Climate pre-feasibility study to assess the vulnerability of selected ecosystems, productive systems, and communities (Phase 1)

Climate Rationale, Climate change vulnerability assessment and section B1 for the funding proposal

The project objective is to conduct a pre-feasibility study following GCF's requirements and guidelines and build a robust climate rationale for the ACCIÓN project to demonstrate the ability of the proposed activities' potential to adapt to the impacts of climate change while promoting sustainable development and a paradigm shift in the Yucatan Peninsula.

Delivery

- *Product 0 - Inception report*
- *Product 1: Draft Climate Rationale*
- *Product 2: Draft Vulnerability Assessment*
- *Product 3: Draft Intervention Plans*
- *Product 4: Collated report and maps and B1*

History

1. *Version 1: Draft Climate Rationale and vulnerability assessment. This version comprises products 1-3 in a draft form – 2023/05/24*
2. *Version 2: Updated climate rational, CCVA, Intervention analysis and Section B1. This version comprises products 1 - 4 – 2023/06/05*
3. *Version 3: Updated climate model validation with observational station data*

Dave Ogier
Climate - Disaster - GIS

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Executive summary

The objective of this report is to undertake a pre-feasibility assessment against the Green Climate Fund guidelines for a proposed adaptation project in Mexico's Yucatán Peninsula (YP). The assessment focuses on the requisite climate rationale (including a climate change vulnerability assessment), as well as developing a list of potential project interventions. A draft version of Section B.1 of the GCF Funding Proposal template is also included as a supplementary deliverable.

Observed and projected climate

A decline in average precipitation has been observed in the peninsula between 1980 and 2010, coupled with an increasing trend in extreme rainfall. Increased drought conditions have also been observed during this period. Future climate changes, i.e., between 2020 and 2050, are expected to drive a decline in annual precipitation in the peninsula, with the most severe declines anticipated in the south-eastern parts of Quintana Roo state. By contrast, the central and south-western areas of the peninsula are anticipated to exhibit an increasing trend in average precipitation. In terms of projected changes in extreme events, periods between rainfall will become longer, drought conditions will intensify, and rainfall events will become more intense.

Regarding temperature, an overall warming trend was observed between 1980 and 2010, where mean annual temperatures, maximum temperatures, and minimum temperatures all increased. The most extreme increases in mean temperatures are expected in southern Yucatan State and the western part of Quintana Roo, with a projected rise of up to 0.29°C per decade. Maximum temperatures are expected to peak in the north-eastern coastal region of the peninsula, with decadal increases of 0.26–0.27°C. Average maximum temperatures will be most pronounced in south-western Campeche, with anticipated increases of up to 0.32°C per decade.

No clear trend in tropical cyclone activity was observed in the peninsula between 1980 and 2010. Uncertainty regarding the future frequency and intensity of tropical cyclones overall prevails, with a range of 50% decrease or increase possible against the current baseline. However, Category 4 and 5 tropical cyclones are expected to increase by 50%, along with increasingly common and severe storm surges.

Observed characteristics of the coastal and marine environment of the peninsula show a sea-level rise of ~2mm per annum since 1990, while there are clear indications of rising sea-surface temperature and increased levels of ocean acidification. Projected sea-level rise sees an increase in the northeastern parts of the peninsula of up to 0.17m by mid-century, with a slightly lower increase of 0.15m in the west. Ocean acidification is anticipated to follow the observed increasing trend between 2020 and 2050.

Observed and projected climate change impacts

Observed impacts in the coastal zone of the peninsula include increasing threats to infrastructure and ecosystems from sea-level rise, while coastal communities with climate-sensitive livelihoods have been exposed to the negative impacts of tropical cyclones and other extreme events. Fisheries are particularly exposed to future climate changes, where fish catch potential is expected to decline by 6.8% and 17% under low and high emissions scenarios, respectively.

Observed impacts from climate change on the water sector include reductions in surface water and groundwater availability. This trend is likely to continue and intensify, with projections indicating that important areas for groundwater infiltration will become increasingly arid and that groundwater recharge may decrease by up to 23% by 2030. The agricultural sector has been and is expected to be similarly impacted by climate change, with increasing demand for water accompanying decreasing supply as temperatures continue to rise and climate hazards such as floods and droughts become

more common. Under a low and medium emissions scenario, water demand in the peninsula will likely increase by ~22% and 19%, respectively. While forest productivity is anticipated to increase marginally as atmospheric CO_2 levels rise, this is offset by climate change impacts such as the loss of mangrove forests from sea-level rise and coastal erosion. Mangrove forest loss increases the exposure of infrastructure, communities, and infrastructure to marine hazards and extreme events, further decreasing resilience in the peninsula.

Observed and projected impacts on the health sector from climate change include impacts related to increasing temperatures, as well as those related to flooding caused by extreme rainfall and the direct effects of extreme climate events such as tropical cyclones. Rising average and maximum temperatures and flooding are increasing the prevalence of infectious and vector-borne diseases such as zika, dengue and malaria, reducing agricultural productivity and therefore also affecting food security. In addition to the sectoral impacts described above, the regional economy of the three peninsula states and the national economy of Mexico will be negatively affected by climate change, including an anticipated increase in the regional poverty rate to ~19% by 2030.

Vulnerability assessment

The climate change vulnerability assessment (CCVA) component of this report spatially determines the areas that have the highest climate vulnerability in the peninsula. The CCVA allows for i) spatially-explicit intervention planning by assessing the relative vulnerability by each of the main climate hazard types and by the critical key elements; ii) sector-level planning by considering vulnerability at the critical key element level; and iii) at a strategic level by considering the overall combined vulnerability of the respective spatial areas. The peninsula was divided into nine spatial areas (A through I), and five primary climatic exposure parameters were considered, i.e., extreme temperatures, extreme precipitation, precipitation variability, tropical cyclones, and ocean impacts. These exposure parameters were considered against the three critical key elements of social, livelihoods, environmental sensitivities and adaptive capacity. The overall[1] CCVA results are as follows:

- The CCVAs per climate hazard type and critical key elements highlight location F (north-eastern Yucatán) as the area that has the highest general vulnerability. This is a combination of being exposed to the greatest increase in tropical cyclone density, and increased ocean hazards such as acidification and varied precipitation. The variables of extreme temperatures and extreme precipitation are not very high here. Area F also has increased livelihood and environmental sensitivity and reduced capacities as it is further away from the larger population hubs.
- The locations of A and B (south-western Campeche) have high CCVA for the extreme precipitation and temperatures. There is also high livelihood and environmental sensitivity in these areas as well as reduced adaptive capacity for all the critical key elements. These areas have medium to high vulnerability.
- Location E to the east of Mérida is somewhat in the middle of all the CCVAs as it is in the interface between the high cyclone and ocean impact to the east and the higher precipitation and temperature exposures to the southwest. This area has a medium vulnerability.
- Locations G, H, and I on the west coast of the peninsula have high exposure to the ocean and tropical cyclone impacts but also have lower sensitivities than the northern areas and have

[1]The climate change vulnerability assessment combined the five climate exposures of extreme temperatures, extreme precipitation, precipitation variability, tropical cyclones, and ocean impacts with the three critical key elements of social, livelihoods, and environmental sensitivities and adaptive capacities. This resulted in 15 CCVAs for each of the climate hazard impacts and for the three critical key elements. This is useful for developing targeted interventions to address particular climate issues within a particular mandate. These were combined to make critical key element-specific CCVAs to inform sectoral-level planning, allowing general mandate intervention targeting. These three CCVAs were combined again to present the overall CCVA to allow for high-level strategic planning. The primary map presented is for the SSP2-45 scenarios, but the SSP3-70 and the SSP5-85 scenarios are also presented.

generally medium to good adaptive capacities. These areas' CCVAs are all similar and are medium to lower vulnerability.

- Locations C and D are far removed enough from the enhanced impacts of the extreme precipitation and temperatures and also have limited sensitives but also low adaptive capacities. These areas seemingly have the lowest overall climate vulnerability.

Intervention planning

The nature of the interventions and activities planned under the ACCIÓN project is aligned with the social, livelihood and environmental critical elements assessed under the CCVA. Interventions should therefore address i) climate challenges that threaten food/water security and reduce poverty, ii) promote livelihood resilience to cope with and recover from chronic stresses and acute climate shocks, while maintaining or enhancing its capabilities and assets, and not undermining the natural resource base, iii) ecosystems security to maintain resilience, functionality, and ecosystem services under conditions of climate change. To that end, this report tables a preliminary selection of potential interventions that can be further assessed during the project development and stakeholder engagement phases. These interventions are grouped thematically under the umbrellas of climate-resilient agriculture, ecosystem-based adaptation, and green infrastructure.

GCF Funding Proposal Section B.1 – climate rationale and context

This report concludes with a write-up of Section B.1 of the GCF template that can be used as-is or excerpted as needed during the development of the SAP FP. This section draws from the primary report and structures this information in the format required by the GCF.

1. Current Climate

Mexico has a diverse and varied climate, divided along the Tropic of Cancer and influenced by the country's wide latitudinal extent and geographical location[2]. The country is bordered by the Pacific Ocean to the west, the Gulf of Mexico and the Caribbean Sea to the east, with the sub-tropical high-pressure systems of the Northern Atlantic and Northeast Pacific Oceans dominating the climate of the country[3,4]. The country comprises two distinct climatic zones, namely: i) a temperate zone that is generally arid, with moderate rainfall, mild to warm summers and cool to cold winters; and ii) a tropical zone, which is mostly rainy and hot[5]. The country's climate varies along four distinct geographic regions, as outlined below and shown in Figure 1.

- *The northern region: with a dry climate, low rainfall, and temperatures as high as 50 degrees in the summer months*[6].
- *The central region: with a temperate climate and year-round precipitation, although the primary rainy season is from May to October. Summers are warm and humid, and winters are cold to very cold, with temperatures below freezing occurring in certain areas*[7].
- *The southern region: with a tropical climate where temperature and humidity are generally high, and heavy rainfall and tropical storms occur during the summer months*[8].
- *The Pacific coast: which is dry in the north and has a tropical climate with high rainfall in the south*[9].

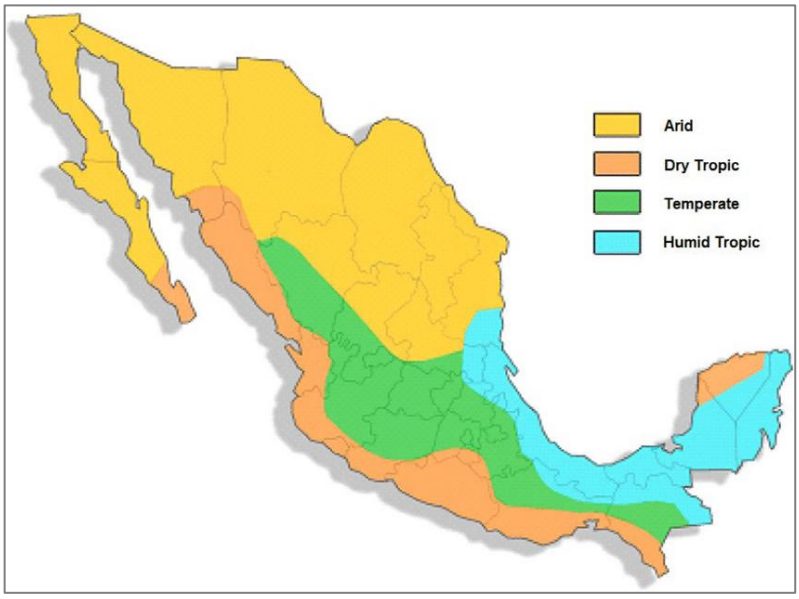


Figure 1. Mexico's four climatic regions[10].

Baseline climate information for each of Mexico's sub-regions is presented below. The table shows *inter alia* maximum average daily temperatures, average nightly minimum temperature, the average number of rainy days and the average volumes of precipitation for each sub-region.

Table 1. Climate information by sub-region[11].

[2] WHO. 2015. Climate and Health Country Profile – 2015.Available here
[3] Worlddata. Available at: here
[4] CMCC. G20 Climate Risk Atlas: Mexico. Available here
[5] CMCC. G20 Climate Risk Atlas: Mexico. Available here
[6] Worlddata. Available at: here
[7] Worlddata. Available at: here
[8] Worlddata. Available at: here
[9] Worlddata. Available at: here
[10] Oropeza-Perez, I., 2016. Comparative economic assessment of the energy performance of air-conditioning within the Mexican residential sector. *Energy reports*, *2*, pp.147-154.
[11] Worlddata. Available at: here

Region	Temperature max Ø day	Temperature min Ø night	Sunshine hours	Rainy days	Precipitation	Humidity
Baja California	30.6 °C	16.5 °C	3,322 h	20	226 l	57.0 %
North	30.7 °C	15.7 °C	3,176 h	30	343 l	51.0 %
Northeast	30.2 °C	17.5 °C	2,519 h	55	697 l	72.0 %
East	29.5 °C	18.0 °C	2,300 h	98	1,511 l	81.0 %
Southwest	30.4 °C	18.5 °C	2,592 h	96	1,420 l	76.0 %
West	29.3 °C	14.1 °C	2,738 h	71	821 l	56.0 %
Yucatan Peninsula	32.8 °C	22.3 °C	2,738 h	94	1,365 l	81.0 %
Central-North	29.0 °C	13.7 °C	2,628 h	72	850 l	56.0 %
Central-South	26.0 °C	10.3 °C	2,665 h	97	891 l	59.0 %

The Yucatán peninsula, comprising the states of Campeche, Quintana Roo and Yucatán, has a subtropical climate where temperatures and precipitation are generally high in the summer months[12]. The climate of the Yucatán peninsula is varied but is predominantly classified as tropical, savannah (Aw[13]) in most of the central part of the peninsula. In the southern parts of the peninsula, a tropical monsoon climate prevails, with areas further southwest having a tropical rainforest climate. In the north, a relatively small area of Yucatán province itself is classified as arid, and along the entire coastline of the peninsula, a temperate climate with year-round rainfall and warm summers prevails. Additional detail on the current climate of Mexico and the Yucatan Peninsula is presented in the sections below, including information on trends in precipitation, temperature, and tropical cyclone activity.

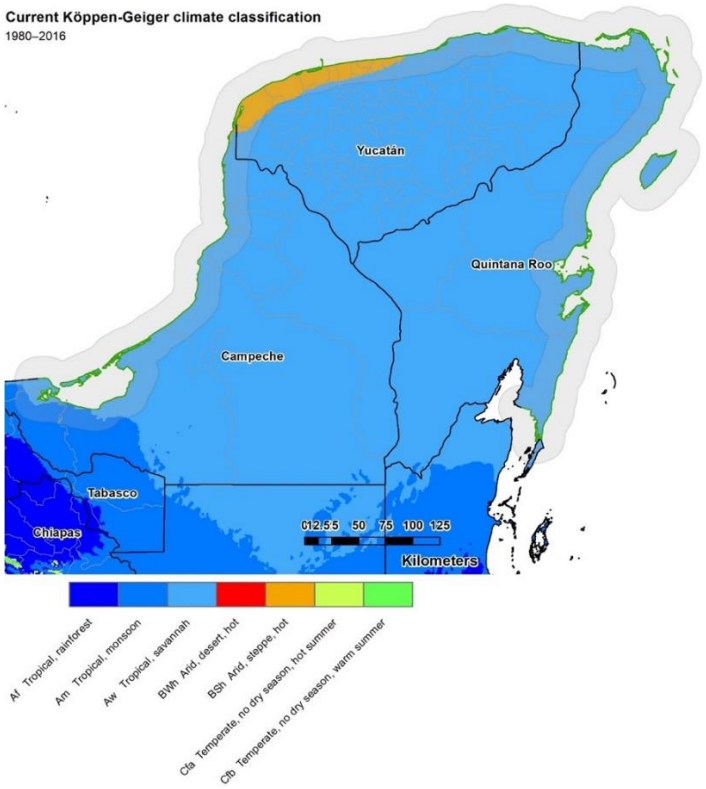


Figure 2. Current Köppen climate classification of the Yucatán Peninsula

1.1. Precipitation

Mexico's precipitation profile varies along the main climatic regions described above. The north of the country is predominantly dry, and the country is generally wettest in the south, where the rainy season extends from June to September and the dry season from December to May. The Yucatán Peninsula is located in an area with higher precipitation rates compared with the rest of Mexico. However, precipitation rates vary across the peninsula, with the eastern coastal areas of Quintana Roo and southern areas of Campeche receiving relatively more rainfall than the northern and central parts of the peninsula. Overall, the peninsula receives a relatively

[12] Worlddata. Available at: here
[13] According to the Köppen-Geiger climate classification system

low annual rainfall of approximately 600–1600 mm, with the southern parts of the region receiving more rainfall overall than the northern parts[14].

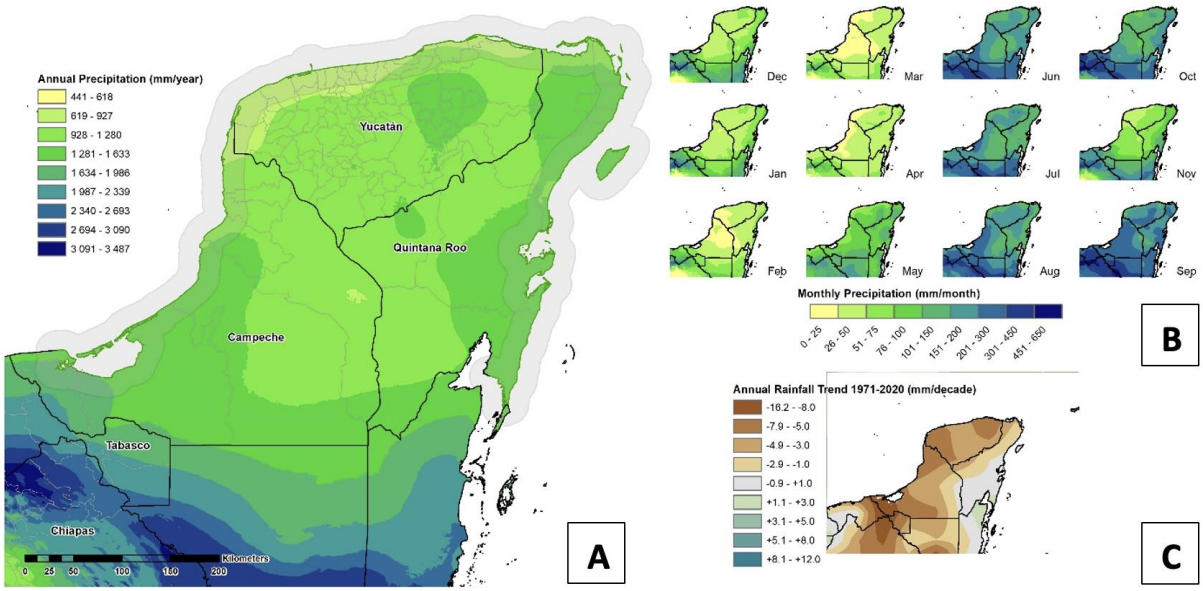


Figure 3. Current annual and monthly rainfall distribution (A and B), and current rainfall trend and precipitation seasonality (C).

Climate change is causing a decrease in overall precipitation in the Yucatán Peninsula. Between 1971 and 2020, there was a notable decrease in average precipitation across the Yucatan peninsula, with a decline of between 8 and 16.2 mm/decade observed in several regions, particularly along the western parts of the peninsula. With the exception of some parts of Quintana Roo, all of the peninsula's subregions have experienced a decrease in average annual rainfall by at least 1–2.9 mm since 1971. Along with a general decrease in average precipitation volumes, climate change is causing rainfall patterns to become increasingly variable, with an increase observed in the occurrence of extreme rainfall and drought conditions in the region.

The change over time in these three coastal locations, southwest, northern, and eastern show local changes in the precipitation profile. In the southwest, there is a varied but ultimately unchanged annual rainfall volume. Changes are however occurring with an increase in the early part of the season in May/June and decreases during the peak period. In the norther area, there is a small increase over time in annual precipitation, through this is not significant. There are noted decreases in the early season (May), and peak season (Sep) and small increases in other months. The eastern coast sees an increase over time with the most consistent increases noted in Oct/Nov in more recent years.

[14] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.

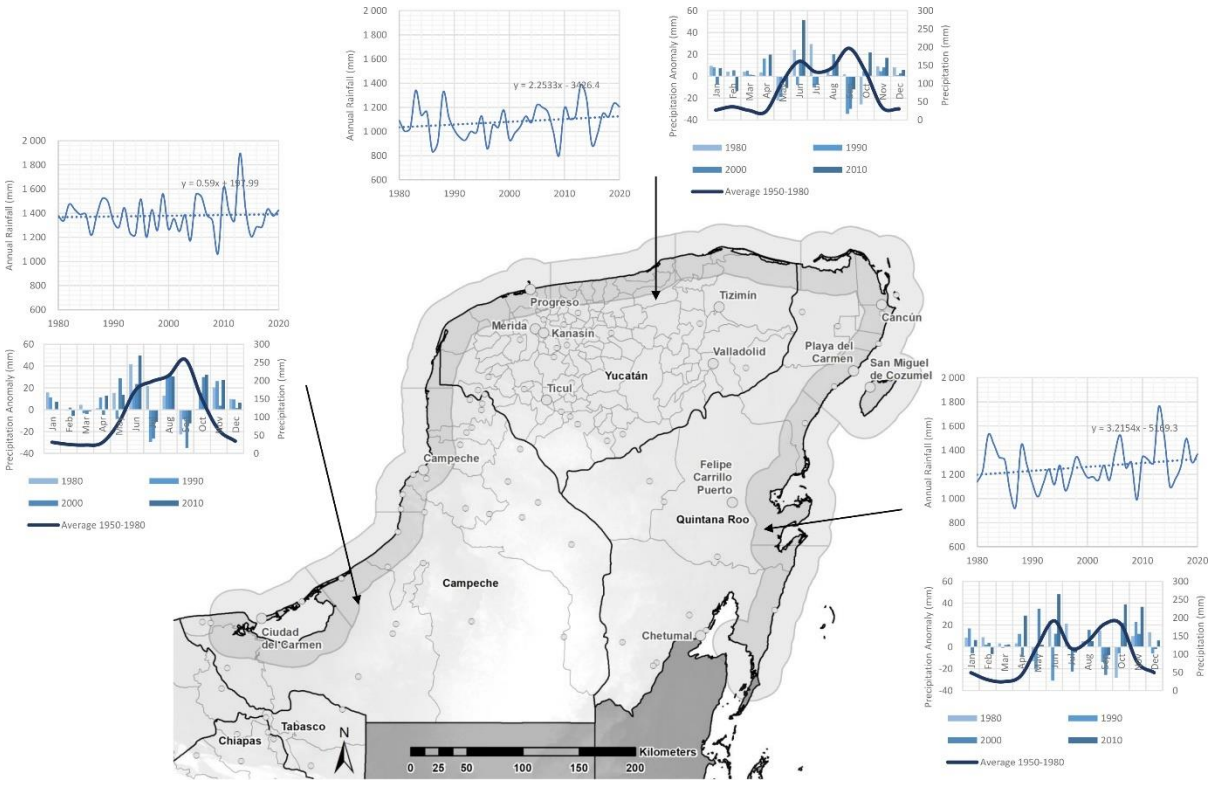


Figure 4. Observational precipitation trends around the Yucatan Peninsula

1.1.1. Extreme rainfall

Figure 5A below shows the current peak rainfall distribution and distribution of extreme rainfall parameters (A) and the current change in peak rainfall distribution and trends of extreme rainfall parameters (B). Extreme rainfall in the region corresponds to overall precipitation rates for the peninsula. On average, extreme rainfall is most common in the southwest of the peninsula, specifically in western Campeche. Comparatively, high levels of peak rainfall also occur in south-central Yucatán and the coastal areas of Quintana Roo.

Since the 1960s, there has been an increase in both 1 and 5-day maximum precipitation rates in the central and northern areas of the Yucatan Peninsula, indicating a possible correlation with the increasing occurrence of tropical cyclones in the region (Figure 5B). In the central areas of the peninsula, the trend in 1 and 5-day events shows a decrease. Overall, precipitation across the Yucatán Peninsula is becoming increasingly variable, with extreme rainfall becoming increasingly frequent in many parts of the region.

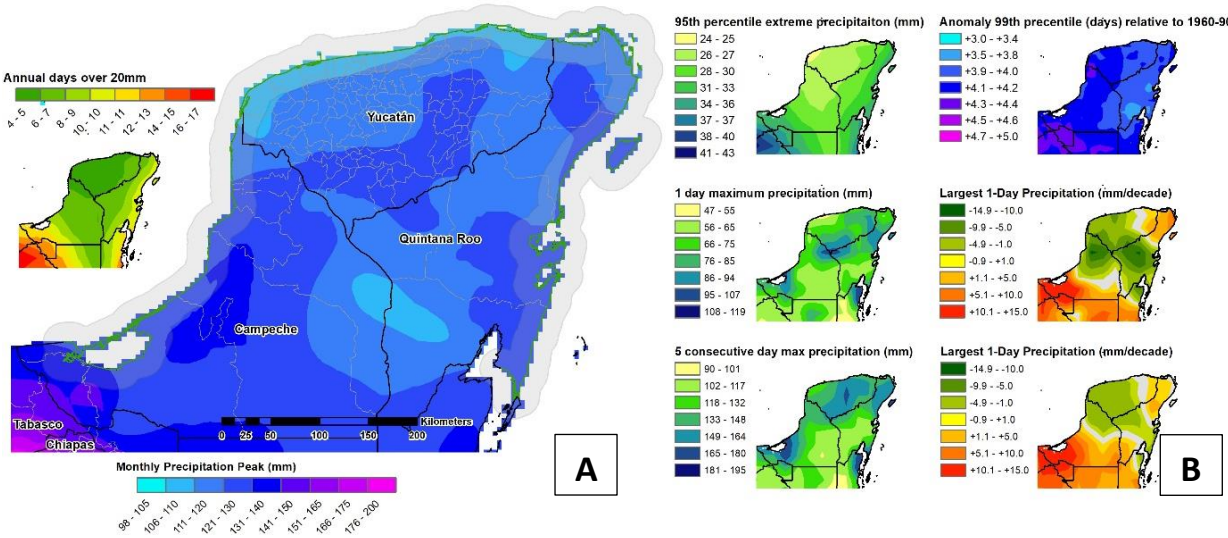


Figure 5. Current peak rainfall distribution and distribution of extreme rainfall parameters; Current change in peak rainfall distribution and trends of extreme rainfall parameters

Over time in the coastal areas, there is a small increase in the average 75th percentile extreme monthly events. These increases are however small and not statistically significant. The area to the southwest sees an increase

of up to 1.0mm in the 2010-2014 period as the largest increase. Other periods are less extreme. The northern area also sees a peak from 2010-2014 of up to 1.2mm but has a steeper trend over time due to lower magnitude events from 1990-1994. The eastern coast sees minimal changes over time but also has a high-volume anomaly average from 2010-2014.

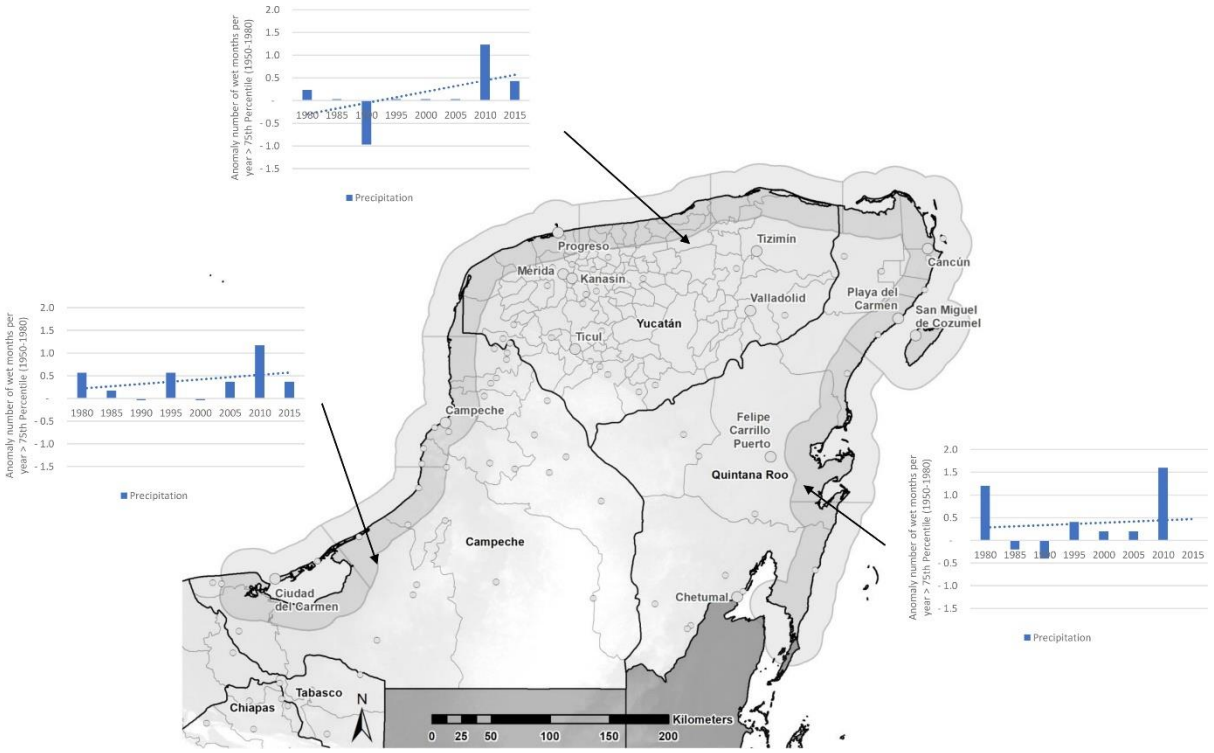


Figure 6. Observational extreme precipitation trends around the Yucatan Peninsula

1.1.2. Drought and variability

Historically, drought has been a regular part of Mexico's climate, particularly in the northern and north-western parts of the country. In these areas, droughts occur approximately every 4.1 years, with a mean duration of 2.2 years[15]. Although droughts are less common in southern regions of the country, they remain a key feature of the climate and occur alongside changes in precipitation. The Yucatán Peninsula was historically considered a homogenous region in terms of precipitation. Recent studies, however, have highlighted four distinct precipitation sub-regions, showing the high degree of climatic variability of the peninsula[16]. Droughts have historically been a recurring problem in the peninsula. Observed trends indicate that average drought occurred across most of the region from 1980 to the present (Figure 7). However, although the overall trend for the peninsula is for average drought during this period, there was high spatial variability in terms of the severity of drought within the sub-regions. There was also temporal variability in terms of drought severity per decade. For example, droughts that occurred in 1980 and the 2000s were considered mild, while those that occurred in the 1990s and 2010 were severe and extreme, respectively. Severe droughts also occurred in later years. For example, in 2015 drought was experienced in 87.5% of the Yucatán Peninsula[17], and from mid-2016 to mid-2017 droughts again occurred over most of the region[18]. In terms of seasonality, the western parts of the peninsula show the largest changes between years, while changes were low on the east coast, despite having similar annual precipitation levels.

[15] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[16] De la Barreda, B., Metcalfe, S.E. and Boyd, D.S., 2020. Precipitation regionalization, anomalies and drought occurrence in the Yucatan Peninsula, Mexico. *International Journal of Climatology*, *40*(10), pp.4541-4555.
[17] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[18] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.

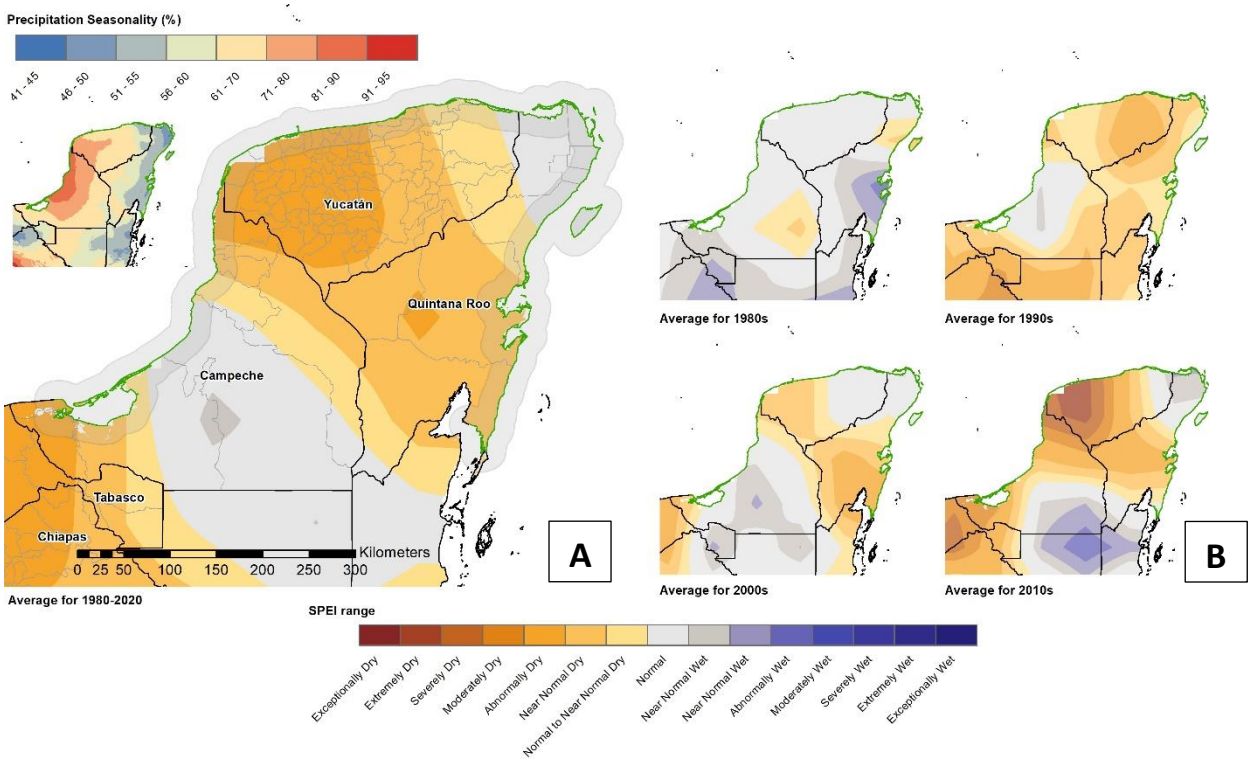


Figure 7. Current SPEI drought classification (A); and Decadal SPEI drought conditions over time (B); Current rainfall trend and precipitation seasonality

1.2. Temperature

Mexico's temperature regime is strongly influenced by its elevation profile and corresponds to the country's topographic layout[19]. Temperatures range between 15–20°C in the central areas of higher elevation, and between 23–27°C in the coastal areas. This trend is also present in the Yucatán Peninsula where average annual temperatures are higher along the coastal areas (see Figure 8A below), corresponding to the region's different climatic zones shown in Figure 2. The peninsula is one of Mexico's warmest regions, with average daily temperatures of approximately 33°C[20]. The hottest months in the region are from April to September, corresponding to the northern hemisphere summer. Long-term temperature trends for the Yucatán Peninsula indicated that increases in average temperatures are largest on the south and east coast of the region (Figure 8B). This trend is in contrast to some central areas of the west coast of the peninsula, such as in the coastal areas between Yucatán and Campeche states, where temperatures show a decreasing trend.

[19] World Bank. 2021. Country: Mexico. Available here.
[20] Worlddata. Available at: https://www.worlddata.info/america/mexico/climate-yucatan-peninsula.php#:~:text=Yucatan%20Peninsula%20is%20one%20of,water%20temperatures%20of%2028%20degrees.

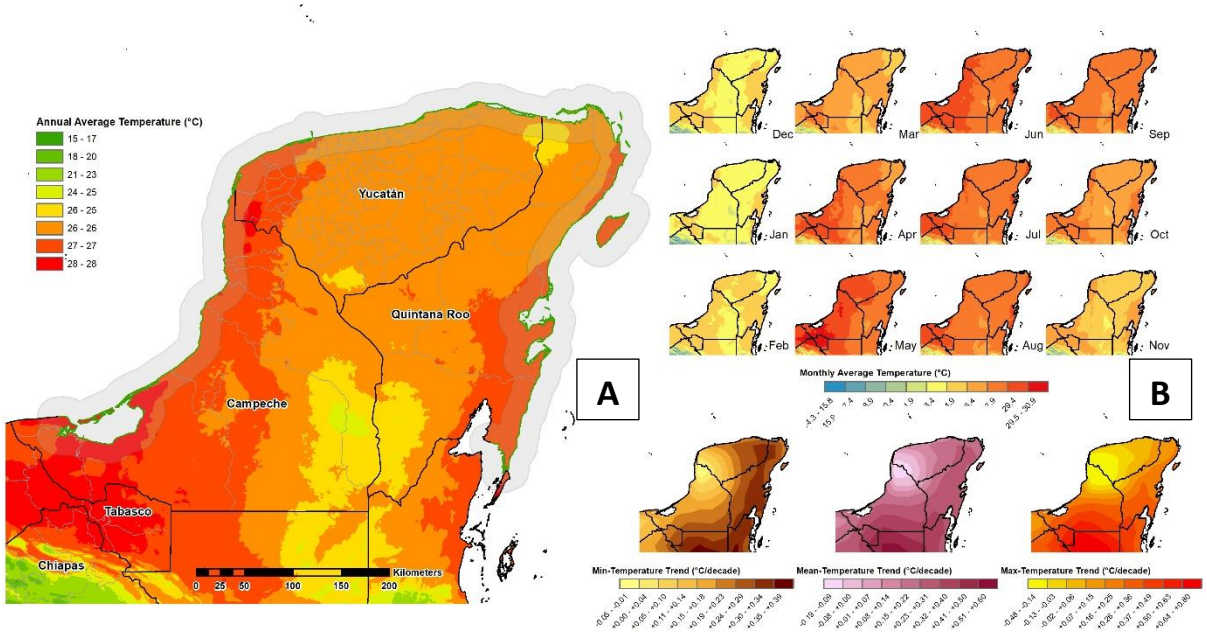


Figure 8. Current annual and monthly average temperature distribution (A) and temperature trends (B)

Temperature changes in the coastal areas have seen general average increases in the observational record. There is a slightly higher rate of increase in the minimum temperatures than in the mean and maximum temperatures. The location to the southwest is currently the warmest and has seen average temperatures increase more rapidly that the other locations. This is the only area where the maximum temperature increase outstrips the minimum temperature. The norther areas see the second highest temperatures and the east coast area sees the lowest temperatures. All the areas have generally warm night-time temperatures and hot average temperatures.

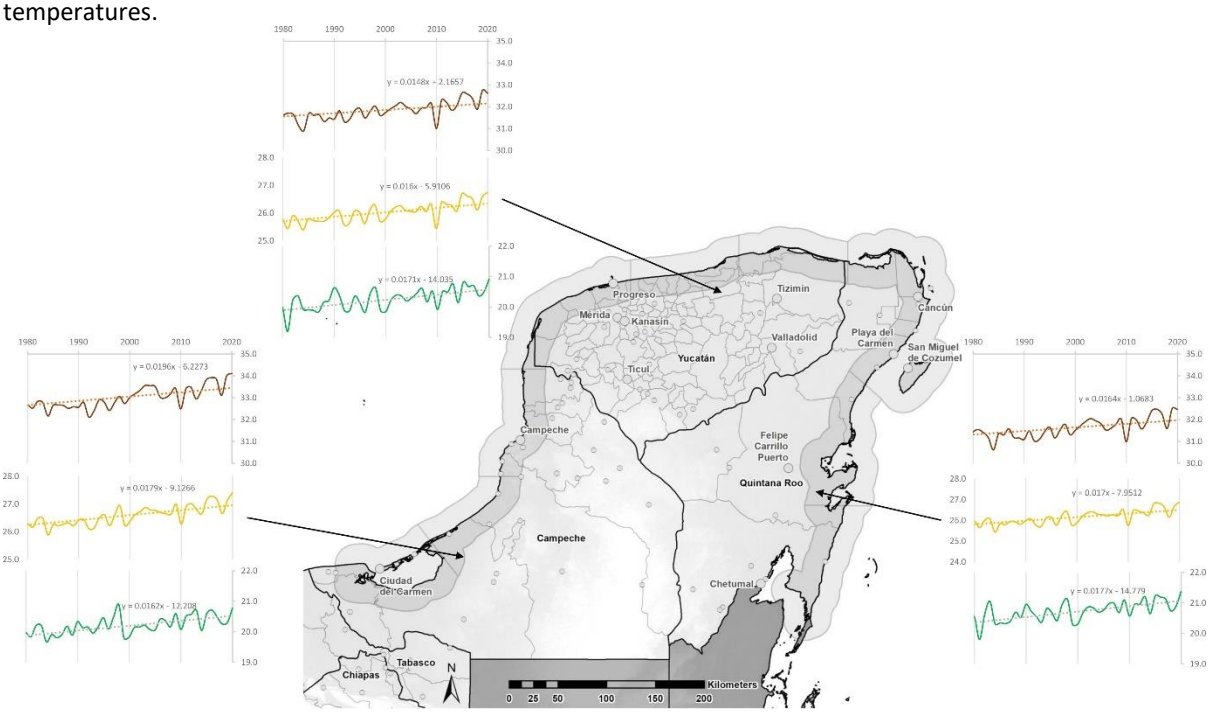


Figure 9. Observational temperature trends around the Yucatan Peninsula

1.2.1. Heatwaves

Monthly maximum temperature peaks are highest in the upland areas towards the western parts of the Yucatán Peninsula, as shown in Figure 10 (A) below. Coastal areas on the eastern side of the peninsula have relatively lower monthly maximum temperature peaks, although these coastal areas have comparatively high average temperatures (Figure 8 above), which indicates that inland areas have more extreme temperature fluctuations than coastal areas. The figure also shows the current change in peak temperature distribution and changes in cooling degree days (B). Between 1960 and 1990, there has been a significant increase in 90th percentile warm spell duration in coastal areas along the east coast of the peninsula. Relative to the baseline period, 99th

percentile event days have also increased significantly compared with western parts of the region. However, there has been no significant increase in the number of days with temperatures of more than 35°C while this has been the case in the central uplands of Campeche in particular.

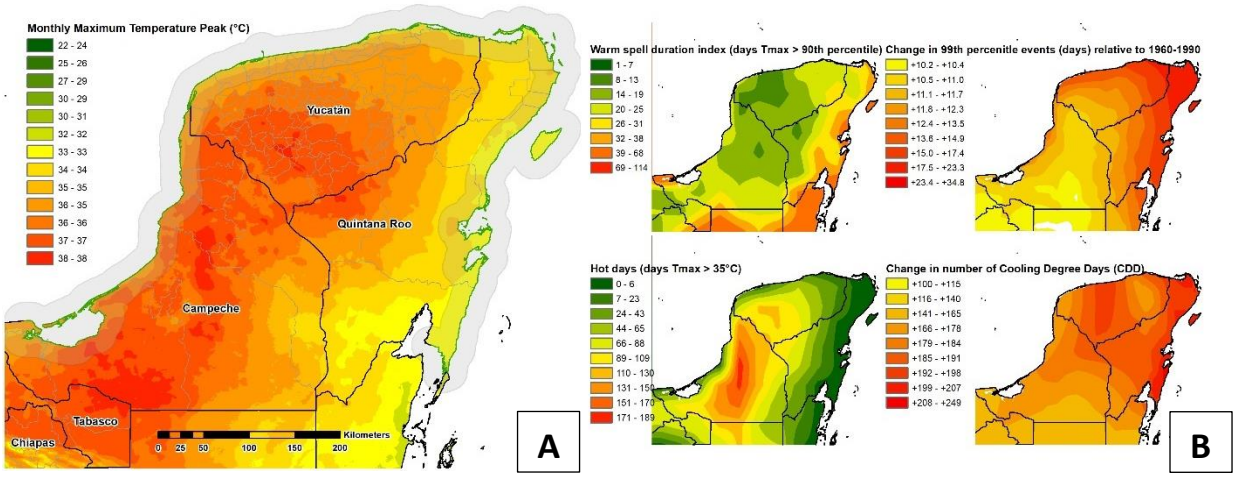


Figure 10. Current peak temperature distribution and distribution of extreme temperature parameters (A) and Current change in peak temperature distribution and change in cooling degree days (B).

