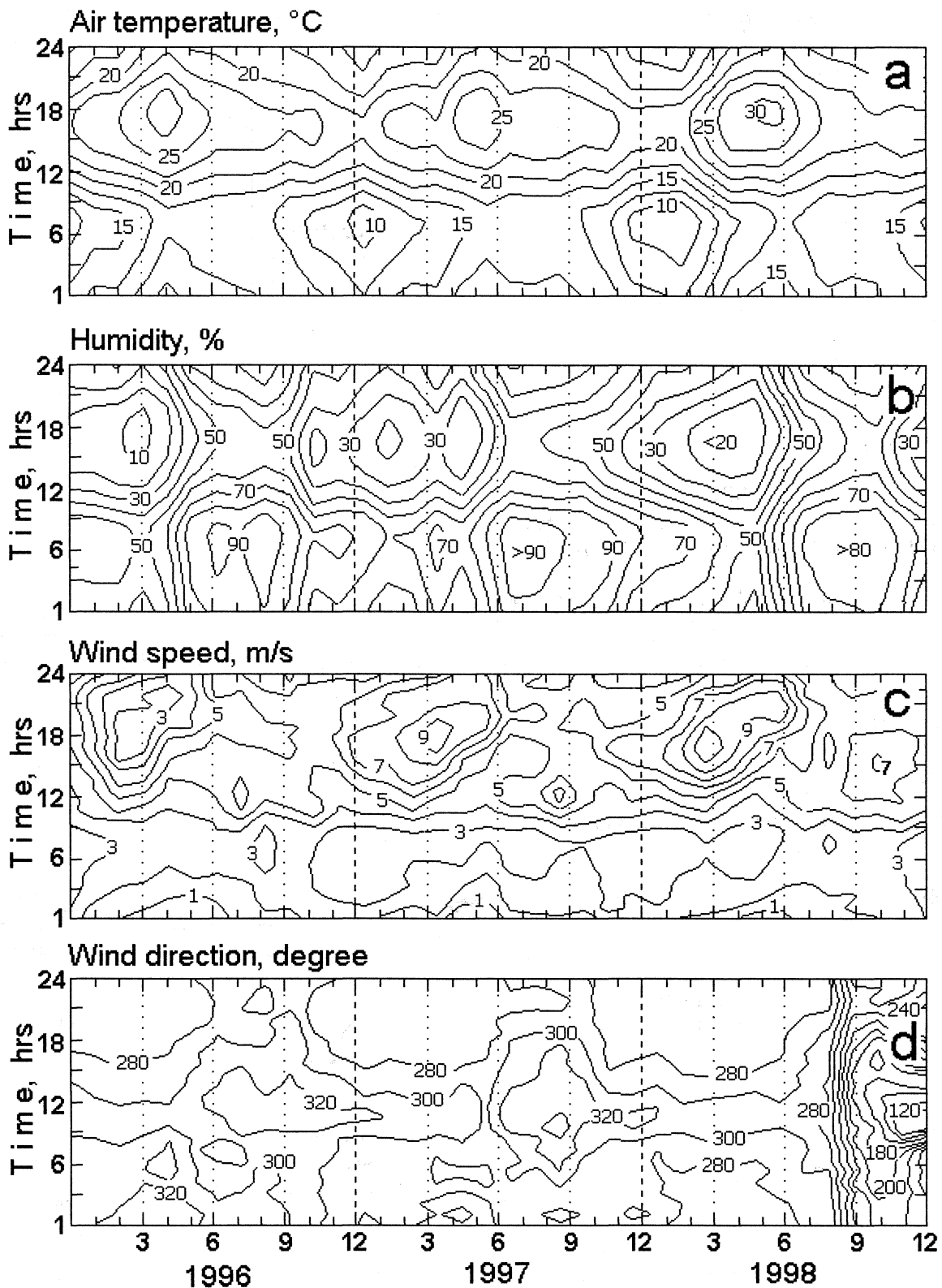
ACKNOWLEDGMENTS

Fig. 6. The distribution of the monthly averages of hourly data in the MZG, station "Center" for 1996-1998. (a) air temperature (°C); (b) relative humidity (%); (c)wind speed (m/s) and (d) wind direction (degree).The figure was built on a basis of a rectangular matrix with the following format. Vertical axis corresponds to day hours and horizontal values correspond to monthly averages of the variables. Within this format, each single value corresponds to the monthly average of hourly data. This form of analysis allows us to eliminate synoptic and high frequency fluctuations. At the same time the analysis highlights large period fluctuations in the data.

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