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THE INFLUENCE OF STRONG EL NINO PHASES ON THE RAINFALL OVER THE YUCATAN PENINSULA, MEXICO

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Abstract: The combination of several large-scale atmospheric influences makes the complex climatology of the Yucatán Peninsula difficult to predict. This study explores the most important physical modulator of the rainfall over México, the El Niño Southern Oscillation (ENSO), and its effects over the peninsula. Two different analyses were applied: non-parametric correlations between the Standardized Anomaly Indices of the long-term seasonal precipitation and the Multivariate ENSO Index; and the assessment of the rainfall response to three case studies, a relatively long hot ENSO phase (1957-58), and the strongest Niños of the twentieth century (1982-1983 and 1997-1998). The main factor determining the ENSO influence over the Yucatan Peninsula precipitation was its intensity: the strong Niños of 1982-83 and 1997-1998 had a positive effect on the rainfall, particularly during the dry-season when conditions were generally wetter than normal over the entire region; furthermore, an unusually wet Nov-Apr period within an intense El Niño phase, provides a reliable indication that rainfall is likely to surpass long-term means for the wet season (May-Oct) as well.

Keywords: *Yucatán Peninsula, rainfall, ENSO, modulator, climate*

I. INTRODUCTION

The main characteristic of the Mexican climate is its complexity (García, 1988; Mosiño and García, 1974). Geographical factors with a strong influence include: latitude, orography, altitude, oceans and continentality. Mexico is particularly interesting climatically owing to its location between tropical and extra-tropical climatological conditions (Cavazos and Hastenrath, 1990). Like other countries that lie in this latitudinal transition, it has been generally less studied than mid and higher latitudes (Vose et al., 2005).

One of the regions that epitomize a complex climatic regime in Mexico is the Yucatán Peninsula. Tropical easterly waves reach the Mexican Caribbean coast almost every year (Mosiño and García, 1974), being directly tied to the northward/southward position of the Bermuda High, and depending also on the location of the Inter-Tropical Convergence Zone (ITCZ) itself (Jáuregui, 1997, Yulaeva and Wallace, 1994). Another regional climatic characteristic is the occurrence of Tropical Cyclones (TCs); indeed, a large percentage of the annual total precipitation is linked to the hurricanes striking the area (Hernández et al., 2001). Unfortunately, the supposedly strong relationship between the increasing (in number and also intensity) TCs and the Global Climate Change (CC) has not yet been fully proven (Pielke et al., 2005; Webster et al., 2005), and this uncertainty also applies to the Yucatan Peninsula. Recurrent dry periods have occurred in the Peninsula, as well. Kenneth et al. (2012) have recently suggested that a long drought may have influenced the downfall of the Mayan civilization. Several techniques have been applied in attempts to map the climatic regionalization of rainfall in Mexico (Englehart and Douglas, 2002; Giddins et al., 2005; Salas-Flores, 2008; Bravo et al., 2012), but some have been hindered by the great influence exerted by land-falling hurricanes; these can completely disrupt the geographical pattern when compared with the neighboring stations not affected by those TCs. Another key characteristic of the total annual precipitation does not necessarily occur during the wet season. Cold fronts (closely related to westerly winds events) can reach far-southern Mexican regions such as the Tehuantepec Isthmus (Harrison and Chiodi, 2009; Trasviña, and Barton, 1997) and the Yucatán Peninsula during (boreal) autumn and winter; depending on how intense these polar air masses are, they can produce additional amounts of rainfall when combining with the moisture from the Gulf of Mexico (Cavazos, 1997; Cortez, 1998). The climate of the Peninsula is further complicated by the El Niño Southern Oscillation (ENSO), which is the main atmospheric control of precipitation over México (Magaña et al., 2003). During the warm phase of ENSO, rainfall amounts during June−August are below normal across the country (Trenberth and Caron, 2000); during winter they are above normal along the Gulf of Mexico coast, northern Mexico, Texas and the Caribbean islands, but have been recorded as below normal in the Tehuantepec Isthmus (Díaz and Kiladis, 1992). Finally, if the characteristics of each ENSO are different, then the rainfall response -including the Yucatán Peninsula- is difficult to predict (Magaña, 2003; Hoerling and Kumar, 1997).

In the present study, the ENSO modulation (through the Multivariate ENSO Index or MEI) of long-term (1950-2010) seasonal rainfall on the Yucatan

Peninsula is first explored by use of non-parametric correlations on the Standardized Anomaly Indices (SAIs) version of the two meteorological variables. Additionally, in the second analysis, the regional rainfall responses are evaluated in three (El Niño) case studies: assessment of 1957-58, although the relatively long spell of El Niño ended until 1959; and also the evaluation of the 1982-83 and 1997-1998 intense hot ENSO phases, the strongest of the 20th century (http://www.esrl.noaa.gov/psd/enso/mei/, visited on 19/05/2013). Regional maps of the SAIs are then used to check the El Niño impacts on the seasonal rainfall over the Yucatán Peninsula.

