

Climatology of landfalling hurricanes and tropical storms in Mexico

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RESUMEN

Se determinó el potencial de daño de los huracanes que entran a tierra en México. Durante el período 1951-2000 los impactos de los huracanes del Pacífico fueron más frecuentes en las áreas costeras del noroeste del país, como Sinaloa y la mitad sur de la península de Baja California, así como en el sur de México (Michoacán). En el lado del Atlántico la península de Yucatán y el estado norteño de Tamaulipas fueron los más expuestos a estas tormentas. Para las dos costas del país, del Pacífico y del Atlántico, la temporada de huracanes alcanza su máxima actividad en septiembre. Durante los 50 años del período de estudio cinco huracanes intensos (categoría 5) tocaron tierra en el lado del Atlántico y uno en el Pacífico. Mientras que los huracanes que afectan las costas del Pacífico muestran un incremento en número durante la última década, los del Atlántico exhiben una disminución notable desde la década de los años 70. Sin embargo, considerando la frecuencia de los huracanes y las tormentas tropicales que impactan tierra en ambos litorales del país, se observa que sus números se han incrementado considerablemente durante la década de 1990.

ABSTRACT

The potential for damage from hurricanes landfalling in Mexico is assessed. During the 1951-2000 period, Pacific hurricane hits were more frequent on coastal areas of the northwest of the country (e.g., Sinaloa and the southern half of Baja California Peninsula) as well as in southern México (Michoacán). On the Atlantic side, the Yucatán Peninsula and the northern state of Tamaulipas were the most exposed to these storms. The hurricane season reaches maximum activity in September for both the Atlantic and Pacific coasts of the country. During the 50 year period, five intense hurricanes (category 5) made landfall on the Gulf/Caribbean coasts, while only one such intense hurricane made a land hit on the Pacific side. While hurricanes affecting Pacific coasts show a marked increase during the last decade, those of the Atlantic side exhibit a marked decrease since the 1970s. However, when considering the frequency of landfalling tropical storms and hurricanes impacting on both littorals of the country, their numbers have considerably increased during the 1990s.

Key words: Hurricanes, Gulf of México, Caribbean, Northeast Pacific

1. Introduction

Hurricane climatology provides a useful tool for the study of potential for damage along the coasts of México, especially when, as is the case, population in coastal areas of the country has increased considerably during the last two decades. In 1990, urban population in the Pacific coasts of México reached more than 2 million, while that in the Gulf reached a million and a half (Aguilar, 1999). In this analysis, storms that had reached hurricane intensity (65 mph or 120 km/h) in their trajectory are considered, as well as those that could have weakened by the time of landfall. With extensive miles of coastline bordering on both oceans, México is particularly vulnerable to hurricanes on both its shores. With all their destructive power, tropical storms and hurricanes are mechanisms that provide a significant amount of the country's moisture. An active hurricane season usually translates into a prosperous year for agricultural activities in most of the country. An attempt by the present author (Jáuregui, 1989) to assess the contribution of 57 hurricanes on both littorals during the 1962-1987 period for the wet season months –July to September– in Northern México (north of the Tropic of Cancer), showed considerable increases (three to four times the normal monthly precipitation) above average, not only in coastal regions, but also inland. On both coasts, rainfall associated with approaching hurricanes is intensified by orographic lifting by the mountain ranges of the Sierra Madre that generally run parallel and close to the coast line, resulting in flooding of coastal settlements. Such was the case of hurricane Pauline that produced rainfall amounts in the order of 400 mm/24 h near Acapulco, causing 147 dead by drowning. For a brief account of the impact of landfalling hurricanes on both coasts of México, see Longshore's Encyclopedia of Hurricanes (1998). In this study, statistics of hurricane and tropical storm landfalls in México are examined, as well as cases of impacts on the population and infrastructure.

