A reconstruction of landfalling tropical cyclones on the Pacific coast of Mexico from 1850 to 1949

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1. INTRODUCTION

The last two decades since the studies reported in Bradley and Jones (1992) were published, have seen a large increase in the number of publications that make use of different variables as well as historical documents as proxies to retrieve information about the past climate. Garcia et al. (2001) and García-Herrera et al. (2003) reconstructed atmospheric circulation changes in the Tropical Pacific from the voyages of the Spanish galleons from 1590 to 1750. They were able to infer that the sailing time between modern Mexico and the Philippines was a function of the strength of the trade winds and the location of the western Pacific monsoon trough. They concluded that the atmospheric circulation of the western Pacific underwent a large multidecadal fluctuation during the XVIIth Century.

The compilation by Garcia-Acosta et al (2003) provides a unique catalogue of climatically-induced agricultural disasters from pre-hispanic times (958AD) to the first half of the XXth Century, making use of codex and colonial documents in the Mesoamerican region. They identified several cases of landfalling cyclones in the Maya region (starting in 1462) as well as a few events that affected the Pacific in 1530 (Sinaloa), in 1573 (Colima) and in 1586 (Nayarit). Only 2 incidences of landfalling were reported in the 1600s in Guerrero and Chiapas (located in the southern coast of Mexico), while 5 landfalling events were reported in the same region in the XVIIIth Century. A systematic study is currently underway to determine the full extent of landfalling cyclones in the aforementioned region (Chiapas and Guerrero) as well as the Yucatán peninsula and the coast of the Gulf of Mexico (Garcia-Acosta and Padilla-Lozoya, personal communication). The tropical cyclone that in 1959 caused the destruction of about of about 3/4 of the town and hundreds of dead in Minatitlan (Colima) has been extensively documented by Padilla-Loyoza (2007). Recently the same general area was affected by the landfall of Hurricane Jova (2011).

Serra (1971) presented a first reconstruction of eastern Pacific tropical cyclone trajectories between 1921 and 1969, calculating a probability higher than 90% that a tropical cyclone would make landfall in one of 5 of the 10 Mexican states considered. The study does not indicate clearly how the trajectories were estimated, presumably based upon ship reports for the ones that are far from land. For the period considered in his study, Serra (1971) estimated that the probabilities of landfall in Baja California Sur and Sinaloa were 0.49 and 0.38, respectively. Englehart et al (2008) have analyzed the period 1921-2005 and conclude that there is non-random behavior in the number of near-shore tropical cyclones and point towards long-term variability.

A general climatology of tropical cyclones in the eastern North Pacific is presented by Romero-Vadillo et al (2007), who also discussed the influence of ENSO on the variability observed. Jauregui (2003) provides a spatial distribution of landfalling cyclones up to 2000, highlighting the large number that affect the southern tip of the Baja California peninsula, already noticed by Serra (1971). The influence of topography on the trajectories was explored by Zavala-Sansón (2004), suggesting that trajectories tend to be "trapped" near the coast, which would lead to more frequent landfalls in the southern parts of the Baja California peninsula, as is observed.
Tropical cyclones that generate in the eastern North Pacific and make landfall in Mexico play a significant role on the availability of water in the arid and semi-arid regions of NW Mexico. Moreover, tropical cyclones activity in this basin influences the summer monsoon in the region. Englehart and Douglas (2001) analyzed the precipitation in 18 stations in western Mexico, from Oaxaca to Baja California Sur and determined the contribution of rainfall associated with tropical cyclones (TC) to the total rainfall. They concluded that TC rainfall was more spatially coherent than non-TC rainfall. More recently, Larson et al (2005)

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extended the results of Englehart and Douglas (2001) using a gridded precipitation dataset for the period 1950-1998 to estimate the influence of TC for the whole of Mexico, identifying the variability in terms of spatial and monthly distributions. Between 80 and 90% of the precipitation in October in NW Mexico is associated with TCs and consistent with the highest frequency of landfall in the region in October.

The limited extent of the available dataset for the eastern Pacific basin from the National Hurricane Center (NHC) from 1949 to the present, extended back to 1921 by Serra (1971), prevents the study of the longer term variability of landfalling tropical cyclones. The objective of this study is to extend the time series of landfalling TC onto western Mexico back to 1850 and evaluate its variability.

