RevMexAA (Serie de Conferencias), **31**, 111–119 (2007)

PLUVIAL PRECIPITATION IN BAJA CALIFORNIA AND THE NATIONAL ASTRONOMICAL OBSERVATORY AT SAN PEDRO MÁRTIR SIERRA

Manuel Álvarez,[1] Raúl Michel,[1] Sergio Reyes-Coca,[2] and Ricardo Troncoso-Gaytan[3]

RESUMEN

Presentamos un análisis de las condiciones climatológicas alrededor del Observatorio Astronómico Nacional localizado en la sierra de San Pedro Mártir en el municipio de Ensenada, Baja California. El análisis se basa en datos obtenidos para la caracterización del lugar desde el punto de vista astronómico, así como en datos de lluvia, humedad, temperatura, viento y otros obtenidos en distintas estaciones climatológicas operadas por la Comisión Nacional del Agua y otras dependencias. Se usan algunos índices derivados de la temperatura superficial del mar (TSM) y de los anillos de crecimiento de corteza en los árboles para estudiar la variación climática del pasado y para predecir un escenario futuro de la precipitación pluvial en Ensenada. Se mencionan las posibles implicaciones que podría tener el Cambio Climático Global en la región del Norte de Baja California.

ABSTRACT

We present an analysis of climatic data around the National Astronomical Observatory at San Pedro Mártir Sierra (OAN-SPM) in Ensenada, B.C. This analysis is based on data taken by several authors, and at different epochs, to characterize this site for astronomical purposes. We used rain precipitation data, relative humidity, wind, and other parameters from the climatological stations operated by Comisión Nacional del Agua and other offices. We use indexes, derived from ocean surface temperature (OST) and tree-ring data analysis, to study past climatic variations to create a possible future scenario for pluvial precipitation. We point out some implications on the Global Climatic Change at the region of Baja California.

Key Words: **SITE TESTING**

1. HISTORICAL BACKGROUND

The National Astronomical Observatory at San Pedro Mártir Sierra (OAN-SPM) in Baja California, México, started operations in 1971. Some meteorological and climatological studies of the site took place from 1967 to 1974 to determinate the principal characteristics of the site to establish the Observatory.

We present a summary of the measurements and their references when they were published. They include the following meteorological and climatological parameters: number of clear days and nights, quality of the observing nights, pluvial precipitation (mainly at night), and relative humidity among others. All these measurements point that San Pedro Mártir is an ideal site for astronomical observations.

[1]Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 877, Ensenada, B.C. 22860, México (alvarez@astrosen.unam.mx).

[2]Centro de Investigación Científica y Educación Superior de Ensenada, Ensenada, B.C. 22860, México (sreyes@cicese.mx).

[3]Centro Regional de Investigación Pesquera, Instituto Nacional de Pesca, Secretaría de Agricultura, Recursos Naturales y Pesca, México (rtron@telnor.net).

2. PUBLISHED DATA: A SUMMARY

2.1. *Insolation Time*

Alvarez & Maisterrena (1977) showed that the percentage of insolation at San Pedro Mártir Sierra is larger than 60% of the time. They compare their data with measurements from other observatories and concluded that the OAN-SPM is at least comparable to Mt. Hopkins in Arizona and Cerro Tololo in Chile, and is undoubtedly a privileged place for solar observations.

More than 60% of short periods (shorter than 10 minutes) of clear line of sight (CLOS) between the observer and the sun are useful for diurnal observations during the months of February, March, April, May, June, September, October, November, and December.

Long periods of CLOS (longer than 2 hours), are present in more than 60% of the time during the months of March, April, May, June, September, and October; the months of February, November, and December reach 50%.

Summer weather, with its associated storm clouds and afternoon showers, is clearly present during July and August: less than 50% of the time of CLOS is available during those months. Winter precipitation, that characterizes Baja California weather, is the cause for having the 50% of the time of CLOS during January.

2.2. *Clear nights at SPM observatory*

Tapia et al. (2007), updated the earlier work by Tapia (2003, 1992) on the quality of the observing nights at SPM. From the log of the observing nights at the 2.1-m telescope from 1982 to 2005, they confirm their results obtained before. They show a slightly improving trend on the long term behavior on the climatic conditions of the area that can be associated to the drought conditions actually present (see § 3.3).

Tapia et al. (2007) report the astronomical observing conditions of more than 23 years of weather conditions for observing nights from July 1982 until December 2005 (a total of 8,585 nights): the 76.2% of the total nights scheduled for astronomical observations (6,541 nights), 71.0% of them were actually devoted to astronomical work.