With the increase in average maximum, mean and minimum temperatures, there has been a shift in the temperature profile and there is a shift in the temperature magnitude of the more extreme events. All of the locations see an increase of up to 2-3°C in the 75th percentile maximum and minimum temperature extreme average month.

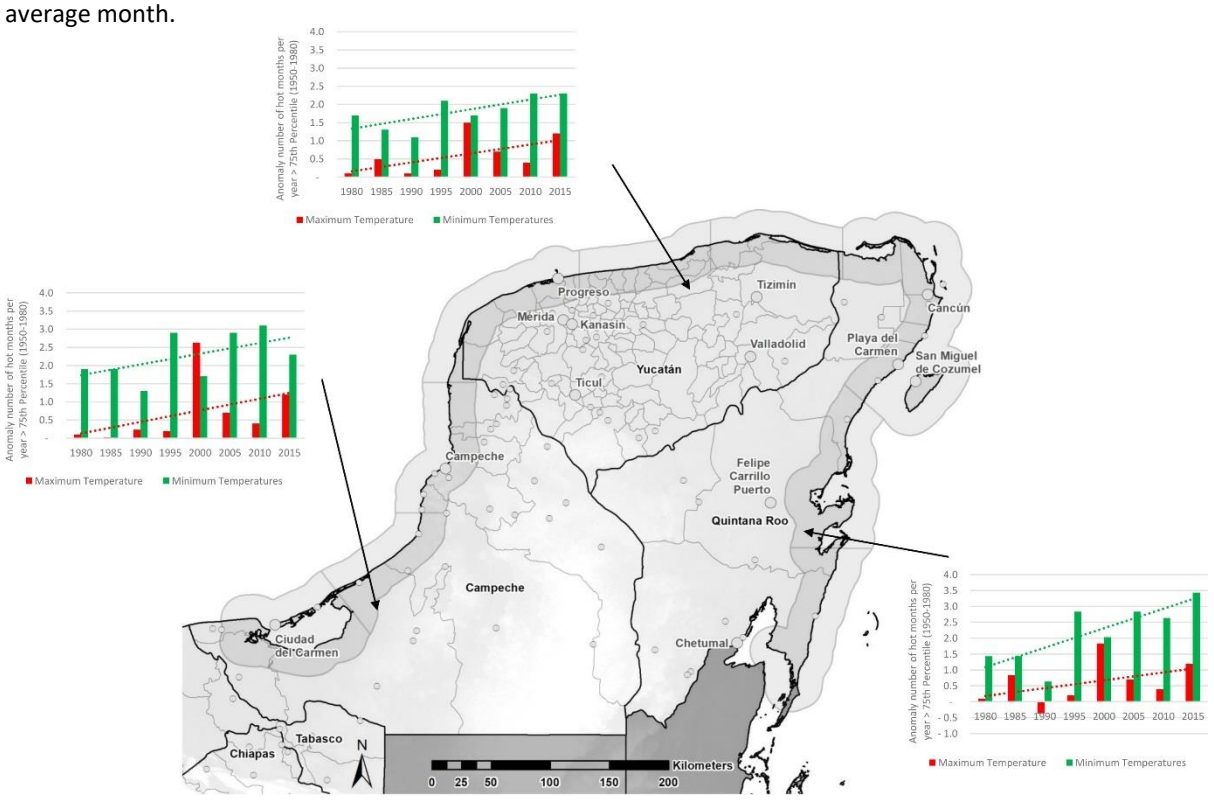


Figure 11. Observational extreme temperature trends around the Yucatan Peninsula

1.3. Tropical Cyclones

Mexico's complex topography and geographic location between two oceans make it vulnerable to the impacts of extreme weather events, including landfalling tropical cyclones along both the Pacific and Atlantic coasts. These cyclones are associated with high wind speeds, extreme rainfall, and the associated flooding, all of which are directly impacting the most vulnerable communities in the country, including those in the Yucatan peninsula[21,22]. Figure 12 below shows the tracks of tropical storms and cyclones that have occurred in the

[21] USAID.2023. Mexico Climate Change Fact Sheet. Available here

[22] Breña-Naranjo, J.A., Pedrozo-Acuña, A., Pozos-Estrada, O., Jiménez-López, S.A. and López-López, M.R., 2015. The contribution of tropical cyclones to rainfall in Mexico. *Physics and Chemistry of the Earth, Parts A/B/C*, *83*, pp.111-122.

Atlantic and Gulf of Mexico since 1941. The Yucatán Peninsula is particularly prone to the occurrence of tropical cyclones, owing to its location between two oceans and the Gulf of Mexico which is generally an area of high tropical cyclone density (Figure 12). The peninsula is disproportionately affected by the occurrence of high-intensity tropical cyclones compared with the northern coast of Mexico and areas further south.

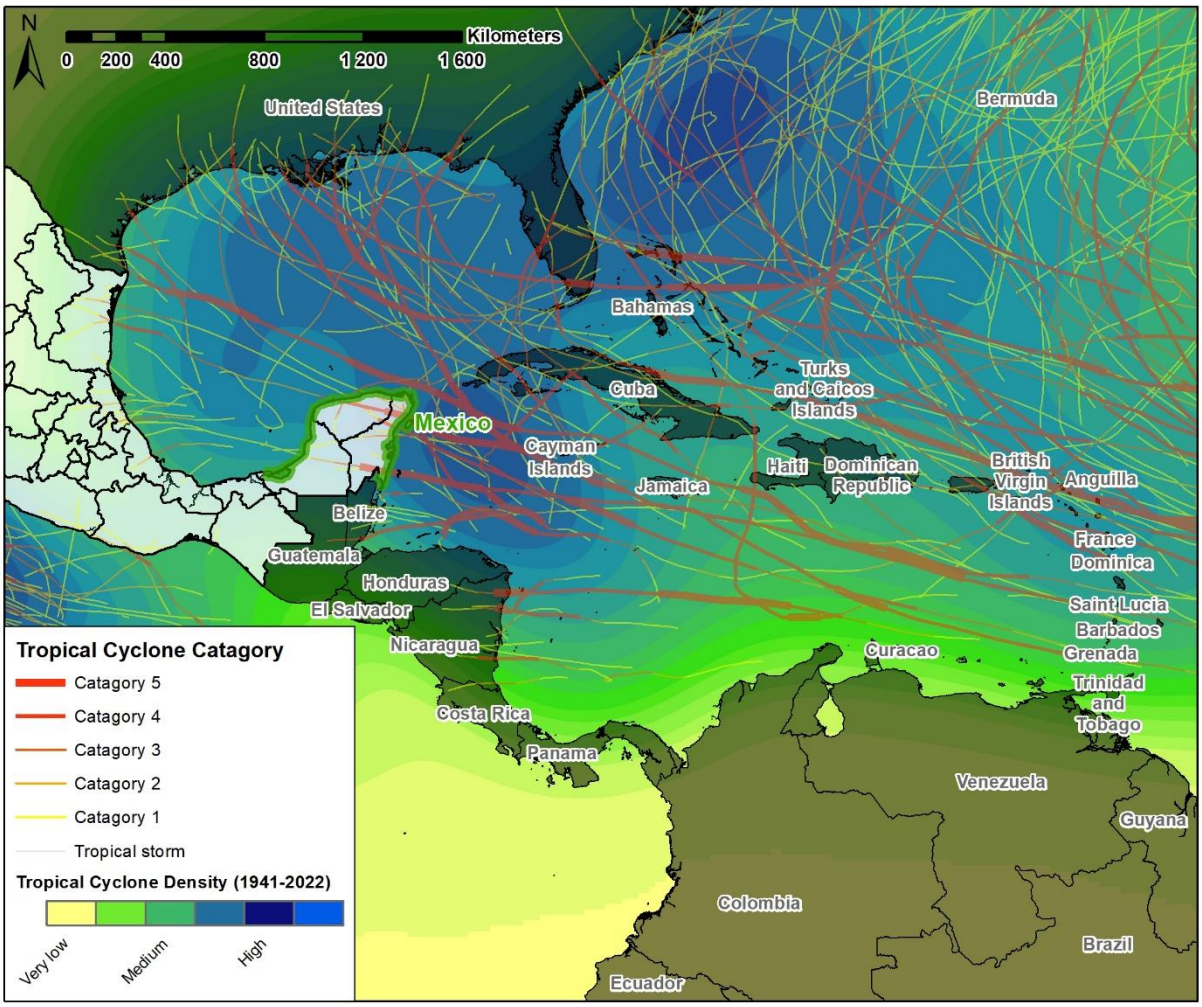


Figure 12. Tropical Cyclone tracks in the Gulf of Mexico and the Atlantic Ocean.

The Yucatán Peninsula has experienced numerous extreme climate events in recent decades, as shown in Figure 13 below. The figure shows the tracks of tropical cyclones, storms and tropical depressions that made landfall in the Yucatan peninsula between 1970 and 2014[23]. During this period, some of the most destructive tropical cyclones that have occurred include Gilbert (1988) and Wilma (2005), both of which developed into Category 5 cyclones[24,25]. The peninsula is therefore exposed to regular floods and given that the economic activity of the region is concentrated along the coast, it is also highly vulnerable to the impacts of sea level rise[26].

[23] Sánchez-Triana, E., Ruitenbeek, J., Enriquez, S. and Siegmann, K. eds., 2019. *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. World Bank Publications. Available here.
[24] NASA. 2005. Hurricane Wilma. Available here.
[25] Sánchez-Triana, E., Ruitenbeek, J., Enriquez, S. and Siegmann, K. eds., 2019. *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. World Bank Publications. Available here.
[26] Breña-Naranjo, J.A., Pedrozo-Acuña, A., Pozos-Estrada, O., Jiménez-López, S.A. and López-López, M.R., 2015. The contribution of tropical cyclones to rainfall in Mexico. *Physics and Chemistry of the Earth, Parts A/B/C, 83*, pp.111-122.

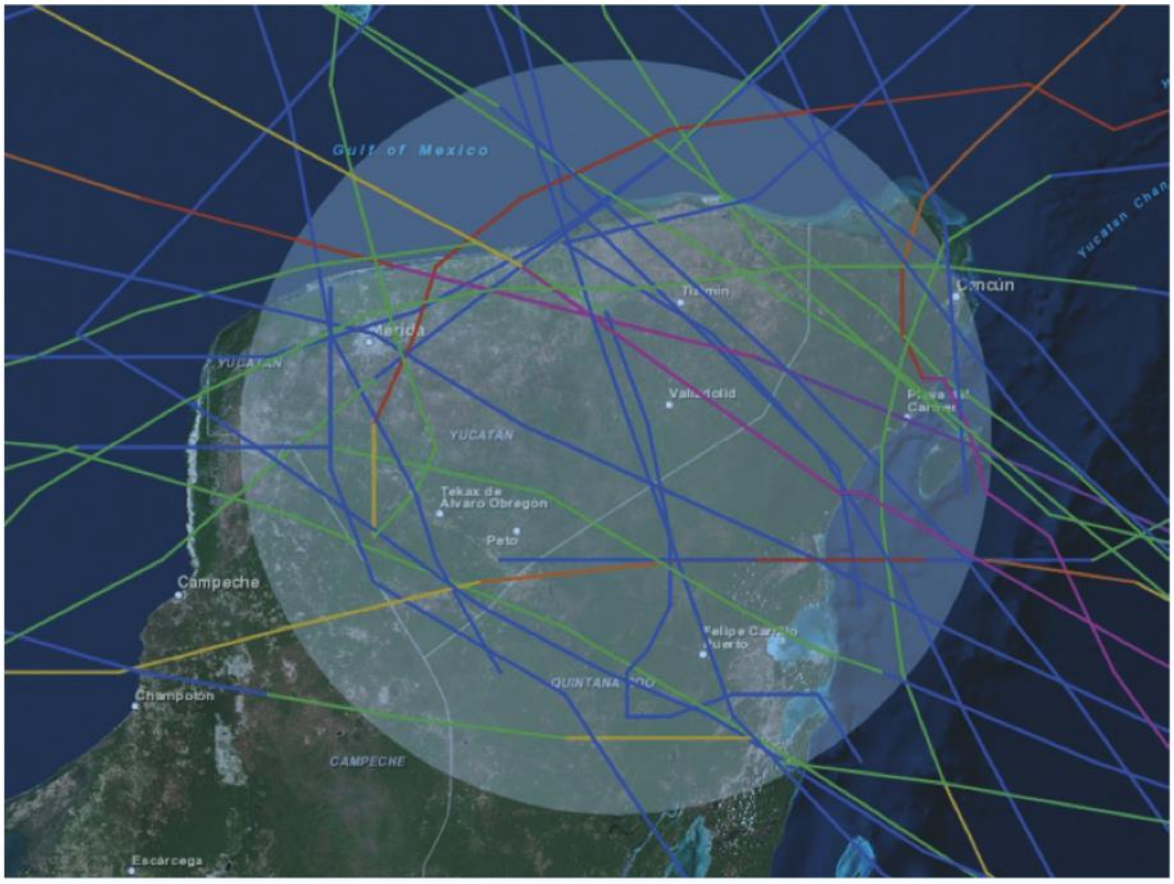
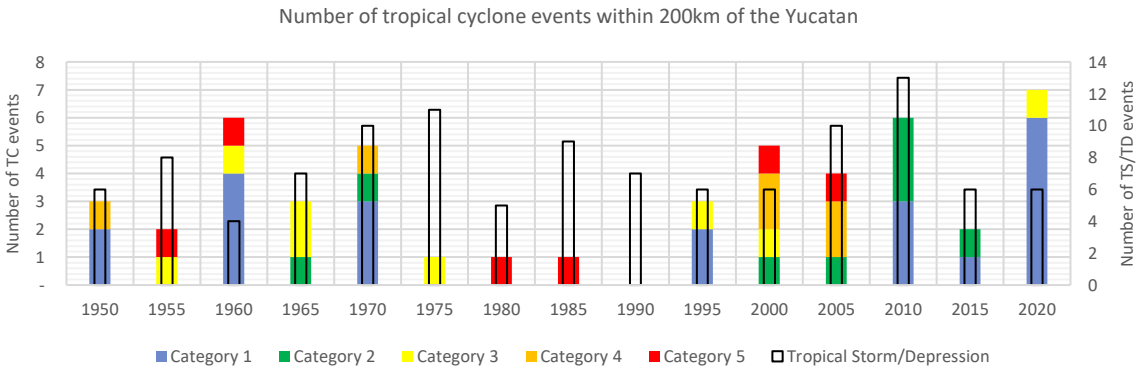
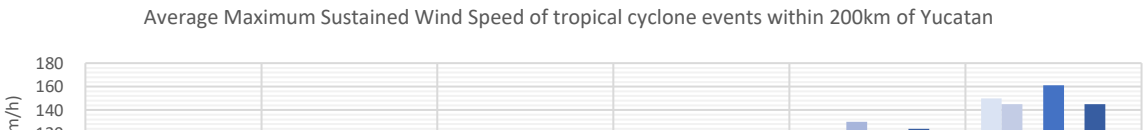


Figure 13. Tropical cyclones, tropical storms and tropical depressions that made landfall in Yucatán between 1970 and 2014[27]*. Green = tropical storms; blue=tropical depression; Yellow=category 1 TC (winds of 119-1753 km/h); Orange = category 2 (154-177 km/h); Red = category 3 (178-208 km/h); Pink = category 4 209-251 km/h).*

The change over time in tropical cyclones and storms/depressions shows an increase from 1950 to the present of ~0.2 events over 5 years. This trend is however not statistically significant due to the generally varied nature of these events. There is a notable decrease in the number of severe events from 1975 to 1990, there were only 2 category 5 events and a single category 3 event, but there were multiple storm events during this period. More recently, from 2000 there has been an increase in severe events with the 2000 and 2005 periods having several events above category 3, and multiple storm events. Since then, there have been more events classed as category 1 or 2 and a high number of tropical storm events (particularly in 2010-2014).
While a clearly discernible trend is not evident, there does appear to be a greater occurrence of tropical cyclone events in more recent times. The maximum sustainable wind speeds also do not show clear long-term trends. They have remained roughly consistent.



[27] Sánchez-Triana, E., Ruitenbeek, J., Enriquez, S. and Siegmann, K. eds., 2019. *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. World Bank Publications. Available here.



	Tropical Storm/Depression	Category 1	Category 2	Category 3	Category 4	Category 5
1950	38	73	-	105	115	150
1960	34	70	85	108	-	145
1970	33	74	92	102	130	-
1980	36	-	-	-	-	161
1990	36	68	-	100	-	-
2000	42	-	93	110	124	145
2010	39	77	88	-	-	-

Figure 14. Number of tropical cyclone events from 1950 to present (top), change in maximum sustained wind speed over time per category (bottom).

1.3.1. Wind speed

The Yucatán Peninsula receives the majority of its winds from the NNE to the ESE, which is where the Caribbean Sea's westerly and easterly portions of the Gulf of Mexico are located. Strong winds are present in the areas to the north of the peninsula, with winds primarily originating from over the Eastern Gulf. The potential for greater wind intensity is found in more exposed locations[28]. These are also the areas with the highest density of tropical cyclone activity. The average wind strength decreases towards the south west and east coasts.

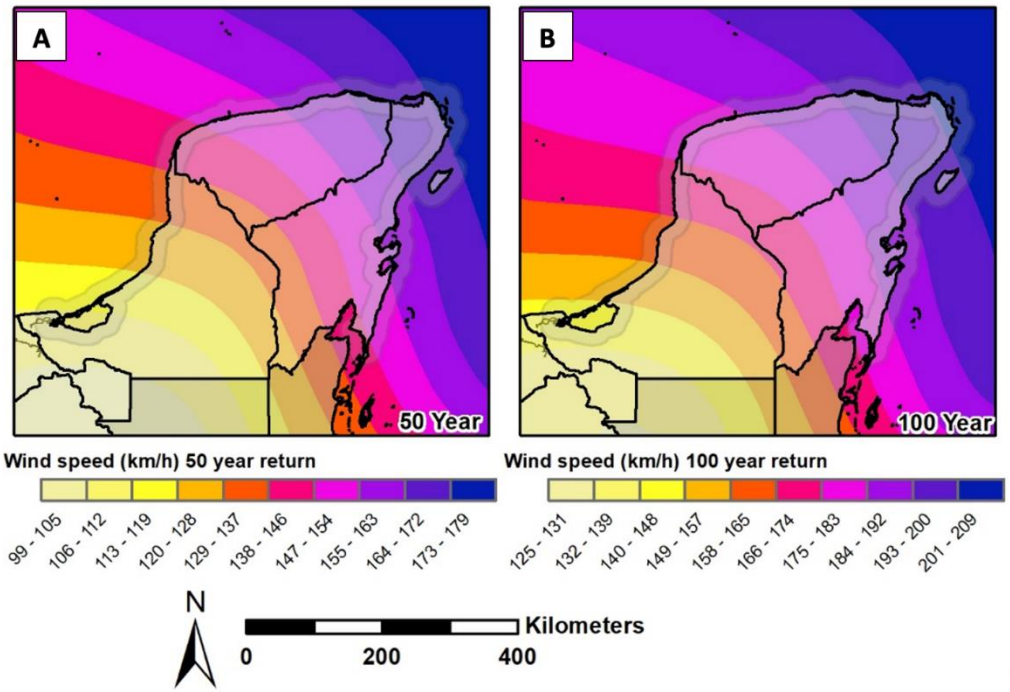


Figure 15. Wind speed (km/h) 50-year return (A) and 100-year return (B).

1.3.2. Storm Surge

Storm surges are a significant concern in coastal regions, including the Yucatan Peninsula. A storm surge is an abnormal rise in sea level generated by a tropical cyclone, hurricane or tropical storm, as it moves over the ocean. The Yucatan Peninsula is vulnerable to storm surge events due to its exposure to the Caribbean Sea and the Gulf of Mexico.

[28] Soler-Bientz, R., Watson, S., & Infield, D. (2010). Wind characteristics on the Yucatán Peninsula based on short term data from meteorological stations. Energy Conversion and Management, 51(4), 754–764. doi:10.1016/j.enconman.2009.10.032

The severity of storm surges can vary depending on various factors, including the intensity and size of the storm, the angle at which it approaches the coast, and the shape of the coastline. The Yucatan Peninsula has a diverse coastline, with both open coast areas and areas protected by offshore islands and reefs. The more exposed areas have a loss of natural vegetation.
They are low-lying areas and communities very near the coast will be more susceptible to damage from the impact of storm surges which can result in coastal flooding, erosion, and significant damage to coastal infrastructure.

The areas to the northeast, which experience a greater density of tropical cyclone activity are also subject to a larger average wave height for all the significant extreme return events. The areas to the northeast, which experience a greater density of tropical cyclone activity are also subject to a larger average wave height for all the significant extreme return events. The areas to the north and those areas to the east that have straight coastlines are also exposed to high wave height but less so than the areas directly to the northeast. Areas to the west and areas along the east coast that have natural coastal protection experience lower storm surge heights.

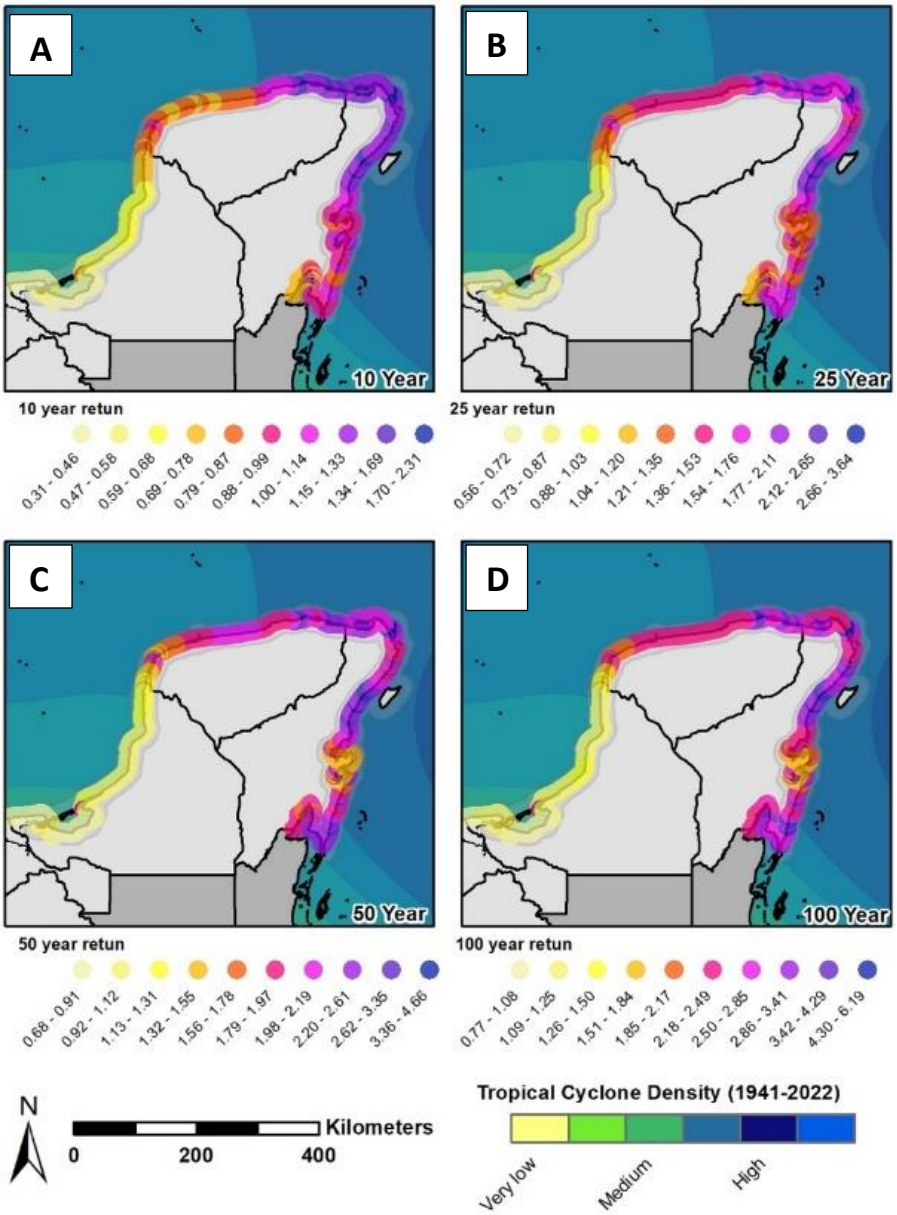


Figure 16. Storm surge 10-year return (A); 25-year return (B); 50-year return (C) and 100-year return (D).

1.4. Ocean characteristics

Mexico's coastal systems are divided into two distinct regions, namely the Pacific region and the Gulf of Mexico[29]. The country's territorial waters are characterised predominantly as subtropical, with mean sea surface temperature reflecting the subtropical climate, with colder waters located in the Pacific zone and warmer waters

[29] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

along the southern coast, particularly in the Gulf of Mexico[30]. The Yucatán Channel, the passage between the Gulf of Mexico and the Caribbean Sea, provides most of the inflow into the Gulf. This northward flow on the western side of the Channel is known as the Yucatan Current, while there is a counter-current flowing southwards on the eastern side of the channel named the Cuban Counter current[31]. The flow of the Yucatán Current is strongest during the summer months[32]. The sections below provide further information on SST in the waters around the Yucatán Peninsula, as well as on acidification and sea level rise.

1.4.1. Sea Surface Temperature

Figure 17 below shows the average annual sea surface temperatures (SST) and monthly average SST for the target region. Annual average SST is highest in the region east of the Yucatán Peninsula. SSTs along the western coast of the peninsula are comparatively lower. The average annual SST is between 28–28.2°C in this region, compared with an average annual temperature range of 25.8–26.1 in the areas to the north of Yucatán State.

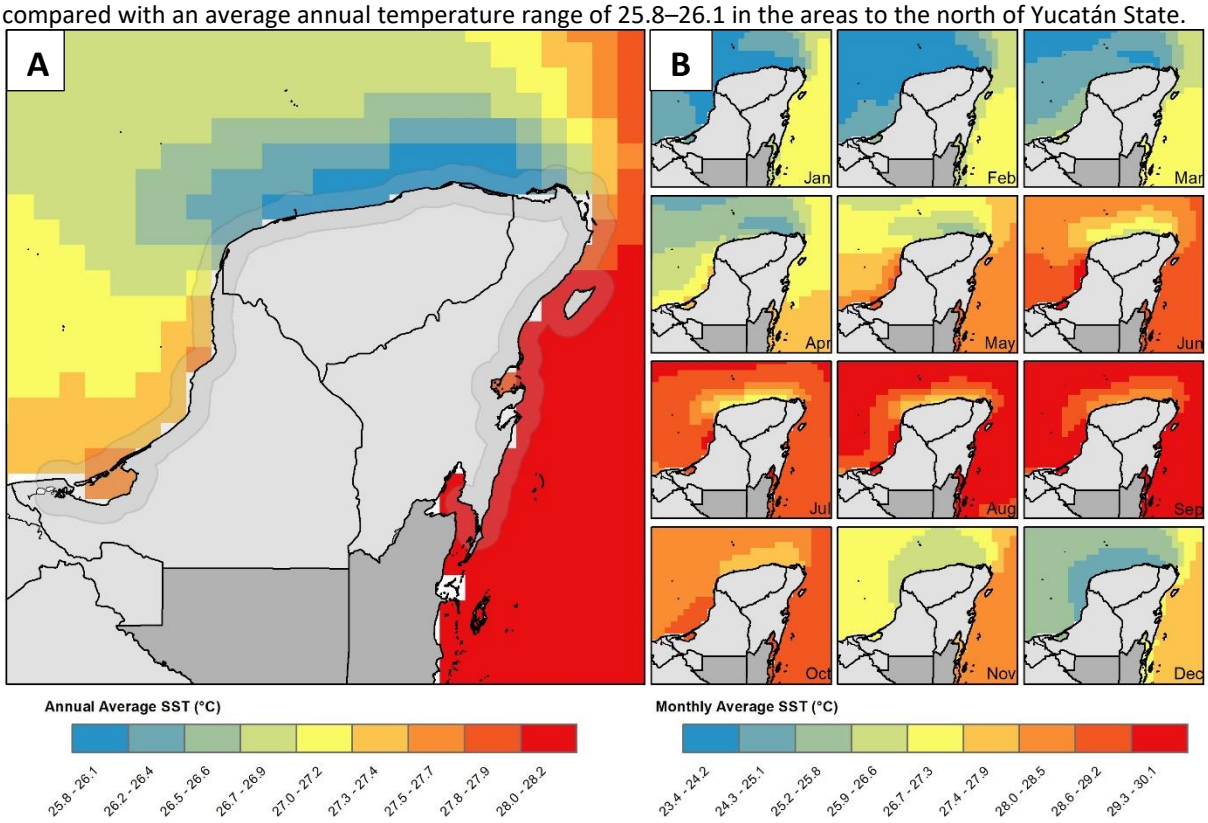


Figure 17. Average annual SST (A); Monthly average SST (B).

1.4.2. Sea Level Rise (SLR)

During the past 100 years, Mexico experienced sea level rise (SLR) at or above the global average[33]. Moreover, the rate at which SLR has occurred in the country has accelerated and reached more than 2 mm/year since 1990. Figure 18 (A) below shows the observed changes in mean sea levels along the coast of the Yucatán Peninsula. Sea levels along the eastern coast of the peninsula have risen comparatively more than areas to the west of the peninsula, corresponding to the higher sea surface temperatures present in this area (Figure 17). Figure 18 (B) indicates that sea levels in the east have increased at a faster rate than areas to the west.

[30] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[31] Gyory, J. Mariano, A.J., Ryan, E.H. 2013. The Yucatan Current. Available here.
[32] Britannica. 2015. Yucatán Current. Available here.
[33] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

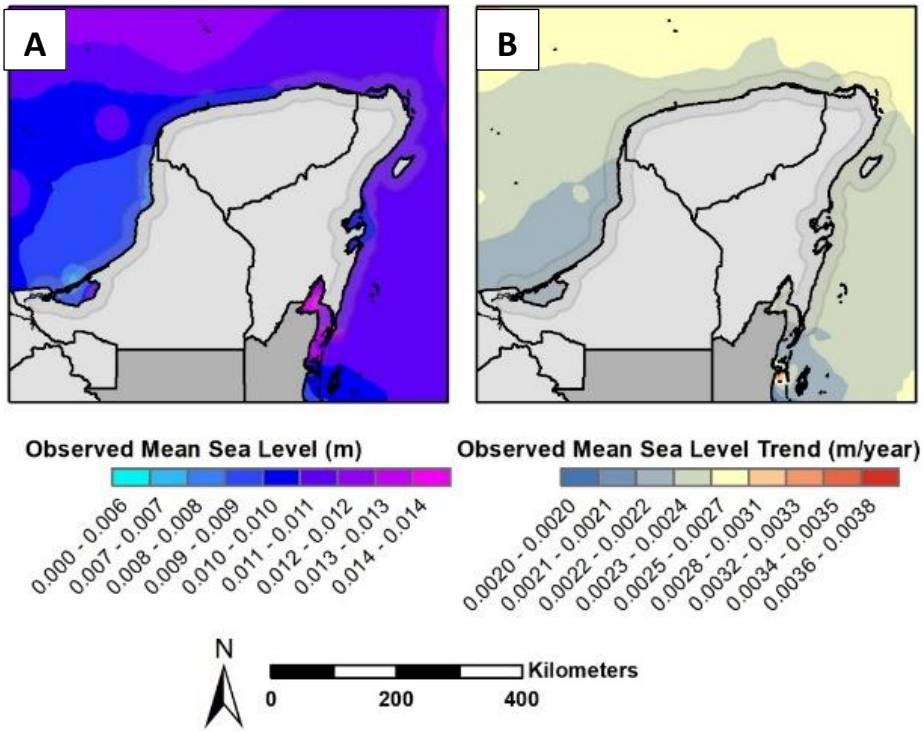


Figure 18. Observed mean sea level (A); Observed mean sea level trend(B).

1.4.3. Acidification

Globally, an increase in atmospheric CO_2 concentrations has already caused an increasing trend in ocean acidification[34]. Over the industrial era, oceans have become approximately 30% more acidic as a result of CO_2 emissions, with this reduction in surface water pH observed across the world. Observations indicate that the acidity of waters around Mexico is increasing as a result of climate change. The figure below shows the decreasing pH of the oceans surrounding Mexico from 1950 to 2014. A clear trend towards acidification is observable.

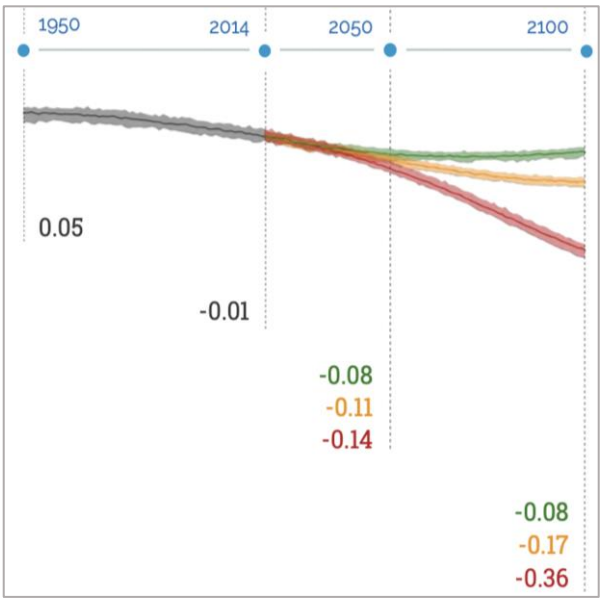


Figure 19. Observed and projected ocean acidification around Mexico for the baseline period of 1950–2014, 2050 and 2100[35].

While the other parameters on the list can also have important impacts on ocean biodiversity and tourism, pH, aragonite saturation state, calcite saturation state, and water salinity are generally considered to be the most critical factors.

The pH of the ocean plays a crucial role in determining the biodiversity of marine ecosystems. A decrease in pH can have negative impacts on many marine species, especially those with calcium carbonate shells and

[34] EEA. Ocean acidification. Available here.
[35] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

skeletons, such as coral reefs, shellfish, and some types of plankton. As the ocean becomes more acidic, it becomes harder for these organisms to build and maintain their shells, which can lead to decreased growth rates, weakened shells, and increased mortality. This can have a ripple effect throughout the food chain, affecting the abundance and diversity of other species that depend on these organisms for food or habitat. Furthermore, changes in pH can also affect the behaviour and physiology of many marine organisms, such as fish and squid. For example, studies have shown that increased acidity can alter the ability of fish to detect predators and affect their ability to swim and find food. This can have cascading effects on the entire ecosystem. This can have cascading effects on the entire ecosystem. Overall, the pH of the ocean is a critical factor in shaping the biodiversity and functioning of marine ecosystems and understanding the impacts of ocean acidification on marine life is essential for developing effective conservation and management strategies.

The aragonite saturation state of the ocean also plays a critical role in shaping the biodiversity of marine ecosystems. Aragonite is a form of calcium carbonate that is used by many marine organisms to build shells and skeletons, similar to how humans use calcium to build bones. When the aragonite saturation state of seawater decreases, it becomes harder for marine organisms to build and maintain their shells and skeletons, which can lead to decreased growth rates, weakened structures, and increased mortality. This can have a cascading effect on other species that depend on these organisms for food or habitat. For example, coral reefs, which are home to a vast array of marine life, are particularly vulnerable to changes in aragonite saturation state. When seawater becomes undersaturated with aragonite, coral growth rates decrease, and coral reefs become more vulnerable to erosion and collapse. Additionally, changes in aragonite saturation state can also affect the physiology and behaviour of marine organisms, such as their ability to reproduce or find food, which can further impact the structure and functioning of marine ecosystems. Overall, the aragonite saturation state of the ocean is a critical factor in shaping the biodiversity and functioning of marine ecosystems, and understanding its impacts on marine life is essential for developing effective conservation and management strategies.

The calcite saturation state of the ocean also plays an essential role in shaping the biodiversity of marine ecosystems. Calcite is another form of calcium carbonate used by many marine organisms to build shells and skeletons. When the calcite saturation state of seawater decreases, it becomes harder for marine organisms to build and maintain their shells and skeletons, which can lead to decreased growth rates, weakened structures, and increased mortality. This can have a cascading effect on other species that depend on these organisms for food or habitat. For example, some species of plankton, such as coccolithophores, which are important primary producers in the ocean food web, rely on calcite to build their protective shells. When seawater becomes undersaturated with calcite, coccolithophore growth rates decrease, which can impact the entire marine food chain. Additionally, changes in the calcite saturation state of the ocean can also affect the acidity of seawater and lead to ocean acidification, as the process of calcification by marine organisms can release carbon dioxide into the water. Overall, the calcite saturation state of the ocean is a critical factor in shaping the biodiversity and functioning of marine ecosystems, and understanding its impacts on marine life is essential for developing effective conservation and management strategies.

The water salinity of the ocean is another critical factor that influences the biodiversity of marine ecosystems. Salinity refers to the concentration of dissolved salts in seawater, which affects its density, temperature, and other physical properties. Changes in water salinity can impact the distribution and abundance of marine organisms, as different species have different tolerances to salinity levels. For example, some marine organisms, such as mangroves and some species of fish, are adapted to live in estuaries and coastal areas with varying salinity levels. Moreover, changes in water salinity can also impact the availability of nutrients and dissolved gases, such as oxygen and carbon dioxide, which are critical for the survival and growth of marine organisms. High salinity can make it more challenging for some marine organisms to regulate their internal water balance, while low salinity can impact their ability to absorb oxygen and remove waste products. Additionally, changes in water salinity can affect the productivity of marine ecosystems, as high salinity levels can limit the growth of phytoplankton, which are the base of the marine food web. Overall, the water salinity of the ocean plays a crucial role in shaping the biodiversity and functioning of marine ecosystems, and understanding its impacts on marine life is essential for developing effective conservation and management strategies.

2. Projected future climate

Projections indicate that in the future, climatic changes across Mexico will intensify – particularly under high-emissions scenarios[36]. A map showing an overview of the future climate of the peninsula is shown in Figure 20

[36] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

below. A shift in climate is projected for much of the western part of Yucatán State and norther-eastern Campeche State. The degree of climate shift in these areas is predicted to be moderate. The sections below provide additional detail on the climatic changes and climate change impacts projected for Mexico and the Yucatán Peninsula specifically.

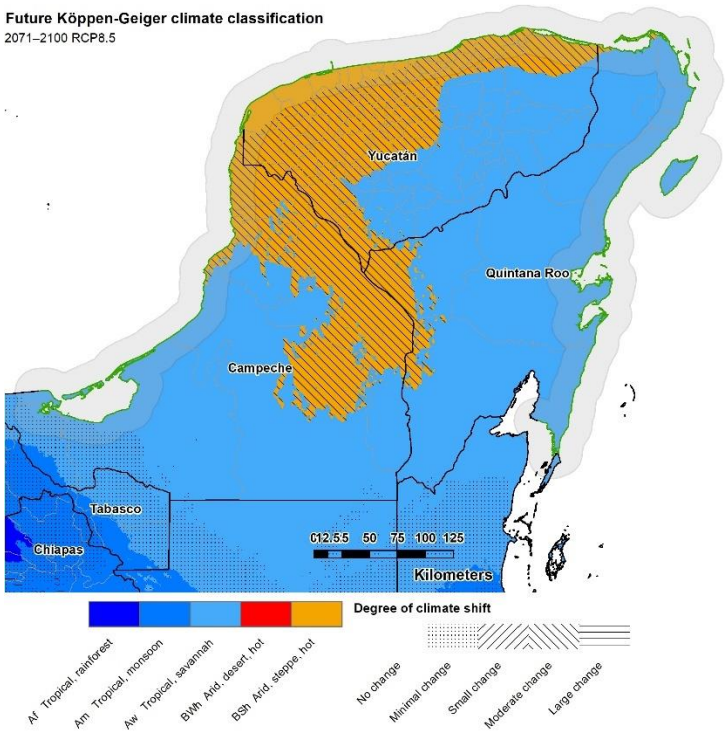


Figure 20. Future Köppen Climate Classification and change in the Yucatán Peninsula[37].

Projected statistical climate analysis is calculated over 9 sections of coastline each of ~100km in order to provide as high a possible resolution of detailed climate impacts at a practical scale.

[37] World Bank. 2023. Mexico. Available here.

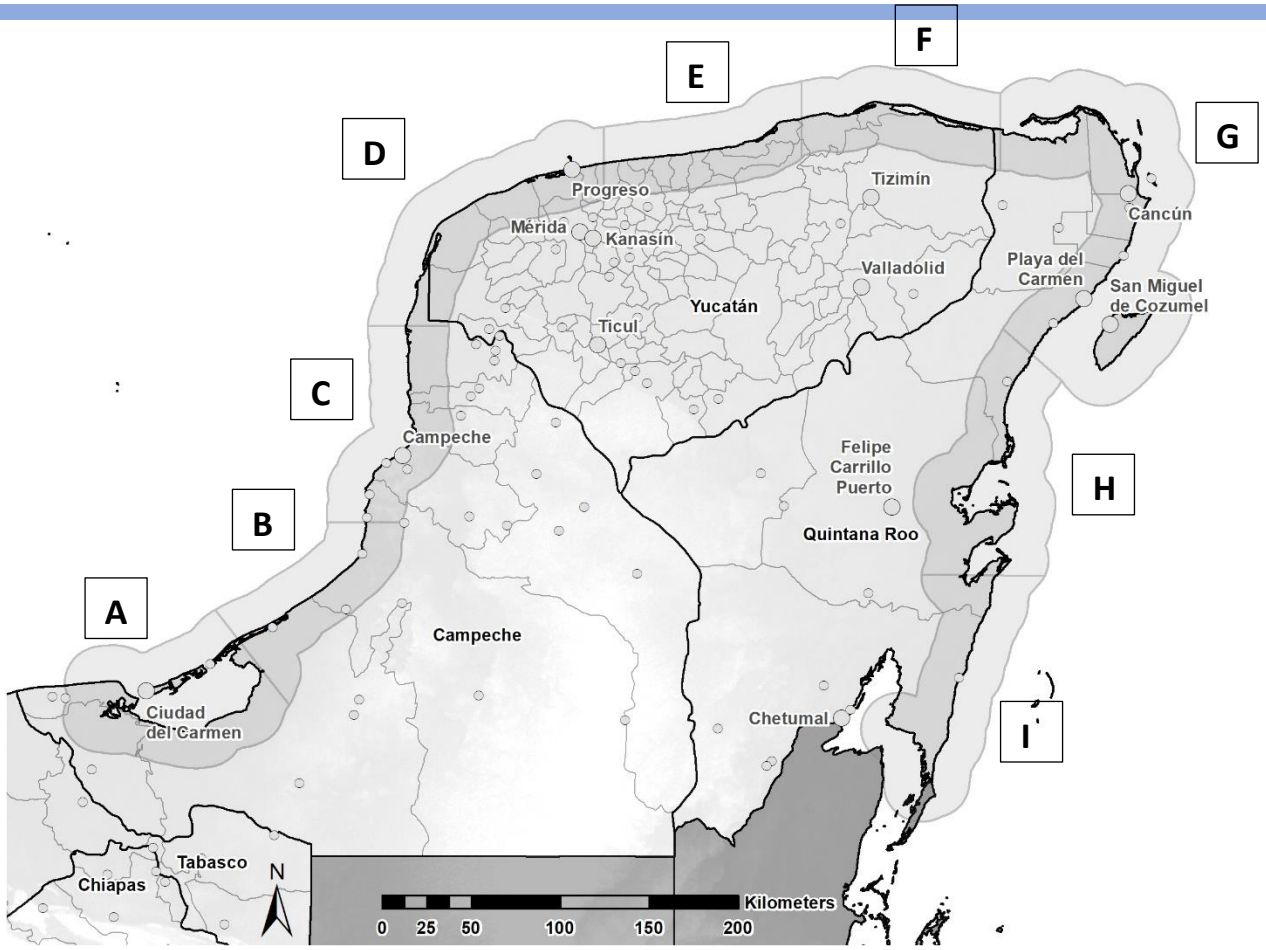


Figure 21. Climate analysis subdivisions of the coastal study area

2.1. Precipitation

Under future climate conditions, changes in average annual total precipitation are uncertain and vary under different emissions scenarios (Figure 22). At 1.5°C of warming, an increase in total precipitation by +0.6% is projected for the country, while decreases of 0.9 and 2.2% are predicted under a medium (2°C of warming) and high (+4°C of warming) scenario, respectively. However, the uncertainty in total precipitation trends is in contrast to projections for precipitation during the wettest month of the year and during the warmest quarter of the year. During the wettest month, increases of 3.3%, 2.8% and 1.5% in precipitation are projected under a low, medium and high emissions scenario, respectively. Concurrently, decreases of 0.9%, 4.7% and 5.6% are predicted under a low, medium and high emissions scenario, respectively. This indicates that droughts during the warmest periods of the year will become increasingly likely. Downscaled projections for the Yucatán Peninsula are in line with those for Mexico as a whole.

