Diagnosis of Extreme Precipitation Events in the Yucatan Peninsula

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INTRODUCTION:

Given the impacts of human-induced global warming on the water cycle, it is important to pay attention to its effects on water security, as it is one of the UN's sustainable development goals. The Yucatan Peninsula (YP), situated in southeast Mexico (Fig. 1), includes the states of Campeche, Yucatan, and Quintana Roo, with a coastline adjacent to the Caribbean Sea and the Gulf of Mexico. It is characterised by a unique climate due to its distinct physiographic features. The area relies solely on rainfall to replenish the aquifer since there is no surface runoff, rivers, or lakes. Total precipitation in the Peninsula has shown a negative trend (Cavazos et al., 2020), and the contribution of extreme precipitation events to the total annual amount has increased (Cerezo-Mota et al., 2020). Additionally, previous studies have focused on extreme thermal climatic phenomena, highlighting the region's high vulnerability to the impact of climate change (Rodríguez-González, 2023). On the other hand, extreme precipitation events and prolonged dry periods can jeopardise water security in the region, as well as create stressful conditions for natural vegetation (Knapp et al., 2008); alterations in land use such as urban expansion and deforestation can disrupt feedback processes vital for sustaining rainy seasons. This project aims to characterise the precipitation trend in the last 30 years and analyze the impacts of land use changes and their relationship with extreme local precipitation in the YP.

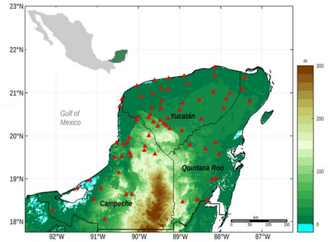


FIG.1: Study area and location of the stations (red triangles).

DATA AND METHODS:

We obtained the variability of precipitation for each of the 3 States that comprise the YP the state through in-situ data from the 69 climatic stations used in Cerezo-Mota et al. (2020) from the National Weather Service from 1980 to 2010 and analysed its annual trend and seasonality. Additionally, we defined and characterised extreme rainfall using the precipitation indices from ETCCDI (Expert Team on Climate Change Detection and Indices). For this purpose, we analysed five indices shown in Table 1, besides the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI), which are widely used to characterise meteorological drought at various time scales. Furthermore, we used Climatol in the software R for data quality control and homogenisation, ClimPACT2 for index calculation, and HydroTSM and SpatialEco packages for data analysis and plots. We also used the Mann-Kendall method to obtain trends and significance of the indices ($p<0.05$). Finally, to represent the distribution and differences of the indexes by State, we used the kernel density function (KDE).

Table 1. ETCCDI precipitation indices selected.

ID (UNITS)	INDICATOR NAME
PRCPTOT (mm)	Annual total wet-day precipitation: Annual total PRCP in wet days (RR>=1mm).
R99p (mm)	Extremely wet days: Annual total PRCP when RR>99th percentile.
CDD (days)	Consecutive dry days: Maximum number of consecutive days with RR<1mm.
CWD (days)	Consecutive wet days: Maximum number of consecutive days with RR>=1mm.
RX5day (mm)	Max 5-day precipitation amount: Monthly maximum consecutive 5-day precipitation.
SPI	Standardized Precipitation Index.
SPEI	Standardized Precipitation-Evapotranspiration Index.