II. METHODS AND DATABASES

A database of 30 stations containing total long-term monthly precipitation from 1950 to 2010 was prepared for the analyses. Five digital sources were used (Salas-Flores, 2008); because there is no national climatic database accepted as a reference in Mexico, quality control of the daily data was necessarily rigorous. Basic statistical parameters were computed and found to agree well with the climatological normals calculated by García (2004). Double-mass plots were then used to detect possible errors or mistyped values on the time-series (Cluis, 1983). A full homogenization analysis was not performed, owing to the impossibility of having the original metadata of the stations, and the lack of consensus for correcting any suspect daily data (Aguilar et al., 2003).

The index selected for exploring the ENSO influence in a broader way is the Multivariate ENSO Index (MEI). Because it is computed as a weighted average of six different variables over the tropical Pacific (Wolter and Timlin, 1993), MEI is said to be more robust and perform better at large-scale correlations and not necessarily at regional scales. Positive values are linked to warm episodes of ENSO (El Niño), while negative are associated with cold periods (La Niña). Annual Standardized anomaly Indices or SAIs (Jones and Hulme, 1996) were calculated for each time-series, with the aim of avoiding large contrasting rainfall fluctuations across the region, and strong external influences as well.

One of the most important climatic features of Mexican precipitation is the existence of two very well defined seasons for most of the country: the wet season, from May to October (Mosiño and García, 1974; Hastenrath, 1967), during which the highest percentage (at least 70%) of the total annual rainfall is concentrated (Cavazos and Hastenrath, 1990); and the dry season from November to April. Standardized Anomaly Indices (SAIs) were prepared for annual values and for wet and dry seasons as well. A non-parametric correlation coefficient, Kendall’s tau-b (τ), was chosen because of the limitations of linear correlations. Kendall's tau deals better (than Spearman's) with small datasets and a large number of tied ranks

(Haylock, 2005); also it is more robust and reliable in the determination of the level of statistical significance.

The formula for Kendall's tau-b (Eq. 1) is:

$$\tau = \frac{\sum_{i<j} \mathrm{sgn}(x_i - x_j)\mathrm{sgn}(y_i - y_j)}{\sqrt{(T_0 - T_1)(T_0 - T_2)}} \qquad (1)$$

, where:

$$T_0 = \frac{n(n-1)}{2} \qquad (2)$$

$$T_1 = \sum \frac{t_i(t_i - 1)}{2} \qquad (3)$$

$$T_2 = \sum \frac{u_i(u_i - 1)}{2} \qquad (4)$$

t_i is the number of tied *x* values in the i_{th} group of tied *x* values, u_i is the number of tied *y* values in the j_{th} group of tied *y* values, *n* is the number of observations and sgn(z) (Eq. 5) is defined as:

$$\mathrm{sgn}(z) = \begin{cases} 1 \; if \;\; z > 0 \\ 0 \; if \;\; z = 0 \\ -1 \; if \;\; z < 0 \end{cases} \qquad (5)$$

This coefficient measures the association of the number of concordant and discordant pairs of observations. A pair of values is said to be concordant if they vary together, and discordant if they vary differently (Crichton, 2001), and it is precisely to measure the association between long-term precipitation over the Yucatán Peninsula and ENSO (through MEI) that Kendall's tau-b correlation coefficient has been used in the analyses.

A slightly different approach - for the second analysis - was then designed to test modulation by ENSO of the regional precipitation under specific climatological conditions. Three widely accepted landmark El Niño periods were selected: 1957-58 hot ENSO phase (relatively long, since it actually ended in 1959) that came just after a long cold period (La Niña); and the 1982-83 and 1997-1998 Niños, considered the strongest of the 20th century, but of shorter duration (Wolter and Timlin, 1998). Mapping the regional SAIs, the rainfall response to these strong Niños was checked.

III. RESULTS AND DISCUSSION

III.1. Non-parametric correlation analyses

The first analysis of this study is the estimation of the Kendall's tau correlation coefficient between the long-term precipitation (1950-2010) and MEI. In order to explore the effects of the ENSO on precipitation over the Yucatán Peninsula, we have divided the analyses into three different seasons: annual, wet (May-Oct) and dry (Nov-Apr). Therefore, combinations between SAIs of seasonal rainfall and MEI would be labeled, for example, Annual-Annual, as that describing annual rainfall versus annual MEI (Kendall tau-b) correlations, similarly Wet-Annual describes the correlation between May-Oct precipitation and Annual MEI. The level of statistical significance at 5% (*) and 1% (**) was calculated as well.

The annual MEI version has an important − but limited − influence over the standardized precipitation on the Yucatan Peninsula, very likely as a direct consequence of the great impact that hurricanes have on the Caribbean coast of Mexico. Although efforts have been made to find the link between ENSO and TCs (Shieh and Colucci, 2010), there is still no plausible mechanism that can successfully produce a seasonal forecast based on this teleconnection. The best results in this analysis are then found when annual MEI and dry-season precipitation are correlated, and this could be mainly the effect of the near absence of hurricane strikes during the Nov-Apr period, making it more regionally homogeneous (Fig. 1). Unfortunately, only around 20% of the total annual rainfall occurs during this season, restricting the usefulness of this result.