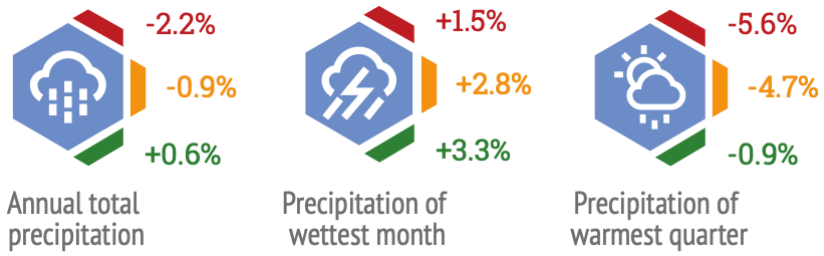


Figure 22. Projected changes in precipitation for Mexico[38].

[38] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

Projections indicate that under future climate conditions, annual precipitation will decline across much of the Yucatán Peninsula.

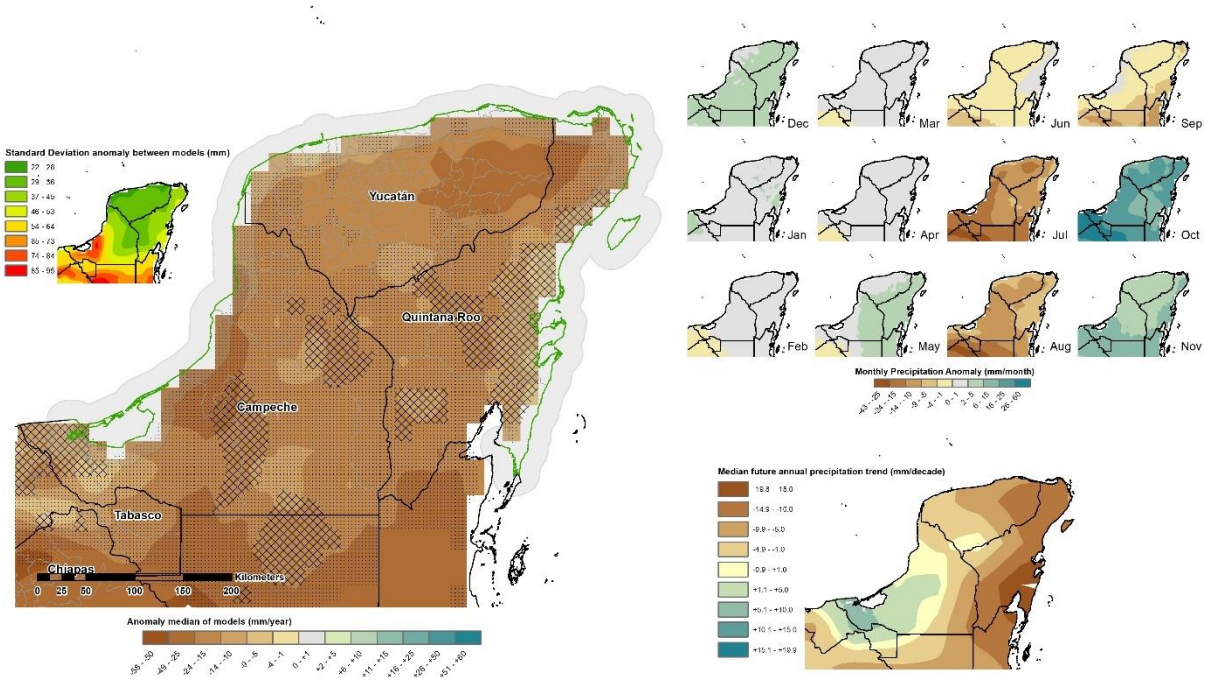


Figure 23(A) shows the median future rainfall and standard deviation between ensemble models for the Yucatán Peninsula.

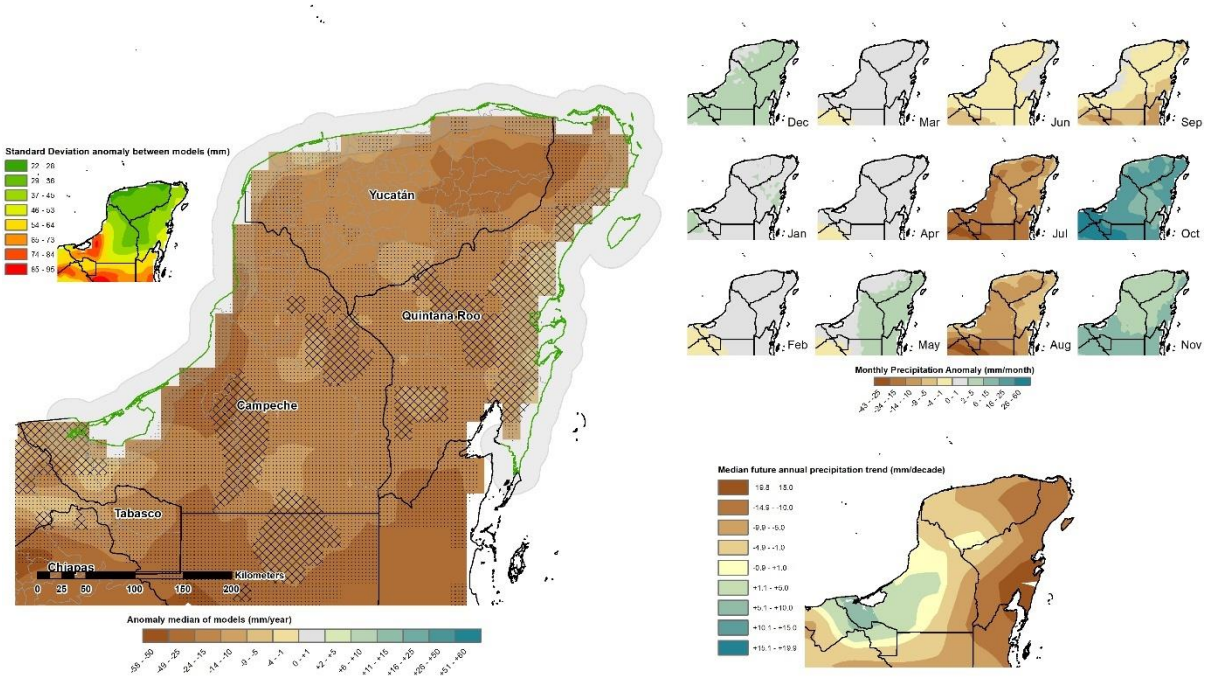


Figure 23 (B) shows model agreement and monthly rainfall changes. Projected rainfall trends and the 10th to 90th percentile range are shown in (C).

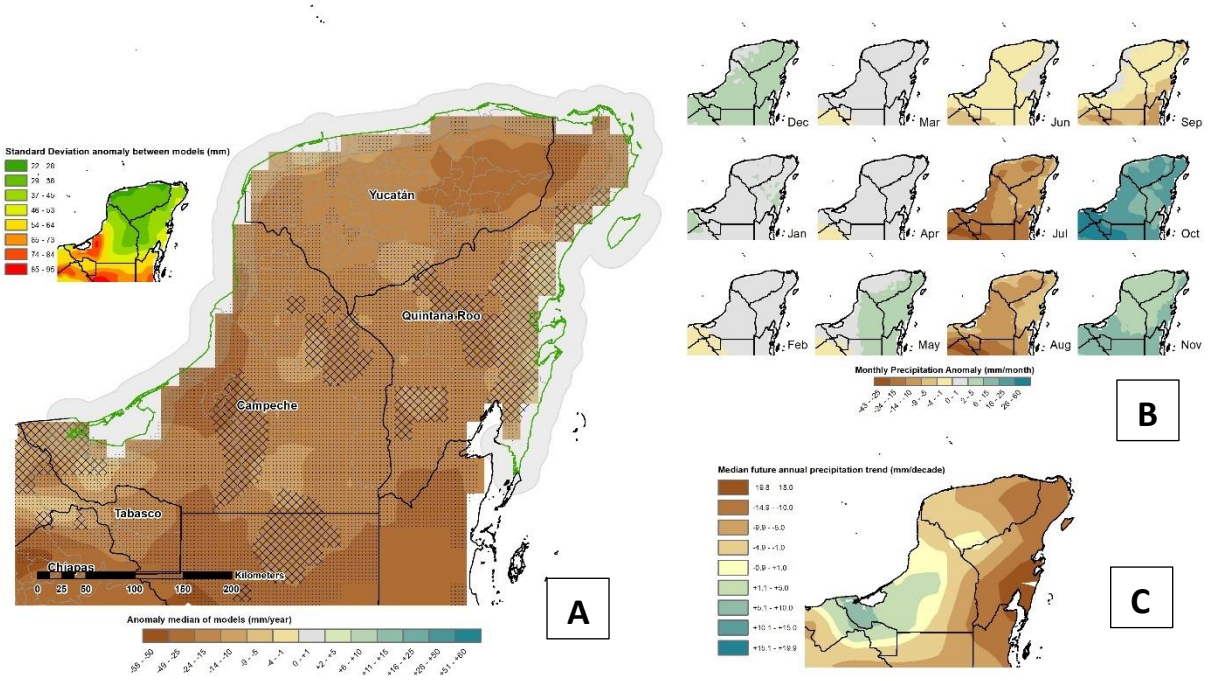
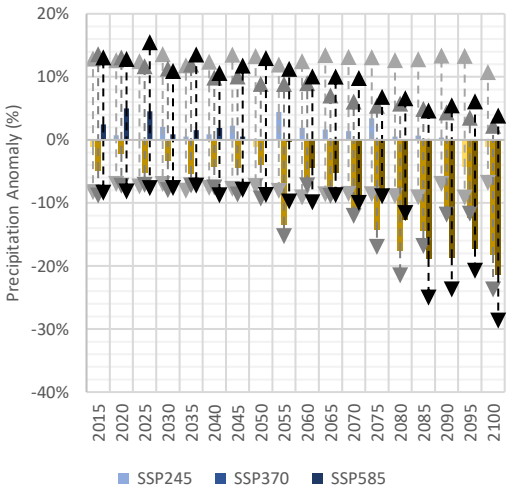
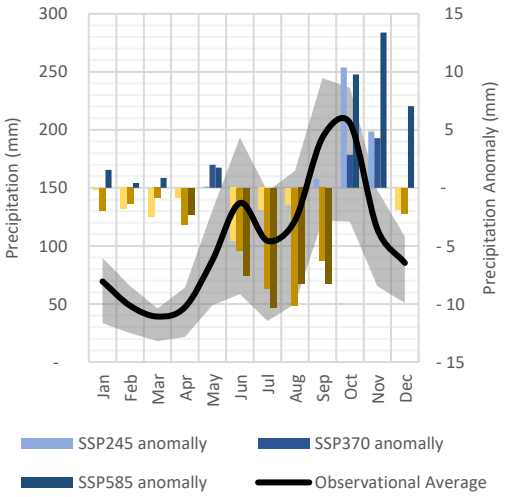
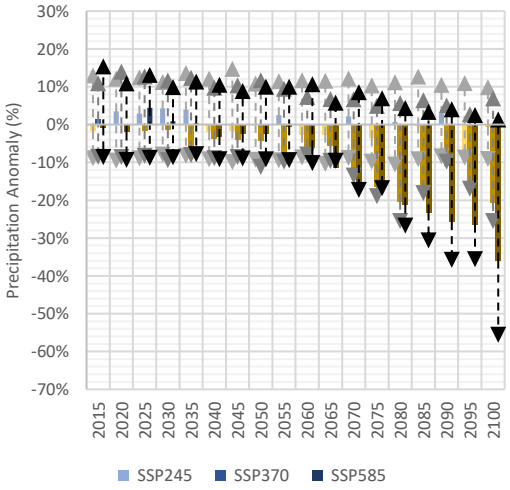


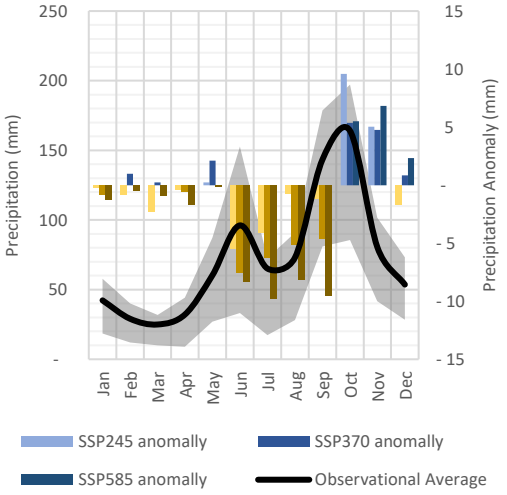
Figure 23. Median future rainfall and standard deviation between ensemble models (A) model agreement and monthly rainfall changes (B) and Projected rainfall trend and 10th to 90th percentile range (C)

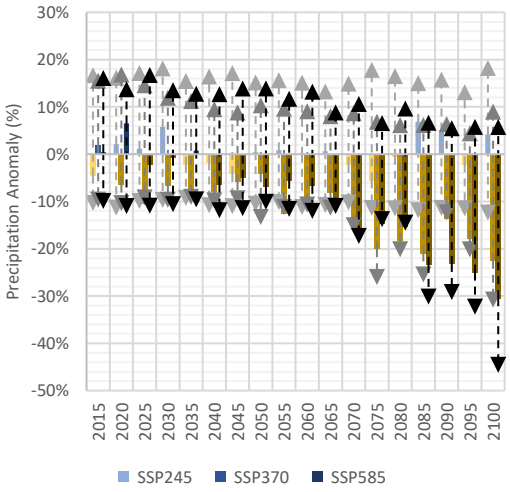
The projected decreasing precipitation trend will be affected by the presence of the central upland areas of the peninsula. The part of the peninsula to the east of these uplands will be most severely affected by decreasing precipitation, with severity increasing towards coastal areas along the Caribbean Sea. The south-eastern parts of Quintana Roo will likely experience the most severe declines of between 15.0 - 19.8 mm per decade. Concurrently, areas to the west of the central uplands will experience less severe declines, and the trend diminishes towards the central and south-western areas of the peninsula. An increasing trend in average precipitation is projected for the central and south-western areas, with some parts of south-western Campeche expected to see precipitation increase by up to 10 mm per decade.

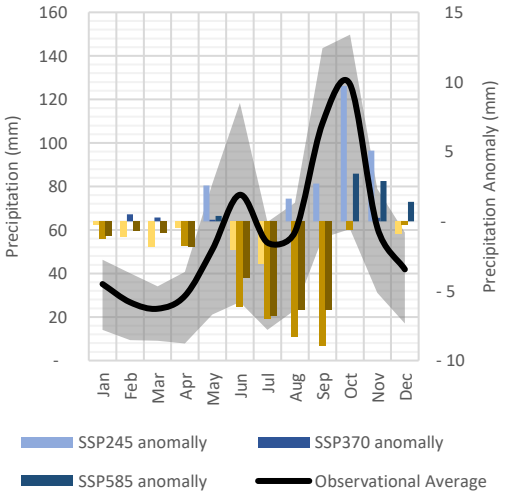

Precipitation Anomaly (%)
SSP245
SSP370
SSP585

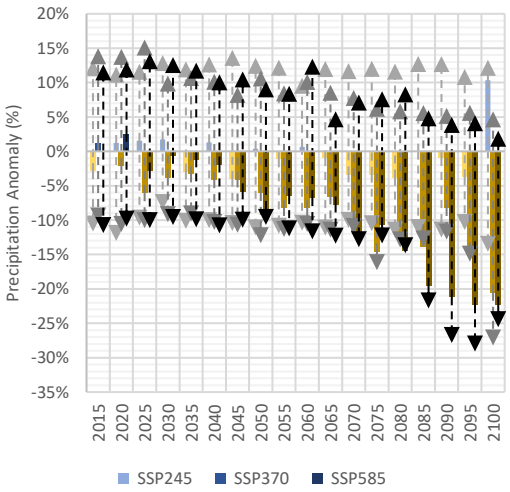

Precipitation (mm)
Precipitation Anomaly (mm)
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

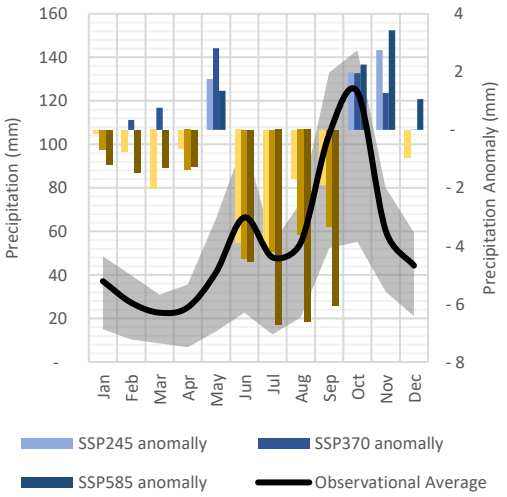

Precipitation Anomaly (%)
SSP245
SSP370
SSP585

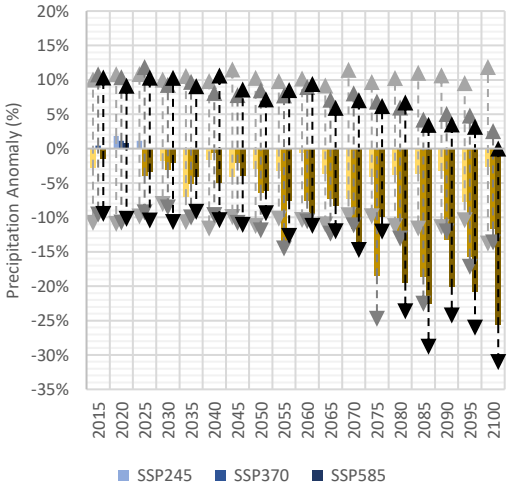

Precipitation (mm)
Precipitation Anomaly (mm)
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

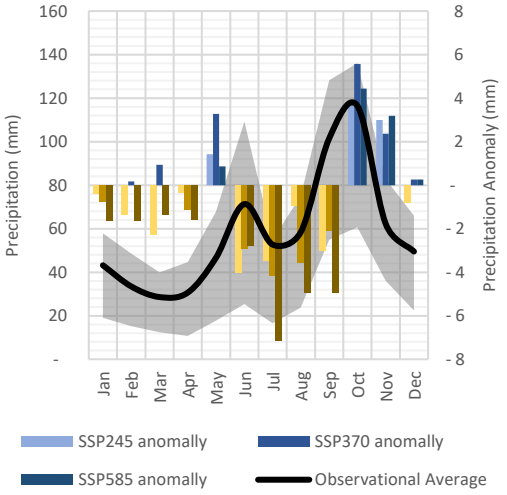

Precipitation Anomaly (%)
SSP245
SSP370
SSP585

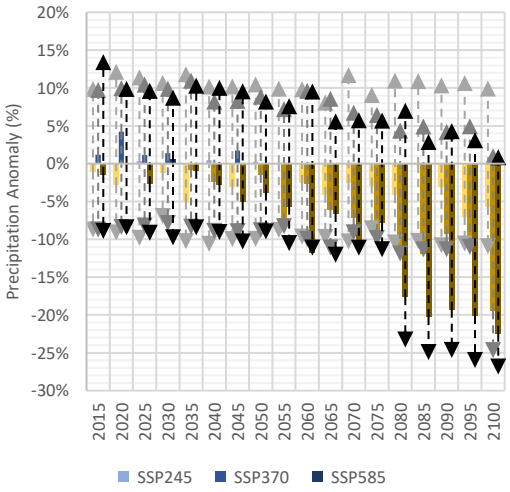

Precipitation (mm)
Precipitation Anomaly (mm)
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

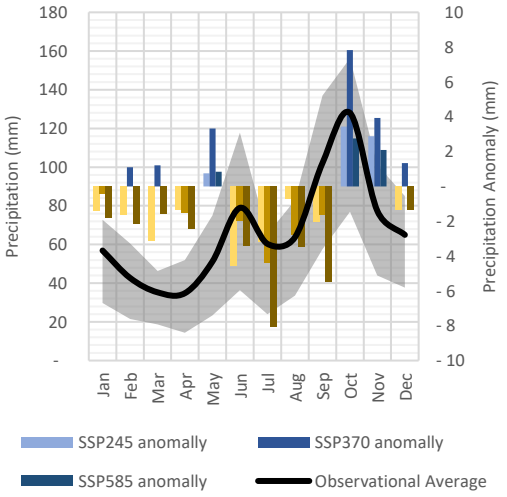

Precipitation Anomaly (%)
SSP245
SSP370
SSP585


Precipitation (mm)
Precipitation Anomaly (mm)
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average


Precipitation Anomaly (%)
SSP245
SSP370
SSP585


Precipitation (mm)
Precipitation Anomaly (mm)
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average


Precipitation Anomaly (%)
SSP245
SSP370
SSP585


Precipitation (mm)
Precipitation Anomaly (mm)
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

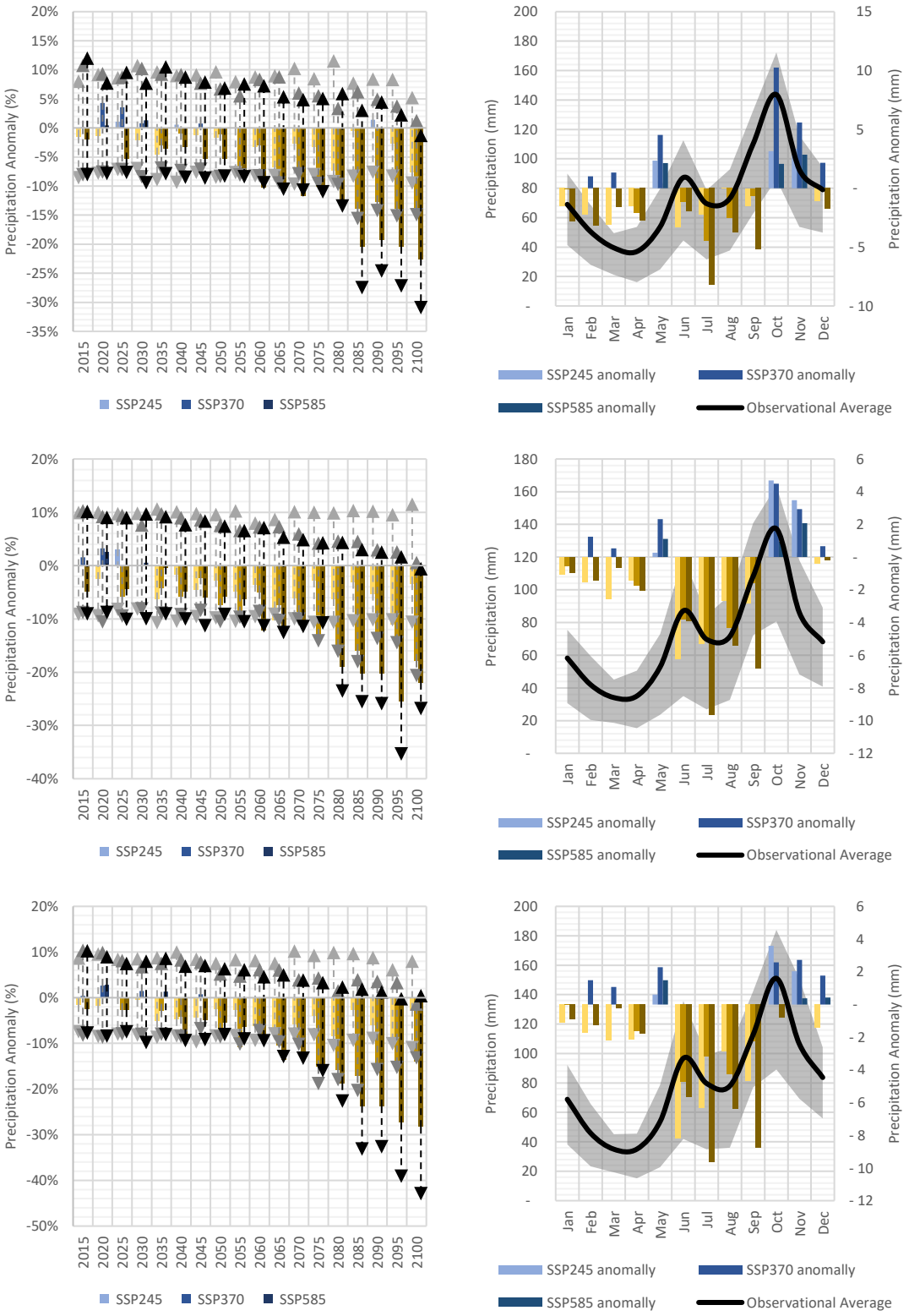


Figure 24. Statistical precipitation characteristics. Annual Changes (left), monthly changes (right). Locations A to I top to bottom.

2.1.1. Extreme rainfall

As noted above, increases in precipitation during the wettest months of the year are projected for Mexico as a whole (Figure 22). Concurrently, a decline in rainfall during the warmest months is predicted, indicating that an intensification in rainfall during the wet season can be expected. In the Yucatán Peninsula, projections of future precipitation extremes are complex and varied with the geography of the region. In eastern coastal areas, increases in monthly precipitation peaks are predicted to be as much as 20.1 mm (Figure 25A), with this trend diminishing further inland, and becoming positive in the interior areas. In south-central parts of Yucatán State, central and eastern Campeche and western Quintana Roo, monthly mean precipitation peaks are predicted to

decline by between 1.0 - 4.9 mm, along with a number of hotspot areas where projections show an increase in peak precipitation. Most parts of the peninsula — particularly southern parts of Quintana Roo and most of Campeche — will experience an increase in the average largest 1-day precipitation anomaly and 1-day precipitation per decade. An increase in both the average largest 5-day cumulative precipitation anomaly and precipitation trend is predicted, with the west coast of the peninsula most severely affected.

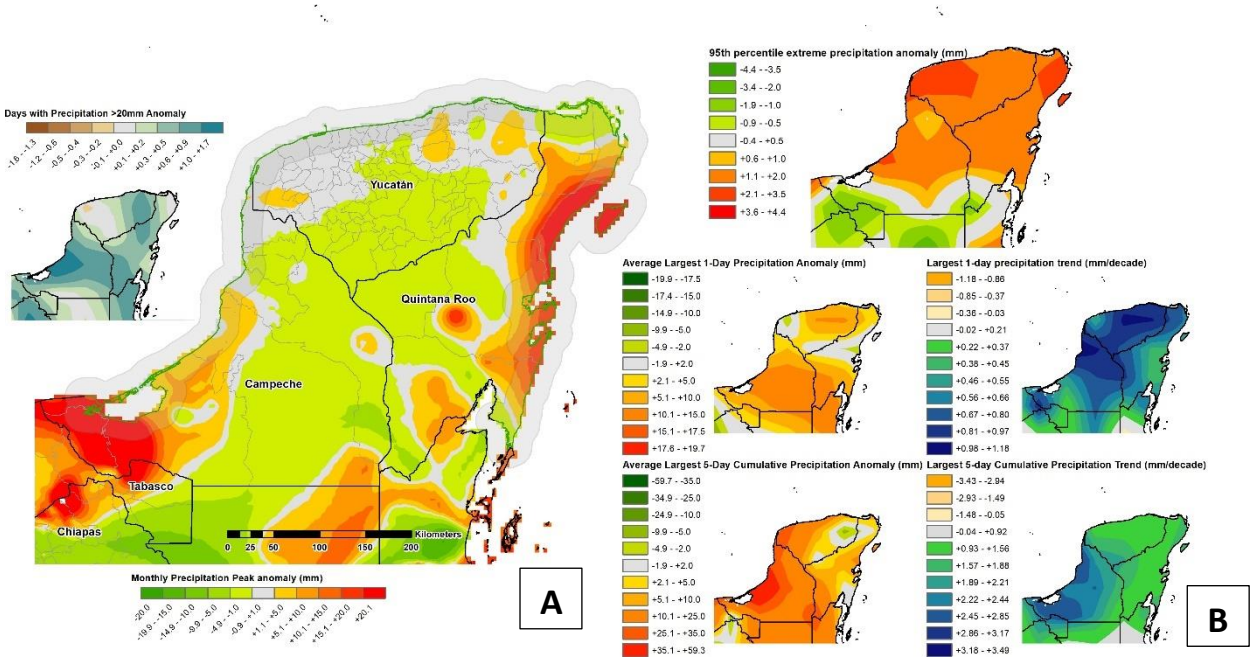
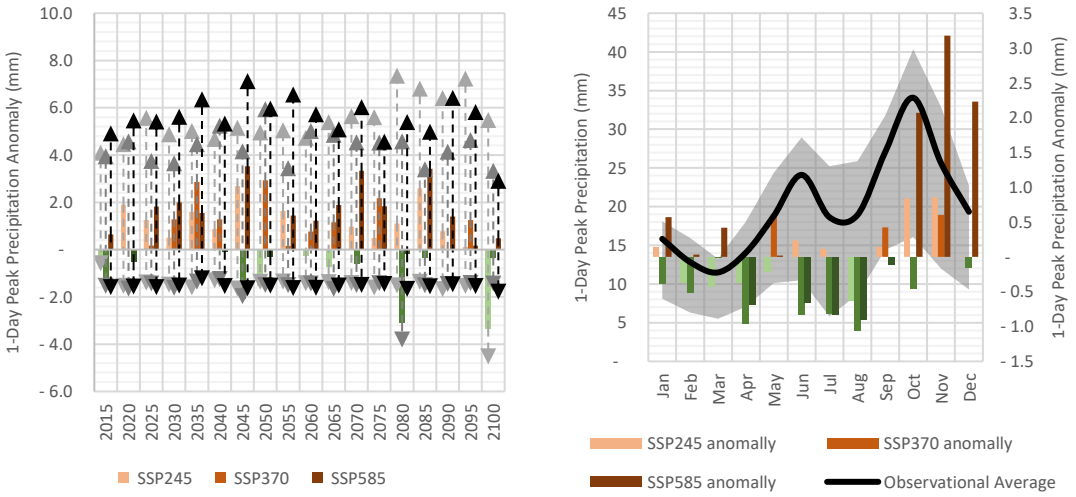
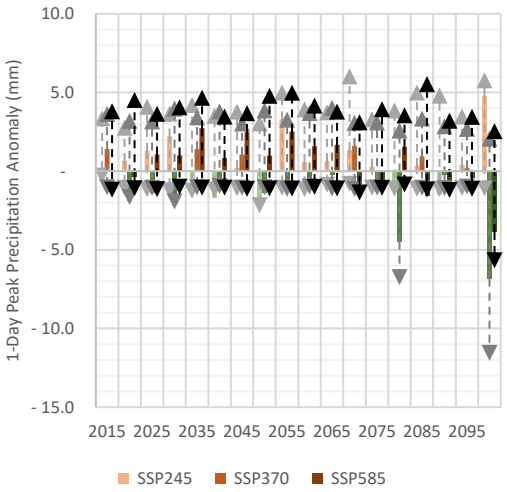
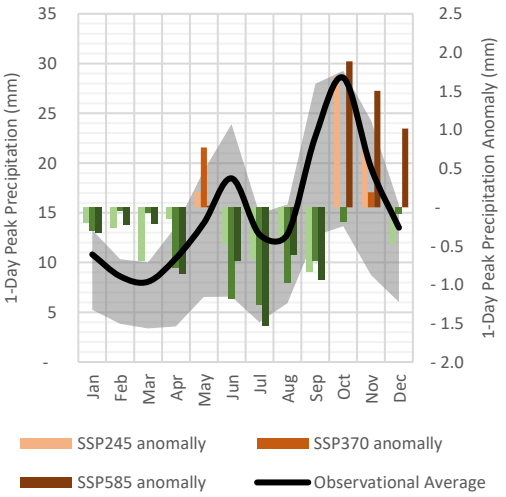
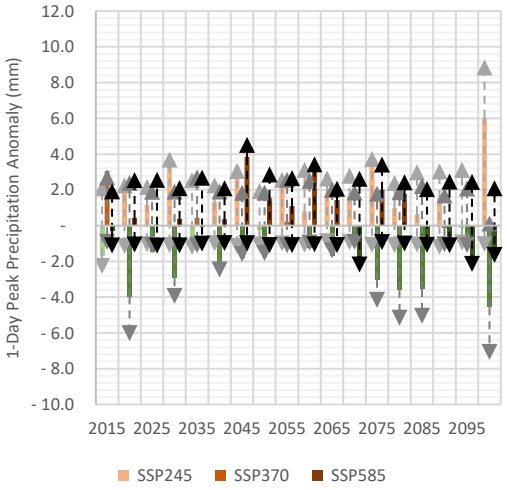


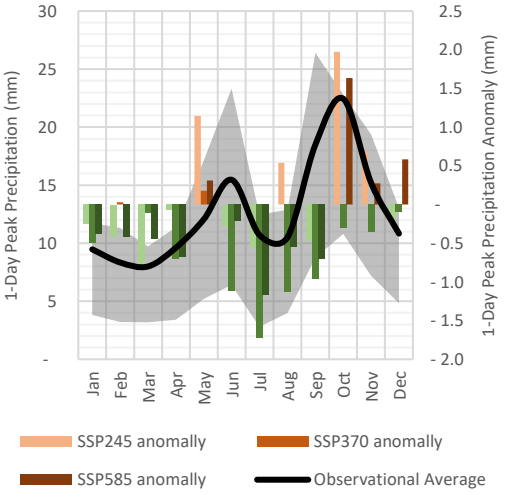
Figure 25. Projected peak rainfall distribution and distribution of extreme rainfall parameters (A); and Projected trend of extreme rainfall parameters (B).

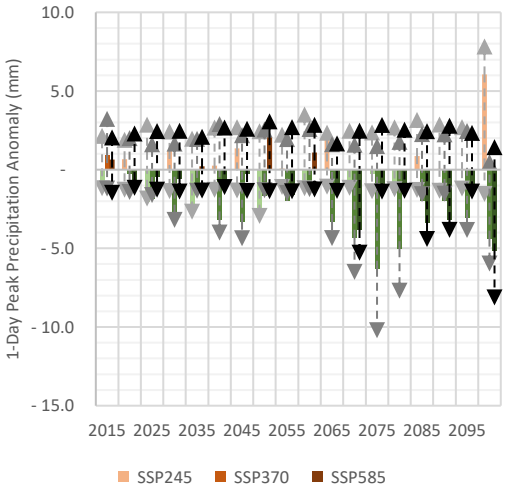


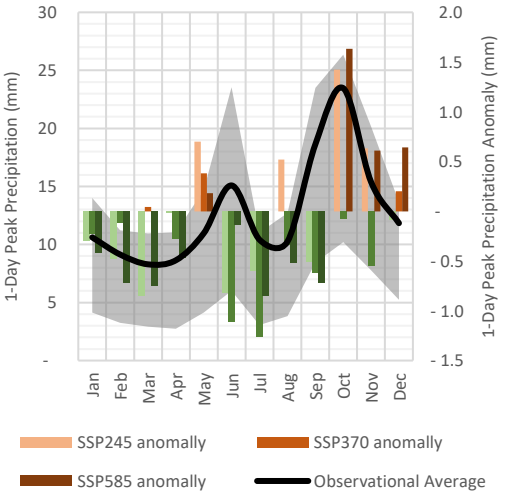

10.0
5.0
-
- 5.0
- 10.0
- 15.0
1-Day Peak Precipitation Anomaly (mm)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585

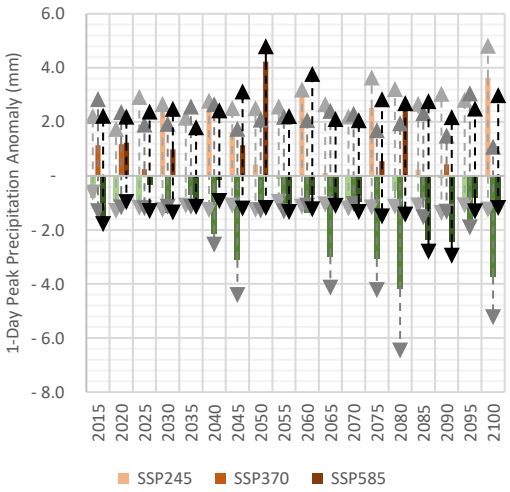

35
30
25
20
15
10
5
-
2.5
2.0
1.5
1.0
0.5
- 0.5
- 1.0
- 1.5
- 2.0
1-Day Peak Precipitation (mm)
1-Day Peak Precipitation Anomaly (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

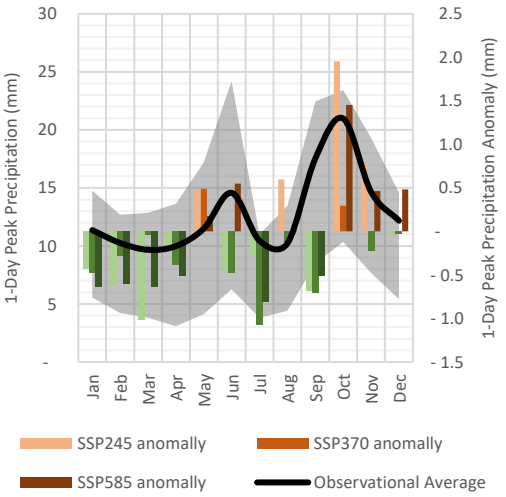

12.0
10.0
8.0
6.0
4.0
2.0
-
- 2.0
- 4.0
- 6.0
- 8.0
- 10.0
1-Day Peak Precipitation Anomaly (mm)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585

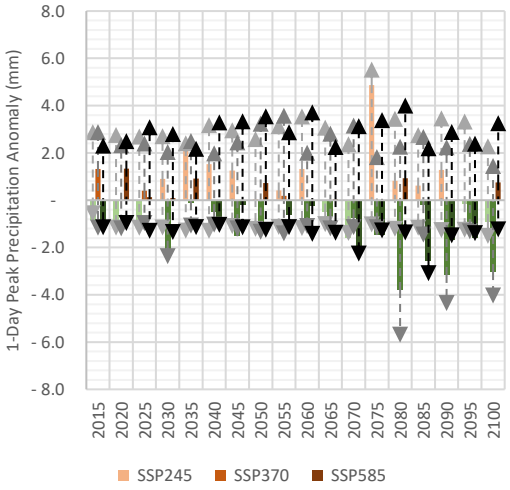

30
25
20
15
10
5
-
2.5
2.0
1.5
1.0
0.5
- 0.5
- 1.0
- 1.5
- 2.0
1-Day Peak Precipitation (mm)
1-Day Peak Precipitation Anomaly (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

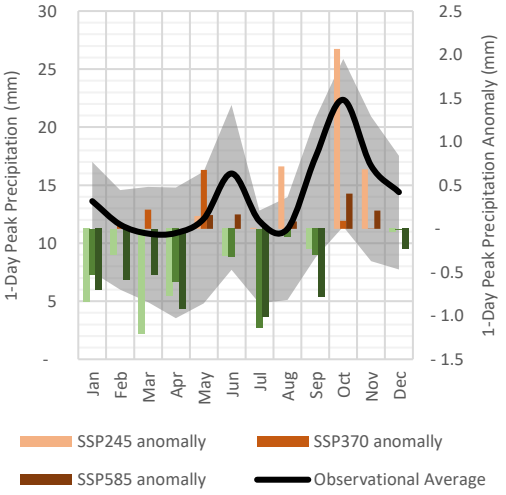

10.0
5.0
-
- 5.0
- 10.0
- 15.0
1-Day Peak Precipitation Anomaly (mm)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585

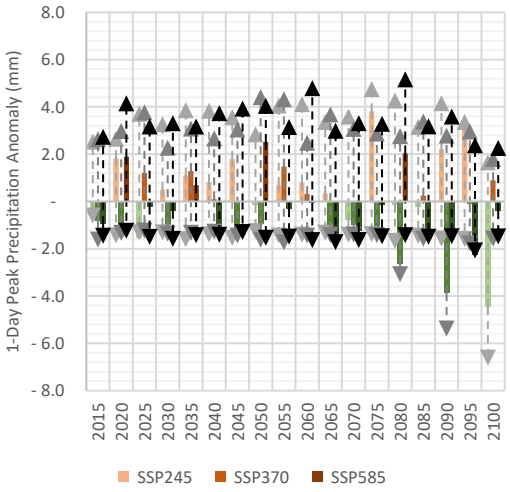

30
25
20
15
10
5
-
2.0
1.5
1.0
0.5
- 0.5
- 1.0
- 1.5
1-Day Peak Precipitation (mm)
1-Day Peak Precipitation Anomaly (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

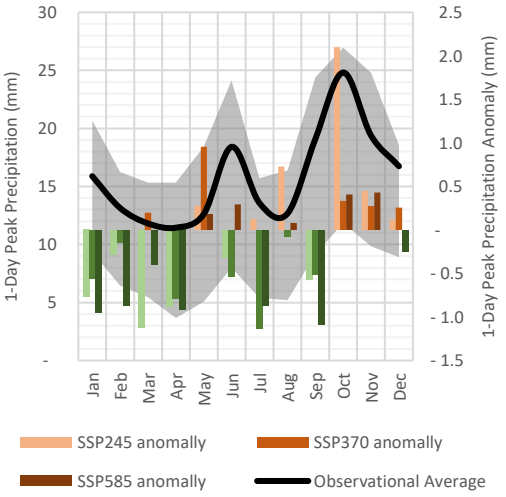

1-Day Peak Precipitation Anomaly (mm)
6.0
4.0
2.0
-
- 2.0
- 4.0
- 6.0
- 8.0
2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100
SSP245
SSP370
SSP585


1-Day Peak Precipitation (mm)
30
25
20
15
10
5
-
2.5
2.0
1.5
1.0
0.5
-
- 0.5
- 1.0
- 1.5
1-Day Peak Precipitation Anomaly (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomaly
SSP370 anomaly
SSP585 anomaly
Observational Average


1-Day Peak Precipitation Anomaly (mm)
8.0
6.0
4.0
2.0
-
- 2.0
- 4.0
- 6.0
- 8.0
2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100
SSP245
SSP370
SSP585


1-Day Peak Precipitation (mm)
30
25
20
15
10
5
-
2.5
2.0
1.5
1.0
0.5
-
- 0.5
- 1.0
- 1.5
1-Day Peak Precipitation Anomaly (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomaly
SSP370 anomaly
SSP585 anomaly
Observational Average


1-Day Peak Precipitation Anomaly (mm)
8.0
6.0
4.0
2.0
-
- 2.0
- 4.0
- 6.0
- 8.0
2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100
SSP245
SSP370
SSP585


1-Day Peak Precipitation (mm)
30
25
20
15
10
5
-
2.5
2.0
1.5
1.0
0.5
-
- 0.5
- 1.0
- 1.5
1-Day Peak Precipitation Anomaly (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomaly
SSP370 anomaly
SSP585 anomaly
Observational Average

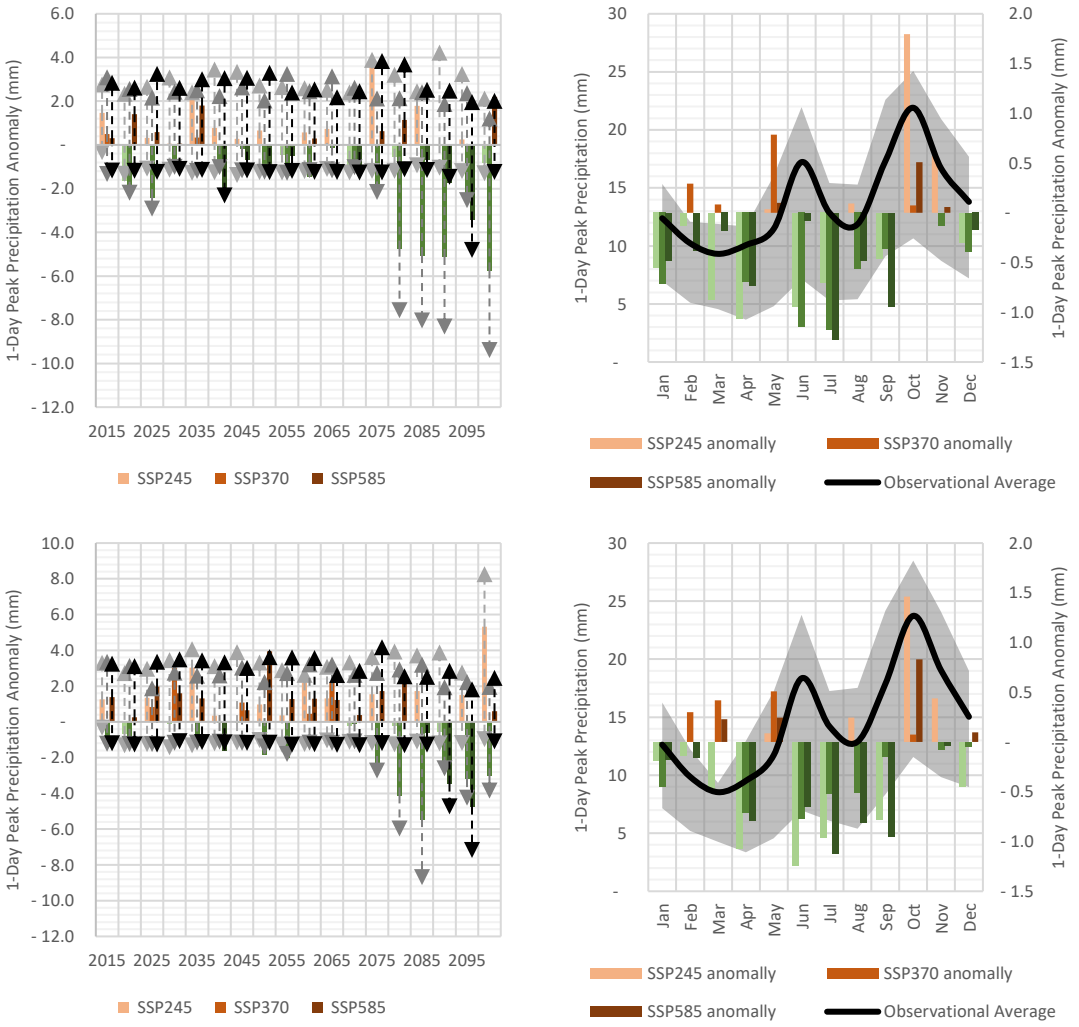


Figure 26. Statistical precipitation characteristics. Annual Changes in 1 day maximum precipitation (left), monthly changes in 1 day maximum precipitation(right). Locations A to I top to bottom.