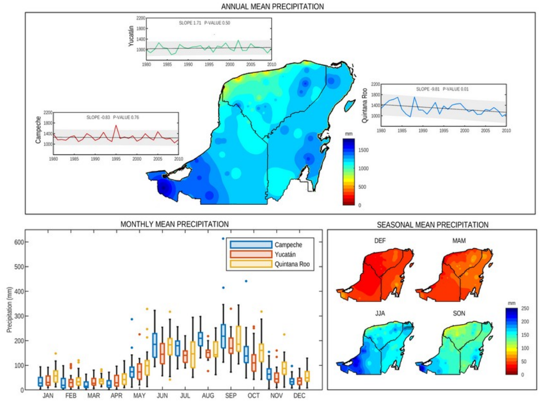


FIG.2: YP Rainfall Characterisation

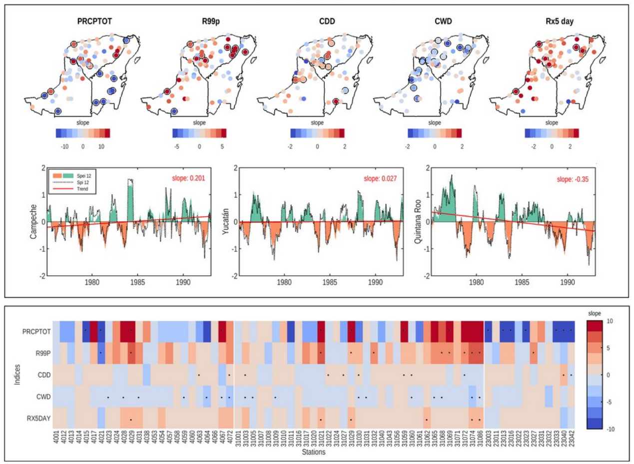
RESULTS

Due to its location, the YP is affected by various hydrometeorological phenomena that determine the rainfall regime in the area and can cause extreme rainfall events, including tropical cyclones, easterly waves, and cold fronts. In the three states of YP, at least 89% of the days in the period show rainfall (>0.1mm). Annually, the average precipitation in the YP ranges from 700 to 1800mm, with the highest values (>1500mm) observed in the southwest of Campeche and the eastern zones of Quintana Roo, while lower values (<1000mm) are found on the coasts of Yucatan (Fig.2). The annual trend in the period 1980-2010 is positive for Campeche and Yucatan, while for Quintana Roo, the accumulated tends to decrease.

Seasonally, a dry season from December to May and a rainy season from June to November can be observed, with the highest accumulations in summer. Yucatan presents the lowest monthly precipitation values, while in Campeche and Quintana Roo, rainfall occurs mainly from June to October, with a maximum in September. Precipitation has a bimodal behaviour, with a decrease in accumulations during July and August in the three States, indicating the presence of the mid-summer drought or "canicula". The atypical maximum precipitation values observed in September in Campeche and Quintana Roo correspond to 1988, 1995, and 2002 and are due to the passage of tropical cyclones.

There are many ways to define "extreme" precipitation, commonly concerning relative percentiles, daily accumulated thresholds, climate indices, or according to the damage caused. For example, Agel et al. (2015) considered multiple characteristics of extreme precipitation using a single definition, the top 1% value in 30 years of daily station data (i.e., the 99th percentile), which will be described in the calculated indices.

PRECIPITATION INDICES AND TRENDS



In general, for Campeche and Yucatan, the trend of precipitation over time is positive (Fig. 3), as well as for the SPI and SPEI indices in the same states, indicating that the intensity and frequency of droughts are increasing in that region, which can have significant implications for water management and agriculture. Together, a positive trend in the PRCPTOT index and a positive trend in the SPI and SPEI can be signal that the region is experiencing climate change that is leading to an increase in the intensity and frequency of extreme weather events, such as heavy rains followed by prolonged droughts.

However, Quintana Roo, the state adjacent to the Caribbean Sea, unlike the rest of the region, shows a significant and marked negative trend in annual total precipitation, as well as in the SPI and SPEI indices, suggesting that the intensity and/or frequency of droughts are decreasing in that zone. The reduction in total precipitation can affect water availability, while the decrease in the intensity and frequency of droughts can improve it. However, it is important to consider other factors that affect the formation and modification of precipitation in the area, such as land use change and vulnerability to hydro-meteorological phenomena (such as easterly waves and tropical cyclones)

On the other hand, the rest of the analysed indices are consistent in most of the region, with extreme events occurrence (above the 99th percentile) being positive. In addition, there tend to be more dry days in the YP and significantly fewer wet days. Finally, extreme rainfall events over five consecutive days are more likely or more intense than in the past, as observed with the Rx5day index.

FIG.3: Extreme precipitation indices for the YP.