The wet MEI is strongly controlling rainfall in the dry season, but not as much (as expected, due to the already described above land-falling hurricane effect) during the wet season; hence, ENSO can only be used cautiously for predicting possible rainfall amounts during the May-Oct period (Fig. 2), the most important rainfall season of the (climatological) year.

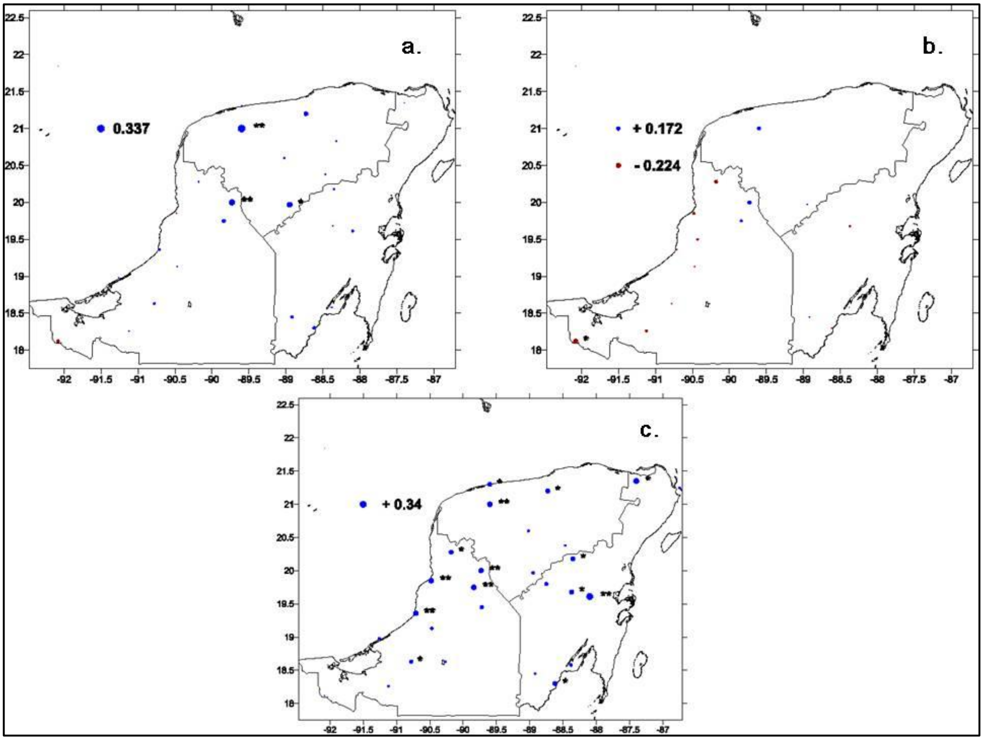

Fig. 1. Kendall-tau correlation coefficients between Annual MEI and SAI of a. total annual, b. wet-season, and c. dry-season rainfall. Statistical significance: 5% (*) and 1% (**).

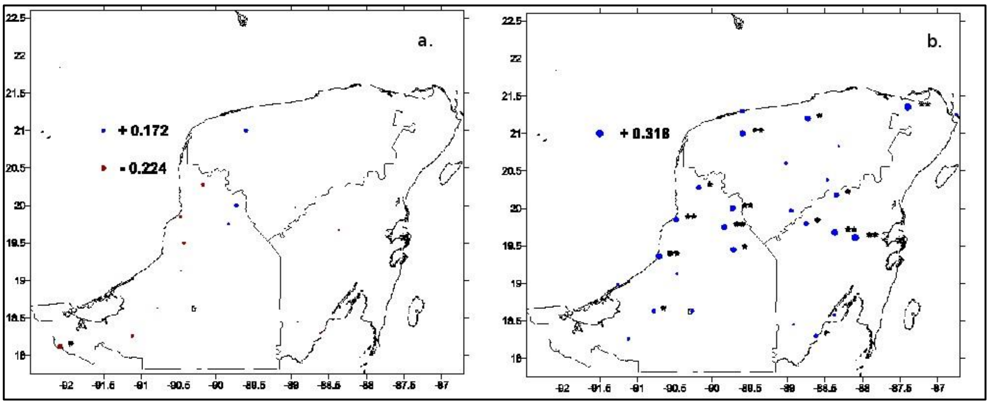

Fig. 2. Kendall-tau correlation coefficients for May-Oct. MEI and SAI of a. wet-season, b. dry-season rainfall. Statistical significance: 5% (*) and 1% (**).

On one hand, when an El Niño phase is developing during Nov-Apr, it should be expected that rainfall amounts during the wet season will be above the climatological normals, although only three of those correlations are statistically significant (Fig. 3a). On the other hand, results are no better for dry season rainfall when modulated by the Nov-Apr ENSO (through MEI); only a few stations have statistically significant correlations (Fig. 3b). Although, for both seasons, only a few correlations are statistically significant, it is clear from the homogeneous distribution of positive anomalies across the peninsula that when the El Niño phase is increasing during the Nov-Apr period, rainfall amounts during both the wet and dry seasons are likely to exceed the long-term mean values for precipitation.