During those 23 years, 1,401 nights (21.4% of the total nights) were lost due to bad weather and 23.2% of the time was not useful for other reasons. In summary, 83.7% of the time at the OAN-SPM during that period had good observing conditions. Mendoza (1971), showed that it might be up to 90% of observing (spectroscopic) nights.

Tapia (2003) shows important data on the number and quality of observing nights: *photometric nights* are defined when the clouds percentage is less than 15% of total surface of the sky and *spectroscopic nights*, when the percentage of clouds at sky is less than 65%. He found that 63.1% and 63.4% of the assigned time were photometric nights, and 80.8% and 89.8% of the assigned time were spectroscopic quality nights. June is the best month with 82% of photometric nights and 93.5% spectroscopic.

April to July, September and October, are above the photometric average (63.1%): August reaches 62%. March, was the less favorable, only 45% of photometric time. A similar situation was observed for spectroscopic nights, where the percentage values are about 17% larger than the corresponding photometric values. There is also a yearly effect (c.f. Figure 2 from Tapia 2003), where over 80% of the time shows *spectroscopic* quality. *Photometric* quality, seems to have improved from 57.2% prior to 1996, to 74.6% from 1996 to date.

2.3. *Quality of the night sky at SPM observatory*

Parrao & Schuster (2003) and Schuster et al. (2002) show, in their careful study of the *atmospheric extinction*, that *night sky brightness* is characterized by the atmospheric extinction k_ν, that has been measured as an integral part of their observing programs. Figure 1 of Parrao & Schuster (2003) plot the results of measurements made with the 13-color system and the *uvby*-β system. They report a mean atmospheric extinction k_ν of 0.14 mag airmass^{-1}. Nearly two-thirds of the photometric nights have k_ν values equal or below 0.13 mag/air and a minimum of about 0.11 mag airmass^{-1}. The comparison with other observatories shows that SPM is one of the best sites from its photometric characteristics. Parrao & Schuster (2003) also show the effects of Pinatubo volcano (June 1991) and Chichón volcanic eruption (June 1982), that increased the atmospheric extinction during several months; due to the Pinatubo volcano activity, the atmospheric extinction, k_ν, almost doubled.

2.4. *Opacity near 1 mm wavelength region*

Hiriart (2003a, 2003b), reports measurements of the atmospheric zenith opacity at a wavelength of 1.4 mm (210 GHz) over San Pedro Martir Observatory made from 1995 to 2002 that complement the early measurements of 1992 (Hiriart et al. 1997). Their measurements and comparison between the different seasons and to other Observatories, show the following values as reported in their very complete work: The total mean sky opacity at 210 GHz was 0.23 nepers; the median values of night time was 0.20 and during the day-time was 0.25 nepers. During the summer, the opacity rises to a maximum of 0.54 nepers on August to 0.48 on July and 0.28 on September; the rest of the time sky opacity is smaller than 0.20 nepers. Night measurements are better than daily values. There is also a yearly variation: 1998 and 2001 show the highest values mainly during day-time.

The measurements made on 1992 by Hiriart et al. (1997) showed a night-time median of 0.20 nepers and the day-time median of 0.24 nepers. These values correspond to 3.68 mm of PWV for night-time and 4.42 mm of PWV for day-time. These values are similar to those obtained at Mauna Kea, Hawaii and Pico Veleta, Spain. The authors obtained seasonal variations larger during the summer months due to the pluvial precipitation registered during the hot and humid summer of the mountains and very stable over large periods of time during the fall and beginning of winter months. They found that during the months of April and early May, better night-time conditions were present. Also, during these months they noticed a fast increment of the optical depth

TABLE 1

MONTHLY MEAN TEMPERATURE[a] - SAN PEDRO MARTIR OBSERVATORY

Month	1969	1970	1971	1972	1973	1974	2000	2001	2002	2003	**1969–74**	**2000–03**
Jan	5.6	2.9		2.5	−0.5	−0.9		**−2.1**	**1.0**	7.6	1.9	**2.2**
Feb	−1.5	1.3		4.5	0.1	**−0.3**		−0.9	3.4	1.4	0.8	1.3
Mar	**−1.9**	**−0.1**		**0.3**	**−3.1**	1.3	**3.3**	3.2	3.5	**−2.1**	**−0.7**	2.0
Apr	6.8	0.8		3.2	0.1	3.4	8.3	5.6	8.1		2.8	7.4
May	9.8	7.5		10.6	6.4	7.4	13.8	12.8	10.8		8.3	12.5
Jun	13.0	12.1		12.8	11.1		15.5		17.2		12.3	16.3
Jul	15.1	**14.6**		**16.9**	**15.9**		**17.0**	15.7	16.8		15.6	16.5
Aug	**16.4**	13.8	**20.5**	13.8	14.1		14.9	**16.0**	**21.6**		**15.7**	**17.5**
Sep	14.0	12.5	17.9	13.5	13.8		14.4	14.5	13.6		14.4	14.2
Oct	9.1	8.8	10.0	8.8	10.0		6.8	9.9	7.6		9.3	8.1
Nov	3.8	8.1	4.8	5.5	1.0	6.2	1.5	4.4	7.1		4.9	4.3
Dec	3.5	6.5	−1.4	2.1	1.8	4.1	4.8	0.5			2.8	2.6
Average	7.8	7.4	10.4[1]	7.9	5.9	3.0	10.0	7.3	10.0	2.3[1]	7.3	8.6