2. DATABASES AND METHODOLOGY

The reconstruction of the time series of landfalling tropical cyclones onto the Pacific coast of Mexico was determined from a variety of sources. Firstly, the National Library of Mexico (Biblioteca Nacional) and the National Newspaper Archive (Hemeroteca Nacional) that constitute the national repositories since 1867 and 1921, respectively. In this first stage of the project, the decision was made to limit the period of study to the 100 years prior to the start of official database from the NHC for the Eastern Pacific basin. Even though there are questions about the validity of the total number of cyclones in the database for this basin before the satellite era, we consider that the database is adequate if we are only focusing on the landfalling cyclones.


EL DEMOCRATA
SINALOENSE
VARIAS CASAS DESTRUIDAS POR EL CICLON
EL LUNES 24 SE DESIGNARA AL PRESIDENTE PROVISIONAL
EL VENDAVAL ALCANZO UNA GRAN FUERZA
EL CORINTO LLEGO YA A MANZANILLO
PORTES GIL SUCEDERA A P. E. CALLES
DECRECE LA VIRUELA EN LA COMARCA
NUEVA ACUSACION EN CONTRA DEL GENERAL DON ANDRES ZAIDIVIA
NI EN MEXICO NI EN CENTRO AMERICA HAY EST. METEOROLOGICAS

Figure 1. *Front page of the newspaper "El Democrata Sinaloense" from Mazatlan, on 22 September 1928 reporting damage from the cyclone that affecte the city 2 days earlier.*

The search at the national repositories provided the startup documentation that was then supplemented by visits to local libraries in several other cities in Mexico (Acapulco, Chilpancingo, Guadalajara, Colima, Mazatlán, Culiacán and La Paz). Documents found in those cities were mostly official government reports requesting financial aid to the central government to cope with the losses associated with meteorological phenomena. The local repositories also had originals of local and regional newspapers (as shown in **Figs 1** and **2**) that provided a wealth of information, which has been catalogued for further research.

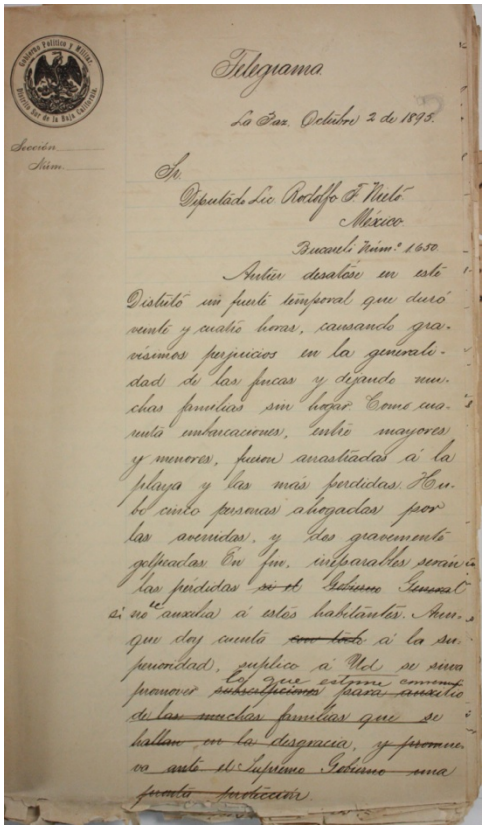
Telegrama
La Paz. Octubre 2 de 1895.
Sr.
Diputado Lic. Rodolfo F. Nieto
México
Bucarli Núm.º 1650
Ayer desató en este
Distrito un fuerte temporal que duró
veinte y cuatro horas, causando gra-
vísimos perjuicios en la generali-
dad de las fincas y dejando mu-
chas familias sin hogar. Como con-
secuencia inundaciones, entre mayores
y menores, fueron arrastradas á la
playa y las más perdidas. Hu-
bo cinco personas ahogadas por
las avenidas, y las gravemente
golpeadas en fin, irreparables serán
las pérdidas ~~en el Gobierno General~~
si no auxilia á estos habitantes. Aten-
to doy cuenta ~~con lo~~ á la su-
perioridad, suplico á Ud se sirva
promover ~~subscripciones~~ para auxilio
de las muchas familias que se
hallan en la desgracia, y promue-
va ante el Supremo Gobierno una
pronta providencia.