2. Data

Data for hurricane trajectories were provided by courtesy of Chris Landsea, Colorado State University and the Tropical Prediction Center (<http://weather.unisys.com/hurricane>). The available periods were 1901-2000 (for the Atlantic) and 1951-2000 for the Pacific. Hurricanes are classified by their damage potential according to a scale developed by R. Simpson and H. Saffir, and is now in wide use. The scale has 5 categories with category 1 being the least intense hurricane (Table 1). The greatest damage and loss of life during hurricanes result from flooding of coastal areas, mud slides in saturated mountain slopes, and ocean surges. The name of these storms is assigned when they reach tropical storm strength. This practice was initiated in 1953. However, there have been exceptions such as hurricane No. 15, class 5, an unnamed storm that devastated the port of Manzanillo in 1959, the impact of which is described below.

Only those hurricanes having category 1 to 5 at landfall were considered for the statistics. Among the tropical storms that made landfall on Mexican coasts (31), seven of them on the

Pacific, had previously attained hurricane force as will be discussed later. Hurricane trajectories on the north east Pacific are less reliable prior to 1963, when satellite imagery was initiated to follow the development of these storms over the oceans.

Table 1. The Saffir/Simpson scale.

Type	Category	Pressure (hpa)	Sustained winds		Surge (ft)	Damage
			(mph)	(km/hr)		
Depression	TD		<39	<62		
Tropical storm	TS		39-63	62-117		
Hurricane	1	>980	64-95	118-153	4-5	Minimal
Hurricane	2	965-980	96-110	154-177	6-8	Moderate
Hurricane	3	945-965	111-130	178-200	9-12	Extensive
Hurricane	4	920-945	131-155	201-250	13-18	Extreme
Hurricane	5	<920	>155	>250	>18	Catastrophic

3. Results

Frequency of landfalling hurricanes by states

Results show that during the second half of the 20th century, Pacific hurricane hits were more frequent in the states of Baja California Sur (19 strikes), Sinaloa (18) and Michoacán (9). In contrast, Gulf/Caribbean landfalls were less frequent (about ½) being the states of Quintana Roo (13) on the eastern Yucatán Peninsula and Tamaulipas (with 7 hits), the most exposed to these storms (Fig. 1).

Long-term variability of landfalling hurricanes on the Gulf of México/Caribbean coast of México during the 20th century

During the 20th century, 58 hurricanes of all categories made landfall on Mexican coasts of the Gulf of México and the state of Quintana Roo's coasts facing the Caribbean. This amount represents only 35 percent of those hurricanes that hit the US' Gulf of México and the Atlantic coasts together.

During the decades 1931-40, 1941-50, the number of hurricanes of all categories (that made landfall on the Gulf of México and Caribbean coasts of México) was well above (72 %) the average (5.8 hurricanes/decade) of the entire century. During this period, 13 hurricanes reached categories 2 and 3 and, one hurricane category 4, but none category 5. These decades correspond to the first half of the 40-year period (1930-1960s) identified by FEMA (2001) as the most active in the Atlantic (also documented by Reading, 1990). After peaking in the 1970, the last two decades of the century have seen a declining and leveling-off trend of hurricanes affecting the Mexican Gulf and its Caribbean coasts. In fact, they were the least active in this regard (Table 2). The same trend has been observed on the northern US coasts of the Gulf (Bove *et al.*, 1998) with no apparent indication of any change in this trend according to these authors.



Fig. 1. Number of landfalling hurricanes (all categories) by states in México. 1951-2000 period.

Comparison of hurricane landfalls on both ocean regions

During the period 1951-2000, only 9% of all hurricane activity (all categories) in the Atlantic made landfall on Gulf/Caribbean coasts of México, while the number of hurricanes that hit the Pacific coast amounted to 18% of the total activity in that ocean region. This means that, in spite of the fact that although the total number of hurricanes in the Pacific was only 25% higher than in the Atlantic for the period, the percentage of landfalling hurricanes was double than those landing on the Atlantic (Table 3).

It is possible that the higher number of landfalling hurricanes on the Pacific may be linked to the relative closeness of the crescent-like Mexican Pacific coast line to their source region on the west of Central America; and also, to the fact that these disturbances reach their maximum intensity not far from the southern coasts of México (see Fig. 6 on Whitney and Hobgood, 1997).