[a]Mean Temperature in °C in **bold** type **max. and min.** value of monthly mean temperature.

[1]Few data points.

in the morning and a corresponding decrease during the afternoon, probably due to a convective moist cell up to the top of San Pedro Mártir. They also notice the probably influence of the *El Niño* condition in 1992, when a precipitation anomaly of +85 mm during Winter was observed.

Recently, Hiriart & Salas (2007) presented an improved analytical relation between the zenith optical depth at 210 GHz and the column density of precipitable water vapor (PWV) at SPM based on modeling and measuring the mid-IR and millimeter atmospheric absorption.

3. CLIMATOLOGY OF SAN PEDRO MÁRTIR SIERRA

The main climatological parameters that have been measured at SPM Sierra are: air temperature, relative humidity, pluvial precipitation, and atmospheric pressure.

The importance of these parameters for the characterization of an astronomical site has been widely recognized. Unfortunately, for many years at San Pedro Mártir we only had sporadic campaigns to measure some of them. Although this fact difficult this analysis, the data we have allows us to point out some interesting facts.

3.1. *Mean air temperature*

Table 1, shows the monthly mean temperatures (in °C), from 1969 to 1974 and from 2000 to 2003. It shows the average values for these two periods.

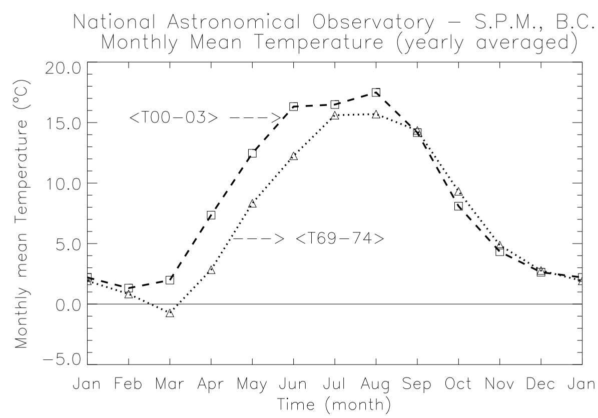

Fig. 1. Mean Temperature-SPM Observatory 1969–1974–2000–2003.

From Table 1, we notice that the mean temperature for the period 1969 to 1974, was 7.3 °C, while for the period 2000–2003 this average temperature was 8.6 °C, showing an increase of 1.3 °C between these two time periods.

Figure 1 shows the monthly mean temperature for the above periods. We can see that there is a clear difference between these two epochs, separated more than 30 years. Spring and summer months of the 2000–2003 period, seem to be on the order of four degrees Celsius warmer than the same months of the period 1969–1974. There is not a clear difference for autumn and winter, where the difference between the monthly temperatures falls within the measurement errors. These differences are on the order of less than one degree Celsius. The possible warming of the spring and summer months need to be verified with other climatological measurements of stations with more complete data, either at Valle de San Quintín and Ensenada City (México), and San Diego City (USA).

From 1969 to 1974, the climatological measurements were taken at top of San Pedro Mártir mountains with a meteorological station in front of the actual 2.12-m telescope building (2830 m altitude). During the period 2000 to 2003, they were obtained at the site of the 1.5-m telescope building (2800 m altitude), in the same mountain ridge.

From Table 1 and Figure 1, July and August are the warmest months; with mean temperatures ranging from 16.4 to 20.5 °C (from 1969 to 1974) and from 16.0 to 21.6 °C (from 2000 to 2003); the coldest period occurs between February and March with a minimum average temperature between −3.1 to +0.3 °C (from 1969 to 1974) and −2.1 to 3.3 °C (from 2000 to 2003).

From 1984 to 1991, there was another meteorological station located at the entrance to the National Park (SARH-95), taking temperature measurements. This station was located at lower elevation (2080 m). At this place, January was the coldest month with 4.1 °C and July was the warmest month with a mean temperature of 18.2 °C. The temperature range at SPM Observatory was 16 °C approximately, while at the SARH-95 station was 14 °C.