The KDEs (Fig.4) indicate that precipitation in Quintana Roo is continuously distributed, covering the entire range of possible values but with a lower density of events with high accumulations than the other States. In contrast, Campeche and Yucatan tend towards a normal distribution centred around ~1000 and ~1200 mm, respectively. While the R99p and Rx5day indices show a similar distribution for Campeche and Yucatan in extreme events, in Quintana Roo, the frequency and accumulation of such events are much lower. The Campeche CDD curve has a considerable skewness towards longer events but with lower density. Whilst Quintana Roo has the highest frequency of dry days. In CWD, there is a higher density of events in Campeche and lower in Yucatan, while in Quintana Roo, the curve skews towards prolonged events. Regarding Spei 12 curves, the average values are above negative values (dry periods) in Campeche and Yucatan, whereas in Quintana Roo, they correspond to positive values (wet periods). To sum up, Campeche stands out for higher frequency and accumulation of precipitation in extreme events, Quintana Roo for lower occurrence, and Yucatan for lower accumulated rainfall.

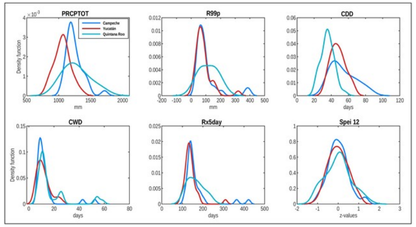


FIG.4: Kernel density distribution function of annual precipitation indices.

CONCLUSIONS:

In Cavazos et al. (2020), most of the results show a negative trend in precipitation from 1980-2010 for YP, except for CHIRPS and RegCM4, where the conditions are similar to those obtained here, positive (negative) for the western (eastern) zone. In this specific study, it is possible to represent with observed data that the precipitation regime in all spatial scales is similar for Campeche and Yucatan; Quintana Roo shows very different results from its neighbouring states, probably related to the hydrometeorological phenomena that affect the state due to its location. This result highlights the importance of regional studies. On the other hand, precipitation climate indices, independently of the annual trend, show that extreme events are more frequent, which agrees with the results obtained by Cerezo-Mota et al. (2019). In addition, an increase in the number of days without rain was obtained throughout YP. Taken together, more extreme rainfall distributed in fewer days of the year points to several societal problems, such as floods or a deficit in water availability for consumption.

FUTURE WORK: The second part of this investigation aims to identify the contribution of different hydrometeorological phenomena (such as tropical cyclones and cold fronts) to the total annual precipitation in the region. Subsequently, we will analyse simulations using RegCM4 to understand the local mechanisms that produce extreme rainfall events and how changes in vegetation and land use due to urbanisation may influence these mechanisms.

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REFERENCES: *Agel, L., Barlow, M., Qian, J. H., Colby, F., Douglas, E., & Eichler, T. (2015). Climatology of daily precipitation and extreme precipitation events in the northeast United States. Journal of Hydrometeorology, 16(6), 2537-2557. / Cavazos, T., Luna-Niño, R., Cerezo-Mota, R., Fuentes-Franco, R., Méndez, M., Pineda Martínez, L. F., & Valenzuela, E. (2020). Climatic trends and regional climate models intercomparison over the CORDEX-CAM (Central America, Caribbean, and Mexico) domain. International Journal of Climatology, 40(3), 1396-1420. / Cerezo-Mota, R., Méndez Pérez, M., Pineda, L. F., Cavazos, T., & Quirino Olvera, L. (2019, December). Changes in extreme temperature and precipitation values in the Yucatan Peninsula (1980-2010). In AGU Fall Meeting Abstracts (Vol. 2019, pp. A51Q-2819). / Rodríguez-González M., Cerezo-Mota R. & De Velasco, G. G (under preparation). Heatwaves and associated circulation patterns in Yucatan, Mexico, to be submitted to the International Journal of Climatology. / Knapp, A. K., Beier, C., Briske, D. D., Classen, A. T., Luo, Y., Reichstein, M., ... & Heisler, J. L. (2008). Consequences of more extreme precipitation regimes for terrestrial ecosystems. Bioscience, 58(9), 811-821*