2.1.2. Drought and variability

Under future climate conditions, drought is predicted to become increasingly common and severe across much of Mexico. Under a high-emissions scenario (at +4°C of warming), the frequency of agricultural and hydrological drought is projected to increase by 72% and 15%, respectively (Figure 27)[39]. Under a low and high emissions scenario, hydrological drought frequency is projected to increase by 10% and 15%, respectively[40].

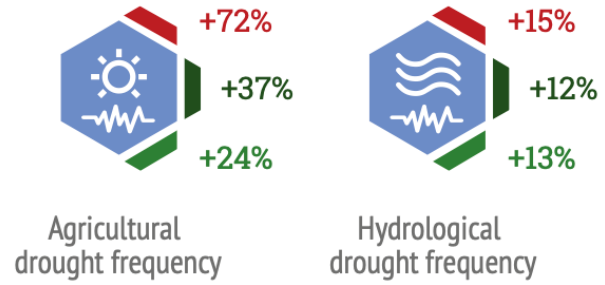


*Figure **27**. Projected changes in agricultural and hydrological drought frequency*[41].

In the Yucatán Peninsula, projections are in line with those for Mexico as a whole and indicate that drier conditions will become increasingly common, with average precipitation decreasing in central areas and increasing in coastal areas. From 2040, drying will occur across the peninsula — a trend that will intensify in the decades leading up to 2100 (Figure 28A). In most areas, the duration of dry spells (Figure 28B (*top*)) is projected

[39] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[40] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[41] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

to increase, by 1.1–2.0 days per year and up to 3 days in large parts of Quintana Roo state. The number of consecutive dry days is also projected to increase, particularly in the uplands of the peninsula and towards the south-eastern coast of Quintana Roo. Concurrently, there will be an increase in the number of consecutive wet days in most of the areas north and east of the uplands. This indicates that periods between rainfall will become longer, with intensifying drought conditions, while rainfall periods will become longer and more intense.

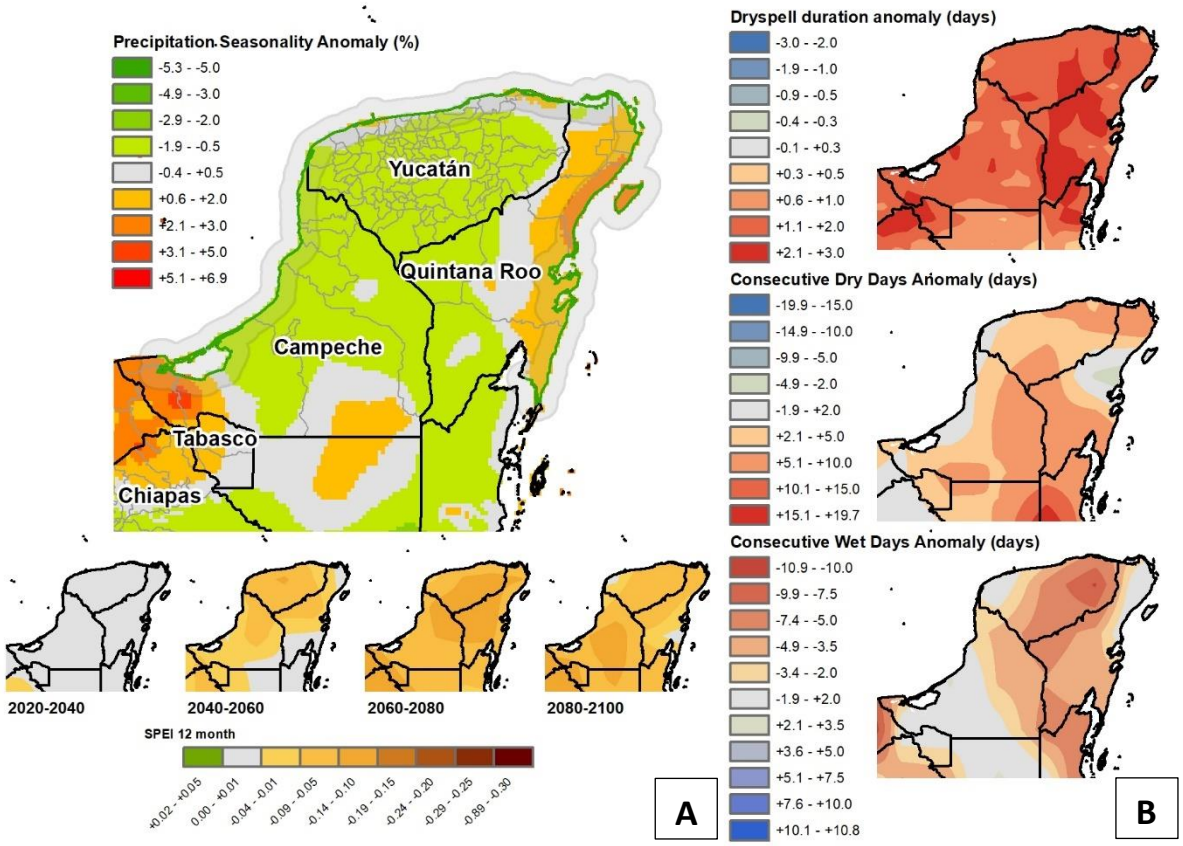
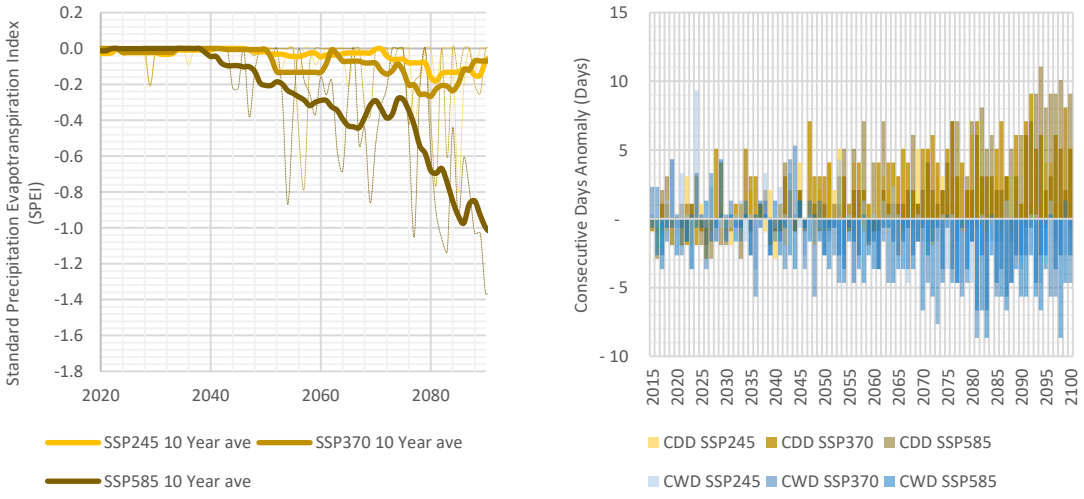
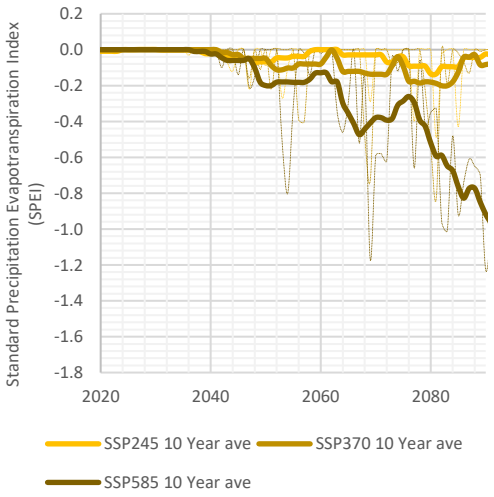
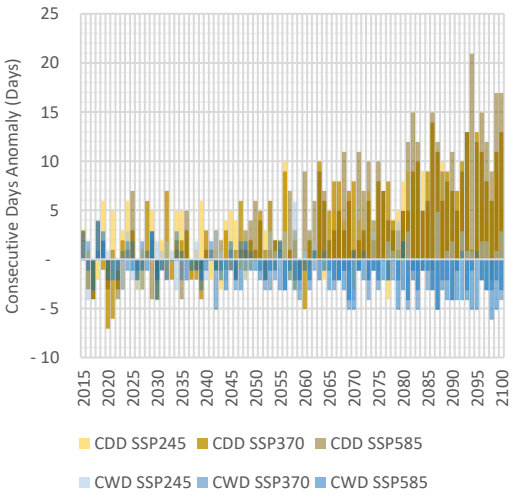
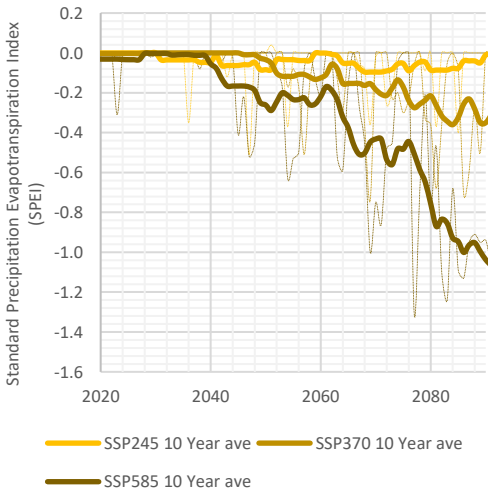


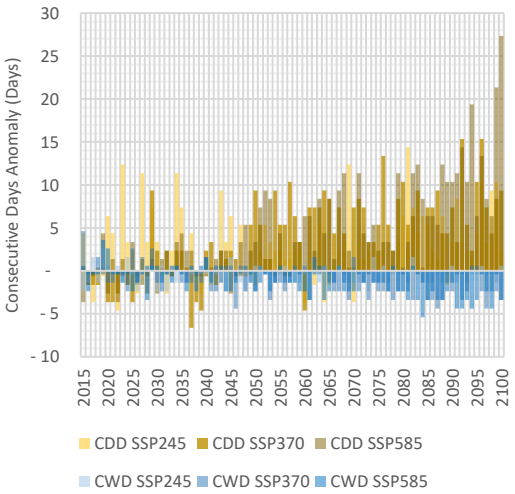
Figure 28. Projected changes in SPEI, dry spell duration, and consecutive dry and wet days (A); and Projected SPEI drought conditions and anomaly dry days over time (B).

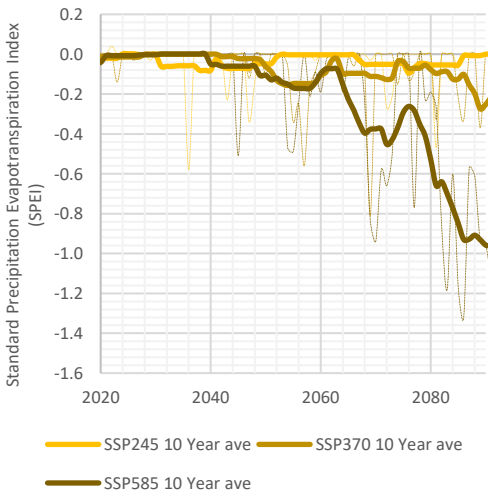


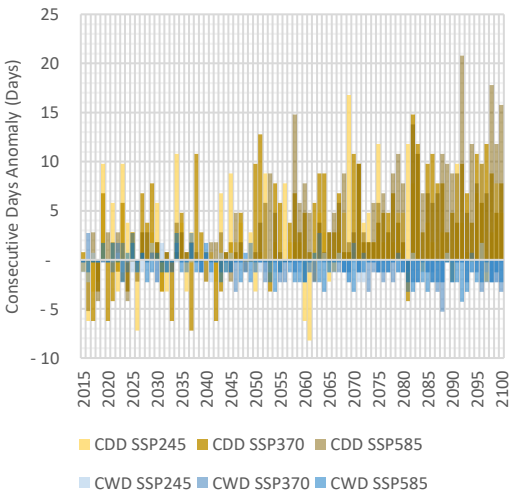

Standard Precipitation Evapotranspiration Index (SPEI)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
2020
2040
2060
2080
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave

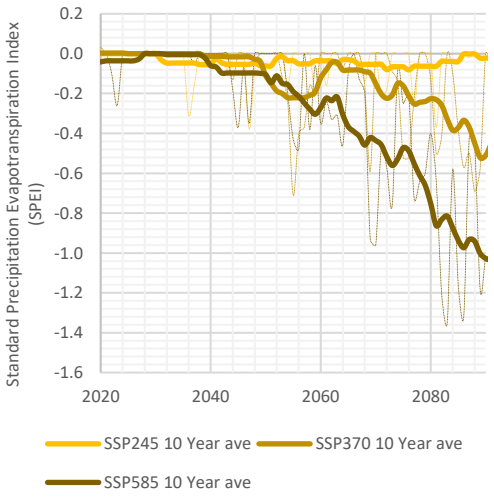

Consecutive Days Anomaly (Days)
25
20
15
10
5
-
- 5
- 10
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
CDD SSP245
CDD SSP370
CDD SSP585
CWD SSP245
CWD SSP370
CWD SSP585

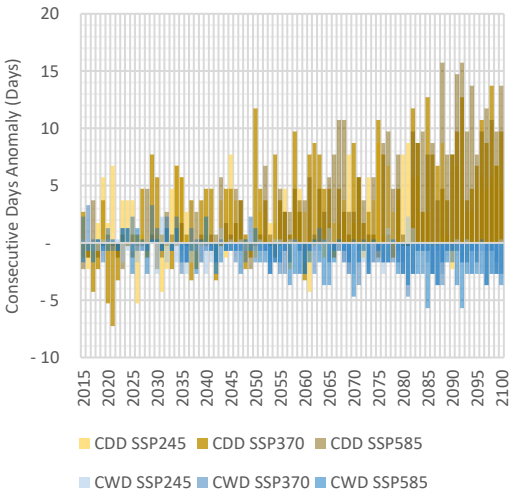

Standard Precipitation Evapotranspiration Index (SPEI)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
2020
2040
2060
2080
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave

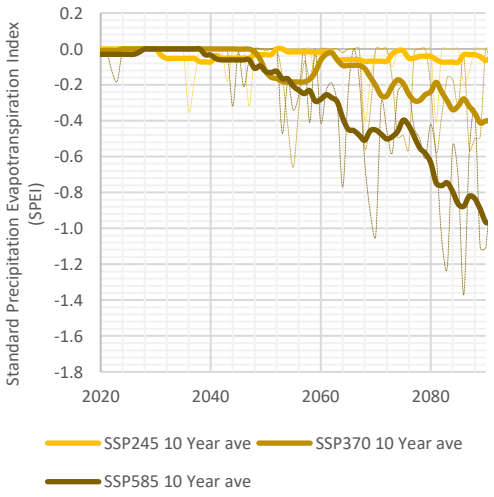

Consecutive Days Anomaly (Days)
30
25
20
15
10
5
-
- 5
- 10
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
CDD SSP245
CDD SSP370
CDD SSP585
CWD SSP245
CWD SSP370
CWD SSP585

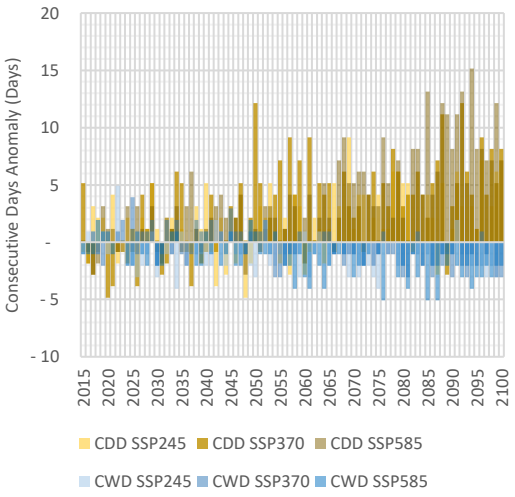

Standard Precipitation Evapotranspiration Index (SPEI)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
2020
2040
2060
2080
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave

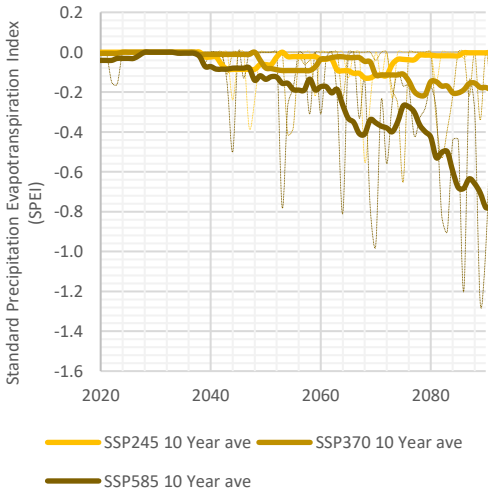

Consecutive Days Anomaly (Days)
25
20
15
10
5
-
- 5
- 10
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
CDD SSP245
CDD SSP370
CDD SSP585
CWD SSP245
CWD SSP370
CWD SSP585

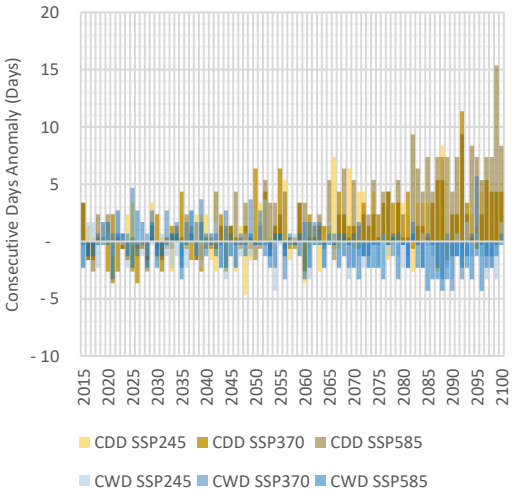

Standard Precipitation Evapotranspiration Index (SPEI)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
2020
2040
2060
2080
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Consecutive Days Anomaly (Days)
20
15
10
5
-
- 5
- 10
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
CDD SSP245
CDD SSP370
CDD SSP585
CWD SSP245
CWD SSP370
CWD SSP585


Standard Precipitation Evapotranspiration Index (SPEI)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
2020
2040
2060
2080
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Consecutive Days Anomaly (Days)
20
15
10
5
-
- 5
- 10
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
CDD SSP245
CDD SSP370
CDD SSP585
CWD SSP245
CWD SSP370
CWD SSP585


Standard Precipitation Evapotranspiration Index (SPEI)
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
2020
2040
2060
2080
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Consecutive Days Anomaly (Days)
20
15
10
5
-
- 5
- 10
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
CDD SSP245
CDD SSP370
CDD SSP585
CWD SSP245
CWD SSP370
CWD SSP585

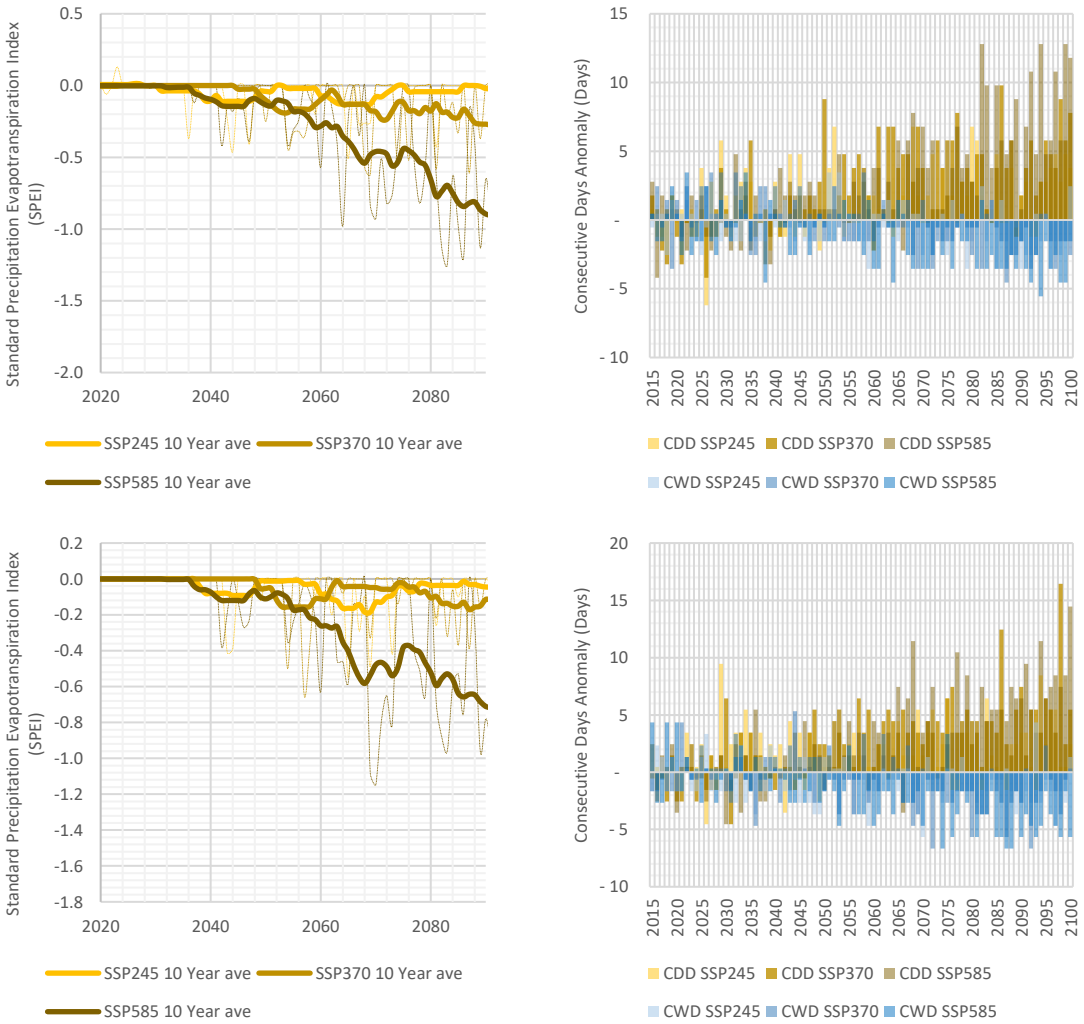


Figure 29. Statistical precipitation characteristics. Annual Changes in drought baseline – SPEI (left), Long term changes in consecutive wet and dry days (right). Locations A to I top to bottom.

2.2. Temperature

Figure 30 shows the median future average temperature and standard deviation between ensemble models (A), monthly temperature anomalies (B), and projected temperature trends and 10th to 90th percentile ranges (C). Under future climate conditions, mean temperature increases are projected for the entire Yucatán Peninsula, with the northern and eastern coastal areas predicted to experience increases of between 0.24–0.26°C per decade. In the south of the Yucatán State and the western part of Quintana Roo, temperature increases of up to 0.29°C per decade are predicted. The south-western parts of Campeche will see the most severe warming, with increases of between 0.30–0.31°C per decade expected. Overall, projections also indicate a rise in average minimum and maximum temperatures (Figure 30C), in line with the geographic differences in mean temperature rise. In the north-eastern coastal region of the peninsula, maximum temperatures are expected to rise by 0.26–0.27°C per decade, with the trend increasing in intensity further southwest. South-western Campeche will experience increases in average maximum temperatures by up to 0.32°C per decade. Concurrently, the average decadal minimum temperatures in the peninsula will increase along the same axis as for maximum temperature — between 0.23–0.24°C per decade in north-eastern Quintana Roo, and up to 0.31°C per decade in the southwest of Campeche.

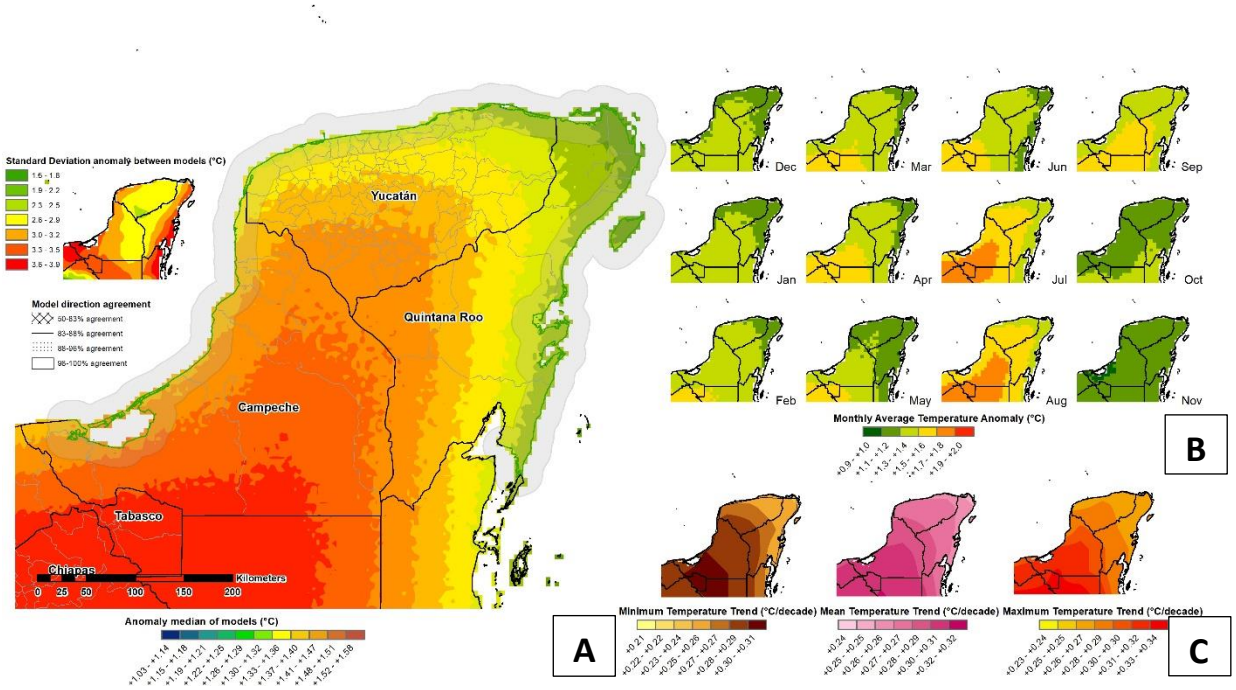
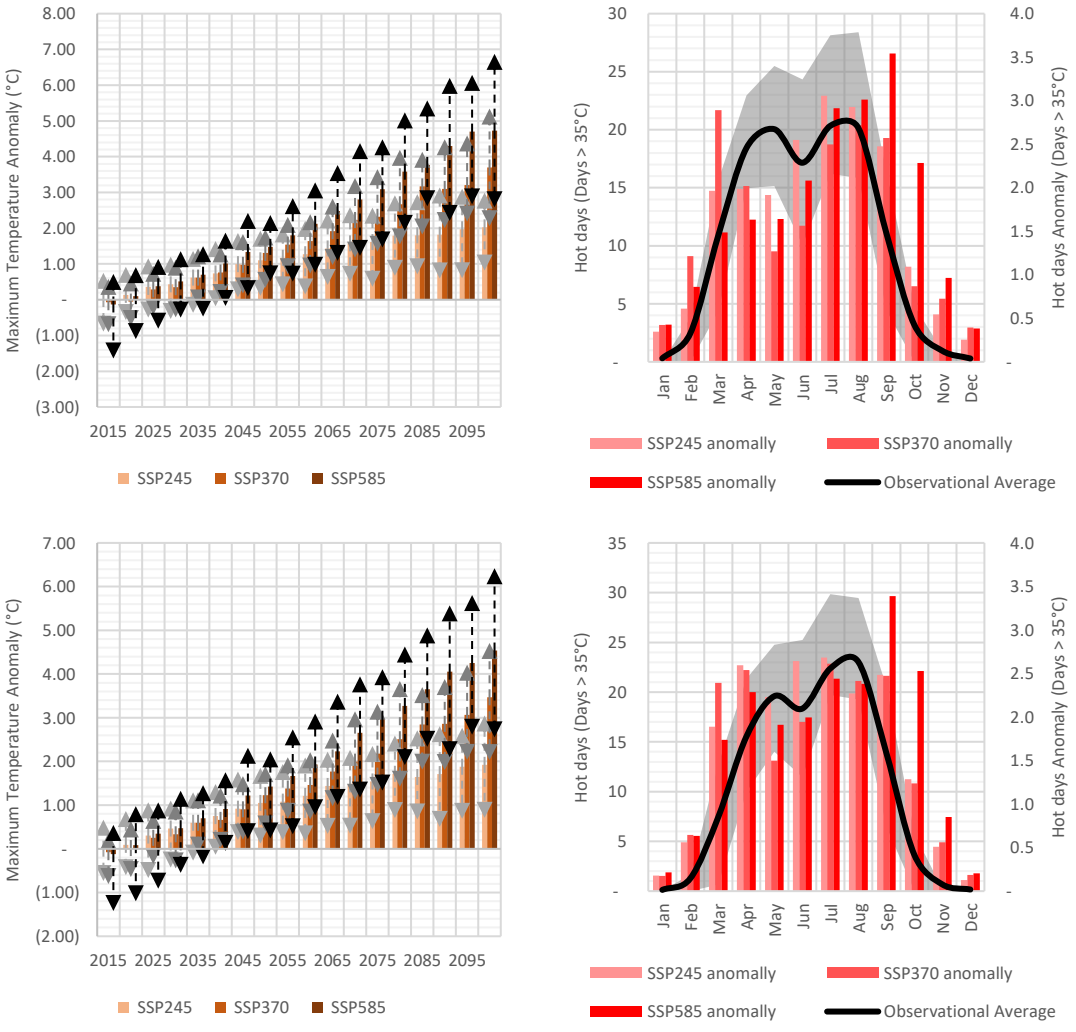
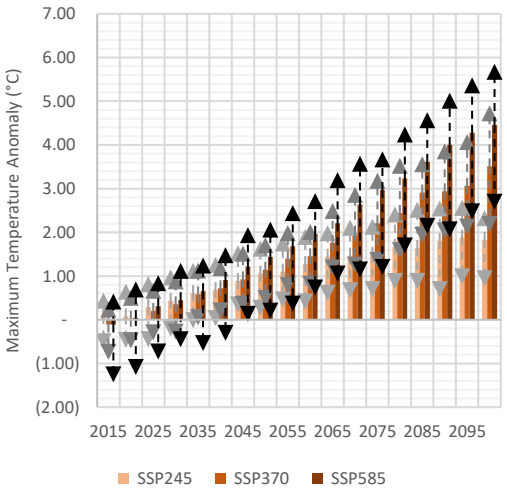
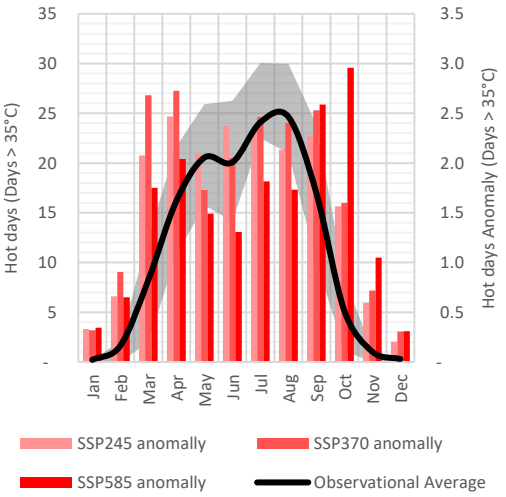
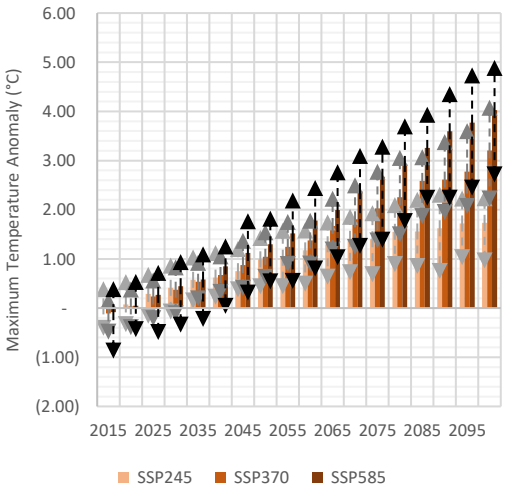


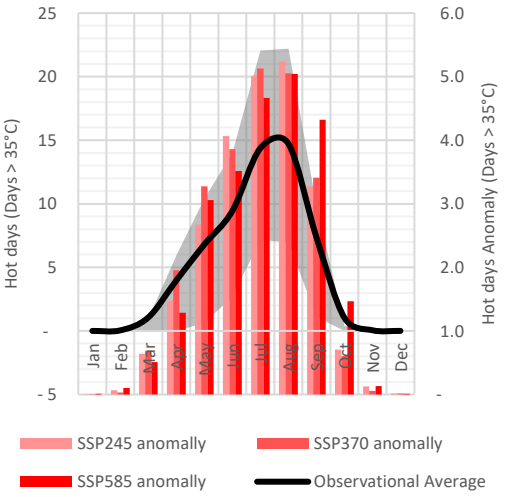
Figure 30. Median future average temperature, standard deviation between ensemble models, model agreement, and monthly temperature anomalies (A); and Projected temperature trends and 10th to 90th percentile ranges (B).

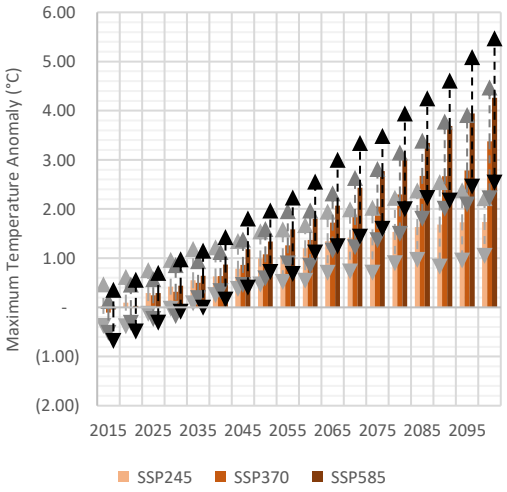


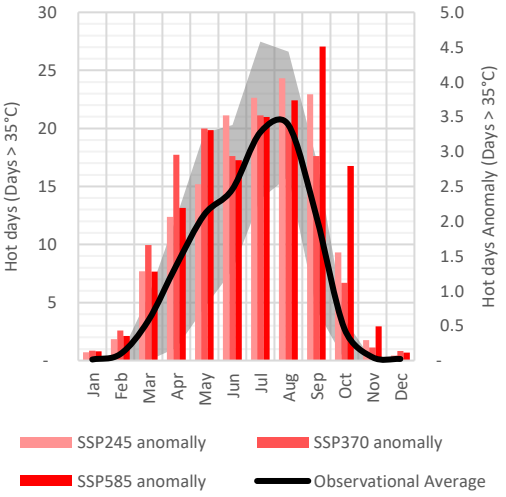

Maximum Temperature Anomaly (°C)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
-
(1.00)
(2.00)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585

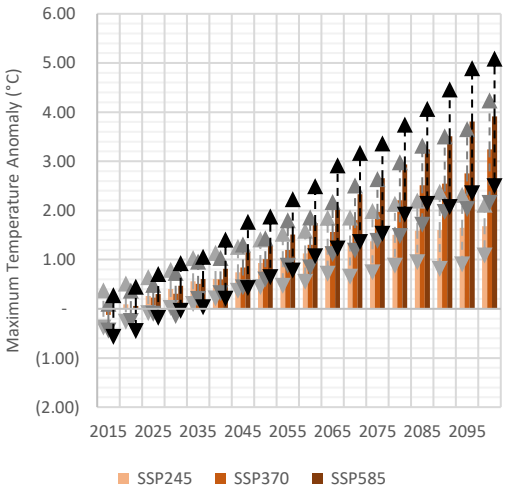

Hot days (Days > 35°C)
Hot days Anomaly (Days > 35°C)
35
30
25
20
15
10
5
-
3.5
3.0
2.5
2.0
1.5
1.0
0.5
-
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

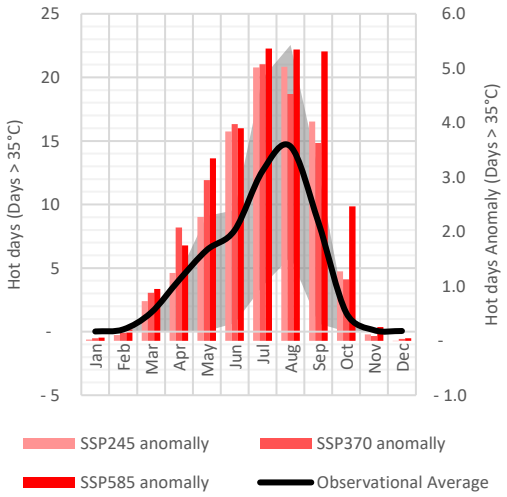

Maximum Temperature Anomaly (°C)
6.00
5.00
4.00
3.00
2.00
1.00
-
(1.00)
(2.00)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585

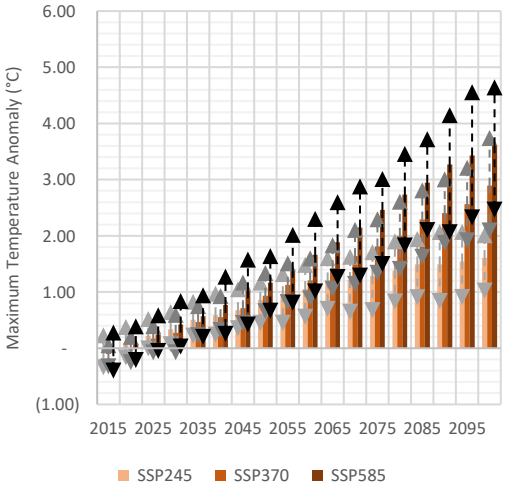

Hot days (Days > 35°C)
Hot days Anomaly (Days > 35°C)
25
20
15
10
5
-
- 5
6.0
5.0
4.0
3.0
2.0
1.0
-
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

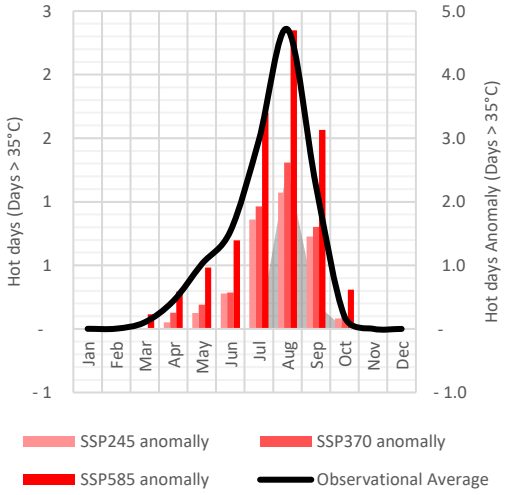

Maximum Temperature Anomaly (°C)
6.00
5.00
4.00
3.00
2.00
1.00
-
(1.00)
(2.00)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585

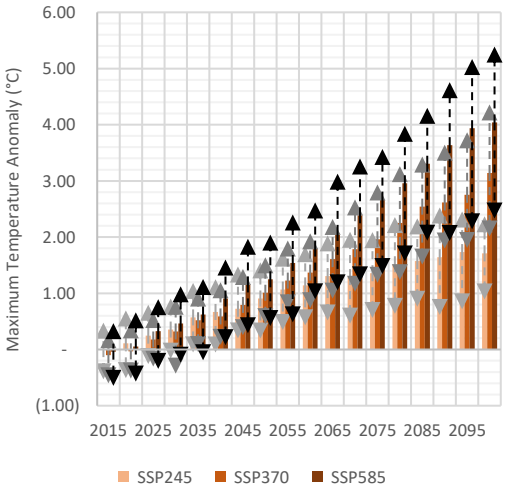

Hot days (Days > 35°C)
Hot days Anomaly (Days > 35°C)
30
25
20
15
10
5
-
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
-
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

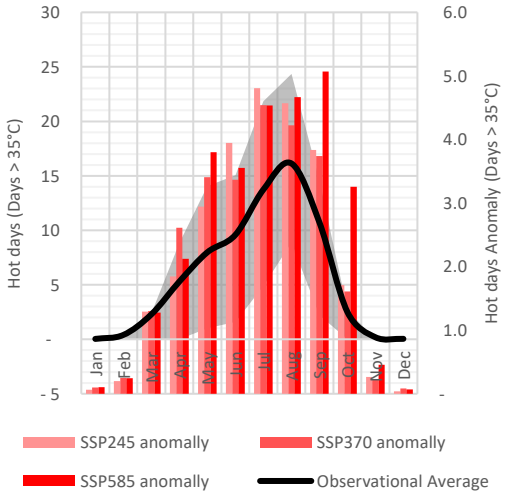

Maximum Temperature Anomaly (°C)
6.00
5.00
4.00
3.00
2.00
1.00
-
(1.00)
(2.00)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585


Hot days (Days > 35°C)
25
20
15
10
5
-
- 5
Hot days Anomaly (Days > 35°C)
6.0
5.0
4.0
3.0
2.0
1.0
-
- 1.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average


Maximum Temperature Anomaly (°C)
6.00
5.00
4.00
3.00
2.00
1.00
-
(1.00)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585


Hot days (Days > 35°C)
3
2
2
1
1
-
- 1
Hot days Anomaly (Days > 35°C)
5.0
4.0
3.0
2.0
1.0
-
- 1.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average


Maximum Temperature Anomaly (°C)
6.00
5.00
4.00
3.00
2.00
1.00
-
(1.00)
2015 2025 2035 2045 2055 2065 2075 2085 2095
SSP245
SSP370
SSP585


Hot days (Days > 35°C)
30
25
20
15
10
5
-
- 5
Hot days Anomaly (Days > 35°C)
6.0
5.0
4.0
3.0
2.0
1.0
-
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
SSP245 anomally
SSP370 anomally
SSP585 anomally
Observational Average

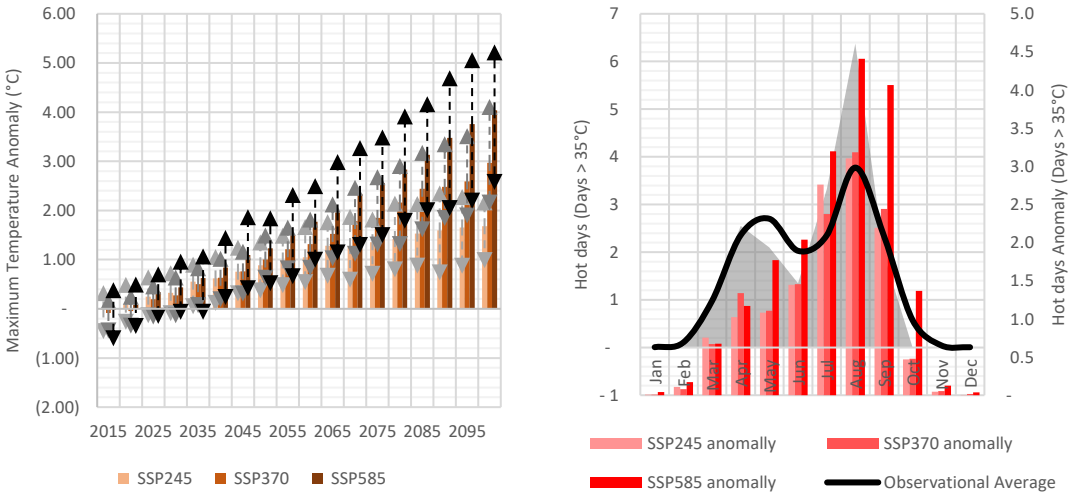


Figure 31. Statistical precipitation characteristics. Annual Changes in maximum temperatures (left), monthly changes in hot days (+35 °C) (right). Locations A to I top to bottom.