Measurements of air temperature at OAN-SPM, among other meteorological quantities, may be found at Michel, Hiriart, & Chapela (2003).

3.2. *Pressure and Relative Humidity*

Table 2 shows the monthly mean of pressure and relative humidity of the 1.5-m telescope weather station, during the period 2000 to 2003. The average value of the period is 560.8 mm Hg and its range went from 558 to 564 mm Hg during the time of measurement.

The average values for the relative humidity is 53.35 % and it goes from 39.7 % to 61.1 %, during the period of measurement.

TABLE 2

MONTHLY MEAN PRESSURE AND RELATIVE HUMIDITY[a] SAN PEDRO MÁRTIR OBSERVATORY

Month	Pressure (kPascal)[†]	Relative humidity (%)
Jan	560.6	50.17
Feb	559.3	56.30
Mar	558.0	58.42
Apr	560.1	46.72
May	561.1	39.71
Jun	558.0	50.69
Jul	563.9	57.74
Aug	563.3	61.12
Sep	562.1	61.06
Oct	560.6	55.86
Nov	561.1	52.63
Dec	560.8	49.61
Average	560.8	53.35

[†]Pressure in mm Hg and RH (%).

1 kPascal = 10 mb (milibar) = 7.5 mm Hg.

3.3. *Rain Precipitation*

Cloud cover is one of the most important parameters at any astronomical observatory, and it is directly related to pluvial precipitation. Although we do not have regular rain and snow measurements at the Observatory, we study some of the data of stations around the observatory to understand the precipitation regime on the mountain.

Around the observatory, there are some climatological stations of the *Comisión Nacional del Agua (CNA)* with several years of precipitation records that we show in Table 4. This table shows the climatological station, their coordinates, altitude, mean annual temperature (° C) and mean annual precipitation (mm). We include also the stations used to show the vertical Temperature Gradient on the western slope of the SPM mountains shown in Figure 4.

Figure 2 shows the precipitation average of the stations operated by the CNA. There is a clear difference between the two climatological regimes.

At the western slope of the mountain and the Pacific coast, precipitation occurs mostly on winter time (November through April); tropical rains (May through October) has a very little influence. The orographic effect increases rain precipitation during summer months on the mountain tops and extends its influence to the eastern slopes. Table 3 shows that the average rain at *Ensenada* station is 285.6 mm and that most of the rain occurs between November and April (254.5 mm (89.1%) and only

TABLE 3

MONTHLY MEAN RAIN PRECIPITATION[a]
CLIMATOLOGICAL STATIONS AROUND SPM

Month	Ens[b]	S.Cruz[b]	SPM[b]	Col[b]	SF[b]
Jan	56.9	49	73.9	5.6	9.1
Feb	54.4	43.7	54.6	11.5	3.7
Mar	47.4	48.9	98.4	3.1	2.7
Apr	23.1	17.2	15.5	1.6	1.4
May	5.9	2.1	6.6	2.5	1.1
Jun	1.8	0.7	0.4	2.8	1.2
Jul	1.4	15.0	23.4	26.8	3.2
Aug	2.5	18.0	45.1	49.4	10.7
Sep	6.8	18.0	23.0	21.5	8.9
Oct	12.7	15.6	5.1	5.2	10.5
Nov	27.6	34.5	46.2	1.3	5.1
Dec	45.1	42.0	56.7	16.0	10.3
Total	285.6	304.7	448.9	147.3	67.9
Winter[c] (†)	254.5	235.3	345.3	39.1	32.3
Nov-Apr	(89.1%)	(77.2%)	(76.9%)	(26.5%)	(47.6%)
Other[c] (†)	18.4	53.8	98.5	103.0	25.1
May-Oct	(6.4%)	(17.7%)	(21.9%)	(69.9%)	(37%)

[a] Mean Rain Precipitation *mm of water*.
[b] Ens=Ensenada, S.Cruz=Santa Cruz, SPM=SPM National Park, Col=Colonia SPM, SF=San Felipe.
[c] Winter (November to April) Other (May to Sep).

31.1 mm (10.9%) from May to October. A similar effect can be seen from the western slope stations *Santa Cruz* that has an average of 304.7 mm of rain, with 235.3 mm (77.2%) winter precipitation and 69.4 mm (22.8%) during the spring and summer months. The SPM National Park has an average of 448.9 mm of rain, with 345.3 mm (76.9%) winter precipitation and 103.6 mm (23.1%) during the Spring and Summer. Figure 2 shows the presence of two maxima for rain precipitation at SPM on March and August.