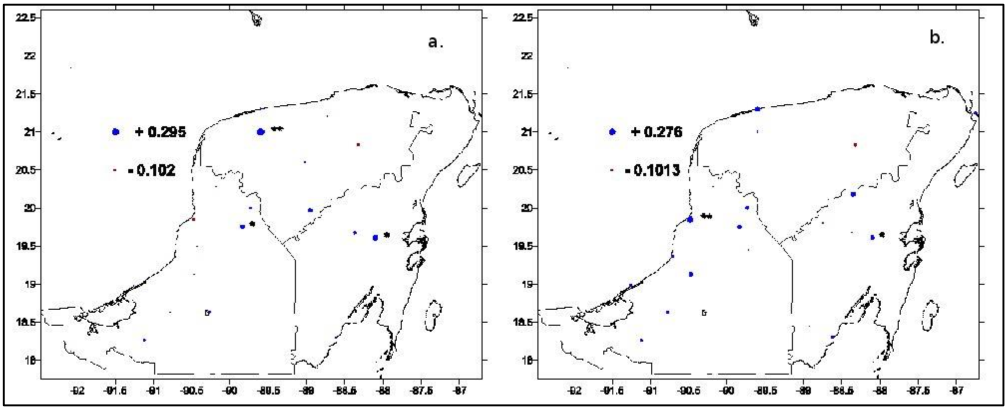

Fig. 3. Kendall-tau correlation coefficients for Nov.-Apr. MEI and SAI of a. wet-season, b. dry-season rainfall. Statistical significance: 5% (*) and 1% (**).

III.2. Case studies

The analysis above has shown the influence of ENSO on the Yucatan Peninsula rainfall, especially during the dry season, but the shortage of statistically significant correlations limits its utility for seasonal rainfall forecasting. A different approach entailed the use of the three different case studies of El Niño phases, 1957-58, 1982-83 and 1997-98. The geographical pattern of annual SAIs is not homogeneous for the years 1957-58 (Fig. 4a and 4b), although clearer for 1982-83 (Fig. 4c and 4d): drier within the E region and wetter over the SW of the Peninsula, having higher positive values as well, i.e. in the case of a strong El Niño (as in 1982-83) annual rainfall easily surpasses the long-term means. Wetter conditions are more evident for the 1997-98 El Niño phase (Fig. 4e and 4f), especially for 1997 when the spatial distributions of the positive anomalies is homogeneous across the whole Yucatán Peninsula.