A glance at the map of tropical storm tracks from Fernández-Partagas and Díaz (1996) article on Atlantic hurricane climatology, shows clearly that the US Gulf and Atlantic coasts get the largest impact of tropical storms generated in the Atlantic region, followed by México, Central America and the Caribbean islands.

Table 2. Number of hurricanes (all categories) that made landfall on the Gulf and Caribbean coasts of México, by decades, 1901-2000.

1901-10	4	1951-60	7
1911-20	5	1961-70	5
1921-30	2	1971-80	7
1931-40	12	1981-90	4
1941-50	8	1991-2000	4

Table 3. Percentage of hurricane hits on coasts of México as related to the total activity on both ocean regions. 1951-2000 period.

Region	Total	No. of landfalls	%
Atlantic	294	27	9
NE Pacific	368	65	18

When the statistics are limited to the Gulf of México during the period 1951-2000, hurricanes landed more frequently on the US region: of a total of 68 hurricanes, 41 (60%) made landfall on US coasts, while the rest (27 or 40%) made hits on Mexican territory. With regard to the rest of the region affected by these storms generated in the Tropical Atlantic, statistics of landfalling hurricanes and tropical storms for Central America and the Caribbean show that, while this region receives 19% of all Atlantic hurricane activity, Cuba –having the largest land mass of the region– gets the largest proportion of these storms (Table 4).

Table 4. Statistics of land falling hurricanes and tropical storms for the Central America and Caribbean region. 1951-2000 period.

	Hurricanes	Tropical Storm	TOTAL
Guatemala	0	8	8
Belize	9	4	13
Honduras	5	4	9
Nicaragua	4	5	9
Panamá	0	1	1
Colombia	1	2	3
Venezuela	0	5	5
Cuba	17	17	34
Jamaica	1	1	2
Haití	9	4	13
República Dominicana	7	7	14
Puerto Rico	4	4	8
Total	57	62	119

Hurricane activity in the second half of the 20th century on both Pacific and Gulf regions

During the 1951-2000 period, 65 hurricanes stroked the Pacific coasts of México, whereas those on the Gulf coasts and Caribbean amounted to 27, meaning that the probability of a hurricane landfall is about two and a half times higher on the Pacific than on the Gulf.

Most hurricanes (77% or 50) affecting the Pacific coasts of México (during period 1951-2000) were categories 1 and 2, while 15 (23%) were major (intense) or categories 3 or higher (Table 5). Only one intense (category 5) hurricane hit the sea-port of Manzanillo in 1959 (see Fig. 2). In contrast, during the same period, 16 intense (see below) hurricanes made landfall on the Gulf/Caribbean side, of which 7 were category 5.

Table 5. Number of hurricanes that made landfall on Mexican coasts. 1951-2000 period.

Category	1	2	3	4	5	Total
Pacific	38	12	6	8	1	65
Gulf of México and Caribbean	9	2	5	4	7	27