The eastern side of the slope (Gulf of California Slope) have a different behavior with little rain precipitation. *Colonia SPM* has an average of 147.3 mm of rain. Winter precipitation has only 39.1 mm (26.5%), and 108.2 mm (73.5%) of the precipitation occurs during July, August and September, with a maximum on August. San Felipe, at the coast of Gulf of California, has very small amount of rain (only 67.9 mm) August through January with 10 mm rain each month and the rest of the time with less than 3 mm each month.

3.4. *Orography effects*

There is another important effect to understand the behavior of the climatic considerations on top of

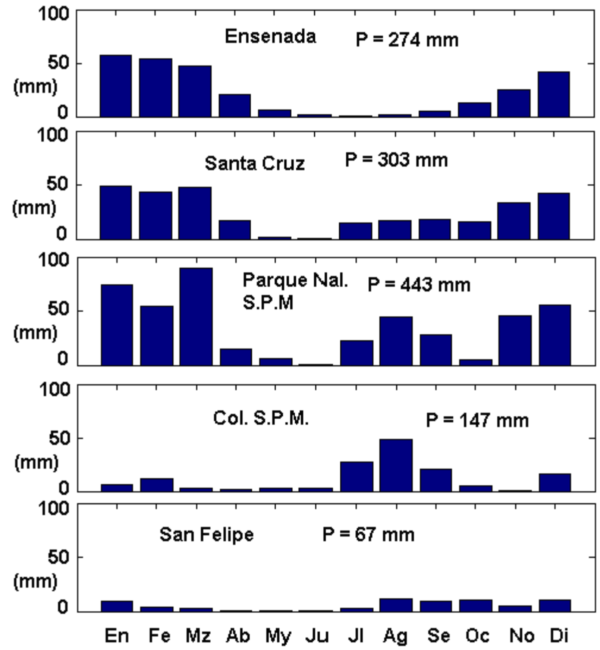

Fig. 2. Precipitation around SPM mountains, western slope shows the *winter regime*, while the eastern slope and the mountain top, shows the influence of the *summer rains*.

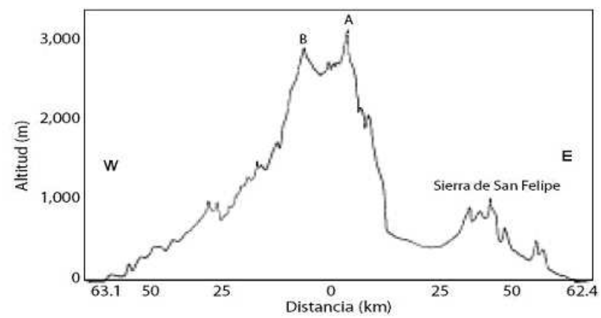

Fig. 3. *Transversal cut* across the Baja California Peninsula, showing the steep gradient at both sides of the mountain. The orography of the mountain chain controls precipitation and helps to keep a stable atmosphere with an almost laminar air flow over the top of the San Pedro Martir Observatory. Horizontal axis in kilometers from the OAN-SPM and vertical axis in meters, from sea level.

a mountain that we want to stress; this is related to the orography that controls the humidity and pluvial precipitation at the mountain tops.

Figure 3 shows a *transversal cut* of the Baja California peninsula through the SPM mountain tops: *point A* corresponds to the Observatory located in the eastern side of the mountain and the peak called

TABLE 4

CLIMATOLOGICAL STATIONS OF THE COMISIÓN NACIONAL DEL AGUA (CNA) LOCATED AROUND SPM SIERRA

Number	- Station name	Latitude (N)	Longitude (W)	Altitude (m)	Mean Temp (° C)	Mean Precip (mm water)
	Pacific Slope	West side	of SPM			
	- San Pedro Mártir[spm]	31°2′46″	115°29′13″	2830	7.3 – 8.6	173.0
	- San Pedro Mártir[np]	30°58′00″	115°34′54″	2080	10.7	448.9
02-001	- El Álamo[a]	31°36′	116°3′	1600	15.6	242.6
02-038	- Santa Catarina[a]	31°34′	115°41′	1000	19.2	116.3
	- Santa Cruz[sc]	30°55′36″	115°38′00″	980		304.7
02-024	- La Providencia[a]	31°23′	116°4′	900	17.9	236.0
02-037	- San Vicente[a]	31°24′	116°15′	300	17.3	173.0
02-036	- San Telmo[a]	30°58′	116°5′	200	16.3	166.6
	- Ensenada City[ens]	31°53′45″	116°35′41″	50	18.1	285.6
04-014	- Las Escobas [a]	30°33′	115°57′	28	15.5	117.2
02-016	- Vicente Guerrero[a]	30°43′	116°0′	4	15.7	142.4
	Gulf of California Slope	East side	of SPM			
	- Colonia SPM[col]	31°02′15″	115°12′30″	100		147.3
02-032	- San Felipe[a,sf]	31°00′52″	114°50′32″	22	24.7	67.9

[spm]SPM observatory station.