2.2.1. Heatwaves

Under future climate conditions, heatwaves are projected to become more common across Mexico. At +1.5°C, +2°C and +4°C of warming, heatwave frequency will increase by 30%, 55% and 98% respectively[42]. Under the same three scenarios, heatwave duration will increase by 195%, 538% and 4,005% respectively[43]. In line with these national projections, a rise in the occurrence of heatwaves is also projected for the Yucatán Peninsula. Figure 32 below shows the projected peak temperature distribution (A) and distribution of extreme temperature parameters, projected change in extreme temperature distribution and change in cooling degree days (B). The analysis indicates an increase in monthly maximum temperature peaks across the entire peninsula, as well as an increase in the duration of warm spells — particularly in coastal areas. The number of 99th percentile days relative to the 1960–1990 baseline period is also projected to increase most severely in coastal areas, but also across the western parts of the entire peninsula to a lesser extent.

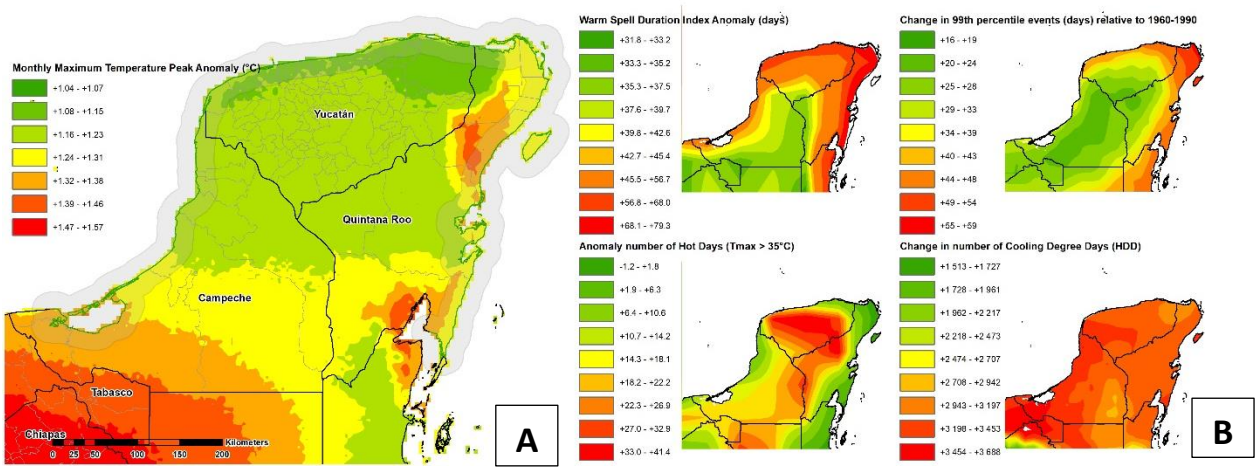
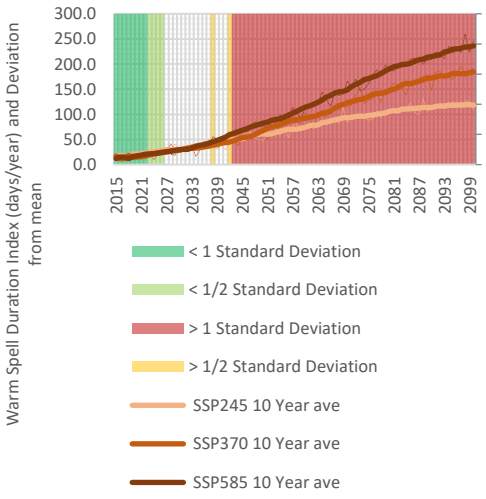
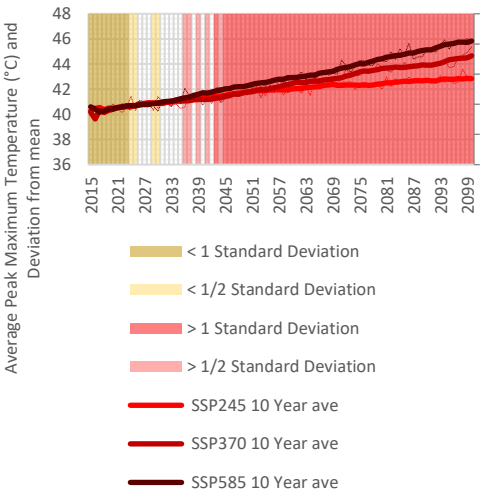


Figure 32. Projected peak temperature distribution and distribution of extreme temperature parameters (A); Projected change in extreme temperature distribution and change in cooling degree days (B).

[42] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[43] CMCC. G20 Climate Risk Atlas: Mexico. Available here.


Warm Spell Duration Index (days/year) and Deviation from mean
300.0
250.0
200.0
150.0
100.0
50.0
0.0
2015
2021
2027
2033
2039
2045
2051
2057
2063
2069
2075
2081
2087
2093
2099
< 1 Standard Deviation
< 1/2 Standard Deviation
> 1 Standard Deviation
> 1/2 Standard Deviation
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Average Peak Maximum Temperature (°C) and Deviation from mean
48
46
44
42
40
38
36
2015
2021
2027
2033
2039
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2051
2057
2063
2069
2075
2081
2087
2093
2099
< 1 Standard Deviation
< 1/2 Standard Deviation
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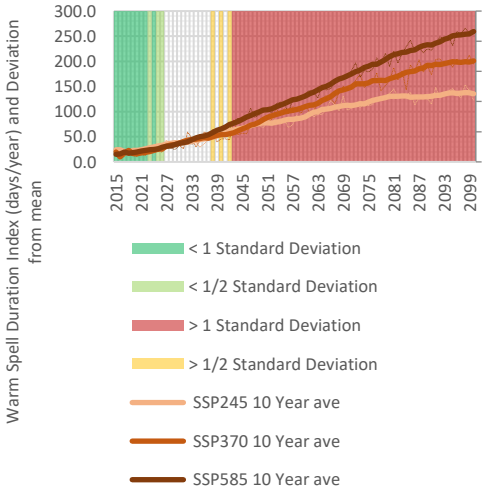
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Warm Spell Duration Index (days/year) and Deviation from mean
300.0
250.0
200.0
150.0
100.0
50.0
0.0
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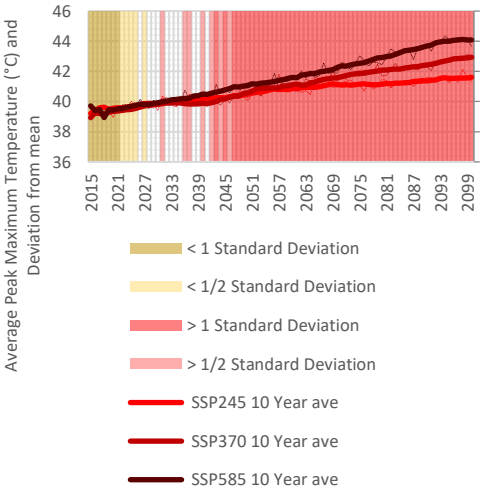
> 1/2 Standard Deviation
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Average Peak Maximum Temperature (°C) and Deviation from mean
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2069
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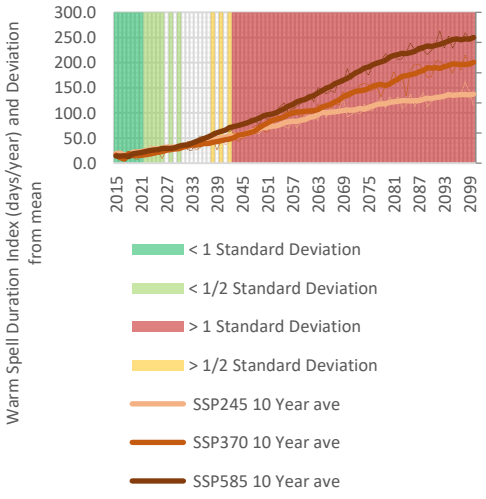
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Warm Spell Duration Index (days/year) and Deviation from mean
300.0
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200.0
150.0
100.0
50.0
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< 1 Standard Deviation
< 1/2 Standard Deviation
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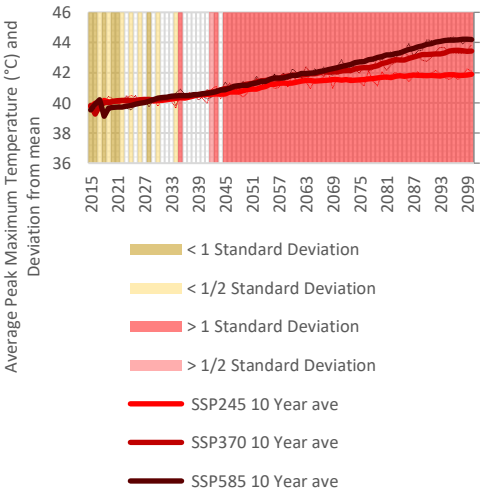
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Average Peak Maximum Temperature (°C) and Deviation from mean
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< 1 Standard Deviation
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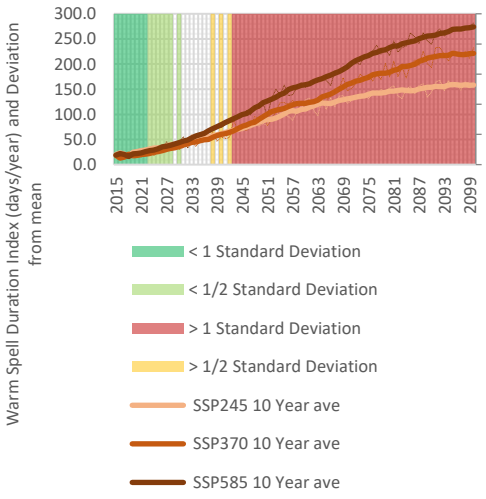
> 1 Standard Deviation
> 1/2 Standard Deviation
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Warm Spell Duration Index (days/year) and Deviation from mean
300.0
250.0
200.0
150.0
100.0
50.0
0.0
2015 2021 2027 2033 2039 2045 2051 2057 2063 2069 2075 2081 2087 2093 2099
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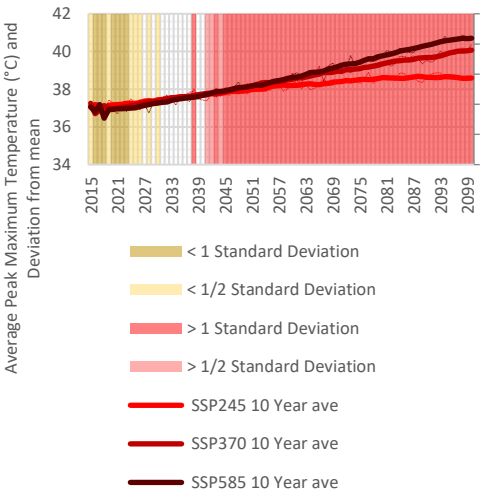
> 1/2 Standard Deviation
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Average Peak Maximum Temperature (°C) and Deviation from mean
42
40
38
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34
2015 2021 2027 2033 2039 2045 2051 2057 2063 2069 2075 2081 2087 2093 2099
< 1 Standard Deviation
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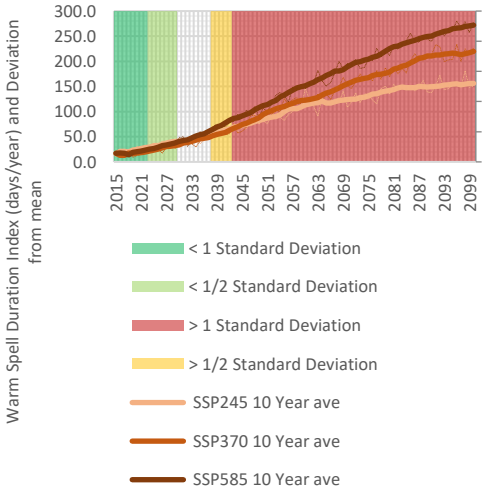
> 1 Standard Deviation
> 1/2 Standard Deviation
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Warm Spell Duration Index (days/year) and Deviation from mean
300.0
250.0
200.0
150.0
100.0
50.0
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2015 2021 2027 2033 2039 2045 2051 2057 2063 2069 2075 2081 2087 2093 2099
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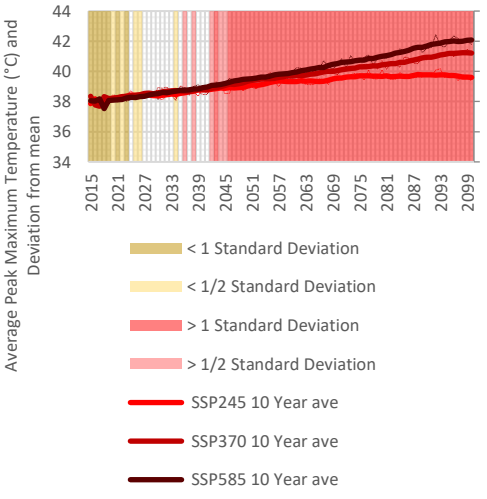
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Average Peak Maximum Temperature (°C) and Deviation from mean
44
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2015 2021 2027 2033 2039 2045 2051 2057 2063 2069 2075 2081 2087 2093 2099
< 1 Standard Deviation
< 1/2 Standard Deviation
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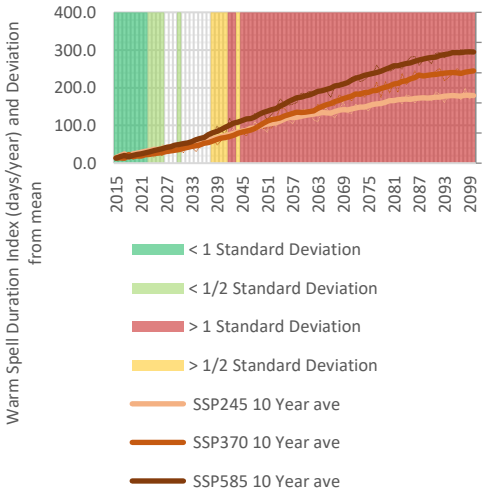
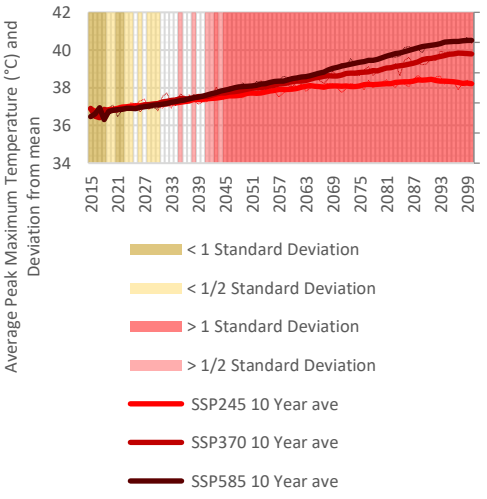
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Warm Spell Duration Index (days/year) and Deviation from mean
400.0
300.0
200.0
100.0
0.0
2015 2021 2027 2033 2039 2045 2051 2057 2063 2069 2075 2081 2087 2093 2099
< 1 Standard Deviation
< 1/2 Standard Deviation
> 1 Standard Deviation
> 1/2 Standard Deviation
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave


Average Peak Maximum Temperature (°C) and Deviation from mean
42
40
38
36
34
2015 2021 2027 2033 2039 2045 2051 2057 2063 2069 2075 2081 2087 2093 2099
< 1 Standard Deviation
< 1/2 Standard Deviation
> 1 Standard Deviation
> 1/2 Standard Deviation
SSP245 10 Year ave
SSP370 10 Year ave
SSP585 10 Year ave

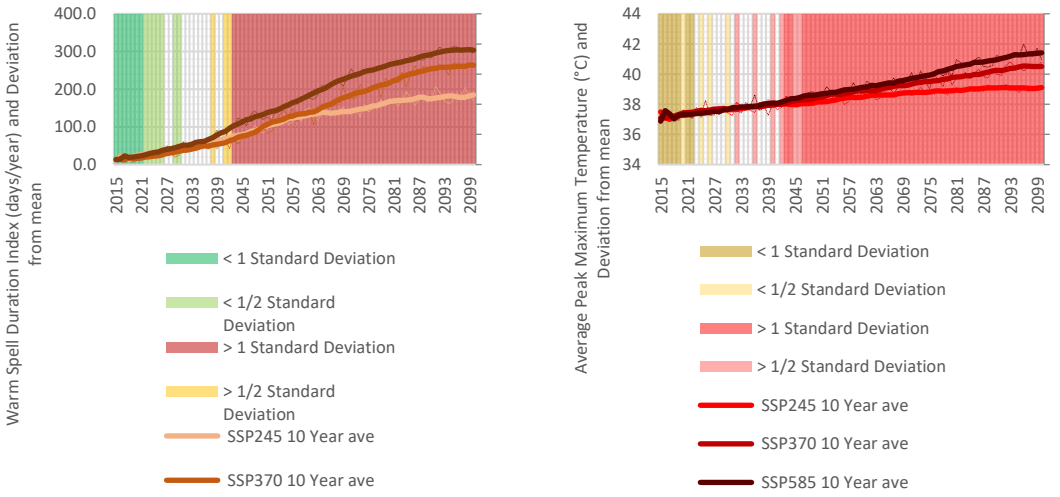


Figure 33. Statistical precipitation characteristics. Annual Changes in warm spell duration (left), annual changes in peak maximum temperatures (right). Locations A to I top to bottom.

2.2.2. Fire weather

The Fire Weather Index (FWI), a global index that assesses the risk of fire, is based on meteorology. It is made up of various factors that take wind and fuel moisture impacts on fire behaviour and spread into account. The likelihood of a wildfire starting increases as the FWI rises, indicating favourable weather conditions[44].

Increases in temperature, reduced annual rainfall, and increased dry spells result in an enhanced drying of vegetation and increased susceptibility for ignitions to be more severe. There is, therefore, an increase in the duration of the fire weather season in all locations around the Yucatan peninsula. The greatest increase is up to ~180 days in the southwestern and south eastern locations. The area to the northeast sees an increase, but only up to 75 days. Both the average and maximum fire weather indexes increase into the future by up to 6 FWI values in all locations other than the coastal area to the northeast, which sees increases of only up to 3 FWI values.

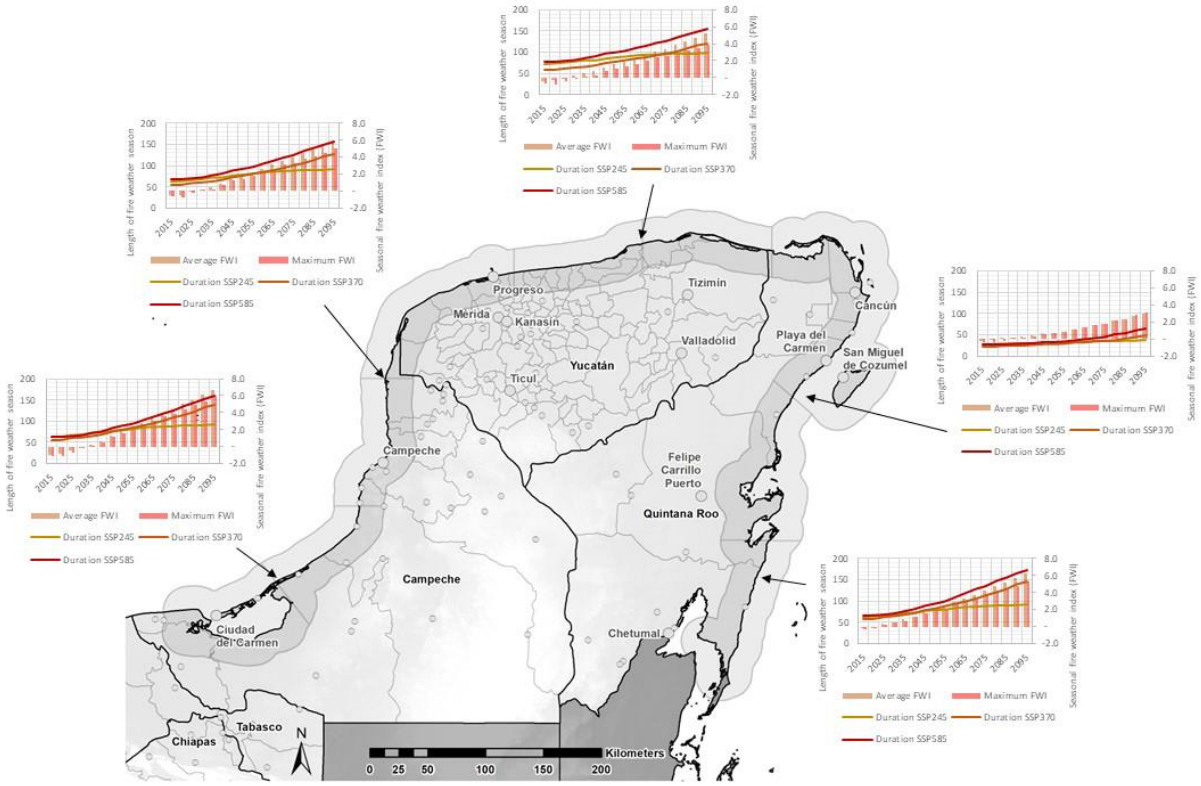


Figure 34. Change over time for the duration of fire season, average and peak changes in fire weather index.

[44] Fire weather index, Copernicus - https://climate.copernicus.eu/fire-weather-index

2.3. Tropical Cyclones

This study aims to assess changes in factors related to the development of Atlantic Hurricanes, in order to infer potential changes more relevant to the Yucatan. While there is still uncertainty in the projected future changes to tropical cyclone activity, the IPCC highlights the following projected changes in the north Atlantic:

- All hurricane activity is highly variable into the future with a likely (67% confidence) ~50% to -50% range on either side of the current occurrence. There is however an expected decrease change overall in the number of events.
- There is a likely frequency range of more intense Category 4 and 5 hurricanes being +200% to -100%. The wide disparity in these projected events is due to the infrequency of these events in the observed record. The likely expected change is an increase of 50% in these larger events.
- There will be a slight increase in the maximum intensity achieved in a hurricane event. The wind profiles of hurricanes are already extreme in nature, and changes in atmospheric and oceanic conditions under projected climate changes will affect the development of hurricane events more so than the already extreme wind character.
- There is projected to be an increase in the precipitation rate associated with these hurricane events.

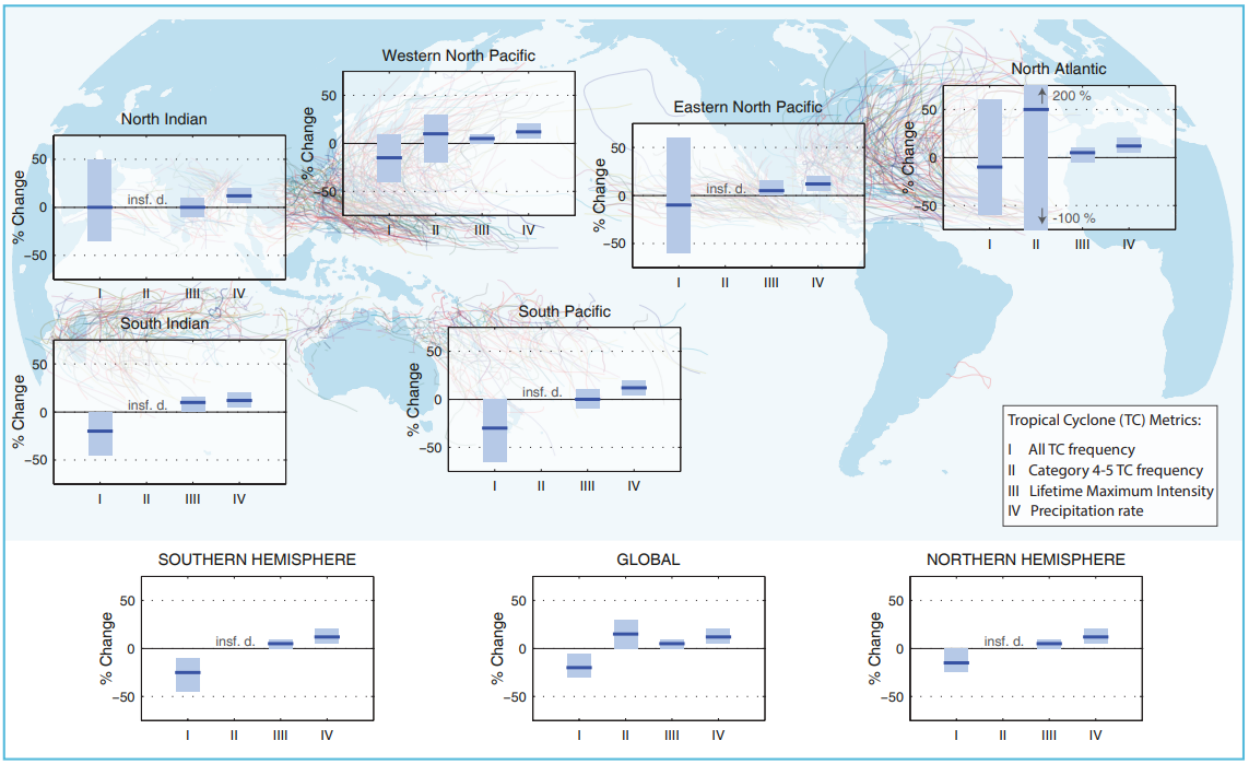


Figure 35. IPCC changes in hurricane characteristics[45].

The assessment of Hurricane activity will remain uncertain due to the many interconnected influencing factors. Models do however suggest a link between certain factors and Hurricane formation. The frequency and intensity of Hurricanes are strongly related to anomalous sea surface temperature (SST) in the main development region, the weakening of vertical wind shear (VWS) in the mid-troposphere during depression development, and the La Nina phase of the El Nino Southern Oscillation (ENSO). Each of these factors may change as a result of future climate change, influencing the characteristics of Hurricanes. ENSO and wind-shear characteristics are highly dynamic and will change on synoptic and annual time scales in response to current conditions. SST changes, on the other hand, will be more linear in nature, and while they will exhibit a seasonal cycle, the baseline trend will not likely revert to oscillations around current SST means. These influencing factors are discussed in greater depth further below.

The domains for assessment are the locations most aligned to observed Hurricane activity. Two factors are assessed. Firstly, the vertical wind shear (VWS) in three 4°x 4° locations in the main development region (MDR)

[45] Christensen, J.H., Kumar, K. Krishna, et al., "Climate Phenomena and Their Relevance for Future Regional Climate Change," in *Climate Change 2013 - The Physical Science Basis*, ed. Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press, 2013), 1217–1308, https://doi.org/10.1017/CBO9781107415324.028.

from 10°N to 20°N between West Africa and the Caribbean. Secondly, the sea surface temperature (SST) over the oceans in the lead-up pathway (18°N, 60°W and 13°N, 48°W) for most Hurricanes affecting the Yucatan.

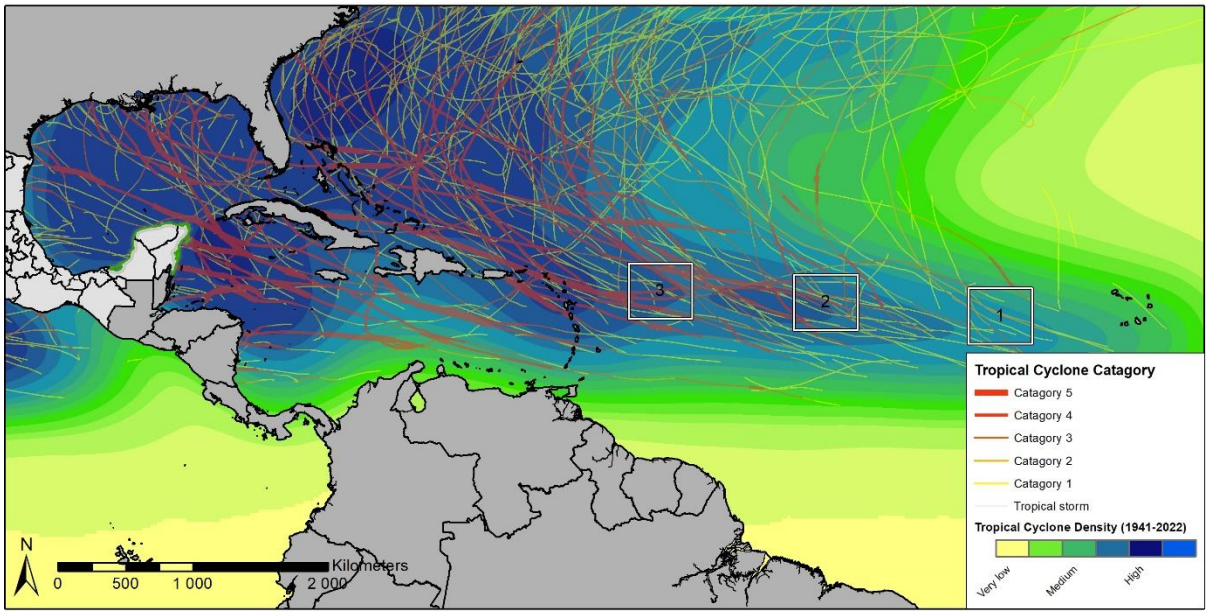


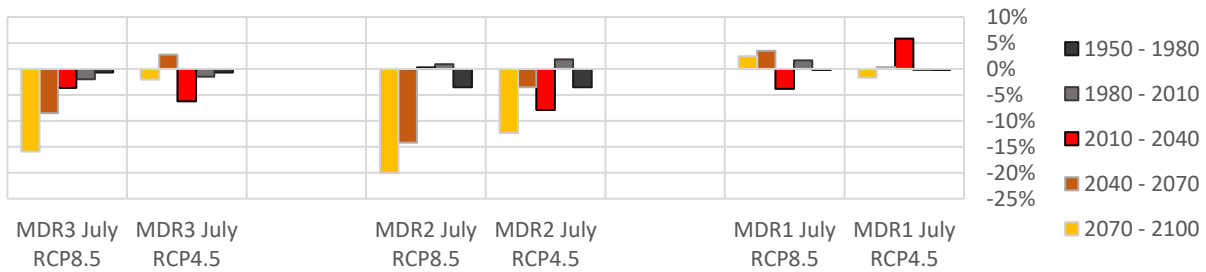
*Figure **36**. Tropical cyclone tracks over the Atlantic Ocean and Gulf of Mexico between 1941 and 2022.*

2.3.1. Vertical Wind Shear (VWS)

Vertical wind shear (VWS) is the vector difference in wind speed and direction between air masses moving vertically through the troposphere. This is significant because VWS is a key indicator in the development of Hurricanes. The effects of VWS on storm development are caused by the deformation of a rotating system in the presence of higher VWS. Increased VWS causes the eyewall of a storm to become asymmetric[46].
This asymmetry may cause the storm to tilt, causing it to weaken from the top down. VWS may overcome vorticity in the upper troposphere, resulting in dispersed air rather than concentrated air descending into the eye. Higher VWS, as a result, compromises Hurricane sustained vorticity and will either weaken or dissipate the system.

As a result of the atmospheric favourability of the development of Hurricanes, the VWS in the development areas would be reduced. The assessment of changes in VWS in the major development regions will indicate the potential change in atmospheric favourability for Hurricane development. The assessment is carried out in three areas along the higher-density development track. The vector difference between 850-700 kPa, 700-500 kPa, and 500-250 kPa was used to calculate tropospheric levels. These pressure levels equate to approximately 1 500m (850 kPa), 3 000m (700 kPa), 5 500m (500 kPa) and 10 000m (250 kPa).

VWS anomalies are summarized into three decadal averages. Atmospheric winds are more influenced by daily synoptic variability than by changes in large-scale climate shifts, resulting in VWS anomaly heterogeneity. Though there is significant noise in the outputs, an underlying signal is present in the data indicating a tendency for decreased VWS in the future for each of the monthly domains.



46 Frank, W.M. and Ritchie, E.A., 2001. Effects of vertical wind shear on the intensity and structure of numerically simulated hurricanes. Monthly weather review, 129(9).

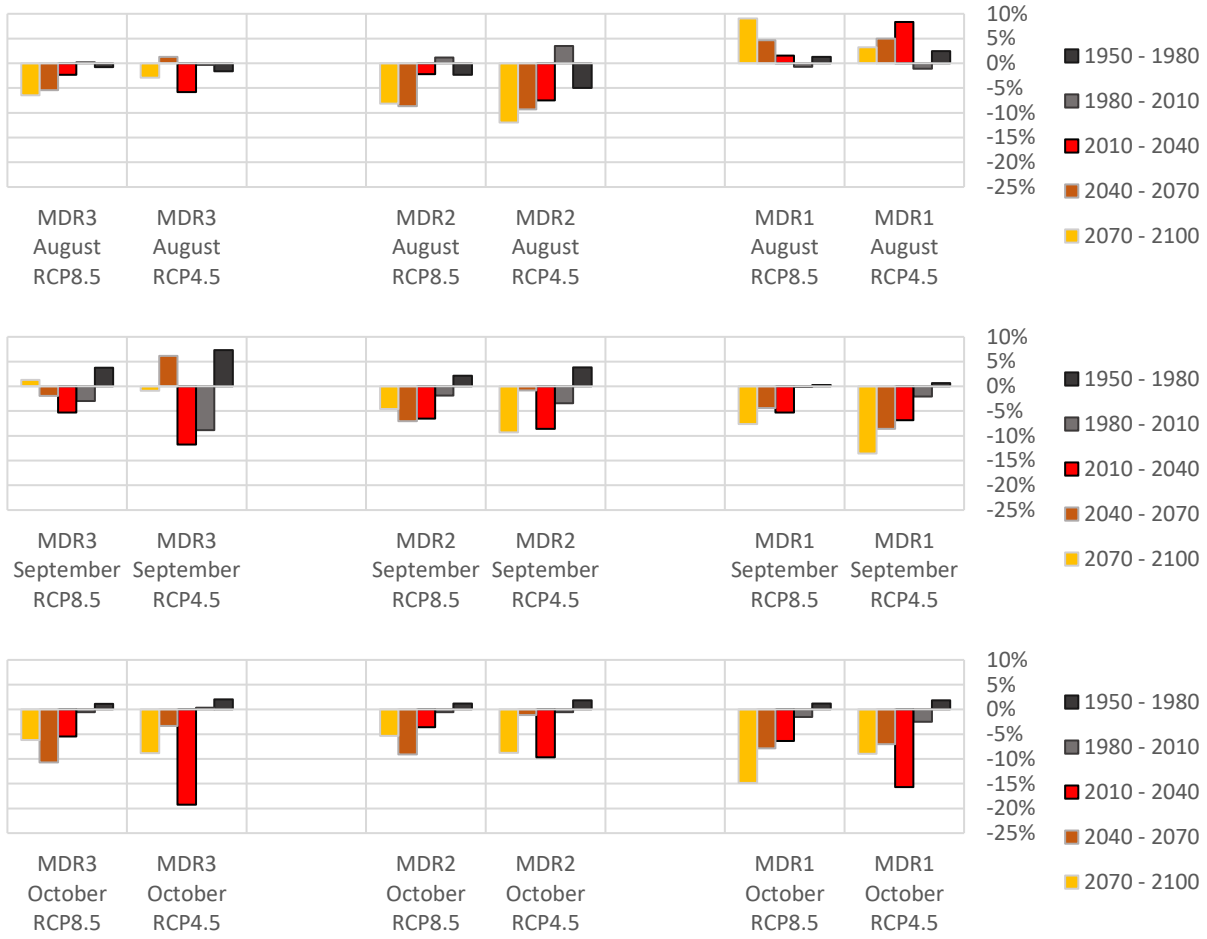


*Figure **37**. Change in VWS from July (top) to October (bottom) for MDR1-3 and under RCP4.5 and RCP8.5 scenarios.*

Future VWS projections are expressed as a percentage increase or deduction from the average vector of the full tropospheric column for each month from 1950 to 2005.

In July and August, **MDR1**, the easternmost domain, sees potential increases in VWS — and potential weakening of Hurricanes. In the latter part of the century, this situation is reversed in September and October, with a 10% -15% average reduction in VWS.

Assessing decadal and multi-level changes reveals more information about the nature of future change. July and August show a decrease in upper troposphere VWS but an increase in lower and mid-troposphere VWS. These anomalies are expected to grow in magnitude as the century progresses. Hurricane formation may be reduced during this time due to disruptions in the lower and mid-atmosphere. However, it is unclear whether the decrease in VWS in the upper troposphere will compensate for this disruption. The lower troposphere VWS anomaly now decreases from baseline climatology in September and October, while the mid-troposphere varies between increases and decreases, but is of a lower magnitude than the anomaly observed in July and August. In the VWS anomalies, RCP4.5 and RCP8.5 have similar shapes; however, the magnitude of the anomaly is generally larger in the RCP8.5 scenario. For example, in July 2090, VWS ranges from -2 to +2 m/s (RCP4.5) and from -5 to +5 m/s (RCP4.5) (RCP8.5).

This assessment does not rule out the possibility of a confluence of events leading to the formation of tropical storms or Hurricanes in MDR1. Instead, it predicts that there will be more days in MDR1 with unfavourable conditions for tropical storms and Hurricane development than days with favourable conditions for this development. This is especially true early in the Hurricane season, in July and August, as well as in September and October.

MDR2, the central VWS domain, demonstrates general agreement in the direction of VWS changes each month. Each of the subsequent 30-year periods from 2010 to 2100 shows a trend of decreasing VWS by 5-10%. As a result, VWS in MDR2 appears likely to enhance or at least not disrupt the development of any tropical storm or Hurricane in the area.

The decadal multi-level assessment reveals the most significant anomalies in the upper troposphere, indicating a lower VWS overall with very few exceptions. The upper troposphere will account for the majority of the average VWS decreases. In July and August, mid-troposphere VWS anomalies are comparable to upper levels; in September and October, these are reduced. In the lower troposphere, VWS magnitude anomalies are reduced. RCP4.5 and RCP8.5 show a magnitude bias toward RCP8.5 in the mid to late century (2050-2100).

With a few exceptions, the general reduction in VWS in MDR2 through the troposphere on all months would almost certainly not reduce hurricane activity or intensity and may in fact result in an atmosphere conducive to further enhancement of already-developed tropical storms and hurricanes moving westwards from MDR1. However, factors such as SST and ENSO must be considered.

MDR3, the westernmost domain, forecasts large differences in VWS anomalies between RCP4.5 and RCP8.5, as well as between each month. Average VWS changes do not show any discernible trends for MDR3 going forward into the century; this is also true under the RCP4.5 scenario, with the greatest VWS decreases occurring in all months from 2010 to 2040, but with the direction of change varying beyond that time frame. In all months except September, RCP8.5 shows a clearer trend, with decreases increasing in magnitude later in the century.

The RCP8.5 multi-level assessment is consistent with decreasing VWS from the lower to upper troposphere, with September being the only notable exception exhibiting greater variability. RCP4.5 shows an increase in VWS over several decades, particularly in the upper troposphere from July to September. The lower tropospheric character tends to mirror the upper tropospheric character but to a lesser extent. The mid-troposphere is expected to have lower VWS for the foreseeable future. October is more variable across the entire atmospheric column, with no discernible trend for VWS.

MDR3 lacks the clear trends observed in MDR2 and is subject to large variations between months, decades into the future, and RCP scenarios. This dataset cannot be evaluated for changes in atmospheric suitability, hurricane development, or enhancement over time.

2.3.2. Sea Surface Temperature (SST)

While moving over the ocean, hurricanes use warmer ocean waters as an easily extracted moisture source for continued development. Hurricanes weaken and lose intensity as they move over land or ocean with lower surface temperatures, which can result in their dissipation as they are overwhelmed by larger synoptic dynamics. The full atmospheric connection between SST and hurricane development and propagation remains unknown. However, according to the IPCC AR5 and several other studies, rising sea levels have resulted in increased hurricane activity[47].