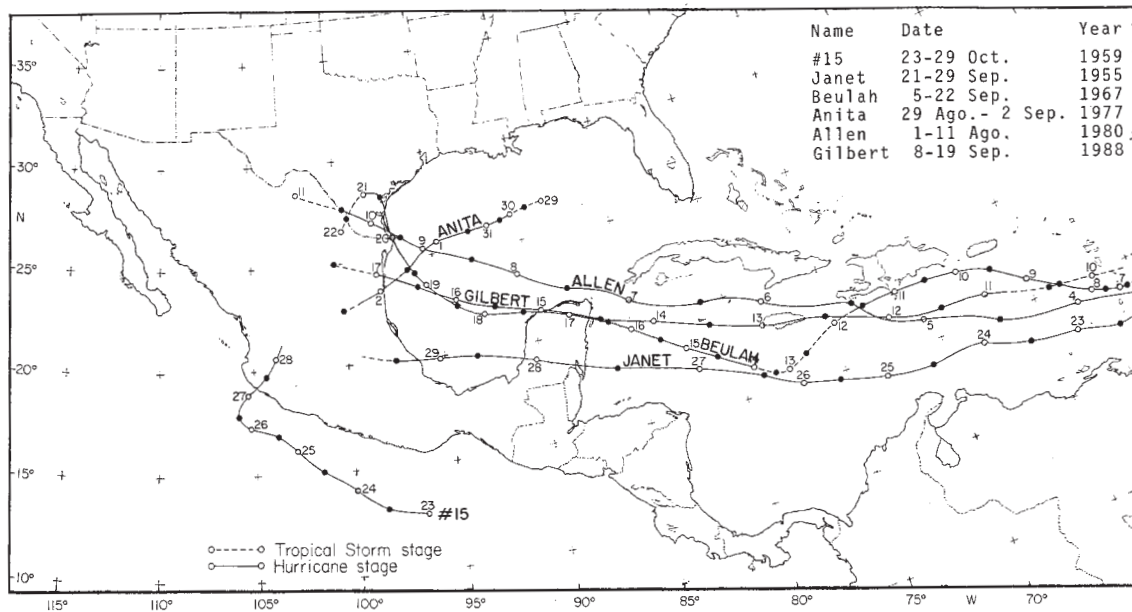


Fig. 2. Trajectories of intense hurricanes (category 5) making landfall on coasts of Mexico. 1951-2000 period.

Decadal variability of intense landfalling hurricanes (ILH). 1951-2000 period

An intense hurricane is defined as having maximum sustained winds of at least 96 kt (178 km/h) which is a category 3 storm on the Saffir-Simpson scale (Bove *et al.*, 1998).

a) Gulf of México/Caribbean. During this period, ILH reached a peak (6/decade) during the 1970s and have markedly declined thereafter (Table 6).

b) Pacific. While no ILH occurred in the 1960's they have increased their frequency particularly during the last decade of the 20th century when 6 ILH hit the Pacific coast of México (Table 6). Hurricane landfalls on the Gulf/Caribbean coasts of México show a seasonal variation from June to October with a clear maximum in September when the most intense hurricane (category 5) hits have been recorded. In contrast, on the Pacific the season stretches over a longer period beginning in May reaching maximum activity in September-October. It is worth noting that a distinct secondary maximum occurs in June (Table 7).

Table 6. Decadal variation of landfalling hurricanes on both littorals by categories. 1951-2000 period.

<i>Pacific</i>							
Categories	1	2	3	4	5	All cat.	Intense (3 to 5)
1951-1960	12	0	0	1	1	14	2
1961-1970	12	0	0	0	0	12	0
1971-1980	7	4	2	2	0	15	4
1981-1990	2	3	2	1	0	8	3
1991-2000	5	5	2	4	0	16	6
Total	38	12	6	8	1	65	15

<i>Gulf of México/Caribbean</i>							
Categories	1	2	3	4	5	All cat.	Intense (3 to 5)
1951-1960	4	0	1	1	1	7	3
1961-1970	1	0	1	1	2	5	4
1971-1980	1	0	2	1	3	7	6
1981-1990	2	1	0	0	1	4	1
1991-2000	1	1	1	1	0	4	2
Total	9	2	5	4	7	27	16

The great (category 5) landfalling hurricanes

Trajectories and impact of some category 5 landfalling hurricanes that occurred on Mexican coasts during the second half of the 20th century

With extended (2825 km) coast lines on both oceans (Gulf of México, Caribbean and Pacific), México is highly vulnerable to the arrival of hurricanes. During the second half of the 20th century,

Table 7. Monthly variation of hurricane hits (all categories) on coasts of México. 1951-2000 period.

	May	June	July	Aug	Sept	Oct	Nov
Pacific	2	12	3	6	22	18	2
Gulf of México and Caribbean	0	1	2	9	12	3	0

nine of the most destructive mature (class 5) hurricanes came ashore on México's coasts. In this section, a description is made of these major tropical cyclones some of them landing with full hurricane force (winds > 249 km/h) (Table 8).

Six great hurricanes made landfall on the Gulf and Caribbean coasts of México during the 1951-2000 period. Three of them followed a west north-west trajectory entering the Gulf either through the Yucatán channel or crossing the Yucatán peninsula carried by the strong trade wind flow (Fig.2). They developed on the warm tropical Atlantic waters east of the Lesser Antilles (e.g. Gilbert, Beulah and Allen) during cold/neutral phase of ENSO. Upon entering the Caribbean sea they intensified their strength probably due to favorable general convergence flow associated with *La Niña* conditions in that region (see Magaña and Pérez, 1998).