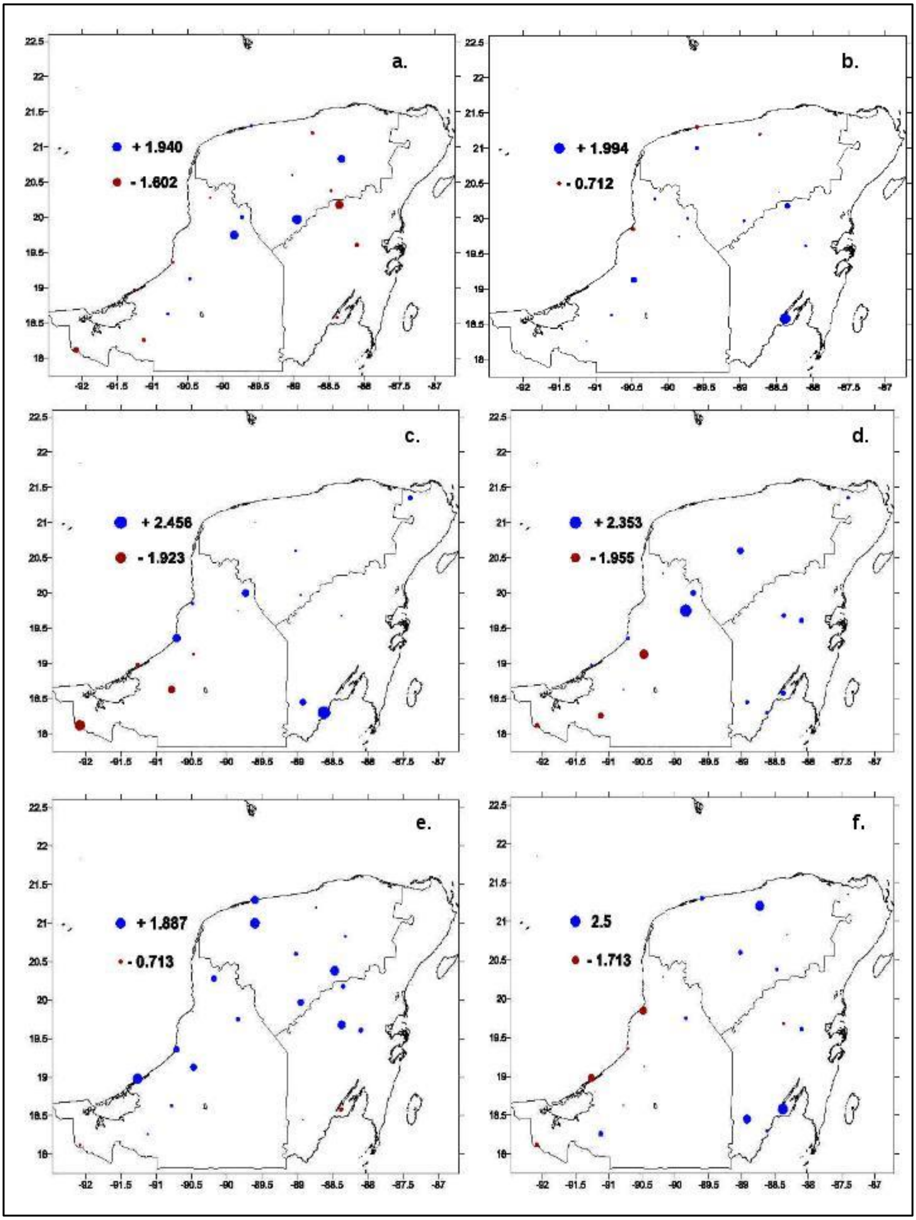

Fig. 4. Standardized Anomaly Indices for the annual rainfall over the Yucatán Peninsula for three different 'El Niño' conditions: a. 1957 b. 1958 c. 1982 d. 1983 e. 1997 and f. 1998. Red dots: negative anomalies. Blue dots: positive anomalies.

The geographical pattern of wet season SAIs during 1957-58 (Fig. 5a and 5b) is mixed between positive and negative, being somewhat clearer in 1957 (Fig. 5a). Nevertheless, values are higher than in the annual analysis. The distribution of SAIs for the years 1982-83 (Fig. 5c and 5d) reflects wetter conditions in the SW. In fact, the TCs corridor is almost free of large positive or negative SAIs, presumably because those years were almost free of hurricane strikes (http://weather.unisys.com/hurricane/, visited on 21/10/2013). Precipitation amounts above long-term means are observed over the eastern half of the Yucatán Peninsula during the 1997-98 El Niño (Fig. 5e and 5f). Positive anomalies are clearer for the 1998 wet season, when the Hurricane Mitch hit this region, and also combined with the intense 1997-98 hot ENSO phase. No clear evidence of a wet-season rainfall modulation during either long or strong El Niño phases can be extracted, except for the combination of a strong El Niño period and one or more hurricanes striking the Peninsula like in 1998.

The ENSO modulation is clearer during the dry season. A transitional response from dry to wetter conditions is seen for the 1957-58 period (Fig. 6a and 6b): the geographical distribution of positive-negative values is mixed in 1957 (Fig. 6a), whereas in 1958 (Fig. 6b) a fairly uniform pattern of large positive SAIs reflects precipitation that exceeded long-term means. An evident pattern of positive SAIs in 1982 is close to homogeneous (Fig. 6c); overall, these SAIs had the largest values of all across the years of the analyses, and they reflect wetter conditions during this strong, hot ENSO phase than in the other years. The 1983 pattern is still one of positive SAIs; although their values are smaller than in 1982, they clearly point to a 1983 Nov-Apr season that was wetter than usual (Fig. 6d). Less homogeneous is the spatial distribution of the positive anomalies during the 1997-98 El Niño phase (Fig. 6e and 6f). Wetter conditions are concentrated over the SE region of the Peninsula, especially in 1997 (Fig. 6e). The 1982-83 and 1997-98 hot ENSO phases clearly shows that during strong El Niño phases the Nov-Apr precipitation (before hurricane season starts in the region) across the whole peninsula is likely to exceed long-term means.