Using this premise, projected future SSTs are analysed to show the potential anomalous state in which hurricanes may form and move later in the century. Assuming stationary hurricane forcing, an increase in SST would indicate increased hurricane activity. The SST rises by 2.0°C near the end of the century and 1.5°C by mid-century with a trend of 0.16°C/decade.

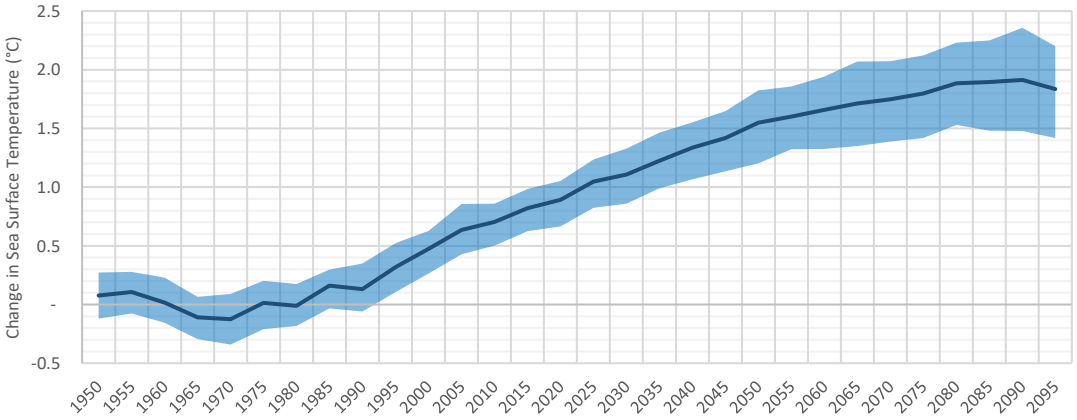


Figure 38. Sea Surface Temperature (SST) changes in the domain leading up to the Yucatan Peninsula

47 Christensen, J.H., et al., 2013: Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Accurate forecasting of future hurricane activity, both global and regional, will be critically dependent on reliable projections of the behaviour of these modes of variability (including ENSO) under climate change, as well as a thorough understanding of their physical connections with hurricanes. At the moment, their projected behaviours are still uncertain, though additional research is being conducted to evaluate the physical influences of a changing climate on hurricane development and intensification.[48]

2.3.3. Storm Surge

The analysis shows that under future climate conditions, storm surges will become increasingly common and severe in many areas along the Yucatán Peninsula's coastline (Figure 39). 10-year return period anomaly surge will increase by 0.006–0.019 m on the southern coastline of Quintana Roo, with higher increases of up to 0.049 m projected for northern Yucatán State. In areas to the west of the peninsula, the 10-year return surge will decrease by 0.229–0.010 m. For the 25-year return surge, projections are similar to those for the 10-year return surge, although the increase will be more severe in southern Quintana Roo, and the decreasing trend weaker on the west coast. For a 100-year return surge, a wider area of the eastern coastline will experience a surge of up to 0.034 m higher than the baseline. However, the trend of decreasing surges on the west coast will prevail.

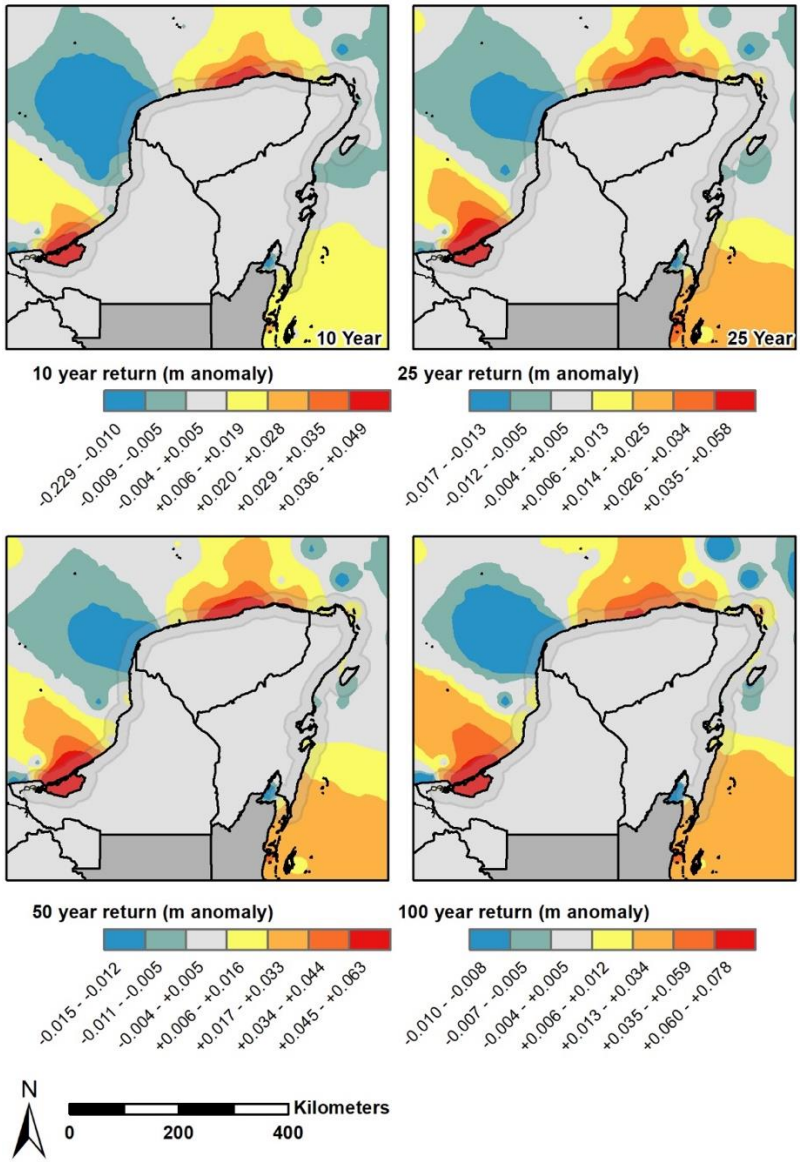


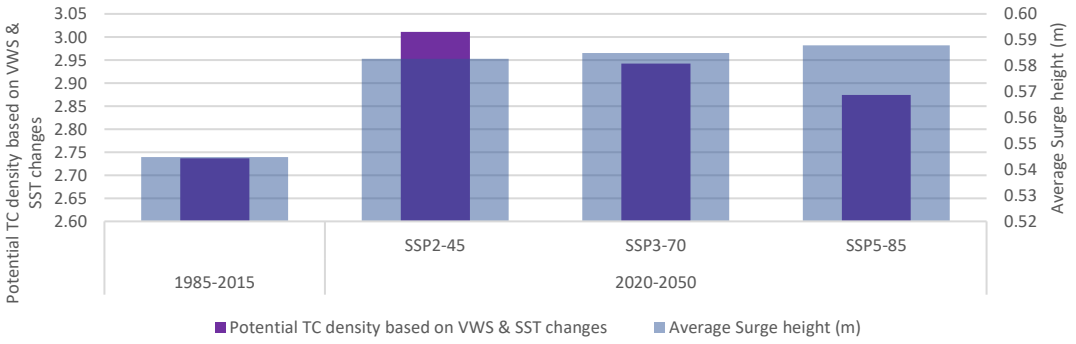
Figure 39. Storm surge at 10-, 25-, 50- and 100-year return periods.[49]

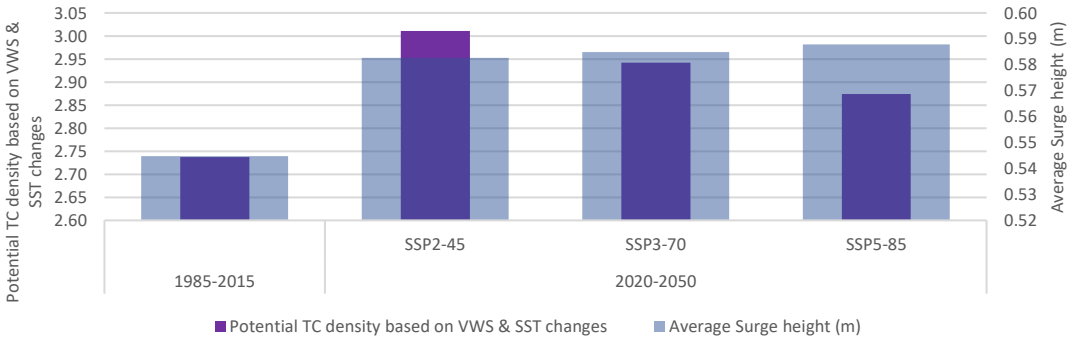
2.3.4. Potential changes in impacts

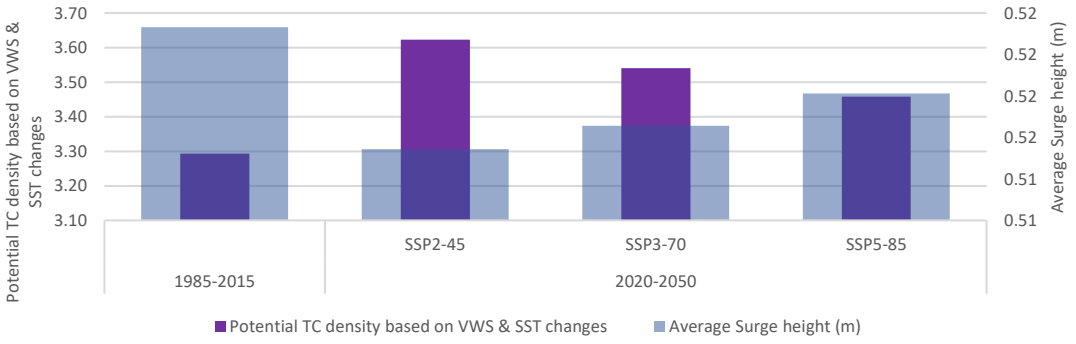
48 Emanuel, K., 2017. Assessing the present and future probability of Hurricane Harvey's rainfall. Proceedings of the National Academy of Sciences, 114(48), pp.12681-12684.

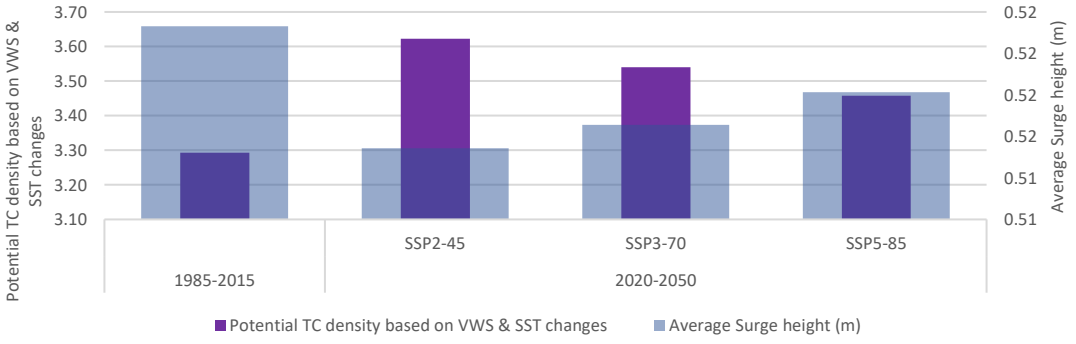
[49] https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-water-level-change-indicators-cmip6?tab=overview

Based on the projected changes in VWS and SST in the development zone against the current tropical cyclone density the following are potential changes in future tropical cyclone and storm surge height[50].









[50] This is based on linear extrapolation of changes in VWS and SST as the drivers of tropical cyclone development and not based on modelling of future cyclone events themselves.

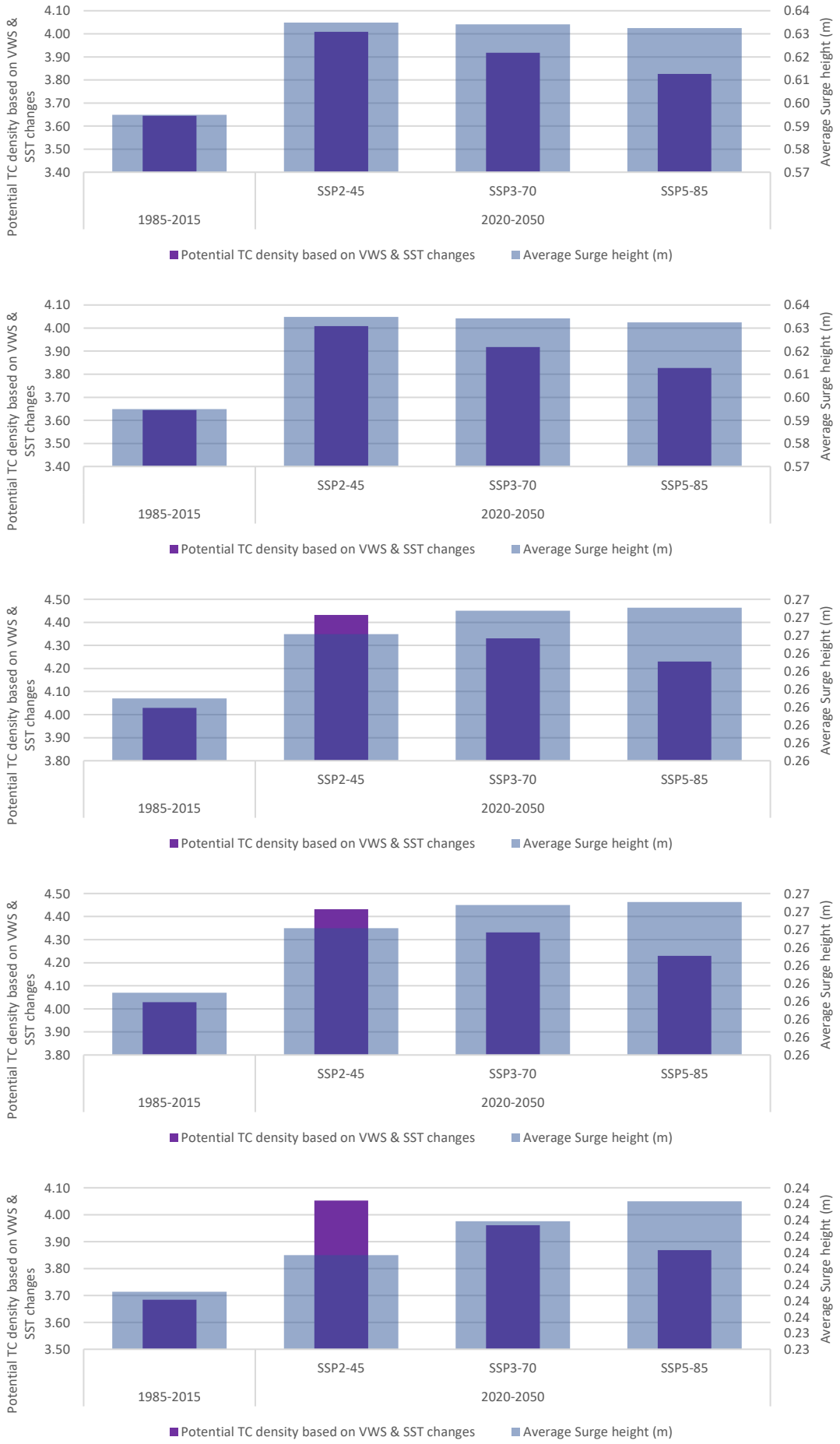
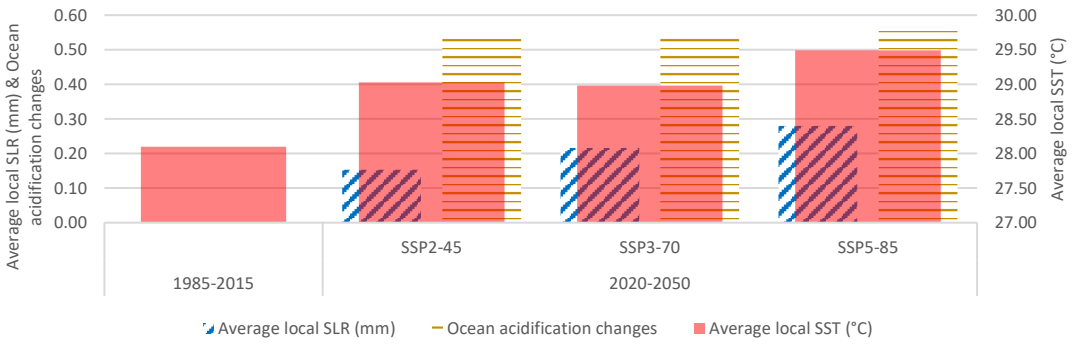


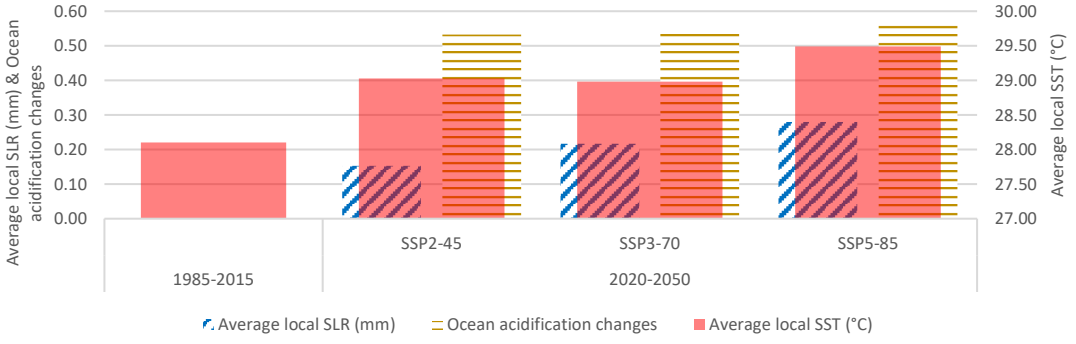
Figure 40. Estimated density of tropical cyclone occurrence based on changes in VWS and SST in the development zone and projected changes in average storm surges. Locations A to I top to bottom.

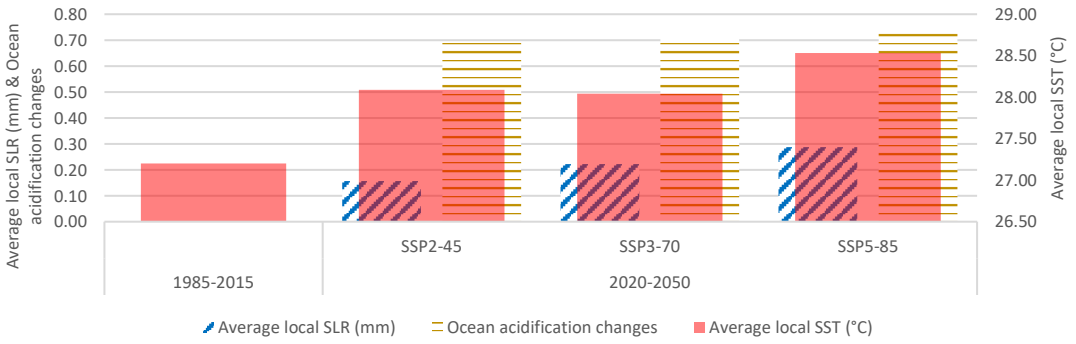
There are noted increases of between 4% (SSP5-85) to 10% (SSP2-45) in all the locations. This is based on the general increase in SSTs in the development domain but also the decrease in VWS. Generally, the VWS decreases more under the SSP2-45 scenario. There is however a low degree of confidence in this analysis.

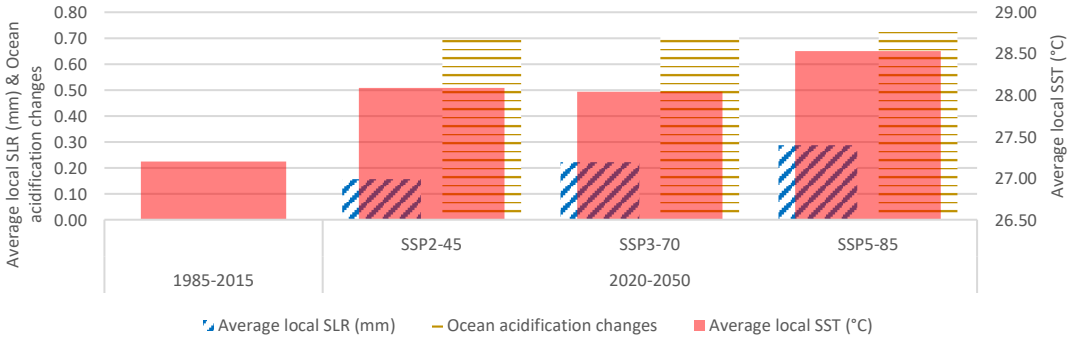
2.4. Ocean characteristics

As noted above in section 2.3.2, under future climate conditions, observed changes in ocean characteristics along the Yucatán Peninsula will prevail. These changes will be in line with those projected for the rest of Mexico, as described in the sections below.









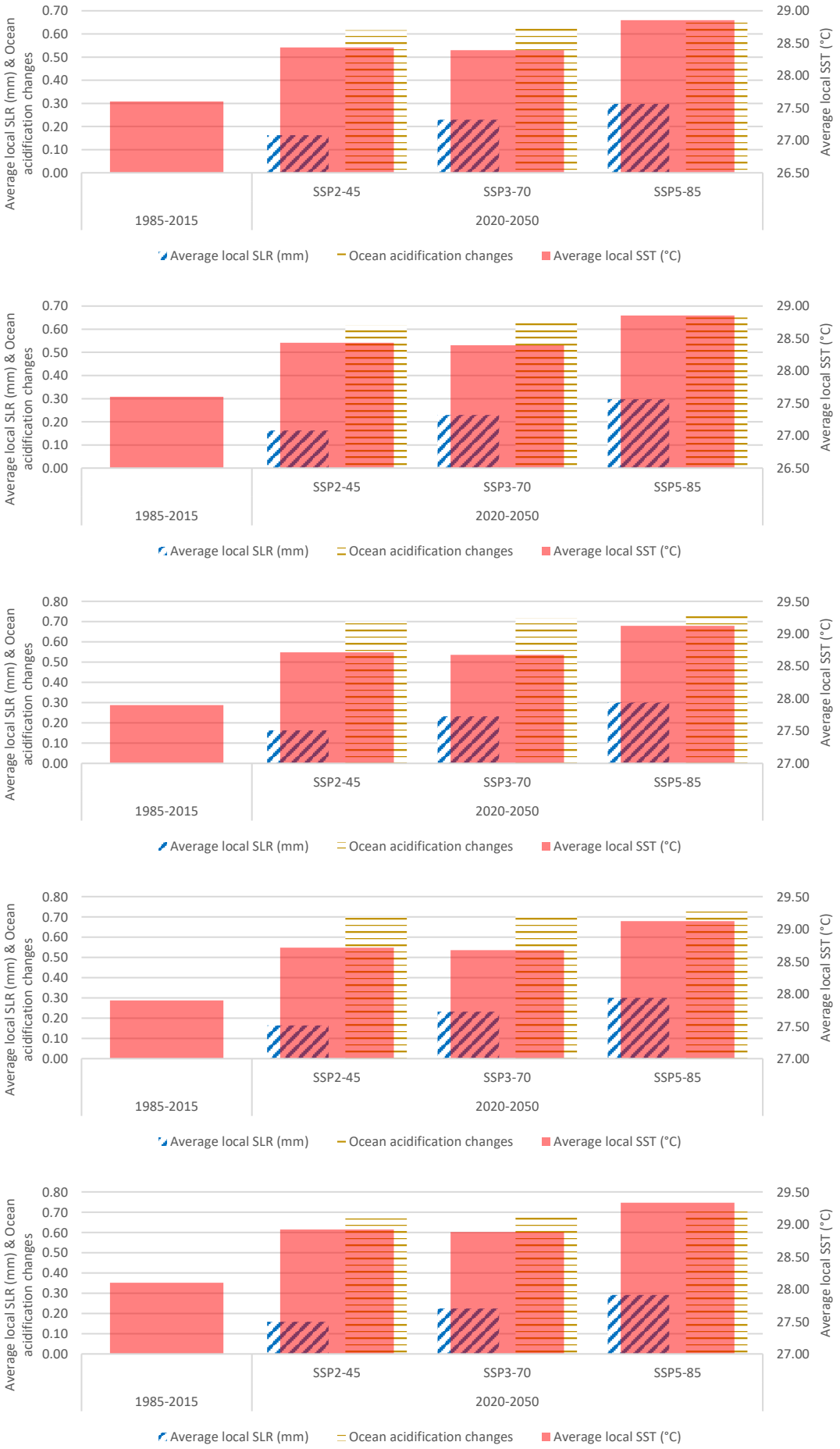


Figure 41. Estimated average SLR, SST, and cumulative absolute change in acidification characteristics of pH, calcite, aragonite and salinity 100km offshore. Locations A to I top to bottom.

2.4.1. Sea surface temperature (SST)

Projections for Mexico as a whole, indicate that SST will continue to rise under future climate conditions under all emissions scenarios by 2050 and 2100, in line with the observed trends for the country described in preceding sections and shown in Figure 42 below[51]. Projected increases in average SST in the Gulf of Mexico and Pacific Ocean are shown in Figure 42 below.

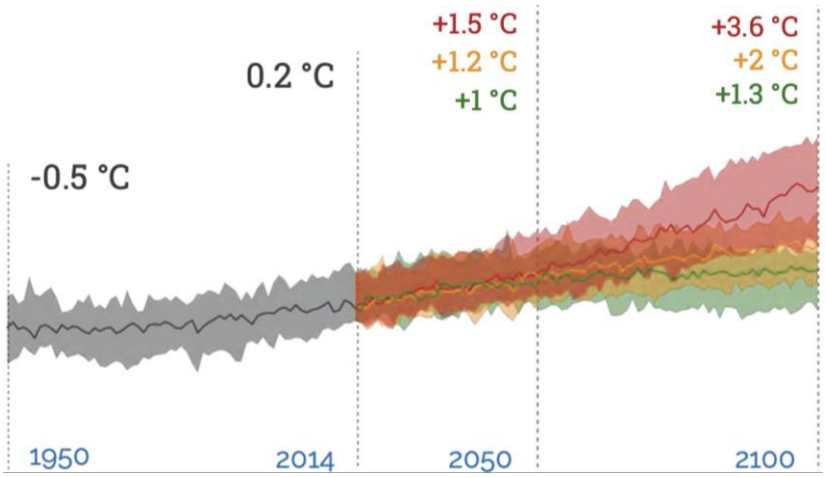


Figure 42. Sea Surface Temperature projections under different emissions scenarios. Green=low, Orange=medium, red=high emissions scenario.

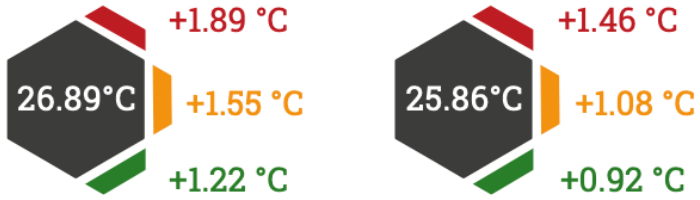


Figure 43. Projected increases in average SST in the Gulf of Mexico (left) and Pacific Ocean (Right), under three emissions scenarios by mid-century (2065). Green=low, Orange=medium, red=high emissions scenario.

As with the rest of Mexico, the waters around the Yucatán Peninsula are also projected to increase under future climate conditions **Figure 44**. This includes a projected increase in average sea surface temperatures (SST) to up to 28.1°C. Areas to the west and east of the peninsula will show a rise in SST of up to 0.94 and 0.86, respectively.

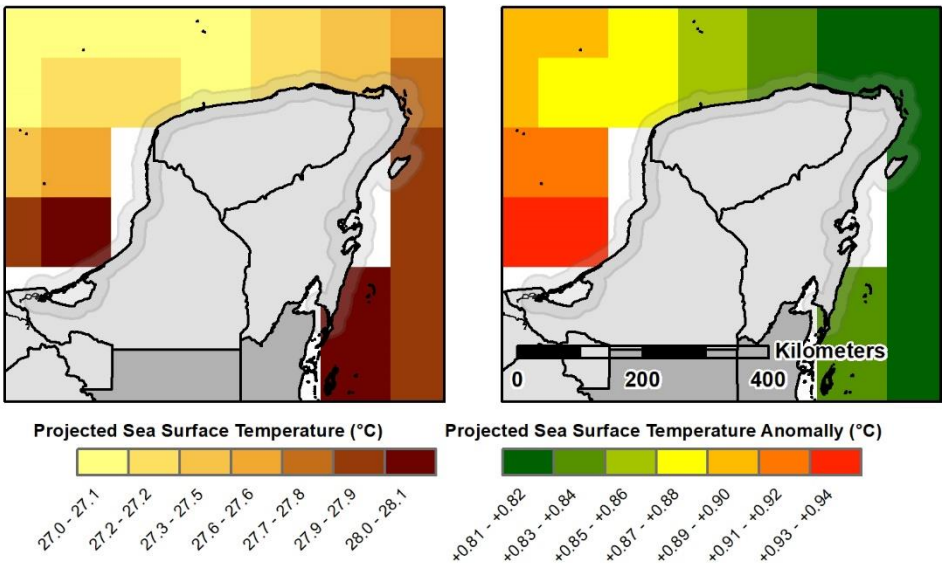


Figure 44. Projected sea surface temperatures and sea surface temperature anomaly.

[51] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

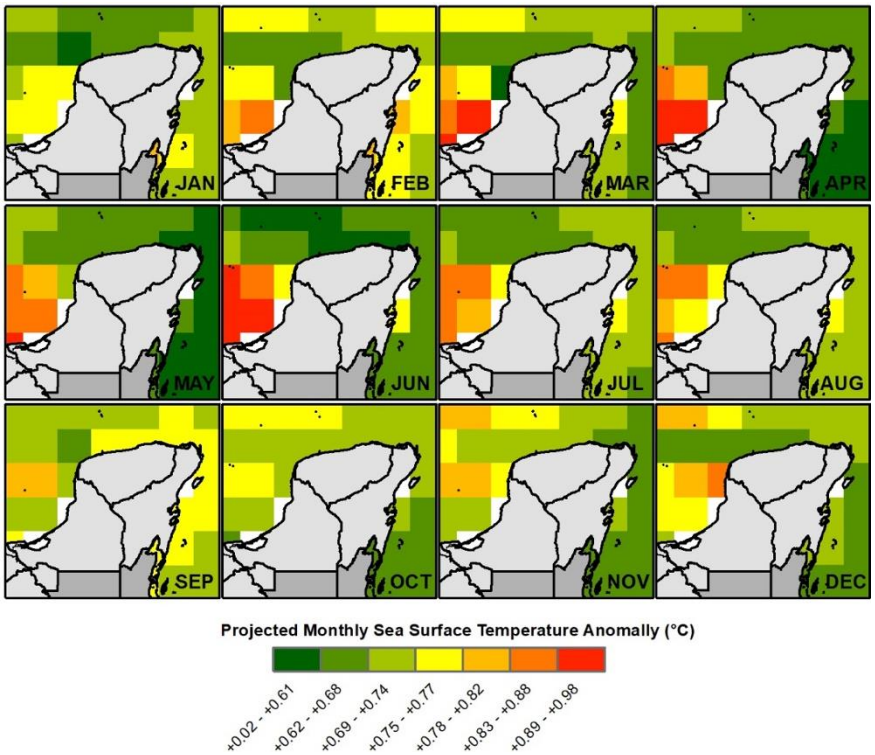
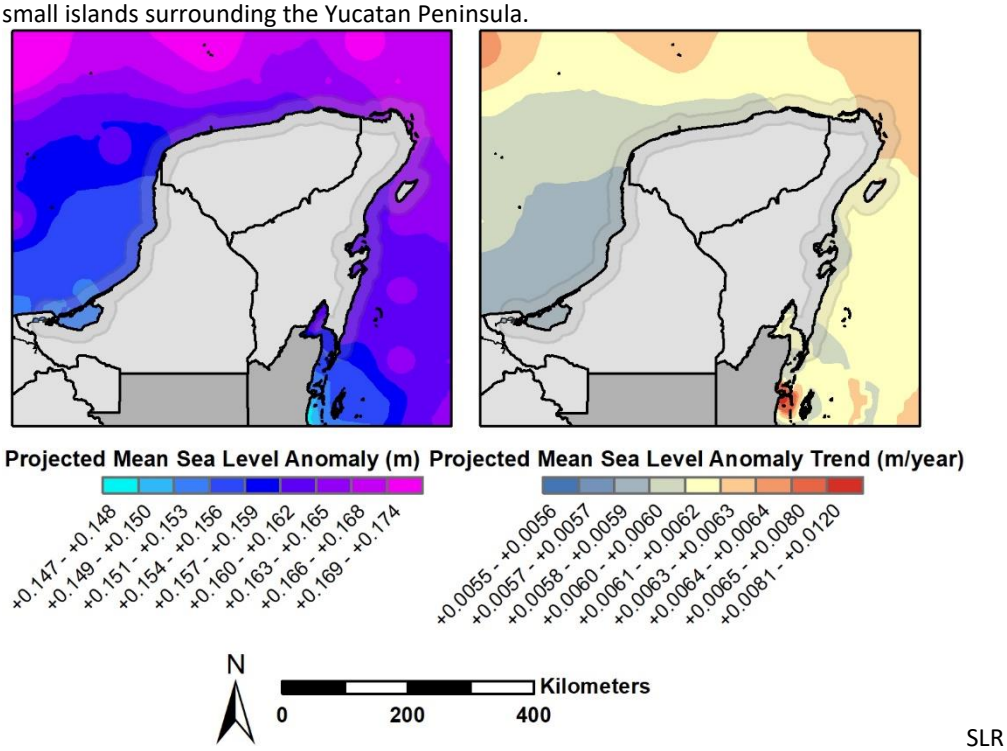


Figure 45. Projected sea surface temperatures and sea surface temperature anomaly.

2.4.2. Sea level rise (SLR)

Projected increases in sea level see the largest change in the north-eastern areas of the Yucatan peninsula of up to +0.17m between 2020 and 2050. Areas to the west are projected to see a lower increase of up to +0.15m. These increases will have a significant impact not only on the coastal mainland but event more so on the many small islands surrounding the Yucatan Peninsula.



SLR

Figure 46. Projected mean sea level anomaly; and projected mean sea level anomaly trend (m/year).

2.4.3. Acidification

Changes in ocean acidification will have a significant impact on marine biodiversity and coastal ecosystems.

Salinity increase can affect marine organisms, particularly those adapted to lower salinity environments such as estuaries or coastal areas. Increased salinity can disrupt the balance of osmosis in marine animals, affecting their

physiological processes and potentially leading to dehydration and death. This can alter the distribution patterns of marine species and disrupt the ecological balance and impact the entire food chain. Additionally, corals are highly sensitive to changes in salinity. Elevated salinity can stress corals and contribute to coral bleaching events. The ocean surrounding the Yucatan is projected to see an increase in salinity of up to +0.3 with the largest increase noted to the west.

There is a projected decrease in calcite concentrations in the future with the largest changes noted to the southwest. A decrease in calcite concentrations can make it challenging for marine organisms like corals, shellfish, and some planktonic species to build and maintain their shells and skeletons. It can also lead to enhanced coral bleaching as coral growth is hindered. This can disrupt the balance of marine ecosystems and impact the survival of various species.

Changes in Aragonite are most noted to the southwest with a decrease of up to -0.44. There is a lower decrease noted in the more norther areas. A decrease in aragonite will limit the development of coral and reef development as well as have negative implications for many marine organisms. This will have significant impacts on biodiversity and ecosystem stability.

Decrease in pH (acidification) are most noted to the west of the Yucatan peninsula. Decreased pH impacts coral reefs' ability to build calcium carbonate structures as well as having reduced growth rates. PH also has negative impacts on Shellfish and Shell-forming Organism's ability to form and maintain shells. The negative consequences to marine life will have a knock-on impact on ecosystems and biodiversity resilience.

Figure 47. Observed and projected ocean acidification[52]

[52] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

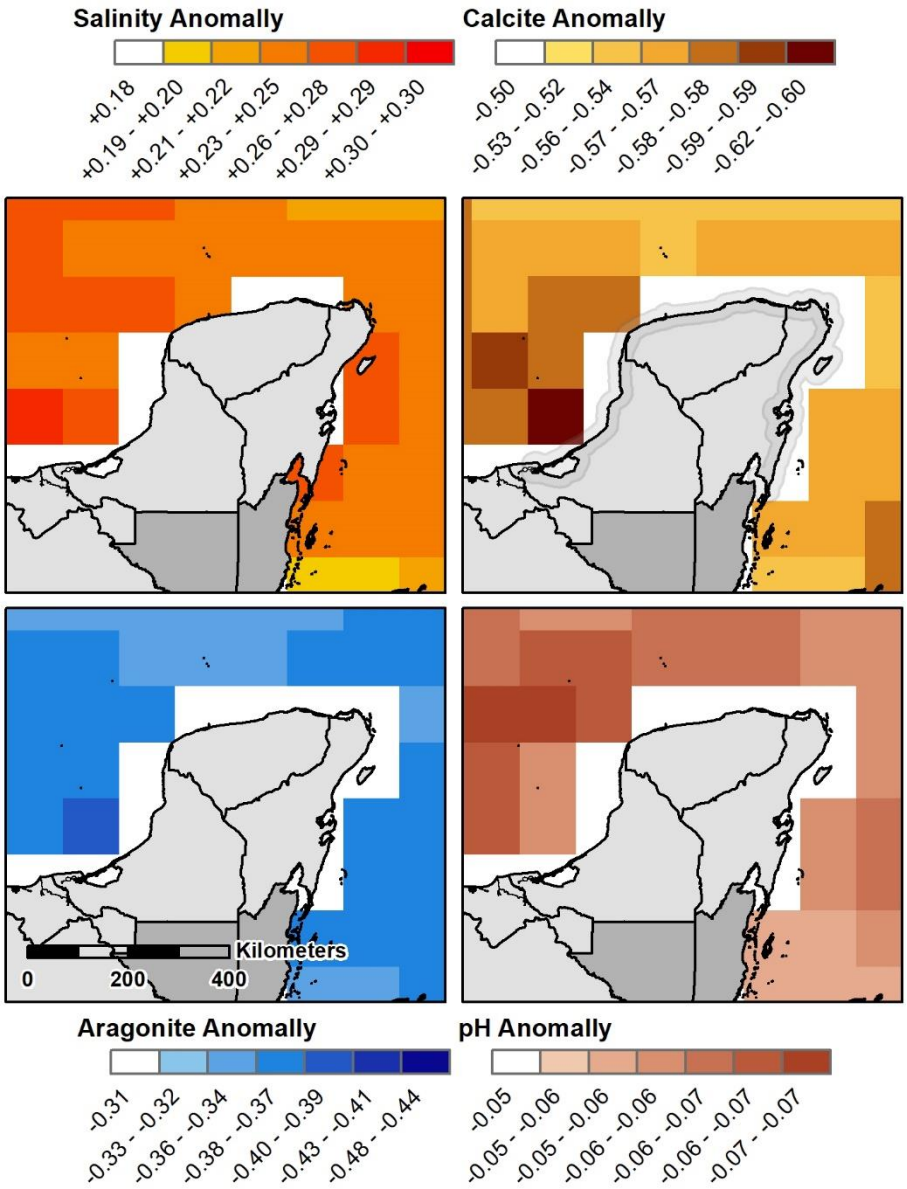


Figure 48. Projected ocean acidification[53]*, Changes in Salinity (top left), Calcite (top right), Aragonite (bottom left), and pH (bottom right)*

2.4.4. Small island changes

The islands around the Yucatan peninsula are popular tourist destinations. The area is known for its natural beauty, vast bird life, pristine beaches, clear waters, coral reefs, and diving and snorkelling opportunities with dolphins. These beaches are however very sensitive ecosystems and will be impacted significantly under the projected future climate scenarios.

The four islands highlighted here are Alcranes Reef, Cayo Arcas, Cozumel, and Chinchorro but all islands around the Yucatan will be similarly vulnerable to climate changes. These impacts include:

- *an increase in sea level resulting in direct physical impacts to the low-lying coastal areas, this includes increased coastal erosion removing beaches and disrupting ecosystems and habitat loss, saline intrusion impacting coastal water tables, significant coastal flooding impacts from the passage of tropical storms and storm surge, displacement of coastal communities, infrastructure and livelihoods, as well as damages to tourist infrastructure and assets. Indirect impacts will be disruption to the local economy, implications to water contamination and water stress for these isolated areas, and tourism perception of the area with reduced capacity.*
- *An increase in sea surface temperatures will lead to further coral bleaching, as well as intensification of acidification. There will be impacts on the timing and distribution of phytoplankton blooms, altering marine*

[53] https://www.eea.europa.eu/ims/ocean-acidification

food chains. There may also be a shift in species distribution or a reduction in marine species populations if the local resources are compromised. The indirect impact of increased surface temperatures will provide more energy and moisture to severe storm events such as tropical cyclones. Changes to corals and marine species may have significant impacts on the tourism draw of the islands.

- *Acidification of the oceans will decrease the capacity of corals to form and maintain structure, compromise species' ability to make shells and exoskeletons and may alter species distribution which will impact other marine species and have indirect negative perception implications for tourism and local livelihoods.*

Figure 49. Critical islands surrounding the Yucatan peninsula exposed to future climate changes.

Table 2. Projected future changes in ocean characteristics around the small selected islands for 2020-2050

Island	Average elevation	Sea level rise	Acidification	Sea surface temperatures
Alcranes Reef	2.05m	+0.1695m	Aragonite: -0.365 Calcite: -0.5675 Salinity: +0.231 pH: -0.066	+0.8511°C
Cayo Arcas	5.02m	+0.1567m	Aragonite: -0.3775 Calcite: -0.5825 Salinity: +0.244 pH: -0.065	+0.9114°C
Cozumel	9.58 (4.84m within 200m from the coast)	+0.1627m	Aragonite: -0.325 Calcite: -0.575 Salinity: +0.226 pH: -0.067	+0.8141°C
Chinchorro	4.57m	+0.1609m	Aragonite: -0.370 Calcite: -0.575 Salinity: +0.240 pH: -0.065	+0.8221°C

The risks for the islands are as follows:

1. *Alcranes Reef – very high. This island has the lowest average elevation but the highest projected sea level rise. The island is mostly reef and the future moderate acidification and temperature increases will likely severely impact the reef itself and the marine species in the area. There will also likely be a very negative indirect impact from tourism loss and compromise of livelihoods.*
2. *Cayo Arcas – high. This island has the lowest land area and only moderate average elevation and the lowest projected sea level rise. This island however has the highest change in acidification and sea surface temperature changes.*
3. *Cozumel -medium high. This island's economy is driven by tourism, diving and charter fishing so changes in marine species, and corals through acidification and sea surface temperatures, as well as damages to coastal infrastructure from sea level rise, will have significant negative impacts on the island. However, this island is the largest in the Yucatan peninsula with the highest average elevation and lowest acidification, sea level and temperature anomalies. It is also better capacitated to cope with disruptions from climate changes than most of the other islands. The major risk driver here is the disruption of local livelihoods and the tourism industry that climate change may have.*
4. *Chinchorro – medium. This island has a very low permanent population and is a complex mix of tidal estuary and marine environments. Changes in sea level are moderate and may result in some habitat losses, particularly in the southern end of the island, the norther parts however seem to be higher vegetation and would have greater resilience. The changes in acidification and temperatures are moderate.*

3. Observed and projected Impacts

The climatic changes described above are directly impacting vulnerable communities and ecosystems, across Mexico as well as in the Yucatán Peninsula specifically. Given the large proportion of Mexico's population (over 50%) living in coastal areas — including those in the Yucatán Peninsula — communities living in these areas will become increasingly vulnerable to the impacts of climate change, particularly the intensifying tropical cyclones that have already been observed[54].