Figure 2. *Handwritten message from the local government in La Paz sent to the representative in the central legislature on 2 October 1895 describing the damage caused by the cyclone that affected the city during 24 hours, including 5 deaths by drowning and 2 seriously injured.*

Over one thousand records were created in association with the information retrieved, and were filed as cards specifically designed for this project. The records were divided into months, and in this study we *only* focus on the evidence of

landfall tropical systems, considering entries from May through November. Most of the Pacific coast of Mexico was considered, encompassing the States of Guerrero, Jalisco (current States of Nayarit and Colima, were part of Jalisco in the XIXth Century), Michoacán, Sinaloa and Baja California Sur. The State of Sonora was not investigated, since in the modern era, all cyclones that have affected this State had first made landfall in Baja California Sur. We also left out the States of Chiapas and Oaxaca where very few cyclones have entered in the modern era.

3. RESULTS

Figure 2 presents the decadal variability as a function of the State where landfall occurred. Two decades indicated very low activity: 1870-1879 and 1910-1919. In both decades there were plenty of documents available, but very few reports of landfalling cyclones .

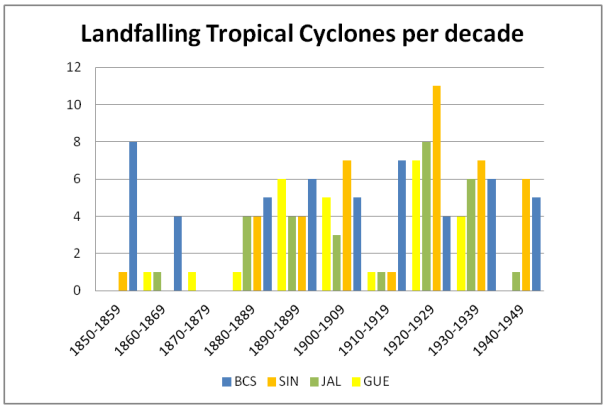

Figure 2. *Total number of landfalling tropical cyclones per decade from 1850 to 1949, for the States of Baja California Sur (BCS, blue), Sinaloa (SIN, orange), Jalisco (JAL, green) and Guerrero (GUE, yellow).*

Note that there seems to be an anti-correlation between landfalls in BCS and Sinaloa on the mainland. Observations from paleotempestology records presented by Liu and Fearn (2000) for the US and by Liu (2007) from China also identify a similar apparent "see-saw" pattern. The hypothesis put forward in those studies relates to changes in the location of the high pressure systems affecting the winds that steer the tropical cyclones over land. It is conceivable that a similar argument could be made for the TC making landfall on the Pacific coast of Mexico.

We combined the time series obtained from 1850 to 1949 with the official NHC record to 2010 to generate a reconstructed time series of 161 years in length and to evaluate its basic statistics and variability. A total of 295 tropical cyclones made landfall for the abovementioned States on the West coast of Mexico in the period 1850-2010, but no cyclones made landfall during 38 of the 161 years, resulting on an estimated average number of landfalls of 1.83 ± 1.57 per year.

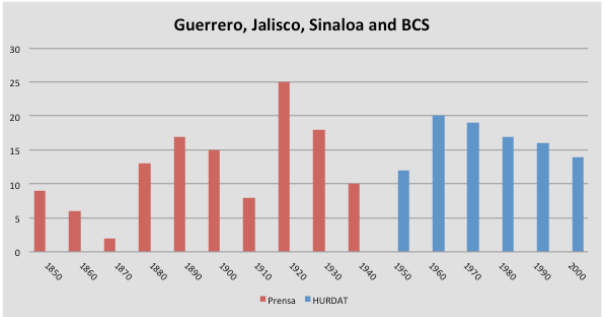

Figure 3. *Combined time series of landfalling tropical cyclones (per decade) from historical reconstruction and NHC official database.*

The wavelet analysis (Fig. 4) indicates that throughout the whole time series there is power associated with phenomena with a 2-5 year period. But most strikingly, there is a large peak in power for periods between 30 and 50 years that started developing towards the end of the XIXth Century.