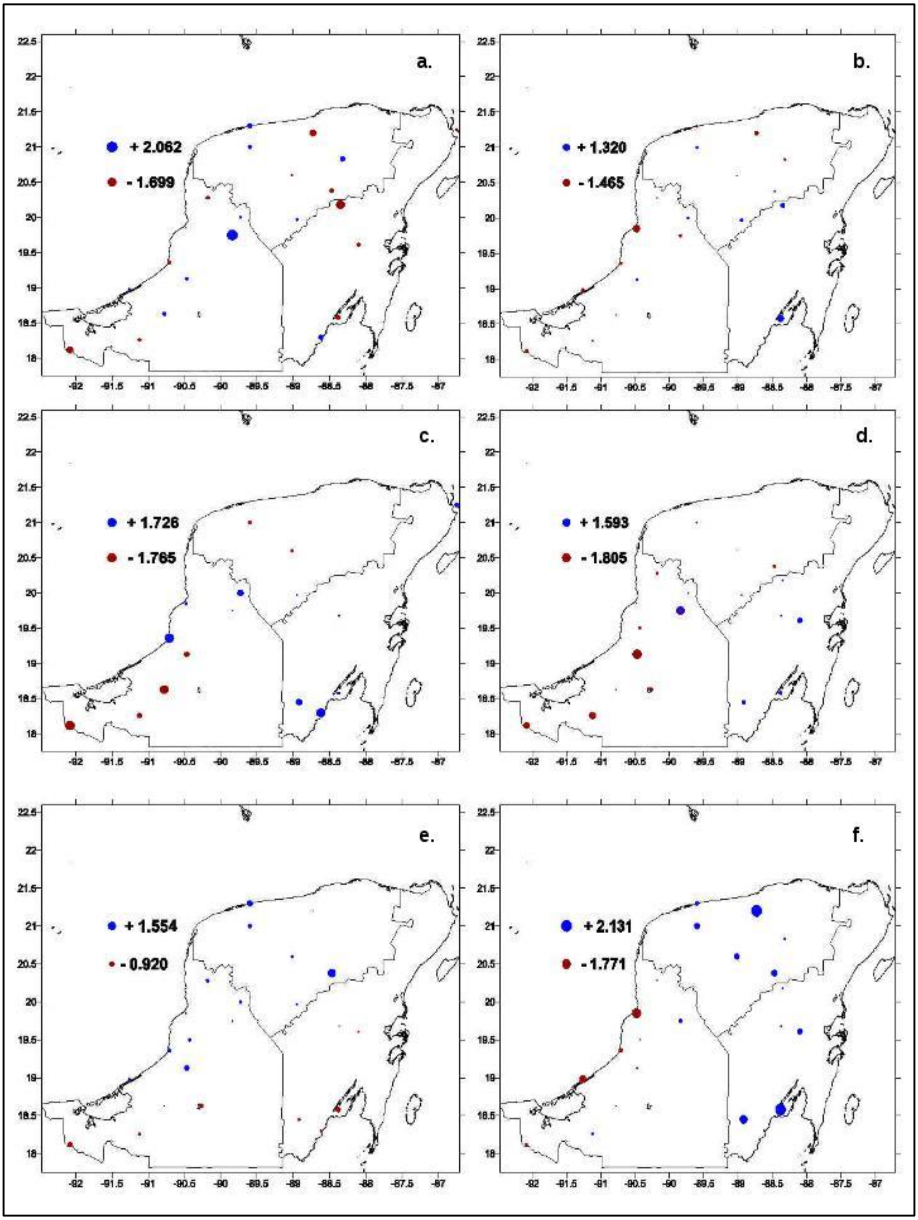

Fig. 5. Standardized Anomaly Indices for the May-Oct rainfall over the Yucatán Peninsula for three different 'El Niño' conditions: a. 1957 b. 1958 c. 1982 d. 1983 e. 1997 and f. 1998. Red dots: negative anomalies. Blue dots: positive anomalies.