The costs of historical climate and hydro-meteorological impacts in Mexico have increased over time with peaks of up to 3 million people being impacted by storms in 2005 and 3.5 million people impacted by storms, floods, extreme temperatures, and drought in 2011. There has also been an increase over time in the estimated damage costs. These peak between 2004 and 2015. There are significantly fewer reported impacts earlier in the record. This however is likely very due to reporting bias.

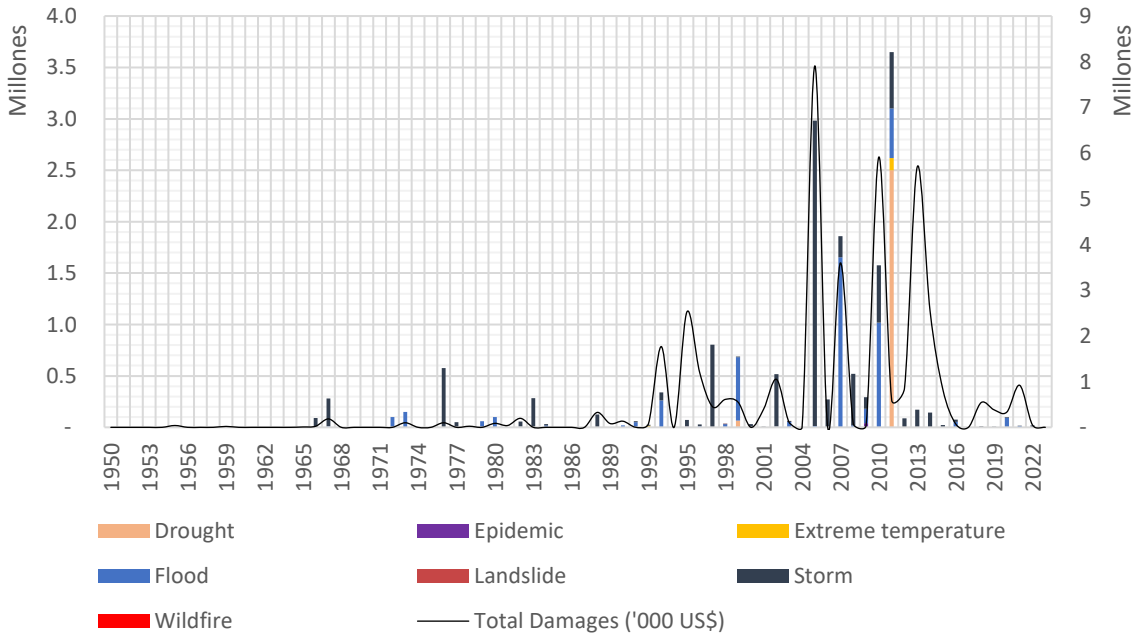


Figure 50. Changes over time in people affected by climate and hydro-meteorological events and estimated damage costs[55]

[54] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[55] D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: The CRED/OFDA International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.

Under future climate conditions, the observed impacts of climate change on vulnerable communities across Mexico are projected to continue and intensify. The sections below provide information on specific observed and projected impacts of climate change in Mexico and the Yucatán Peninsula.

3.1. Impacts on coastal areas

The coastline of Mexico is highly vulnerable to the impacts of climate change. The effects of rising sea levels pose a severe threat to infrastructure and investments, while tropical cyclones and extreme weather threaten the lives and livelihoods of local communities that depend on coastal zones for their survival[56].

In coastal areas, climate change is exacerbating the effects of unsustainable urban development which has already adversely affected ecosystems such as mangrove forests, beach dunes, shallow seagrass beds and coral reefs[57]. Under future climate conditions, coastal zones around Mexico will be strongly affected by rising SST and the acidification of ocean water. The coastal ecosystems that will most strongly be impacted by future climate change will be wetlands (91% of the total), followed by mangroves, beaches, and dunes. As coastal ecosystems continue to be affected by climate change, projections indicate that an overall negative impact can be expected on Mexico's fisheries[58]. While some species will experience productivity increases, approximately 84% of species studied in one analysis showed potential negative impacts in terms of catch potential under future climate change. Under low and high emissions scenarios, fish catch potential will decrease by 6.8% and 17%, respectively by 2050[59].

Along the coastline of the Yucatán Peninsula, climate change is already causing numerous impacts. These include the spread of invasive aquatic plants such as sargassum which reduces the tourism value of the beaches as well as coastal erosion caused by SLR and storm surges. The Mexican Department of Tourism estimates the current rate of coastal erosion in Quintana Roo at between 1.2 and 4.9 m per year. This erosion, however, is not only the result of climate change but also improper management of coastal areas and mass development along the coastline. In addition, the development of this beachfront infrastructure is often too close to the water and therefore highly exposed to the impacts of storm surge and SLR. Climate change is also affecting ecosystems in coastal areas which local communities depend on for their livelihoods. This includes more than 350,000 fishers that depend on fisheries around the country's coastal areas. Climate change is exacerbating the impacts of already unsustainable fishing practices that threaten the sustainability of these communities' livelihoods.

3.2. Impacts on water

Mexico receives approximately 1.4 billion m^3 of rain per year, 67% of which falls between June and September[60]. The distribution of this rainfall, however, is extremely spatially unequal and much of it is lost to evapotranspiration (73%)[61]. Given that almost a third of the country is considered water-stressed, increasing temperatures and precipitation variability are acutely affecting water availability across the country[62]. Large parts of the country are arid or semi-arid and lack significant surface water bodies, and groundwater is an important resource for Mexico's population and critical to its socio-economic development. Approximately 6% of the country's total precipitation infiltrates into aquifers annually, supplying 30% of the total water demand of the country, including 30% of the total irrigated land and the majority of water supply in rural areas[63].

- *Groundwater in the Yucatán Peninsula*

As with Mexico as a whole, groundwater is also a critical natural resource in the Yucatán Peninsula. The topography of the peninsula is relatively flat overall, with most of the region being at low elevation [64]. However, rainfall patterns are influenced by the presence of an upland region that stretches from north to south in the central part of the peninsula. This region forms the primary watershed and catchment area of the peninsula, with surface flow being towards the Gulf of Mexico on the western side of the uplands and towards the Caribbean Sea on the eastern side (

[56] NDC Partnership. 2018. Impacts of Climate Change on the Coastal Zone of Mexico: An Integrated Ecosystem Approach in the Gulf of Mexico to Support Coastal Zone Management Legislation. Available here.
[57] NDC Partnership. 2018. Impacts of Climate Change on the Coastal Zone of Mexico: An Integrated Ecosystem Approach in the Gulf of Mexico to Support Coastal Zone Management Legislation. Available here.
[58] Cisneros-Mata, M.A., Mangin, T., Bone, J., Rodriguez, L., Smith, S.L. and Gaines, S.D., 2019. Fisheries governance in the face of climate change: Assessment of policy reform implications for Mexican fisheries. *PloS one*, *14*(10), p.e0222317.
[59] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[60] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[61] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[62] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[63] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[64] Bauer-Gottwein, P., Gondwe, B.R., Charvet, G., Marín, L.E., Rebolledo-Vieyra, M. and Merediz-Alonso, G., 2011. the Yucatán Peninsula karst aquifer, Mexico. *Hydrogeology Journal*, *3*(19), pp.507-524.

Figure 52)[65]. While the region's hydrology is strongly influenced by the central uplands, the entire peninsula serves as a groundwater recharge zone[66].

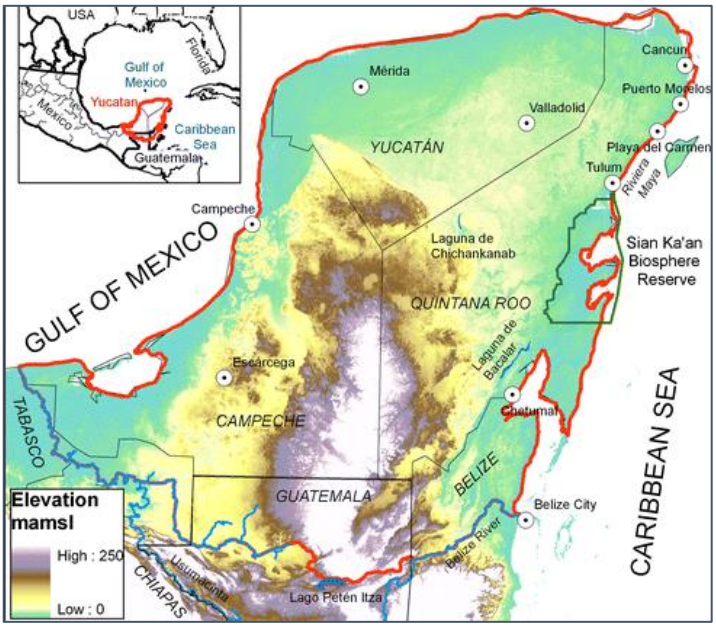


Figure 51. The elevation map of the Yucatán Peninsula[67].

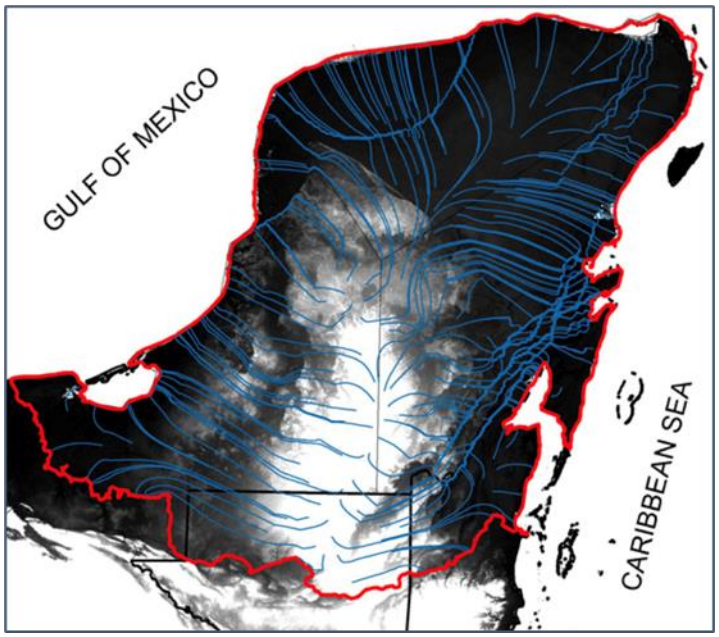


Figure 52. Surface flow direction from the central uplands of the Yucatán Peninsula[68].

The peninsula's limestone geology is characterised by an extensive karst aquifer system — known as the Yucatán Peninsula karst aquifer — and a limited amount of surface water availability[69]. This has resulted in a high dependence of local communities on groundwater, particularly during the dry season[70]. The most important areas for groundwater recharge are in the interior of the Peninsula, specifically in the southwestern parts of

[65] Bauer-Gottwein, P., Gondwe, B.R., Charvet, G., Marín, L.E., Rebolledo-Vieyra, M. and Merediz-Alonso, G., 2011. the Yucatán Peninsula karst aquifer, Mexico. *Hydrogeology Journal*, *3*(19), pp.507-524.
[66] Rodríguez-Huerta, E., Rosas-Casals, M. and Hernandez-Terrones, L.M., 2019. Water societal metabolism in the Yucatan Peninsula. The impact of climate change on the recharge of groundwater by 2030. *Journal of cleaner production*, *235*, pp.272-287.
[67] Bauer-Gottwein, P., Gondwe, B.R., Charvet, G., Marín, L.E., Rebolledo-Vieyra, M. and Merediz-Alonso, G., 2011. the Yucatán Peninsula karst aquifer, Mexico. *Hydrogeology Journal*, *3*(19), pp.507-524.
[68] Bauer-Gottwein, P., Gondwe, B.R., Charvet, G., Marín, L.E., Rebolledo-Vieyra, M. and Merediz-Alonso, G., 2011. the Yucatán Peninsula karst aquifer, Mexico. *Hydrogeology Journal*, *3*(19), pp.507-524.
[69] Bauer-Gottwein, P., Gondwe, B.R., Charvet, G., Marín, L.E., Rebolledo-Vieyra, M. and Merediz-Alonso, G., 2011. the Yucatán Peninsula karst aquifer, Mexico. *Hydrogeology Journal*, *3*(19), pp.507-524.
[70] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.

Yucatán State and north-eastern Campeche[71]. Research in the peninsula has shown that in some areas, no groundwater recharge is produced below approximately 800 mm of annual rainfall[72]. Since the region is highly dependent on groundwater infiltration, therefore, climate change has the potential to directly affect the availability of water for use by vulnerable communities – particularly those who do not have access to piped water for domestic and irrigation use[73].

- *Projected changes in surface run-off and groundwater infiltration*

Projections for Mexico as a whole indicate that the impact of climate change on surface water run-off will be different between different emissions scenarios. On average, an increase in surface water run-off of 13.3% is expected under a low-emissions scenario, while an overall decline of 4.4% is expected under a high-emissions scenario. In some regions, however, surface water run-off will decrease by up to 20%[74]. Projections also indicate that along with changing levels of surface water run-off, decreasing groundwater recharge will occur across Mexico. Under low and high emissions scenarios, groundwater recharge is expected to decrease by 3.3% and 4.7% over the country[75].

In the Yucatán Peninsula, changing precipitation patterns will likely impact surface water availability, but groundwater is overall of more importance than surface water, with the exception of areas in the south of the peninsula[76]. Projections indicate that as annual precipitation declines in most of the eastern parts of the Yucatán Peninsula, important areas for groundwater infiltration will become increasingly arid (Figure 20). By some estimates, groundwater recharge will decrease by up to 23% by 2030[77]. This will have severe consequences for rural communities that are dependent on these groundwater resources for domestic and agricultural use. Some parts of the peninsula will likely see rising demand for water while supply will become diminished as a result of climate change. In the north-western parts of the peninsula where approximately 45% of the population of the entire peninsula (2,000,000 people) lives, population growth of approximately 20% is expected by 2030[78]. This region is already accounting for 20% of the water use of the peninsula and given the changing climatic conditions in key groundwater recharge zones, a significant reduction in per capita water supply can be expected. Demand in the tourism sector will contribute to an increase in water demand, particularly in Quintana Roo[79].

- *Increasing frequency of floods*

Along with changes in water availability for domestic and agricultural use, climate change is also affecting vulnerable local communities through intensifying floods. Floods are a regular occurrence in many parts of Mexico and occur yearly as a result of tropical hurricanes and heavy precipitation events. However, during the 20th Century, an increase in the impacts of floods has been observed. Heavier rainfall and more frequent high-intensity storm events – in combination with the compaction of soils and a reduction of vegetation caused by recurring droughts – are increasing the ratio of rainfall lost as run-off. In the Yucatán Peninsula, there is currently a high level of risk of flooding. In Quintana Roo state, fluvial and coastal flooding hazard is classified as high, meaning that severe flooding occurs at least once every 10 years[80]. The risk of urban flood in the state is classified as medium. In Yucatán and Campeche States, all types of flooding (including urban, riverine and coastal) are classified as high risk[81].

Under future climate conditions, floods will become more frequent and intense as tropical cyclones become more regular. Drought conditions cause a reduction in vegetation cover, compaction of soils and an increase in water lost as surface run-off, and rainfall intensity increases. This problem will impact the Yucatán Peninsula particularly severely, as tropical cyclone activity in the Caribbean Sea and the Gulf of Mexico is expected to increase while drought conditions across the peninsula are expected to intensify. Flooding will be particularly severe in coastal areas.

[71] Rodríguez-Huerta, E., Rosas Casals, M. and Hernández Terrones, L.M., 2019. Climate change effects on groundwater recharge in Yucatan Peninsula. Application of water balance models to GCMs.
[72] Rodríguez-Huerta, E., Rosas Casals, M. and Hernández Terrones, L.M., 2019. Climate change effects on groundwater recharge in Yucatan Peninsula. Application of water balance models to GCMs.
[73] Rodríguez-Huerta, E., Rosas Casals, M. and Hernández Terrones, L.M., 2019. Climate change effects on groundwater recharge in Yucatan Peninsula. Application of water balance models to GCMs.
[74] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
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[76] Rodríguez-Huerta, E., Rosas Casals, M. and Hernández Terrones, L.M., 2019. Climate change effects on groundwater recharge in Yucatan Peninsula. Application of water balance models to GCMs.
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[78] Rodríguez-Huerta, E., Rosas Casals, M. and Hernández Terrones, L.M., 2019. Climate change effects on groundwater recharge in Yucatan Peninsula. Application of water balance models to GCMs.
[79] Rodríguez-Huerta, E., Rosas-Casals, M. and Hernandez-Terrones, L.M., 2019. Water societal metabolism in the Yucatan Peninsula. The impact of climate change on the recharge of groundwater by 2030. *Journal of cleaner production*, *235*, pp.272-287.
[80] GFDRR. No date. Mexico. Available here.
[81] GFDRR. No date. Mexico. Available here.

3.3. Impacts on agriculture

In Mexico, agriculture represents only 3% of the country's GDP, but employs 13% of the labour force, with smallholder farmers comprising 85% of the population working in the sector[82]. The most important crop grown in the country is maize (33%), along with other crops such as beans, sorghum, wheat, coffee and fruit[83]. Agriculture is a large water user and accounted for approximately 76% of water use in 2017[84]. Across the country, rising temperatures, decreasing annual precipitation and intensifying extreme climate events are directly affecting agriculture, with a trend towards reduced yields and decreasing food quality already observed[85]. In the Yucatán Peninsula, water stress caused by droughts is already directly impacting vulnerable local communities through impacts on agriculture. These communities (many of which lack piped water) have reported shortages of water for human use, as well as impacts on agricultural production[86].

- *Crop and livestock productivity*

In recent decades, droughts have caused a reduction in water available for crop production across the Yucatán Peninsula. In many communities, high temperatures and water stress have already caused crop damage, particularly where they are dependent on rain-fed agriculture. Even in areas where irrigation infrastructure is better developed, droughts have reduced the availability of irrigation water, and where water is still available, the quality is often lower as a result of higher salinity due to increased evaporation caused by temperature rise[87].

In the Yucatán Peninsula, a reduction in the productivity of many crops has been reported, including garden crops such as chilli, coriander and radish. Delayed and shorter rains have also reduced the maize yield, which is a staple in the region[88]. Maize is produced through the *'Milpa'* system, which is a form of intercropping of maize, beans and squash. This system, however, has traditionally involved the clearing of new farmland through methods such as slash and burn, contributing to deforestation, higher CO_2 emissions and loss of biodiversity. As a result of the decreasing productivity under *milpa,* climate change is therefore contributing indirectly to further landscape degradation in the Yucatán Peninsula, which is intensifying the adverse effects of droughts and floods.

Along with impacts on crop production, livestock productivity in the Yucatán Peninsula has also been adversely affected by climate change in recent decades. Droughts have already caused a decrease in grazing, a decline in the fertility of cattle and a drying of water holes and wells across the peninsula, with adverse impacts on food security[89]. Secondary agricultural activity has also been affected by climate change, including a reported loss in honey production because of reduced flowering of key species being impacted by dry conditions[90]. In addition, dry conditions have also caused an increase in damage to crops by wild animals and pests, with some smallholders reporting losses of up to 50%[91].

The projected changes in climatic conditions across Mexico and in the Yucatán Peninsula specifically will directly affect agricultural production and productivity. Increasing average and maximum temperatures, more variable rainfall patterns, the occurrence of heat waves and the projected rise in the frequency and intensity of tropical cyclones and extreme rainfall events will directly affect crop yields and livestock productivity. Several key cereal crops will be affected across the country under future climate conditions. For example, by 2050, the productivity of maize is expected to decline by 12.6% and 8.8% under a low and medium emissions scenario while a similar trend is projected for other crops. The overall decreasing trend in maize productivity will also occur in the Yucatán Peninsula (Figure 53).

[82] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[83] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[84] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[85] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[86] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
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[88] CIMMYT. 2017. Helping farming families thrive while fighting climate change in Mexico. Available here..
[89] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[90] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[91] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.

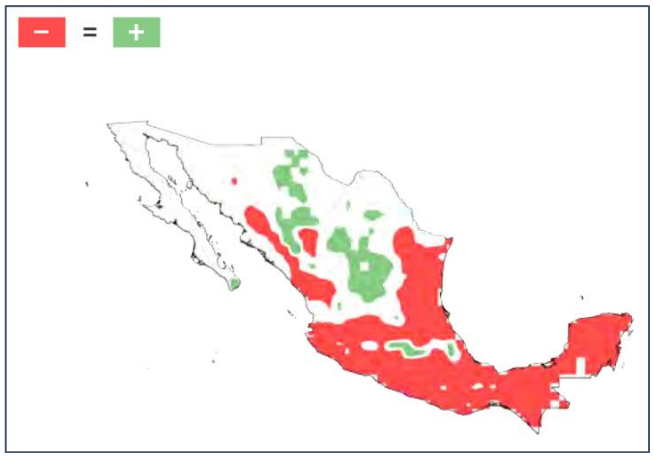


Figure 53. Projected changes in maize yield across Mexico[92].

Along with the direct impacts of climate change on agricultural productivity, projections also indicate a likely increase in agricultural water demand as a result of increased rates of evapotranspiration. Under a low and medium emissions scenario, water demand will likely increase by 21.6% and 18.9%, respectively[93].

3.4. Impacts on forests

Mexico's forests are rich in biodiversity and support an important natural resource for the country's population. Approximately 30% of the country's forests are classified as tropical, with the rest classified as temperate. Mangrove forests are also an important forest resource and grow along most of the Atlantic and Pacific coastlines[94]. In recent decades, forest productivity has been adversely affected by climate change across the country. Along the Pacific coast, the increasing length of the dry season has caused a severe decrease in forest productivity. However, forest productivity in the Yucatán Peninsula has shown a weak increase in recent decades as a result of the effect of increasing CO_2 concentrations in the atmosphere. As a result of this fertilising effect of higher atmospheric CO_2 levels, an increase in forest productivity is expected for the Yucatán Peninsula under future climate conditions[95]. This is in contrast to projected declines in productivity along the central Pacific coast. Changes in forest productivity will occur alongside increases in forest fires across the country, as a result of drier conditions and higher temperatures. However, no increase in fires is expected in the Yucatán Peninsula. Under a low-emissions scenario, forest fires in the peninsula are projected to decrease in frequency overall[96].

Regardless of the potential positive effects of higher atmospheric CO_2 concentrations on forest productivity, however, sea level rise is posing a severe threat to coastal mangrove forests along the coastline of the Yucatán Peninsula, which impacts the capacity of these areas to buffer coastal areas against tropical cyclones and associated storm surge[97]. Climate change is not only adding additional pressure on the health of these mangrove ecosystems[98], but forest degradation caused by unregulated development and population growth along the coastline of the peninsula has also degraded the capacity of existing mangrove forests to buffer communities against climate impacts. Research has shown that mangroves affected by human activity are more vulnerable to climate impacts, and therefore not only have a higher risk of further impacts by climate change but also lower capacity to provide ecosystem services[99]. As the population of the peninsula continues to grow and sea level rise continues to affect coastal ecosystems, mangrove forests will become increasingly degraded and their capacity to provide ecosystem services under future climate conditions will become diminished.

3.5. Impacts on health

Across Mexico, climate change has already directly and indirectly, affected the health and wellbeing of the country's population. This trend has been especially prevalent in the country's urban areas where the majority of the population lives. Mexico has an urbanisation rate of 80%, and projections indicate that 88% of the country's population will be living in cities by 2050[100]. In urban areas across the country, an increase in heatwaves has been observed. As a result of the high density of buildings in these areas, soil sealing, limited

[92] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[93] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[94] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[95] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[96] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[97] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[98] https://www.sciencedirect.com/science/article/abs/pii/S096456912030106X
[99] Cinco-Castro, S. and Herrera-Silveira, J., 2020. Vulnerability of mangrove ecosystems to climate change effects: The case of the Yucatan Peninsula. *Ocean & coastal management*, *192*, p.105196.
[100] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

green space and heat generated from human activity, Mexican cities are also exposed to the urban heat island effect. In recent decades, mortality as a result of heat has increased by 3.22% for people older than 65[101]. Climate change in Mexico, specifically increasing average and maximum temperatures, is directly affecting labour productivity. This is occurring because higher temperatures not only reduce the number of hours that a person can work but also the productivity of workers during active work hours[102].

- *Infectious and vector-borne disease*

The increasing temperatures and rising incidence of flooding in Mexico are causing an increase in the occurrence of infectious and vector-borne diseases. These include diseases such as Zika, Malaria and Dengue. Given that Mexico's economy contracted by 8.3% during the Covid 19 pandemic in 2020, it is clear that the spread of diseases can have severe consequences for the economy[103].

- *Heat-related mortality*

As noted above, climate change has increased the prevalence of heat-related health impacts on Mexico's population. Under future climate conditions, this trend is projected to intensify. Between 1961 and 1990, approximately 3 deaths per 100,000 were attributable to heat-related factors. By 2080, this number is projected to increase to 11 deaths per 100,000 under a low-emissions scenario and 54 deaths per 100, 000 under a high-emissions scenario[104].

- *Disease*

Under future climate conditions, the prevalence of infectious and vector-borne diseases will increase significantly. These include inter alia zika, dengue and malaria. Estimates show that by 2050, under a medium emissions scenario, approximately 74% of the country's population will be at risk of dengue and 73.3% under a high emissions scenario. For zika, the percentage of the population at risk by 2050 will be 51.7% and 52.5% under a medium and high emissions scenario, respectively[105]. Under a low and high emissions scenario, the percentage of the population at risk of Malaria will be 53.8% and 57%, respectively[106].

3.6. Impacts on the economy

Mexico has an extensive coastline that is highly exposed to the impacts of extreme climate events, particularly damages from tropical cyclones and floods[107]. A large proportion of Mexico's population (more than 50%) lives along the country's coastal areas where many communities depend on coastal ecosystems for their livelihoods[108]. Tourism comprises approximately 8.7% of the country's GDP (2018) [109]. In the Yucatán Peninsula, the economy of the three states comprising the peninsula is diverse but depends significantly on coastal areas[110]. Coastal zones have significant tourism potential, and their reefs and dunes provide essential ecosystem services such as wave attenuation and habitats for fish. Indeed, Quintana Roo is already the country's second-largest tourism destination[111]. Climate change is affecting coastal areas through SLR, increased storm activity and storm surge, which affect the capacity of local communities to depend on these areas for their livelihood[112].

Overall, the climate impacts described above will, directly and indirectly, affect the economy of Mexico, as well as that of the three states comprising the Yucatán Peninsula. Aggregate damages from climate change will reach approximately 5.54% of Mexico's GDP by 2100[113]. Agriculture is predicted to be the most severely affected sector. In the Yucatán Peninsula, tourism will be severely affected by climate change in the absence of intervention. Coastal zones in the region, particularly along the east coast, will be directly impacted by sea level rise, increased tropical cyclone activity, higher temperatures, and more intense rainfall, all of which will affect ecosystems and infrastructure upon which the sector is dependent. Quintana Roo is one of Mexico's most significant tourist destinations, and also one of the most climate-vulnerable areas of the country[114]. Overall,

[101] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[102] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[103] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[104] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[105] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[106] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[107] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[108] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[109] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[110] Sánchez-Triana, E., Ruitenbeek, J., Enriquez, S. and Siegmann, K. eds., 2019. *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. World Bank Publications. Available here.
[111] Sánchez-Triana, E., Ruitenbeek, J., Enriquez, S. and Siegmann, K. eds., 2019. *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. World Bank Publications. Available here.
[112] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[113] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[114] USAID. 2017. Climate Risk Profile Mexico. Available here.

climate change is projected to strongly influence the economy of all three states in the Yucatán Peninsula and will potentially increase the poverty rate in the region from approximately 15% to 18.8% by 2030[115].

4. Modelling methodology

4.1. Model Data

The Coupled Model Intercomparison Project Phase 6 (CMIP6) is a large-scale climate modelling effort aimed at providing the most up-to-date and reliable projections of future climate change. It is a collaborative project involving climate modelling groups from all over the world, and it is intended to help the Intergovernmental Panel on Climate Change (IPCC) in its assessments of the state of the climate system.[116][117]

CMIP6 simulates the behaviour of the Earth's climate system using a variety of modelling methodologies, including atmosphere-only models, ocean-only models, and fully coupled atmosphere-ocean-land models. These models represent the physical, chemical, and biological processes that govern the climate system, and they are used to simulate past and future climate conditions under a variety of greenhouse gas concentrations and other climate drivers.

- *Atmosphere-only models simulate atmospheric behaviour to assess physical processes such as atmospheric circulation, radiation, and cloud formation, among others.*
- *Ocean-only models simulate the ocean's circulation, mixing, and heat transport.*
- *Fully coupled models, on the other hand, simulate the interactions between the atmosphere, ocean, land surface, and cryosphere, allowing for a more comprehensive understanding of the climate system and how it responds to external forcing.*
- *CMIP6 also includes Earth system models that incorporate the biogeochemical cycles of carbon, nitrogen, and other elements into the climate system, in addition to these modelling approaches. These models provide a more complete representation of the interactions between the Earth's physical and biological components, as well as their feedback to climate change.* [118][119]

The variety of modelling methodologies used in CMIP6 enables a comprehensive assessment of the uncertainties and range of future climate change projections, which is critical for informing climate policy and adaptation strategies.

The CMIP6 project expands on previous phases of the Coupled Model Intercomparison Project (CMIP), which have provided valuable information on the past and future evolution of the Earth's climate system. This analysis is based on CMIP6 data, which includes 134 models from 53 modelling centres. The publication of CMIP6 data began in 2019, with the majority of the data expected to be published by 2022, with CMIP6 scientific analyses used in the IPCC's 6th Assessment Report (AR6).[120] The CMIP6 models used for this analysis are as follows:

ACCESS-CM2 (Australia)
ACCESS-ESM1-5 (Australia)
AWI-CM-1-1-MR (Germany)
AWI-ESM-1-1-LR (Germany)
BCC-CSM2-MR (China)
BCC-ESM1 (China)
CAMS-CSM1-0 (China)
CanESM5 (Canada)
CanESM5-CanOE (Canada)
CESM2 (USA)
CESM2-FV2 (USA)
CESM2-WACCM (USA)
CESM2-WACCM-FV2 (USA)
CIESM (China)
CMCC-CM2-HR4 (Italy)
CMCC-CM2-SR5 (Italy)
CMCC-ESM2 (Italy)
CNRM-CM6-1 (France)
CNRM-CM6-1-HR (France)
CNRM-ESM2-1 (France)
E3SM-1-0 (USA)
E3SM-1-1 (USA)
E3SM-1-1-ECA (USA)
EC-Earth3 (Europe)
EC-Earth3-AerChem (Europe)
EC-Earth3-CC (Europe)
EC-Earth3-Veg (Europe)
EC-Earth3-Veg-LR (Europe)
FGOALS-f3-L (China)
FGOALS-g3 (China)
FIO-ESM-2-0 (China)
GFDL-ESM4 (USA)
GISS-E2-1-G (USA)
GISS-E2-1-H (USA)
HadGEM3-GC31-LL (UK)
HadGEM3-GC31-MM (UK)
IITM-ESM (India)
INM-CM4-8 (Russia)
INM-CM5-0 (Russia)
IPSL-CM5A2-INCA (France)
IPSL-CM6A-LR (France)
KACE-1-0-G (South Korea)

[115] Sánchez-Triana, E., Ruitenbeek, J., Enriquez, S. and Siegmann, K. eds., 2019. *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. World Bank Publications. Available here.
[116] Eyring, V., et al. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geoscientific Model Development, 9(5), 1937-1958.
[117] IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press.
[118] Eyring, V., et al. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geoscientific Model Development, 9(5), 1937-1958.
[119] IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press.
[120] ECMWF, CMIP6 climate projections, information.

KIOST-ESM (South Korea)
MCM-UA-1-0 (USA)
MIROC6 (Japan)
MIROC-ES2H (Japan)
MIROC-ES2L (Japan)
MPI-ESM-1-2-HAM (Switzerland)
MPI-ESM1-2-HR (Germany)
MPI-ESM1-2-LR (Germany)
MRI-ESM2-0 (Japan)
NESM3 (China)
NorCPM1 (Norway)
NorESM2-LM (Norway)
NorESM2-MM (Norway)
SAM0-UNICON (South Korea)
TaiESM1 (Taiwan)
UKESM1-0-LL (UK)

Because CMIP6 includes more advanced representations of the physical, chemical, and biological processes that govern the climate system than previous phases, it allows for a more comprehensive understanding of the complex interactions between the atmosphere, oceans, land surface, and cryosphere, and how they are likely to change in response to increasing greenhouse gas concentrations and other climate change drivers.

4.2. Model validation

Model validation should be performed in locations of varying climate drivers and forcing mechanisms to ensure there is a robust simulation of the current and future climate scenario.

Servicio Meteorológico Nacional has 5466 observational meteorological stations distributed throughout Mexico. Of these, only 2926 stations are currently operational. In the provinces of Yucatán, Campeche, and Quintana Roo these stations are 97 total stations with 67 operational, 82 total stations with 56 operational, and 61 total stations with 46 operational respectively. The observational stations selected for validation should be operational within the study area, or as near as possible to the study area and have at least 30 years of accurate daily observational data. The study area of this project is 20km from the coastal along the Yucatan peninsula. Within the study area, there are a total of 42 observational stations of which only 28 stations are currently operational. Of these stations, only 23 stations have more than 30 years of observational data

Table 3. Observational stations in the study area with at least 30 years of data

ID number	Station	Province	Data start year	Data end year	Record length (years)
4003	CAMPECHE (OBS)	CAMPECHE	1878	2018	140
4007	EL CARMEN (SMN)	CAMPECHE	1926	2018	92
4014	ISLA ARENAS	CAMPECHE	1970	2018	48
4015	ISLA AGUADA	CAMPECHE	1959	2018	59
4029	SABANCUY	CAMPECHE	1953	2018	65
4038	CAMPECHE (DGE)	CAMPECHE	1952	2017	65
4041	CHAMPOTON (DGE)	CAMPECHE	1986	2018	32
4052	CANASAYAB	CAMPECHE	1975	2018	43
4053	SANTA CRISTINA	CAMPECHE	1976	2018	42
4068	CHINA	CAMPECHE	1983	2018	35
4072	SIHO CHAC	CAMPECHE	1982	2018	36
23023	SOLFERINO	QUINTANA ROO	1969	2017	48
23025	TULUM	QUINTANA ROO	1964	2017	53
23048	COZUMEL (DGE)	QUINTANA ROO	1994	2012	18
23155	CANCUN	QUINTANA ROO	1988	2012	24
23158	MAHAHUAL	QUINTANA ROO	1999	2011	12
23163	PLAYA DEL CARMEN	QUINTANA ROO	1998	2012	14
23166	CENTRAL VALLARTA	QUINTANA ROO	2000	2012	12
31007	CHICXULUB PUERTO	YUCATAN	1963	2016	53
31010	DZILAM DE BRAVO	YUCATAN	1961	2016	55
31012	EL CUYO	YUCATAN	1954	2016	62
31023	PROGRESO (OBS)	YUCATAN	1951	2017	66
31024	RIO LAGARTOS	YUCATAN	1962	2016	54
31029	SISAL	YUCATAN	1957	2016	59
31031	TELCHAC PUERTO	YUCATAN	1952	2016	64

31040	CELESTUN (DGE)	YUCATAN	1961	2016	55
31083	YALSIHON	YUCATAN	1982	2016	34
31094	DZIDZANTUM	YUCATAN	1986	2016	30

The stations selected for the validation were based on data quality, being in the study area, record length, and distribution around the Yucatan peninsula covering the various climates. The stations selected were as follows:

Table 4. Stations selected for model validation.

Geographic Location	Coastal southwest Yucatan peninsula	Coastal northwest Yucatan peninsula	Coastal north Yucatan peninsula	Coastal east Yucatan peninsula
Station ID	4007	4014	31010	23025
Name	**El Carmen**	**Isla Arenas**	**Dzilam De Bravo**	**Tulum**
Municipality	Carmen	Calkini	Dzilam De Bravo	Solidaridad
Latitude (°N)	18.653	20.69	21.393	20.226
Longitude (°W)	91.761	90.453	88.891	87.458
Altitude (metres asl)	5	1	2	10
Duration of record (years)	92	48	55	53

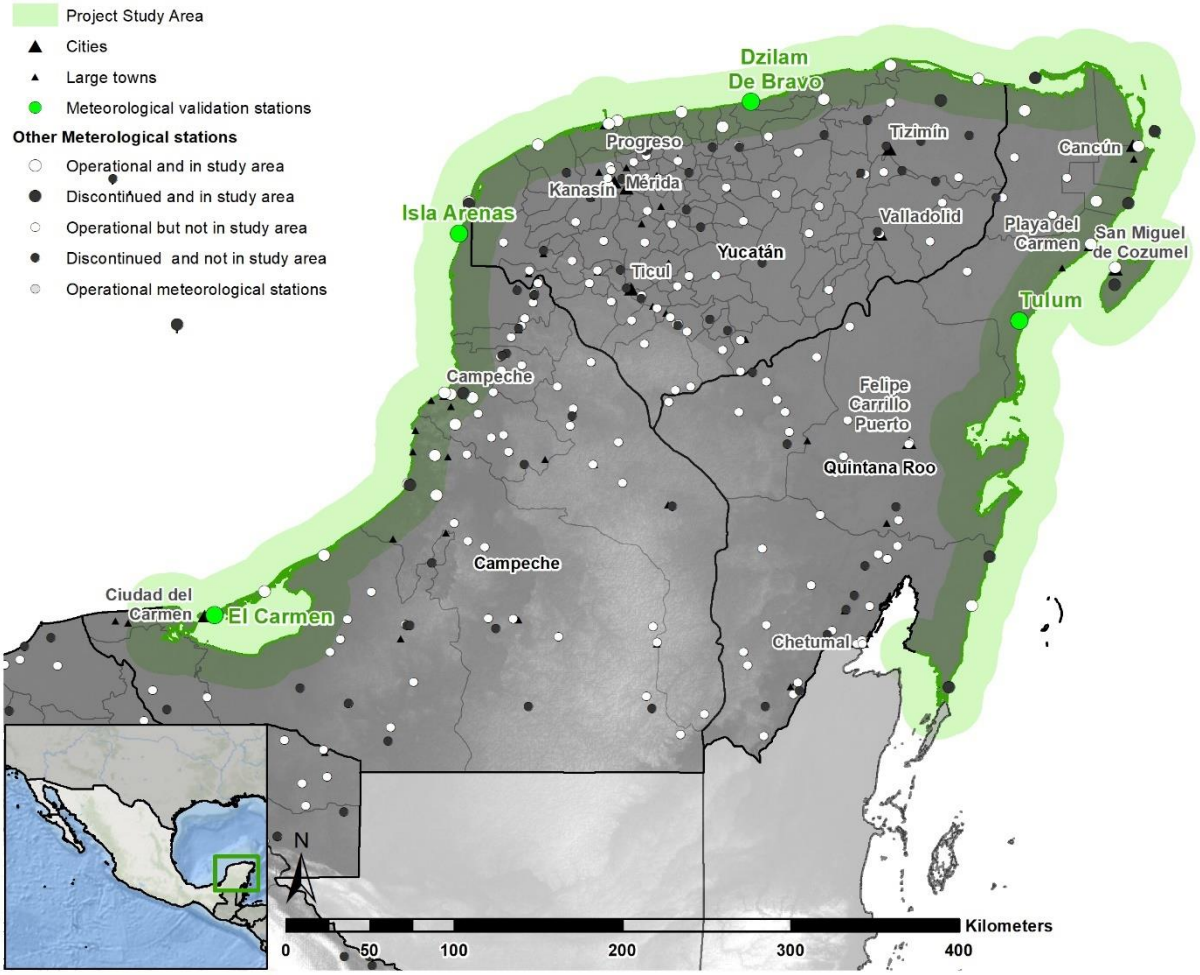


Figure 54. Location of observational meteorological stations and selected stations for validation.

Validation of Precipitation data

Rainfall is very challenging to model, particularly in a dynamic area such as the Yucatan. However, given that future drought and water stress is of paramount importance to the country, validation of rainfall is essential in more accurately representing future rainfall scenarios.

Seasonal signal

The agreement in the seasonality of models to observational data is important as this reflects the sub-annual dynamics that will have impacts on water security agriculture and disaster planning. Models that have the lowest seasonal anomalies are the best at representing these sub-annual dynamics and will likely be more realistic in the projected future.

The seasonal rainfall signal is well-matched between the modelled ensemble and the station data. Models are able to simulate the early season false peak, the slight decrease mid-season and the late season peak. Some models are showing significant seasonal outliers of several times higher volumes in the early season. These are excluded. slightly lower volumes are simulated by the models compared to the station data. The models are closest to the station data in El Carmen. In Tulum, the early season peak is only captured by some models and isn't reflected in the ensemble.

The best-performing models with the simulation closest to the station data are mpi-esm1-2-hr, ipsl-cm6a-lr, miroc-es2l, kace-1-0-g, and noresm2-lm.

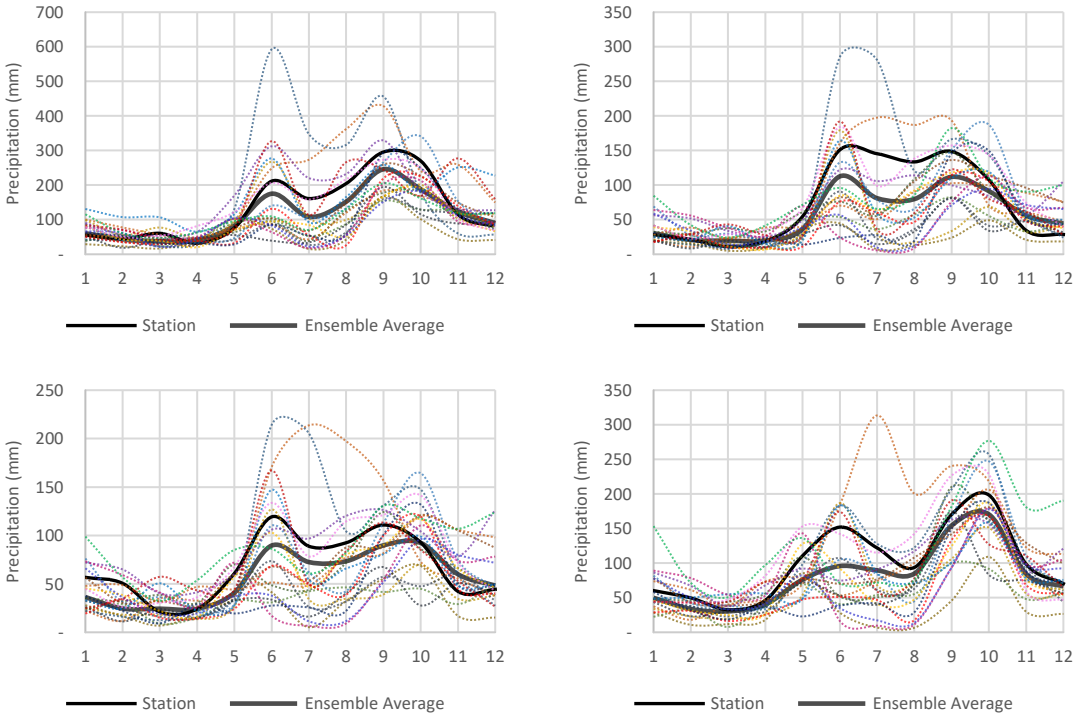


Figure 55. Seasonal rainfall for the observational reanalysis, model ensemble and individual modes for El Carmen (top left), Isla Arenas (top right), Dzilam De Bravo (bottom left), and Tulum (bottom right)

Variability

Rainfall variability is likely to range that can be expected within a normal season. This will impact water supply and ground water recharge. If models are better able to estimate the potential variability, this will indicate a more accurate modelled representation of the past climate.