Most of these intense hurricanes made a double strike landfalling, first on the Yucatán peninsula and, after crossing the Gulf of México, made a second hit on the Tamaulipas/Veracruz coasts (Fig.2). An exception was hurricane Anita which displayed an anomalous track.

Impact of some intense (category 5) landfalling hurricanes

Hurricane No. 15

This unnamed hurricane struck the sea-port of Manzanillo on the Pacific coast, with powerful gales

Table 8. Mature hurricanes (category 5) that made a landfall on Mexican coasts. 1951-2000 period.

Name	Date	Minimum pressure (hPa)	Max Speed wind (km/h)	Category on landfall	Site of landfall
Gulf and Caribbean					
1. Janet	Sep/28/1955	938	277	5	Chetumal, Q.R.
Janet	Sep/29/1955	950	176	2	Tuxpan, Ver.
2. Beulah	Sep/20/1967	931	259	5	Matamoros, Tamps.
3. Anita	Sep/02/1977	926	277	5	Soto la Marina, Tamps.
4. Allen	Ago/07/1980	899	305	5	Cabo Catoche, Q.R.
Allen	Ago/10/1980	945	185	3	Matamoros, Tamps.
5. Gilbert	Sep/13/1988	905	259	5	Cancún, Q.R.
Gilbert	Sep/16/1988	950	213	4	Tamaulipas, and Monterrey, N. L.
Pacific					
6. # 15	Oct/23/1959	958	259	5	Manzanillo, Col.

on October 23, 1959. An estimated 25% of homes were destroyed in neighboring Cihuatlán, three merchant ships capsized and 1500 people were killed (CENAPRED, 2001).

Hurricane Anita

Hurricane Anita originated in the warm waters of the eastern Gulf of México. As it started to move in a south-easterly direction, Anita crossed a pool of warm waters and a period of sudden intensification followed. Anita landed in a sparsely populated area near the fishing village of La Pesca in southern Tamaulipas State on September 2, 1977 as a category 5 hurricane. As noted by Longshore (1998), Anita provided evidence not only of a direct link between the presence of warm water eddies and a hurricane's abrupt intensification, but also, a cooling of the sea surface waters after the passage of the storm. In spite of its powerful winds and high storm surge, no human losses were reported (Gross and Lawrence, 1989).

Hurricane Gilbert

Hurricane Gilbert firstly developed as a low-level circulation off the African coast on September 3; after becoming a tropical storm a week later, it reached hurricane intensity east of the Lesser Antilles. Following Gilbert's passage over Jamaica, rapid intensification occurred. Pressure fell 72 hPa/24h to reach a minimum pressure of 888 hPa (the lowest ever recorded sea-level pressure in the Western hemisphere (Gross and Lawrence, 1989). On September 14, it made landfall on northeast Yucatán Peninsula near Cozumel. Sustained winds at landfall were estimated at 241 km/h corresponding to a category 5 of the Simpson/Saffir scale. During the next two days, Gilbert continued the same west-northwest course across the Gulf and making landfall late on the 16, as a category 3 near the town of La Pesca in southern Tamaulipas State. After moving inland, the weakening storm passed south of Monterrey on the 17 and then turned north-bound across western Texas. Torrential rains accompanied the storm over the coast and mountainous areas. The normally dry bed of the Santa Catarina River that crosses Monterrey was flooded, and more than 100 persons died when passenger buses were trapped and overturned in the rising waters.

Overall, the reported death toll from Gilbert, including those from Yucatán, was 202; damage (including 60,000 destroyed homes) was estimated between 1 and 2 billion dollars (Gross and Lawrence, 1989).

Landfalling Tropical Storms

Tropical depressions and tropical storms (sustained wind speed 39-73 mph) often affect both Pacific and Gulf littorals of México. Although most of them maintained their status during their life cycle before making landfall, some of these storms (11) had been hurricanes that decayed to tropical storms or depressions before hitting the coast. The number of tropical storms that affected both coasts during the period was 67.