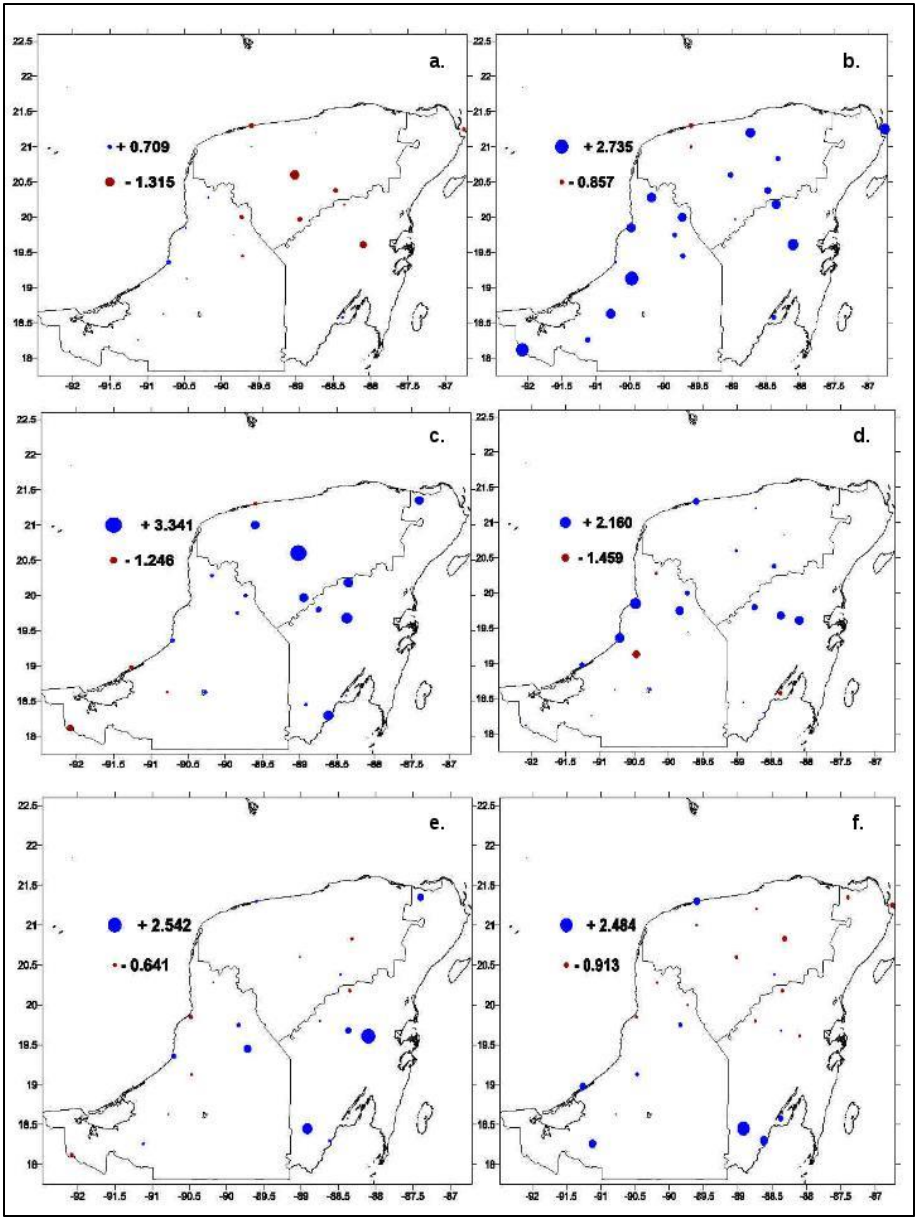

Fig. 6. Standardized Anomaly Indices for the Nov-Apr rainfall over the Yucatán Peninsula for three different 'El Niño' conditions: a. 1957 b. 1958 c. 1982 d. 1983 e. 1997 and f. 1998. Red dots: negative anomalies. Blue dots: positive anomalies.

IV. CONCLUSIONS

This study aimed to increase the understanding of the complex climatology of the Yucatan Peninsula, exploring the relationship between ENSO (through MEI) and the long-term (1950-2010) regional rainfall. Two different analyses were performed in this research. First, non-parametric correlations for precipitation on the Yucatan Peninsula and the MEI are not conclusive; the best values are observed during the dry season (Nov-Apr), but this result is not so useful since the smallest percentage (around 20 to 30%) of the total annual precipitation occurs during this period. On the second analysis, we applied a different approach. Three important 'El Niño' events were selected: 1957-58, as a long El Niño event; also the 1982-83 and 1997-98 were selected as very strong hot ENSO (El Niño) phases, and then mapping the rainfall SAIs for each station to test the precipitation response. The main modulator of the precipitation over the Yucatan Peninsula is the ENSO intensity. The very strong 1982-83 and 1997-98 El Niño events caused an almost spatially homogeneous wetter conditions across the region for the annual and May-Oct (wet) seasons, but the clearest positive anomalies were observed during the Nov-Apr season; furthermore, an unusually wet Nov-Apr period within a very strong El Niño phase, provides a reliable indication that rainfall is likely to surpass long-term means for the wet season (May-Oct) as well. In conclusion, in agreement with a recent study (England et al., 2014), precipitation amounts above long-term climatological normals can be expected during strong El Niño phases over the Yucatán Peninsula.

References

Aguilar E., Auer I., Brunet M., Peterson T.C. and Wieringa J.: Guidance on metadata and homogenization. WMO-TD, 1186, (WCDMP, 53), 51. 2003.

Bravo C. J.L., Azpra E.R., Zarraluqui S.V., Gay C. and Estrada F. P.: Cluster Analysis for Validated Climatology Stations using Precipitation in Mexico. Atmósfera. 25 (4), 339-354. 2012.

Cavazos T.: Downscaling large-scale circulation to local winter rainfall in north-eastern Mexico. International Journal of Climatology. 17, 1069-1082. 1997

Cavazos T. and Hastenrath S.: Convection and rainfall over Mexico and their modulation by the Southern Oscillation. International Journal of Climatology. 10, 377- 386. 1990.

Cortez V. M.: El ciclo anual de la actividad convectiva en México con base en el análisis de valores medios para 5 días de OLR (Outgoing Logwave Radiation), Tesis de Maestría (Geografía). Facultad de Filosofía y Letras, Universidad Nacional Autónoma de México. 1998.

Cluis D.A.: Visual techniques for the detection of water quality trends: Double-mass curves and CUSUM functions. Environmental Monitoring and Assessment. 3, 173-184. 1983.

Crichton N. J.: Information point: Kendall's tau, Journal of Clinical Nursing. 10, 707-715. 2001.

Diaz H. F. and Kiladis G. N.: Atmospheric teleconnections associated with the extreme phases of the Southern Oscillation. In Diaz H. F. and Markgraf V. (Eds.). El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation. Cambridge University Press. 7-28. 1992.

England H. M., McGregor S., Spence P., Meehl A.G., Timmermann A., Cai W., Gupta S. A., McPhaden J. M., Purich A. and Santoso A.: Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus. Nature Climate Change. 4, 222–227. 2014. DOI:10.1038/nclimate2106.