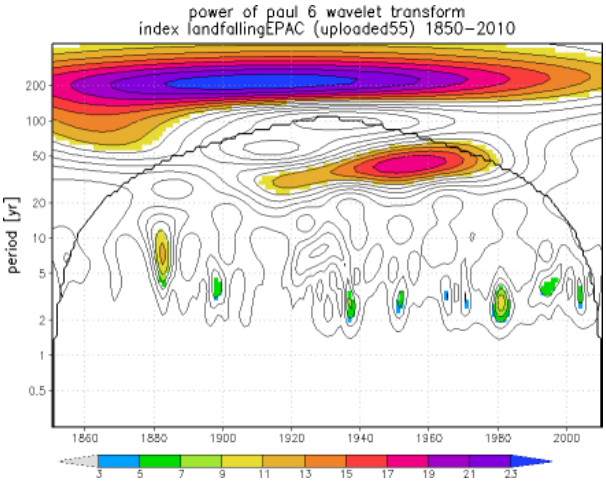

Figure 3. *Wavelet analysis of th time series of the total number of tropical cyclones that made landfall between 1850 and 2010 onto the Pacific Mexican States of Guerrero, Jalisco, Sinaloa and Baja California Sur (the black heavy line indicates the influence cone)*

In order to explore the nature of this variability, we consider the natural modes of the system: ENSO and the North Atlantic Oscillation (NAO). These internal modes and the Madden-Julian Oscillation (MJO) may modulate the landfall in the intraseason to interannual frequency, as shown in the observations (Fig 3). There is, however, a much more important influence in the multi-decadal period.

The Pacific Decadal Oscillation (PDO) is a long-term fluctuation of the Pacific Ocean first noted by Mantua et al (1997) on the sea surface temperature (SST) records, with a change of phase every 20-30 years. The SST, surface pressure distributions and geopotential heights all exhibit anomalies throughout the Pacific and North America, affecting the winds at that steer the tropical cyclones.

Table I. Spearman correlation coefficient between the reconstructed time series of landfalling tropical cyclones and climate indices related to well established patterns (NAO: North Atlantic Oscillation; SOI: Southern Oscillation Index; PDO: Pacific Decadal Oscillation). The indices were provided by the Climate Prediction Center of the National Oceanic and Atmospheric Administration.

Period	Index	Correlation
1850-2010	NAO	0.22
1866-2009	SOI	0.13
1900-2010	PDO	0.31
1856-2010	Niño3	0.22

The Spearman correlation coefficients calculated between the reconstructed landfalling time series and several climate indices are shown in Table I. Both ENSO (as characterized by the Niño3 index) and the NAO show the same correlation (0.22). The largest correlation of the landfalling time series is with the PDO index (0.31). Even though the PDO is not a mode of variability, this pattern appears to also correlate with other observations in the region, consistent with our results that the number of landfalling TCs is primarily modulated by the PDO from Guerrero to Baja California Sur. Englehart and Douglas (2002) explored the relationship of rainfall variability in western Mexico with the Equatorial rainfall Index (ERI) and an index for the PDO and determined that the first mode of variability of the *TC rainfall* is significantly (95%) related to the PDO. Moreover, Brito-Castillo et al (2002) also observed that the fill capacity of dams (related to the precipitation over land) was correlated with the PDO.

4. CONCLUSIONS

A time series of landfalling cyclones onto the Pacific coast of Mexico was reconstructed for a 100-year period (1850-1949) from archived newspapers and historical documents. The variability observed in the reconstructed time series is quite similar to that observed in the official NHC database (from 1949 to the present). The analysis of the full time series from 1850 to 2010 results in an average yearly landfall on the West coast of México of 1.8 ± 1.6. There appears to be a "see-saw" pattern in the record between landfalls in BCS and Sinaloa that requires further investigation.

The analysis to determine the nature of the variability of the landfalling time series indicates that both ENSO and the NAO have comparable influences and are observed throughout the whole period of 161 years. A multidecadal modulation is also observed, particularly strong for the period 1950-1970, but present since the late XIXth Century. The largest correlation is found with the PDO index. The suggestion on long-term variability presented by Englehart et al (2008) in their analysis of the period 1921-2005, has now been confirmed with the dataset from 1850-2010 developed in this study.

Acknowledgements

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