The ratio of landfalling tropical storms (LFTS) in the Pacific with respect to those landing on the

Gulf/Caribbean coasts is 2.2 which is similar to that for landfalling hurricanes. The number of LFTS has markedly increased on the Atlantic side during the 1990s, while that on the Pacific shows a slight increase during the same period. (Table 9).

With regard to the most vulnerable regions to these storms, geographic distribution is somewhat similar to that of hurricanes, except for the states of Baja California, Jalisco and Oaxaca on the Pacific side, where the probability of landfalling tropical storms dominates over hurricane hits (Fig. 3). Interesting to note from Table 9 is that the total number of tropical storm landfalls on both oceanic coasts of the country is not very different from the corresponding numbers for hurricane hits.

Table 9. Decadal variability of landfalling tropical storms on both littorals. 1951-2000 period.

	1951-60	1961-70	1971-80	1981-90	1991-00	Total sum
Gulf/Caribbean	8	7	8	2	6	31
Pacific	12	17	15	10	13	67

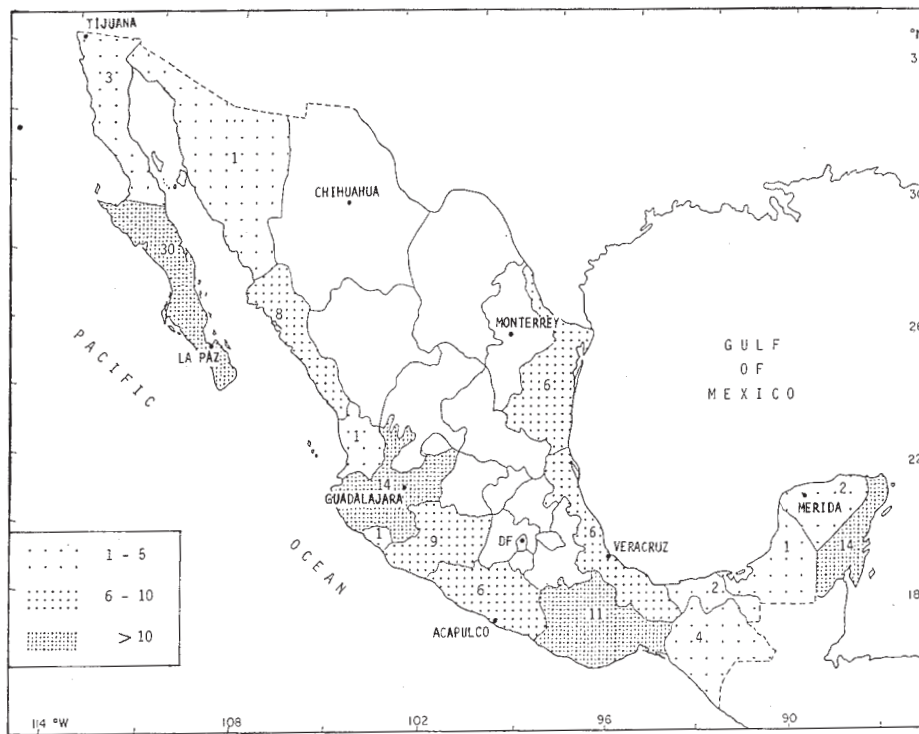


Fig. 3. Number of landfalling tropical storms in México by states. 1951-2000 period.

4. Concluding remarks

México is particularly vulnerable to tropical storms of both Atlantic and Pacific oceans. During the 1951-2000 period hurricanes making landfall on the country's coasts amounted to 9% and 18% of all hurricane activity on the Atlantic and northeastern Pacific, respectively. The probability of a hurricane landfall is two and-a-half times higher on the Pacific than on the Gulf/Caribbean coasts of the country (Table 3). Both Atlantic and Pacific coasts are vulnerable to the same number of intense (categories 3 to 5) hurricanes. However, great hurricanes (category 5) making landfall on the Atlantic side, were more numerous (7) than those on the Pacific coasts (1).