Englehart P. J. and Douglas A. V.: Mexico's summer rainfall patterns: an analysis of regional modes and changes in their teleconnectivity. Atmósfera. 15,147-164. 2002.

García E.: Modificaciones al sistema de clasificación climática de Köppen. Instituto de Geografía, UNAM. México. 90pp. 2004. (in Spanish).

Giddings L., Soto M., Rutherford B.M. and Maarouf A.: Standardized Precipitation Index Zones for México. Atmósfera 18,33-56. 2005.

Harrison D.E.and Chiodi A. M.: Pre- and Post-1997/98 Westerly Wind Events and Equatorial Pacific Cold Tongue Warming. Journal of Climate 22: 568-581. 2009.

Hastenrath S. L.: Rainfall Distribution and Regime in Central America. Arch. Meteorol. Geophys. Biokimatol. Ser.B 15:201-241. 1967.

Haylock M.: Linear Regression Analysis for STARDEX. http://www.cru.uea.ac.uk/projects/stardex/Linear_regression.pdf. 2005.

Hernández M. E., Azpra E. R., Carrasco G. A., Delgado O. D. and Villicaña F. J. C.: Los Ciclones Tropicales de México. Instituto de Geografía. Plaza y Valdés Editores. Primera Edición. México. 120pp. 2001 (in Spanish).

Hoerling M. P. and Kumar A.: Why do North American climate anomalies differ from one El Niño event to another? Geophys. Res. Lett. 24, 1059-1062. 1997.

Jáuregui E. O.: Climate changes in Mexico during the historical and instrumented periods. Quaternary International 43/44, 7-17. 1997.

Jones P. D. and Hulme M.: Calculating Regional Climatic Time Series for Temperature and Precipitation: methods and illustrations. International Journal of Climatology. 16, 361-377. 1996.

Kenneth D. J., Breitenbach S. F. M., Aquino VV., Asmeron Y., Awe J., Baldini J. U. L., Bartelein P., Culleton B. J., Ebert C., Jazwa C., Macri M. J., Marwan M., Polyak V., Prufer K. M., Ridley H. E., Sodemann H., Winterhalder B. and Haug G. H.: Development and Disintegration of Maya Political Systems in Response to Climate Change. Science. 388, 788-791. 2012.

Livezey E. R., Masutani M., Leetmaa A., Rui H., Ji M. and Kumar A.: Teleconnective Response of the Pacific-North American Region Atmosphere to Large Central Equatorial Pacific SST Anomalies. Journal of Climate. 10, 1787-1819. 1997.

Magaña R. V. O., Vázquez J. L., Pérez J. L. and Pérez J. B.: Impact of El Niño on precipitation in Mexico. Geofísica Internacional. 42(3), 313-330. 2003.

Mosiño A. P. and García E. A.: The climate of Mexico. In Bryson R. A. and Hare F. K. (Eds) Climates of North America, World Survey of Climatology. Elsevier Publ. Co. Amsterdam, Netherlands. 11, 345-404. 1974.

Pielke Jr R. A., Landsea C., Mayfield M., Laver J. and Pasch R.: Hurricanes and Global Warming. Bulletin of the American Meteorological Society 86(11), 1571-1575. 2005.

Salas-Flores M. A.: Assessing the variability of long-term Mexican instrumental records and the ENSO modulating force. PhD Thesis. University of East Anglia, Norwich, GB. http://www.cru.uea.ac.uk/cru/pubs/thesis/2008-salas/ 2008.

Shieh O. H. and Colucci S. J.: Local minimum of tropical cyclogenesis in the eastern Caribbean. Bulletin of the American Meteorological Society. 95, 185-196. 2010.

Trasviña A. and Barton E. D.: Los 'Nortes' del Golfo de Tehuantepec: Dinámica del océano costero. Capítulo 2 de la Monografía de la Unión Geofísica Mexicana 3, 'La Oceanografía Física en México' 1997. (In Spanish).

Trenberth M. D. and Caron J. M.: The Southern Oscillation revisited: Sea level pressures, surface temperatures, and precipitation. Journal of Climate. 13, 4358-4365. 2000.

Vose R. S., Easterling D. R. and Gleason B.: Maximum and minimum temperatures trends for the globe: An update through 2004. Geographical Research Letters. 32, L23822. 2005.

Webster P. J., Holland G. J., Curry J. A. and Chang H. R.: Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment. Science. 309 (5742), 1844-1846. 2005.

Wolter K. and Timlin M. S.: Monitoring ENSO in COADS with a seasonally adjusted principal component index. Proc. 17th Climate Diagnostics Workshop, Norman, OK, NOAA/NMC/CAC. 52-57. 1993

Wolter K. and Timlin M. S.: Measuring the strength of ENSO events - how does 1997/98 rank? Weather 53, 315-324. 1998.

Yulaeva E. and Wallace J. M.: The Signature of ENSO in Global Temperature and Precipitation Fields Derived from the Microwave Sounding Unit. Journal of Climate 7: 1719-1736. 1994.

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