[np]Located at the entrance of the Park with partial data from 1977 to date.

[sc]Data from 1960 to 2000.

[ens]Good coverage from 1894 to 2006 (some years missing during the Mexican Revolution).

[col]Partial data from 1981 to 1998.

[sf]Partial data from 1960 to 1982.

[a]From Alvarez & Maisterrena (1977).

La Corona, point B, the highest peak at the western side of SPM. Most of the time the prevalent low velocity winds from the Pacific Ocean come from the west and the relatively steep gradient of the mountain insures homogeneous atmospheric layers on top of the Observatory, as can be seen from many of the astronomical observations made so far (see *Section 2, specially clear nights and quality of the night sky*).

Temperature measurements of the climatological stations on the western side of the mountain, show a very clear temperature inversion layer present on the west side of the mountain range as shown by Alvarez & Maisterrena (1977). As described early, in our Table 4 we show the mean temperature of these stations and we include other stations closer to the Observatory in our Figure 4. This temperature inversion layer (evident at 1000 m altitude), keeps most of the moisture out of the top layers of the atmosphere, helping to keep the top of the mountain clear and cloud less most of the time, having an important effect on the precipitation regime. The east side of SPM Sierra shows also an stable temperature regime that favors the sky quality of the SPM Observatory.

4. VARIABILITY ON THE PRECIPITATION REGIME

In a study of the winter precipitation and its variability in the northwestern Baja California peninsula, Reyes-Coca & Troncoso-Gaytán (2004) made a model of the possible scenario of the precipitation regime during the 21st century.

They used the precipitation data from Ensenada, Baja California, and San Diego, California. The values from Ensenada weather station are shown in Figure 5 for the period of 1965 to 2005 to illustrate the raining conditions of Ensenada during the time that the OAN-SPM has been in operation. Winter precipitation accounts for 89.1% of the total rain; although there has been few years with a different behavior; for example, 1972, 1986, and 2004.

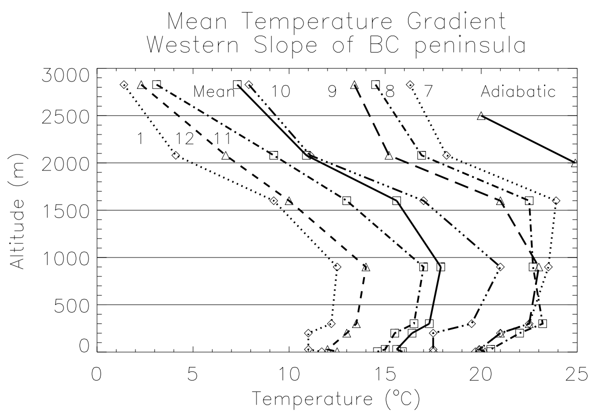

Fig. 4. Temperature Gradient - SPM Mountains. The average temperature of several climatological stations are plotted versus the altitude of the station showing the stability of the atmosphere. The humidity of the lower layers stays most of the time below 1000 m altitude. The adiabatic gradient of the atmosphere is also shown.

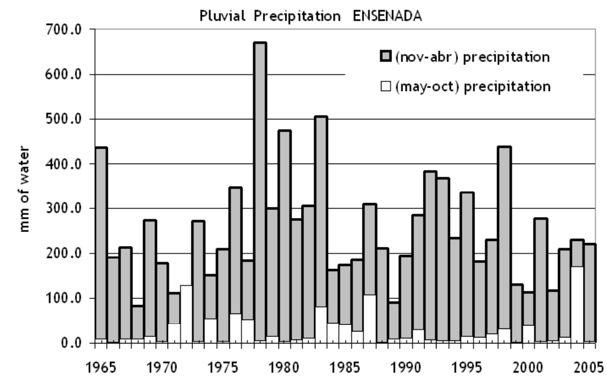

Fig. 5. Winter precipitation at Ensenada from 1965 to 2005. Site testing at SPM mountains started in 1967. During those years, precipitation was below average (286 mm of water) most of the time. The heavy rains from 1978 to 1983 are clearly seen. Winter precipitation (November through April) is shown as black bars and summer precipitation (May trough October) as white bars.