Most vulnerable regions in the country to hurricanes are those in the NW (Sinaloa and the southern part of Baja California peninsula) followed by Michoacán state. On the Atlantic side, the state of Tamaulipas and the Yucatán peninsula are most susceptible to these storms. September is the month of highest hurricane landfalls on both oceanic coasts of the country. While hurricanes making landfall on the Pacific coasts of México show a marked increase since the 1960s, those landing on the Gulf/Caribbean coasts of México have markedly declined. However, the overall number of hurricane landfalls on both littorals has significantly increased since the 1980s. After a reduction of activity during the 1980s, tropical storm landfalls on the Atlantic side of the country have markedly increased compensating somehow for the decline in hurricane landfalls in that region.

While hurricanes affecting the Pacific coasts show a marked increase since the 1980s (Table 10), those impacting on the Gulf and Caribbean seem to have markedly decreased in numbers during the last two decades of the 20th century. This last result seems to be in contradiction to what is occurring at the scale of the whole Atlantic basin where according to FEMA, 1995-2000 was the busiest period of North Atlantic hurricane activity ever measured.

Since as it has been suggested (FEMA), the Atlantic and Caribbean sea surface temperatures are shifting toward a warm phase, it is likely that more hurricanes will affect the Gulf and Caribbean coasts of México in the coming years. However, as noted by Bove *et al.* (1998), no indication of a change to an increasing trend is apparent. An analysis made over the period during the period 1951-2000 revealed that hurricane activity in the Northeast Pacific increased markedly (99.95% significance). While the marked observed increase in landfalling hurricane activity over the Pacific coasts of México (Table 10) in the 1990s decade is not statistically significant, this increase might be linked to more frequent and extensive warm waters of El Niño events that occurred in this decade.

In conclusion, it may be said that landfalling hurricanes have significantly declined during the second half of the 20th century on the Gulf/Caribbean coasts of México. Hurricane activity in the Pacific has markedly increased in the last decade as compared with 1980s decade. Even though the 1951-2000 landfalling hurricane trend is significantly negative for both coasts of the country, it should be noted that the slight positive trend is evident after the 1980s.

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References

- Aguilar, G. 1999. Human settlements and climate change in México –A scenario of regional vulnerability-. In: *El cambio climático en México*. C. Gay ed., 171-194. INE/PUMA.
- Bove, M., D. Zierden and J. O'Brien, 1998. Are Gulf landfalling hurricanes getting stronger? *Bull. Amer. Meteor. Soc.* **79**, 1327-1328.
- CENAPRED, 2001. Diagnóstico de peligros e identificación de riesgos de desastres en México. Atlas Nacional de Desastres. 219 p. México.
- FEMA, 2001. (Federal Emergency Management Agency) U.S. to see above normal hurricane activity over next several decades. In: <http://www.fema.gov>.
- Fernández-Partagás, J. and H. Díaz. 1996. Atlantic Hurricanes in the second half of the 19th Century. *Bull. Amer. Meteor. Soc.*, **77**, 2899-2906.
- Gross, J.M. and M.B. Lawrence. 1989. North Atlantic Tropical Cyclones, 1988. *Mariner's Weather Log*, **33**, 8-14.
- Jáuregui, E. 1989. El impacto de los huracanes en la precipitación en el norte de México. *Ingeniería Hidráulica en México*. Sept.-Dic. 43-50.
- Longshore, D. 1998. *Encyclopedia of hurricanes, typhoons and cyclones*. 362 p. Facts on File, Inc.
- Magaña, V. and J.L. Pérez, 1998. Variabilidad climática en los mares interamericanos. Proceed. VIII OMMAC Congress. 28-30 Oct/98. 69-72. Veracruz, México.
- Reading, A. 1990. Caribbean tropical storm activity over the past four centuries. *Int. J. of Climatology* **10**, 365-376.
- Whitney, L. and J. Hobgood, 1997. The relationship between sea surface temperature and maximum intensity of tropical cyclones in the Eastern North Pacific Ocean. *J. of Climate*, **10**, 2921-2930.