As has already been mentioned, Ensenada (México) and San Diego (USA) are representative of the precipitation regime of the area. Ensenada's precipitation records contains more than 100 years (1894 to 2001 that we have extended to 2005). For their analysis, Reyes-Coca & Troncoso-Gaytán (2004) included also the Southern Oscillation Index (SOI) and the Pacific Decadal Oscillation (PDO). Reyes-Coca & Troncoso-Gaytán point out that many of the meteorological and climatic phenomena of Baja California, such as rainfall, drought, heat waves, Santa Ana winds, etc., are highly influenced and controlled by the irregular tropical phenomenon of *El Niño Southern Oscillation (ENSO)*. In their analysis, they also use the climatic indices of Ocean Superficial Temperature (OST).

4.1. *Anomaly of the winter precipitation*

The anomaly of the *winter rain precipitation* is the difference of the monthly precipitation that happens during the winter period (November through April) minus the average value during this period of time. Figure 6 shows this anomaly for Ensenada during the period 1965 to 2005.

The average monthly winter precipitation for the period from 1894 to 2005 is 254.5 mm. The average total precipitation was 285.6 mm. During the spring and summer months the total precipitation was 31.1 mm.

Reyes-Coca & Troncoso-Gaytán point out that, when there are periods with 100 mm less rain than the average, there is intense drought in the area with risk of fires as well as urban and rural problems associated with the lack of water supply. On the contrary, there are floods and wash outs in cities, highways, and rivers when the total annual rain is larger than 150 mm above the average.

Of the 112 studied years, 70 of them (62.5%) showed precipitation smaller or equal than the mean; the rest 42 years (37.5%), rains were heavier than the mean.Extreme drought prevailed on 31 years (27.7% of the total) with annual rain less than 100 mm below average. Only 12 years (10.7% of the total) had strong rains (precipitation larger than 150 mm above the mean).

There is a very high inter-annual variability that produces some heavy rain winters (e.g. 1895, 1905–06, 1908, 1942–43, 1977–78–79, 1982–83, 1997–98) with rain precipitation being almost the double of the mean that caused great and devastating floods. However, in some other winters, the lack of rain may cause severe droughts that can last for several years (1898–1904, 1920–22, 1953–54, 1970–71, 1983–84, 1988–89, 2001–02). In this last condition, the rain precipitation is on the order of half of the mean. This inter-annual variability is associated with the phases warm *El Niño* and cold *La Niña* of the irregular oscillation of the Tropical Pacific, known as *El Niño/ Southern Oscillation* (NSO).

The inter-decennial variability (i.e. variation between 10 or more year periods) is also very important. During the periods from 1906 to the middle of the 1940's, and from 1976 to 1997 there were strong rains on the area. However, from the end of 1940's to

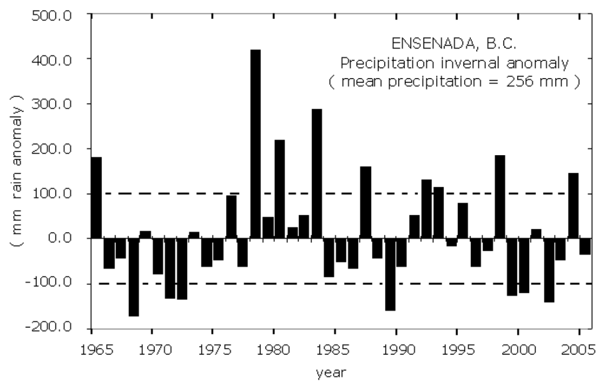

Fig. 6. Precipitation anomaly of Ensenada from 1965 to 2005.The years with a rain anomaly below the horizontal line at −100 mm of the average precipitation, corresponds to epochs of severe droughts. For those years with rain anomaly above 150 mm of water, severe rains and floods occurred.

1976 and from 1998 to 2005 there have been several years of scarcely rains. These periods correspond very well with warm and cold phases of the Pacific Decadal Oscillation (PDO).[4]

5. WAVELET SPECTRAL ANALYSIS

A wavelet spectral analysis is used by Reyes-Coca & Troncoso-Gaytán (2004) to obtain time series information of their data. They used the Morlet wavelet which is a Gaussian-modulated flat wave that has a satisfactory representation in the Fourier domain that goes from the Nyquist frequency (maximum) to the length of the time series (minimum frequency). For Ensenada's winter precipitation data used, the time series analysis shows at least two statistically significant areas at about 15 and 40 years during the 20th. century, especially after 1940. They show that it seems to be evidence of isolated areas in the ENSO band of activity (2–7 years).

5.1. *Wavelet analysis of tree-ring growth*

It is interesting to study other sources of data in order to have a different perspective of the climatic events from the past and to try to understand some of the future events of the climate. The analysis of tree-ring growth seems to be a promissory subject to study.

A general description of the subject, points to the fact that the growth of the trees is a function of several parameters, but probably some of the most important have to be temperature and rain precipitation either in form of rain or snow. When there is heavy precipitation, the tree-ring associated with the corresponding annual cycle, has a larger probability to grow. Hence the tree-ring analysis may help us to understand the long range climatic variations along the life of the tree.

Some work has been started on tree-ring analysis for an area of San Pedro Mártir Sierra called *La Tasajera*. The results obtained after the *tree-ring power series analysis*, shows some well marked regions with the presence of clear signals that need to be analyzed and understood. The signal associated with a period between 50 and 70 years is very clear. There is also some signal between 10 and 30 years, with a much more complex structure. However, the signals derived from the *El Niño Southern Oscillation* of a few years are not clearly visible. This interesting problem will be worked out in the near future.

[4]For references and additional information, see `http://www.jisao.washington.edu/pdo/`

6. POSSIBLE SCENARIOS OF CLIMATIC CHANGE

The international scientific community proposes several scenarios of the possible impacts for an increase on the global temperature on the order of 1°C per 100 yr:

- It will be an increase on the Earth‘s surface evaporation and a loss of soil humidity, therefore becoming more arid;
- it will be an increase in the internal energy of the atmosphere and the oceans, increasing the number and intensity of storms;
- when internal energy of Earth's system increases, it may increase also the intensity of climatic variability; it may produce strong floods (warm events of *El Niño* type) and more severe droughts (cold events of *La Niña* type);
- it may produce a strong instability on the global system generating "climatic jumps" at interannual e inter-decennial scale;
- and it might be an increase on the temperature of oceans, with an increment on its mean level.

What are the short- and mid-term expectations in Baja California?

- Mean winter temperature may increase from 2 to 3 °C, while at summer time it may increase from 1 to 1.5 °C. That is to say, warmer years with more evapo-transpiration of plants and loss of soil humidity.
- Consequently, subsoil water may be under more tension, mainly at the over exploited aquifers where saline intrusion is more intense.

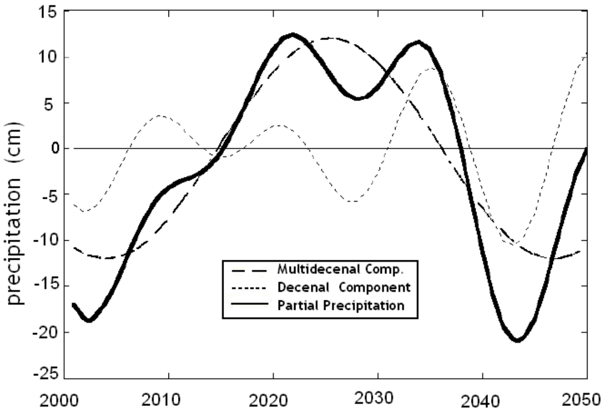

Fig. 7. Future scenario of significant low frequency variability (decadal to inter-decadal) for Ensenada precipitation derived from the wavelet model (no inter-annual variability, like ENSO, considered). Dotted line corresponds to the decennial component of the model present in the observed precipitation regime. Dashed lines are the multi-decenal component of the model. Solid heavy line is the resultant component of both. It can be seen that the *minimum rain* was reached at 2004. During the next 8 to 10 years precipitation may increase reaching the average around 2015. A maximum of precipitation will be reached around 2020 and 2035.

- It may also increase Hadley's cell, associated with the semi-permanent high pressure center, located west of Baja California, blocking extra tropical winter storms, turning them to the North of California and Canada. This will produce good observing conditions at San Pedro Mártir Sierra.

Reyes-Coca & Troncoso-Gaytan (2004), made a computational model for a mid term scenarios (2000–2050) of the rain behavior in Ensenada, B.C. Their results are shown in Figure 7. Their model shows a small rain precipitation regime from 1999 to 2015, with maximum droughts during 2002 to 2004. The actual evidence shows that we have reached the minimum precipitation epoch and it seems that we still are under the decennial deficient rain regime.

If global temperature stays constant in the following years, the scenario shown in the Figure 7 may be very close to reality; hence it will be a probability that in the following years there will be a tendency to rain recovery starting at 2015. However, the most likely is that (as it has been publicly acknowledge by the Intergovernmental Panel on Climatic Change) air temperature on the planet will continuously increase and hence it may modify this scenario to have fewer rains and more frequent droughts.

We want to thank the Team of the Workshop on Astronomical Site Evaluation, that kindly invited us to present a poster at the meeting and to write this paper. We thank D. Hiriart for his very valuable suggestions to improve this paper.

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