There is a wide range in the annual and seasonal standard deviations for the models. These models slightly overestimate the variability in most locations and over each season the variability is consistently higher than the station data. This is most evident in the annual data. Thes low rainfall season of DJF and MAM see little variability between the stations and the model data. There is slightly more disparity in the higher rainfall seasons of JJA and SON.

The models that performed the best in the coastal area were bcc-csm2-mr, cmcc-cm2-sr5, and cmcc-esm2, while inland the models that performed well were taiesm1, cmcc-esm2, and cmcc-cm2-sr5.

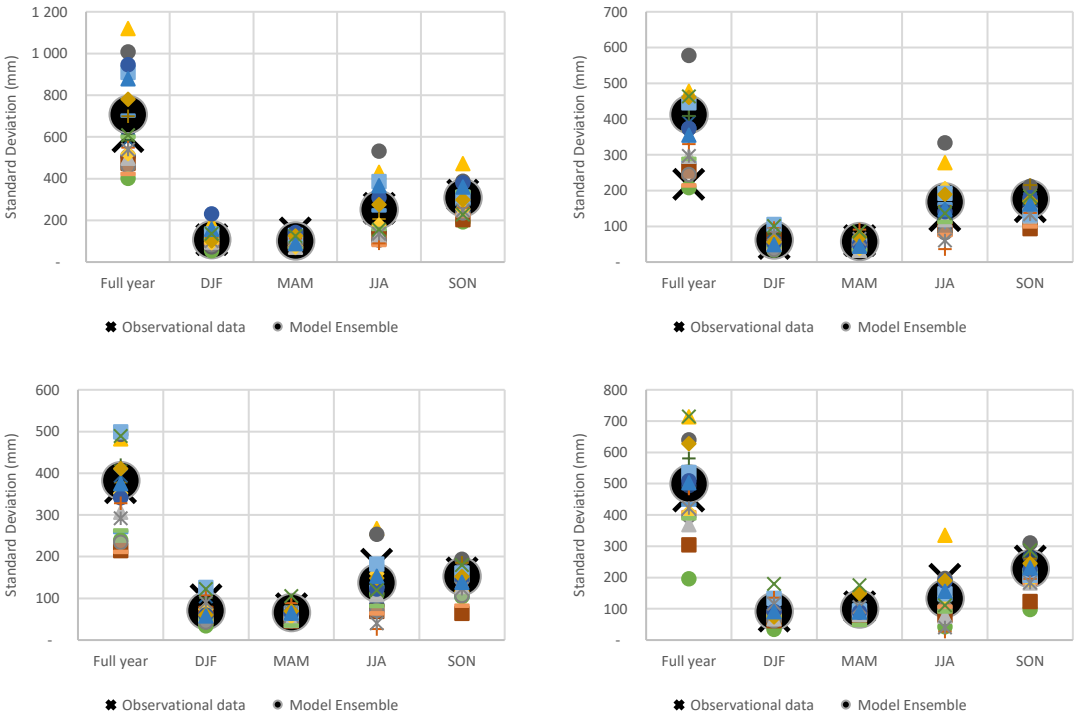


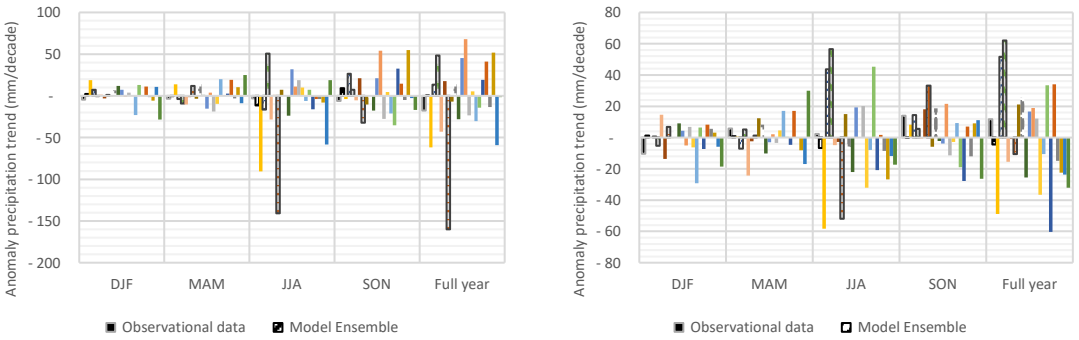
Figure 56. Annual and seasonal rainfall variability of the station and individual models for El Carmen (top left), Isla Arenas (top right), Dzilam De Bravo (bottom left), and Tulum (bottom right)

Trends

The long-term trends of the observational data may give an indication of the local response to current climate changes and pre-empt further future changes. The model's ability to replicate the trends of the observational data is indicative of the adherence of the model to the local climate forcing principles.

There is a wide disparity between the trends of the models and the station data in the same location. The disparity in trends is lower in the lower rainfall season of DJF and MAM and higher in the more dynamic rainfall seasons of JJA and SON. The overall trends in the station data sets, other than Dzilam De Bravo are generally small (<20mm per decade change). Dzilam De Bravo sees generally increased trends annually and from MAM, JJA and SON, but a decrease in DJF. This particular system is not well simulated by the models.

The models that performed the best area were gfdl-esm4, access-esm1-5, ipsl-cm6a-lr, cmcc-cm2-sr5, inm-cm4-8, and mpi-esm1-2-hr.



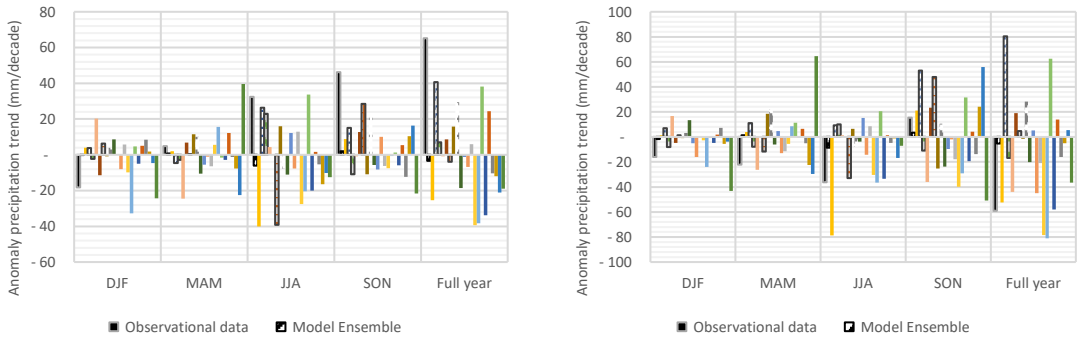


Figure 57. Long-term trends of station data, model ensemble, and individual model for El Carmen (top left), Isla Arenas (top right), Dzilam De Bravo (bottom left), and Tulum (bottom right)

Validation of Temperature data

Modelling temperature is less changing than modelling rainfall. As the noted impacts in the Yucatan area are water security and drought, the validation and scoring of models in their performance for temperature agreement are weighted lower than the agreement of rainfall models to observation.

Seasonal signal

The agreement in the temperature seasonality of models to observational data is important as this reflects the sub-annual dynamics that will have impacts on water security agriculture and disaster planning. Models that have the lowest seasonal anomalies are the best at representing these sub-annual dynamics and will likely be more realistic in the projected future.

The climate models seem to consistently overestimate the maximum temperatures from June to October, and underestimate temperature in the first half of the year for Isla Arenas and Dzilam De Bravo. Generally, however, they do tend to match the seasonal timing of the cooler and hot periods noted in the station data.

The models performing best are cnrm-esm2-1, inm-cm5-0, inm-cm4-8, mri-esm2-0, and mpi-esm1-2-hr.

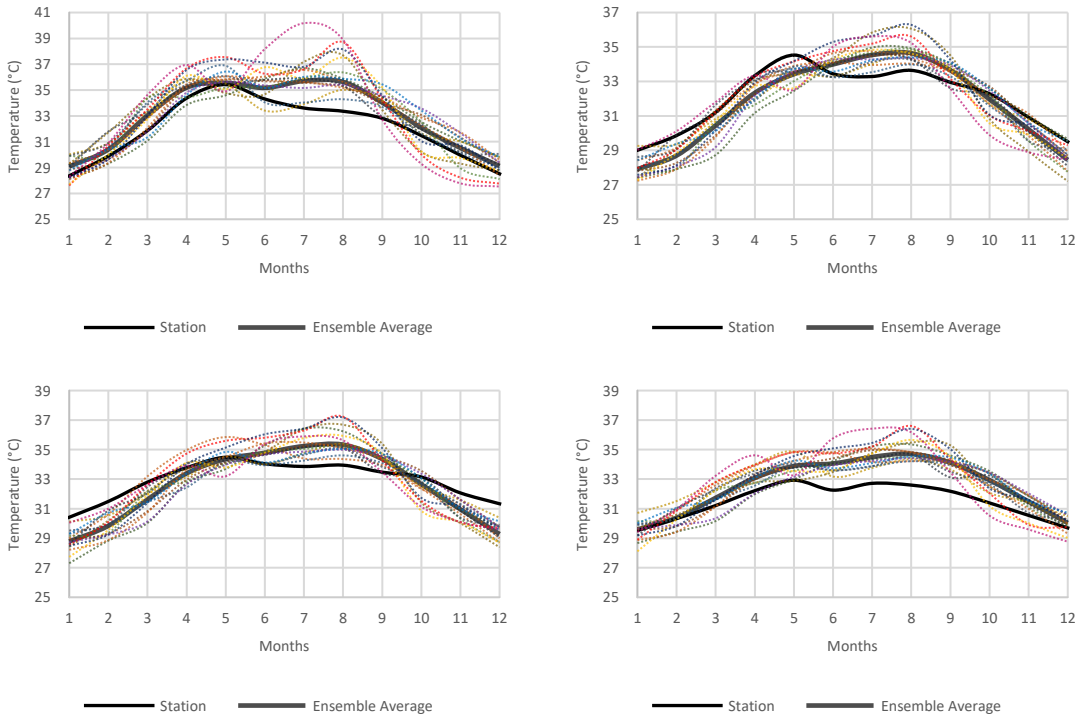


Figure 58. Seasonal rainfall for the observational reanalysis, model ensemble and individual modes for El Carmen (top left), Isla Arenas (top right), Dzilam De Bravo (bottom left), and Tulum (bottom right)

Variability

Temperature variability is likely ranges that can be expected day to day and within a normal season. This will impact evaporation and evapotranspiration and heat wave occurrence. If models are better able to estimate the potential variability, this will indicate a more accurate modelled representation of the past climate.

The models underestimate the variability of station temperatures in all locations other than El Carmen. This underestimation is quite severe as the station's variability is near the outlying models. No models perform particularly well here, but the best-performing models in the coastal area were ipsl-cm6a-lr and nesm3.

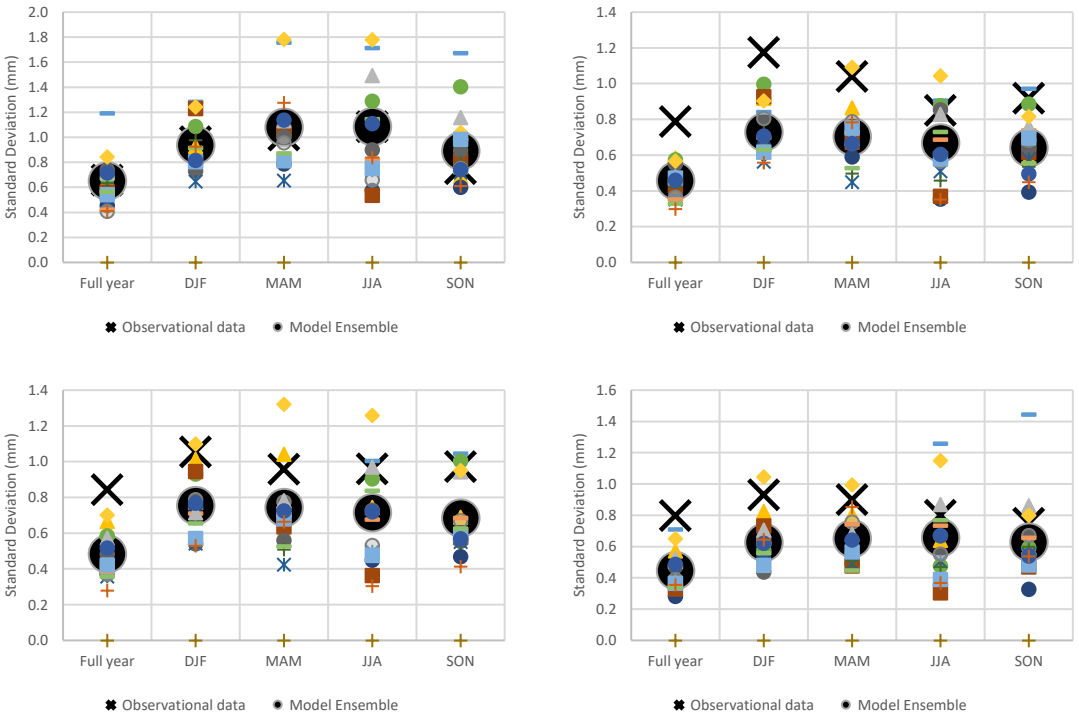
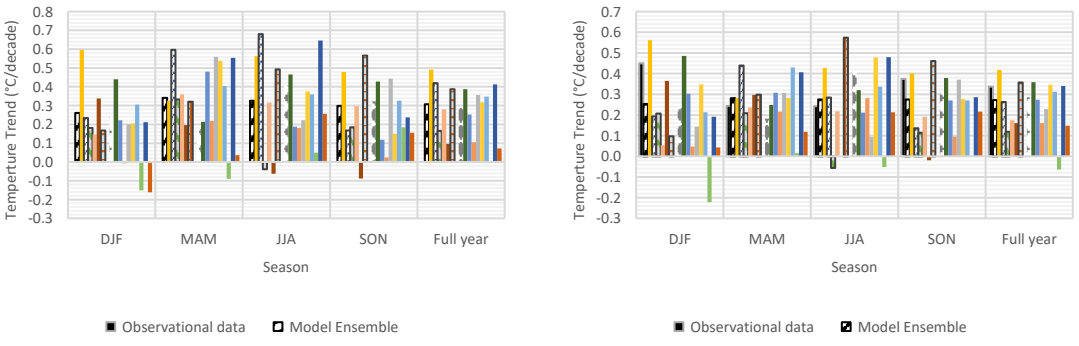


Figure 59. Annual and seasonal rainfall variability of the station and individual models for El Carmen (top left), Isla Arenas (top right), Dzilam De Bravo (bottom left), and Tulum (bottom right)

Trends

The long-term trends of the observational data may give an indication of the local response to current climate changes and pre-empt further future changes. The model's ability to replicate the trends of the observational data is indicative of the adherence of the model to the local climate forcing principles.

Nearly all the models simulate the increasing temperature trends noted in the station data for El Carmen, Isla Arenas and Tulum. There is some variability between the magnitude of the trends though but overall most do a good job and see a trend with 0.1 to 0.2 °C of the station for each season. The trends in the station data for Dzilam De Bravo are higher than the others and are higher than some of the outlier models and the models do not quite reach the higher trends noted in the station data. The best-performing models were access-esm1-5, canesm5, cmcc-esm2, and hadgem3-gc31-ll.



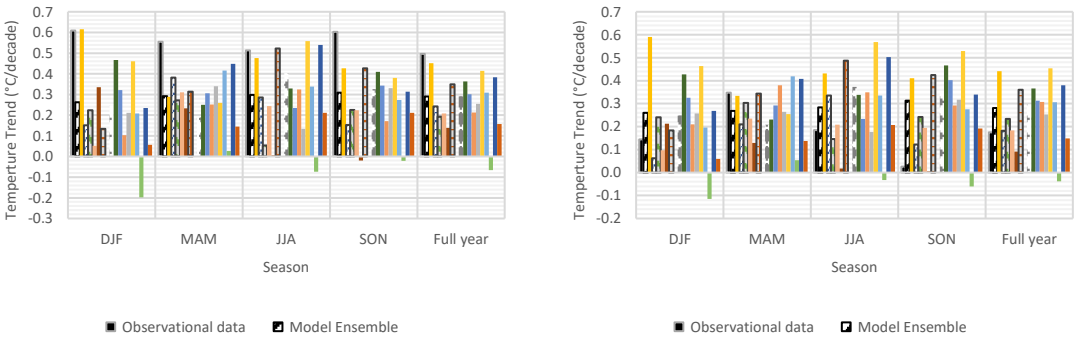


Figure 60. Long-term trends of station data, model ensemble, and individual model for El Carmen (top left), Isla Arenas (top right), Dzilam De Bravo (bottom left), and Tulum (bottom right)

Model selection

The choice of models for the projected analysis needs to represent as near as possible the observed climate, seasonal signal, variability, trends, and magnitude profile, and where possible have as small as possible bias correction needed. The combination of agreement of precipitation and temperature trends, seasonality and bias will give the best possible representation of the localised climate.

There is no single model that is the best at simulating all the aspects of precipitation and temperature relative to the four stations, however, the models that best and consistently reflected high adherence to the historical data, particularly for rainfall were mpi-esm1-2-hr, ipsl-cm6a-lr, and cmcc-cm2-sr5. All analyses will use these models as an ensemble.

4.3. Timeframe and scenario selection

The U.N. climate panel report released on August 9th, 2021, about the physical science of climate change, uses five possible scenarios for the future. The scenarios are the result of complex calculations that depend on how quickly humans curb greenhouse gas emissions. But the calculations are also meant to capture socioeconomic changes in areas such as population, urban density, education, land use and wealth. For example, a rise in population is assumed to lead to higher demand for fossil fuels and water. Education can affect the rate of technological development.

Emissions increase when land is converted from forest to agricultural land. Each scenario is labelled to identify both the emissions level and the so-called Shared Socioeconomic Pathway, or SSP, used in those calculations.[121]
Scenario 1 – Most optimistic: 1.5C by 2050 - SSP1-1.9:

- *The IPCC's most optimistic scenario describes a world where global CO2 emissions are cut to net zero around 2050. Societies switch to more sustainable practices, with the focus shifting from economic growth to overall well-being. Investments in education and health go up. Inequality falls. Extreme weather is more common, but the world has dodged the worst impacts of climate change.*
- *This first scenario is the only one that meets the Paris Agreement's goal of keeping global warming to around 1.5°C above preindustrial temperatures, with warming hitting 1.5C but then dipping back down and stabilizing around 1.4C by the end of the century.*

Scenario 2 – Next Best: 1.8C by 2100 - SSP1-2.6:

- *In the next-best scenario, global CO2 emissions are cut severely, but not as fast, reaching net zero after 2050. It imagines the same socioeconomic shifts towards sustainability as SSP1-1.9. But temperatures stabilize around 1.8C higher by the end of the century.*

Scenario 3 – Middle of the road: 2.7C by 2100 - SSP2-4.5:

- *This is a "middle of the road" scenario. CO2 emissions hover around current levels before starting to fall mid-century but do not reach net zero by 2100. Socioeconomic factors follow their historic trends, with no notable shifts. Progress toward sustainability is slow, with development and income growing unevenly. In this scenario, temperatures rise by 2.7°C by the end of the century.*

Scenario 4 – Dangerous: 3.6C by 2100 - SSP3-7.0:

121 Five future scenarios' Climate Report AR6 IPCC 2021 https://www.climateneutralgroup.com/en/news/five-future-scenarios-ar6-ipcc/

- *On this path, emissions and temperatures rise steadily and CO2 emissions roughly double from current levels by 2100. Countries become more competitive with one another, shifting toward national security and ensuring their food supplies. By the end of the century, average temperatures have risen by 3.6C.*

Scenario 5 – Avoid at all costs: 4.4C by 2100 - SSP5-8.5:

- *This is a future to avoid at all costs. Current CO2 emissions levels roughly double by 2050. The global economy grows quickly, but this growth is fuelled by exploiting fossil fuels and energy-intensive lifestyles. By 2100, the average global temperature is a scorching 4.4C higher.*

The IPCC Sixth Assessment Report 2021[122] (AR6) confirms that the world is on the verge of major tipping points and that immediate climate action is critical for our survival. It emphasizes the most recent and sophisticated physical understanding of the climate system and climate change[123]. It combines multiple pieces of evidence from past observations of the ecosystem, scientific and process understanding, and provides data and information to global and regional climate models to formulate advice on climate variables such as weather and climate extremes in a specific situation under various emissions criteria.

Despite the NDCs, recent global emissions indicate that we are unlikely to meet the SSP1 scenario milestones. SSP5 is the worst-case scenario and mitigation measures are anticipated to make this an avoided reality. This scenario is however presented as the extreme potential range along with the SSP3-70 scenario. **The majority of the assessment uses the SSP2-4.5 scenario as the most likely future.**

Climate modelling is the assessment of the long-term anticipated changes in the climate system. These are normally done for 30 years at the mid-century (2040-2069) and late-century (2070-2099) time intervals. However, the need for interventions to adapt to climate change requires the development of intervention actions in the short term. The planning and adaptation horizons should match the projected climate analysis timeframes. **The 30-year time frame of 2020-2050 with a mid-point of 2035 is therefore used for the assessment of the near future climate changes**. The baseline of the current climate used is 1990-2020 unless otherwise stipulated. Future anomalies are derived from this baseline. There are some datasets where varying institutions have used alternative baselines. These are noted in each scenario.

5. Climate Change Vulnerability Assessment

The purpose of this evaluation is to determine the areas that have the highest climate vulnerability and to allow for; (i) spatial targeted intervention planning by assessing the relative vulnerability by each of the main climate hazard types and by the critical key elements; (ii) sector level planning by looking at the vulnerability at the critical key element level; and (iii) at a high strategic level by looking at the overall combined vulnerability.
The main climate hazards are classified by the uniqueness of their adaptation interventions. These hazards are:

1. *Extreme temperatures which comprise heat waves, and extreme single-day events, increase in the general temperature profiles.*
2. *Extreme precipitation comprises changes in the number of high-volume single and consecutive-day rainfall events and changes in the 95th and 99th percentile volumes.*
3. *Precipitation variability comprises changes in the consecutive wet and dry days, changes in the rainfall onset and cessation, changes in the year-on-year rainfall volumes and magnitude and frequency of drought events.*
4. *Tropical cyclones comprise changes in occurrence and event density based on vertical wind shear and sea surface temperatures in the hurricane development region, and changes in storm surge.*
5. *Ocean impacts comprise changes in local sea surface temperatures, local sea level rise, and changes in acidification which will impact marine ecosystems. The acidification is assessed through changes in calcite, salinity, aragonite and pH measures.*

The critical key elements are the important themes in the Yucatan peninsula. While there is certainly synergy between these themes, they are assessed as follows:

1. *Environment: considers the natural environment and includes but is not limited to forest cover and integrity, mangrove area and trends, NDVI trends, and interface with development and agriculture.*

122 IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.
123 IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.

2. *Livelihoods: considers primarily agriculture and fishery as the livelihoods that have the largest spatial footprint and are most sensitive to projected climate changes. Other livelihoods assessed include agro-forestry and bee keeping.*
3. *Social aspects: considers all aspects related to communities and their resilience including population growth, poverty and inequality, and resource security.*

5.1. Methodology

The climate change vulnerability assessment follows the standard approach to vulnerability and is based on the most widely used definition provided by the Fourth Assessment Report of the IPCC (AR4) as "the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity."

- *Current/Projected Exposure: The potential impacts associated with significant climatic parameter variations to which a system, community, ecosystem, or livelihood may be subject.*
- *Sensitivity: The degree to which a system can be affected either adversely or beneficially, by current and projected climate-related stimuli*
- *Potential Direct Impacts: The potential disruption to an area or system as a result of climate exposure and the underlying sensitivity of the area*
- *Adaptive Capacity: the ability of a system or community to recover from/adapt to, changes in baseline climate variables due to beneficial factors that will moderate potential damages/consequences.*
- *Vulnerability: is the difference between climate impact potential and the resilience of a system or area to these changes*

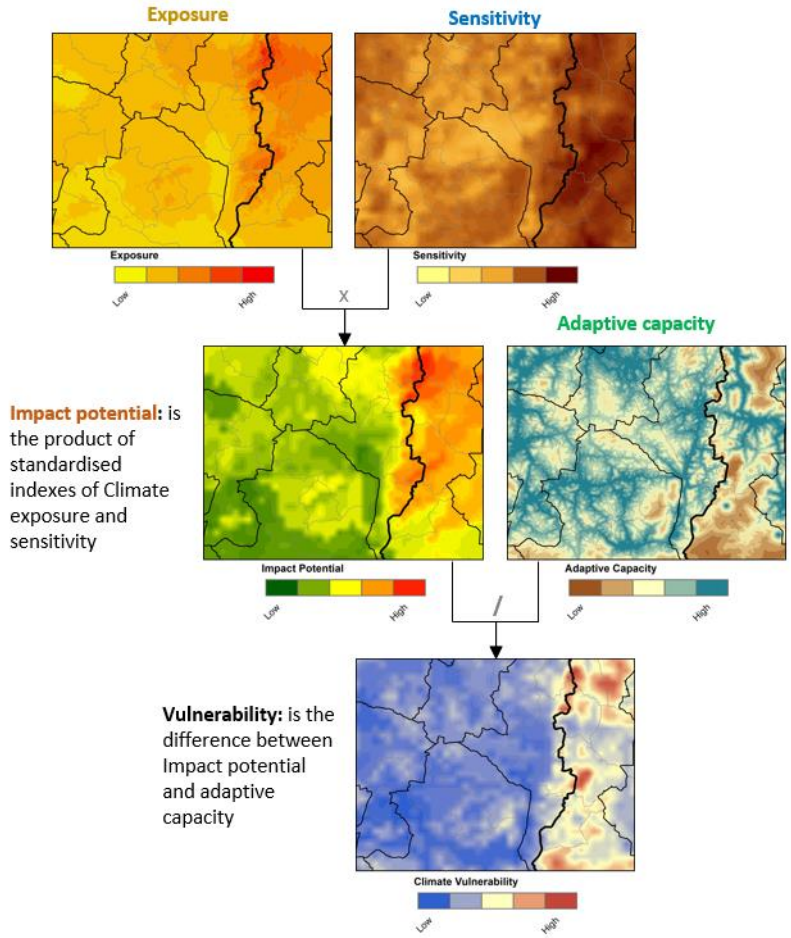


Figure 61. The standard representation of the climate change vulnerability assessment methodology

However, the uniqueness of the climate hazards and the critical key elements necessitated the assessment of each independently. Each of the vulnerability assessments was therefore conducted for each of the climate hazards and each of the critical key elements.

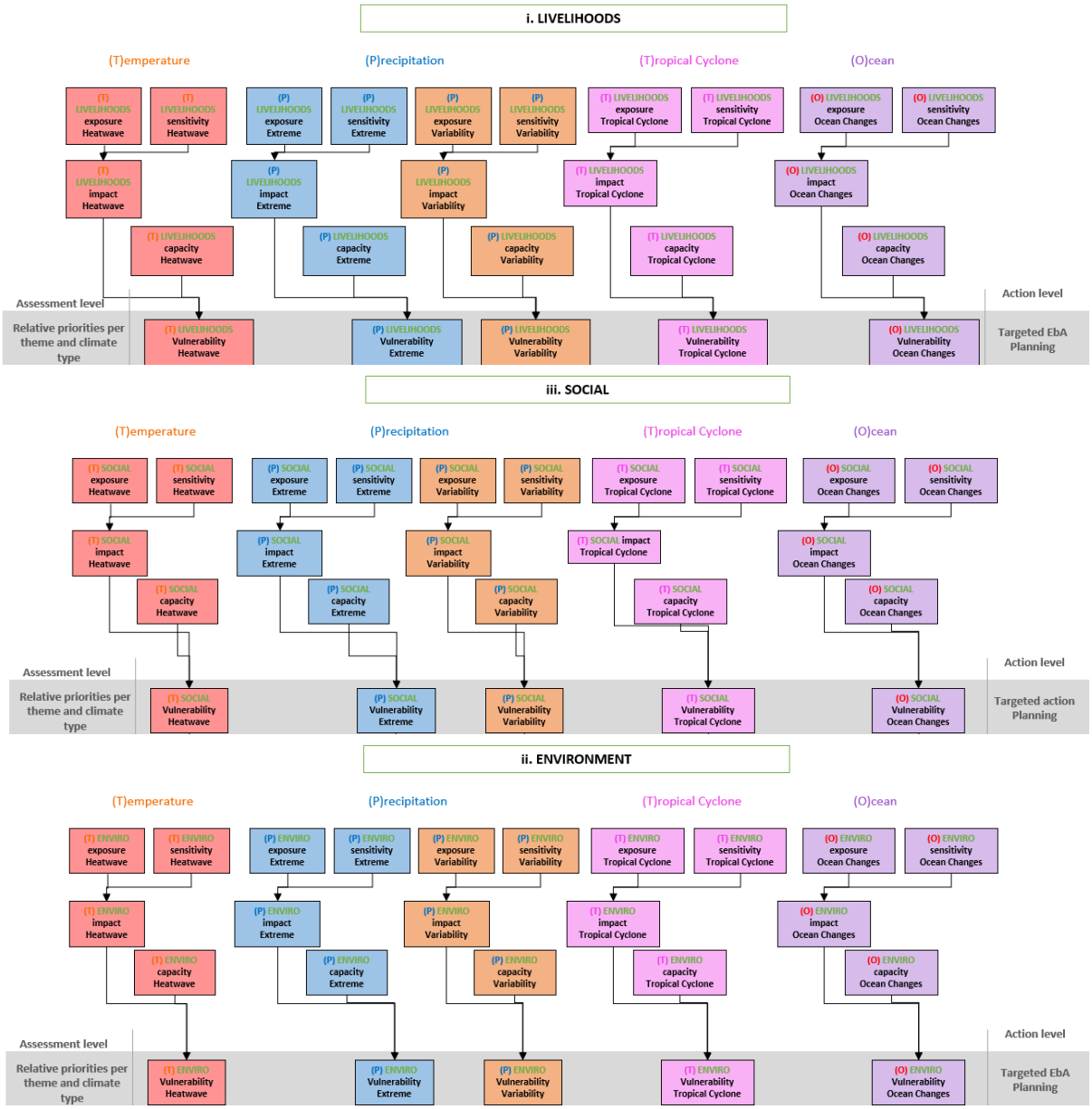


Figure 62. Structure of the CCVA for each of the critical key elements and the climate hazards

The approach results in five climate hazard outputs for each of the three elements or 15 CCVAs in total. This level of detail allows for tangible intervention on the ground for specific hazards rather than for generic climate (all-encompassing) vulnerability. These 15 CCVAs are combined by element to present three sector-level vulnerabilities and are combined again to present one over all climate vulnerability. This approach allows for differential engagement with the CCVA based on the decision-makers.

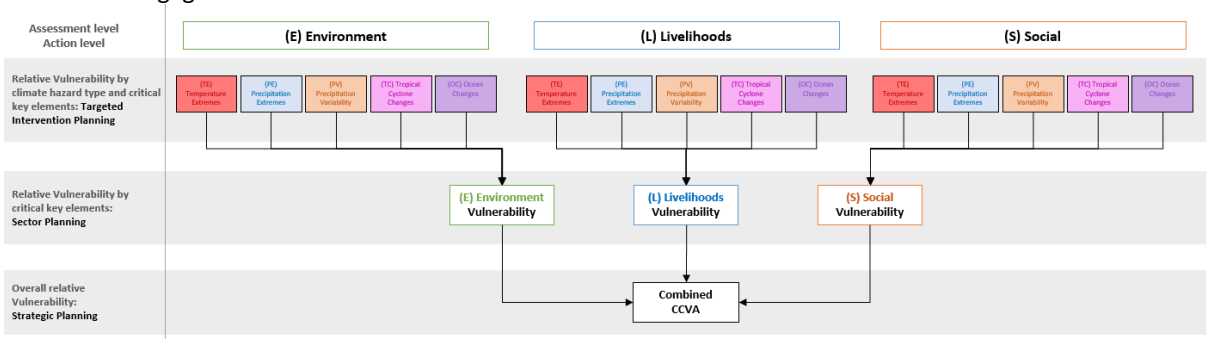


Figure 63. The different levels of CCVA output. Targeted Intervention Planning (top), Sector Planning (middle), and Strategic Planning (bottom)

5.2. Critical key criteria

5.2.1. Environment

Geology and topography

The coastal areas in the north and west of the Yucatán Peninsula are low-lying, sandy and semi-arid while the east coast is characterised by bluffs, bays and numerous islands[124]. The largest and most developed of these islands are Cozumel and Isla Mujeres[125]. The peninsula is composed predominantly of coralline and porous limestone rock beds which form a landscape that rises gradually from north to south, and there are numerous sinkholes and caverns across the landscape[126]. The geography of the three states that comprise the Yucatán Peninsula is varied but has common features. Across the peninsula, there are more than 2000 water-filled sink holes (*cenotes*) where seawater intrudes into freshwater aquifers, creating dense mangrove ecosystems. Campeche state is characterised by low-lying limestone plains, with rivers in the humid southern parts and hills in the arid north while Quintana Roo has numerous *cenotes* and limestone caves[127]. Yucatán State also has numerous *cenotes* along its limestone lowlands, as well as coastal wetlands, semi-arid hills and plains[128]. Along the entire coastline of the peninsula, there are numerous beaches, with the most popular tourism beaches being those at Cancún in the northeast[129].

Ecosystems (terrestrial, freshwater, and marine)

Mexico is considered one of the world's most biodiverse countries in the world[130] and the Yucatán Peninsula has a wide variety of diverse ecosystems, including tropical rainforests, tropical reefs, mangroves (including *petenes*), dunes, *cenotes* and other ecosystems related to its limestone geography (including caves and subterranean rivers)[131]. The three states that comprise the peninsula essentially share one common ecosystem — the great Mayan Forest which covers approximately 13 million hectares[132]. The peninsula has the largest remaining area of tropical forest in Mexico and therefore has significant cultural and environmental value[133]. Western Campeche receives sufficient rainfall to support the growth of forests with species such as *inter alia* mahogany, sapodilla, vanilla, and logwood[134]. The lagoons across the peninsula as well as much of the seaboard are fringed by logwood forests[135]. The Yucatán Peninsula is home to numerous species of animals, including mammals such as monkeys, manatees, deer and wild boar, as well as reptiles such as snakes and iguanas[136]. The Peninsula is home to the most important population of jaguars in Mexico[137], as well as numerous rare and endangered species. These include the white-lipped peccary, the tapir and howler monkey[138]. In some areas, such as the Bay of Campeche, crocodiles and turtles are common[139]. The peninsula also hosts a wide variety of bird species, including turkeys, quails and parrots[140], as well as rare species such as the scarlet macaw and harpy eagle[141].

Along the coastline of the Yucatán Peninsula, there are five subtypes of biomes that can be distinguished. These include[142]: i) the coastline itself, with seagrass vegetation and macroalgae; ii) beaches and shoal, with coastal dune vegetation; iii) savannah and medium-flooded forest, with tulles and aquatic vegetation; iv) tropical low deciduous forests; and v) swamps, with coastal lagoons, temporary wetlands, grasslands, and mangroves. The Yucatán Peninsula holds large areas of coastal wetlands, particularly mangrove forests which are critical for their ecological importance. The peninsula contains approximately 55% of the mangroves in Mexico (~423,700 ha). Of this total, Yucatan State contains 99,640 ha[143]. Mangroves provide critical ecosystem services, including control of coastal erosion, regulation of water quality and providing a buffer against wave action caused by tropical cyclones[144]. The peninsula's coastal wetlands are furthermore critical habitats and breeding grounds for fish, lobster and shrimp, and support numerous species of bird — including pink flamingo, wood stork, pelican, roseate spoonbill, white ibis and several types of herons[145]. As noted above, the peninsula is characterised by

[124] Britannica. No date. Yucatán Peninsula. Available here.
[125] Britannica. No date. Yucatán Peninsula. Available here.
[126] Britannica. No date. Yucatán Peninsula. Available here.
[127] Britannica. No date. Campeche. Available here.
[128] Britannica. No date. Yucatán. Available here.
[129] Britannica. No date. Yucatán Peninsula. Available here.
[130] TNC. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. Available here.
[131] Panorama. 2022. Harnessing the power of AI and community centred approaches to monitor Jaguars in the Yucatan Peninsula. Available: here.
[132] TNC. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. Available here.
[133] TNC. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. Available here.
[134] Britannica. No date. Yucatán Peninsula. Available here.
[135] Britannica. No date. Yucatán Peninsula. Available here.
[136] Britannica. No date. Yucatán Peninsula. Available here.
[137] Panorama. 2022. Harnessing the power of AI and community centred approaches to monitor Jaguars in the Yucatan Peninsula. Available: here.
[138] TNC. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. Available here.
[139] Britannica. No date. Campeche. Available here.
[140] Britannica. No date. Yucatán Peninsula. Available here.
[141] TNC. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. Available here.
[142] Sampedro, E.B., The Mangroves: Characterisation and environmental services. Available here.
[143] Sampedro, E.B., The Mangroves: Characterisation and environmental services. Available here.
[144] Sampedro, E.B., The Mangroves: Characterisation and environmental services. Available here.
[145] Sampedro, E.B., The Mangroves: Characterisation and environmental services. Available here.

several thousand *cenotes* that support highly productive wetland ecosystems and provide habitat for numerous bird, fish and amphibian species[146].

The mangroves of the Yucatán Peninsula are also important carbon sinks as mangroves are carbon-dense[147]. Studies have shown that mangroves along the coastal areas of the peninsula, particularly those associated with groundwater and 'cenotes' described above, have carbon stocks exceeding 1000 Mg C ha^{-1}. [148] In some sites, such as in Casa Cenote, values of up to 2792 Mg C ha^{-1} were measured. This is the result of deep soils that have been preserved over millennia and high soil carbon content of greater than 38%[149]. Mangroves in the Yucatán Peninsula are highly productive and have biological and hydrological characteristics that enable high root productivity and allow them to accumulate vertically, thereby keeping pace with historical sea level rise that has occurred periodically over the past millennia[150]. However, at exceptionally high and rapid rates of SLR, these mangroves could inhibit the capacity of Yucatán's mangroves to adapt.

Ecosystem degradation

The peninsula's ecosystems have rapidly deteriorated in recent decades as a result of anthropogenic pressures and climate change. At present, 80% of the rainforests are degraded, and only 22% of the peninsula's total area contains mature vegetation. Most of this vegetation is concentrated in protected areas[151]. The primary challenges currently facing ecosystems in the Yucatán Peninsula are land-use change, biodiversity loss and vulnerability to extreme events such as tropical cyclones, flooding, and forest fires[152].

It is estimated that the forests of the Yucatán Peninsula lose approximately 80,000 hectares per year as a result of expanding crop and livestock agriculture[153].

Tourism and urban development have also adversely impacted mangroves over the past 30 years, particularly in Yucatán State[154]. These developments included the construction of roads, which affected water flows into mangroves, as well as harbours and ports which caused direct damage to these areas[155]. While protected areas have been successful at reducing ecosystem degradation, deforestation has continued rapidly outside of these areas[156]. The exceptionally large carbon stocks of Yucatán's mangroves are therefore also threatened, which has adverse impacts not only on their potential for adaptation but also for mitigation.

Water

The Yucatán Peninsula has one of the largest karst aquifer systems in the world, with a total area of permeable limestone covering approximately 165,000 km^2.[157] With the exception of some southern parts of the peninsula, there are no natural lakes or surface-level rivers flowing overland in the peninsula, and most of the water is located in subterranean rivers and lagoons. The peninsula's water supply is dependent predominantly on this system, and groundwater is the main source of water for domestic and agricultural use[158]. Indeed, approximately 90% of the water supply is derived from this source and it under pins the demographic and economic growth of the region[159]. Between 1961–2000, groundwater recharge was approximately 118 ± 33mm·$year^{-1}$, representing 10% of the total precipitation[160]. In the north of the peninsula, the main water supply for crops and livestock is the deep grottoes in the Puuc hills[161].

5.2.2. Livelihoods

Livelihood activities in the Yucatán Peninsula (YP) are diverse and have evolved over millennia[162]. These activities occur on an economic spectrum from subsistence to commercial (including semi-commercial), as well as a spatial

[146] Adame, M.F., Santini, N.S., Torres-Talamante, O. and Rogers, K., 2021. Mangrove sinkholes (cenotes) of the Yucatan Peninsula, a global hotspot of carbon sequestration. *Biology letters*, *17*(5), p.20210037.
[147] Adame, M.F., Santini, N.S., Torres-Talamante, O. and Rogers, K., 2021. Mangrove sinkholes (cenotes) of the Yucatan Peninsula, a global hotspot of carbon sequestration. *Biology letters*, *17*(5), p.20210037.
[148] Adame, M.F., Santini, N.S., Torres-Talamante, O. and Rogers, K., 2021. Mangrove sinkholes (cenotes) of the Yucatan Peninsula, a global hotspot of carbon sequestration. *Biology letters*, *17*(5), p.20210037.
[149] Adame, M.F., Santini, N.S., Torres-Talamante, O. and Rogers, K., 2021. Mangrove sinkholes (cenotes) of the Yucatan Peninsula, a global hotspot of carbon sequestration. *Biology letters*, *17*(5), p.20210037.
[150] Adame, M.F., Santini, N.S., Torres-Talamante, O. and Rogers, K., 2021. Mangrove sinkholes (cenotes) of the Yucatan Peninsula, a global hotspot of carbon sequestration. *Biology letters*, *17*(5), p.20210037.
[151] Panorama. 2022. Harnessing the power of AI and community centred approaches to monitor Jaguars in the Yucatan Peninsula. Available: here.
[152] Panorama. 2022. Harnessing the power of AI and community centred approaches to monitor Jaguars in the Yucatan Peninsula. Available: here.
[153] TNC. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. Available here.
[154] Sampedro, E.B., The Mangroves: Characterisation and environmental services. Available here.
[155] Sampedro, E.B., The Mangroves: Characterisation and environmental services. Available here.
[156] TNC. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. Available here.
[157] Adame, M.F., Santini, N.S., Torres-Talamante, O. and Rogers, K., 2021. Mangrove sinkholes (cenotes) of the Yucatan Peninsula, a global hotspot of carbon sequestration. *Biology letters*, *17*(5), p.20210037.
[158] Rodríguez-Huerta, E., Rosas-Casals, M. and Hernández-Terrones, L.M., 2020. A water balance model to estimate climate change impact on groundwater recharge in Yucatan Peninsula, Mexico. *Hydrological Sciences Journal*, *65*(3), pp.470-486. Available here.
[159] Rodríguez-Huerta, E., Rosas-Casals, M. and Hernández-Terrones, L.M., 2020. A water balance model to estimate climate change impact on groundwater recharge in Yucatan Peninsula, Mexico. *Hydrological Sciences Journal*, *65*(3), pp.470-486. Available here.
[160] Rodríguez-Huerta, E., Rosas-Casals, M. and Hernández-Terrones, L.M., 2020. A water balance model to estimate climate change impact on groundwater recharge in Yucatan Peninsula, Mexico. *Hydrological Sciences Journal*, *65*(3), pp.470-486. Available here.
[161] Britannica. No date. Yucatán Peninsula. Available here.
[162] Schneider, M.A.L., and Haller, T. 2017. *A Region Under Threat? Climate Change Impacts, Institutional Change and Response of Local Communities in Coastal Yucatán*. In Filho, W.L., and Keenan, J.M. (eds). Climate Change Adaptation in North America, Climate Change Management, p. 161-177. [Online]. Available: https://doi.org/10.1007/978-3-319-53742-9_10

continuum of micro/small-scale, to large-scale/extensive. Unless indicated otherwise, 'livelihoods' or 'livelihood activities' should be taken to mean small-scale, semi-commercial, or subsistence livelihood activities that are climate-sensitive, i.e., they are exposed to climate hazards and are expected to become increasingly marginal/unviable under future climate changes. The focus of this analysis is therefore on livelihoods that rely on the terrestrial, aquatic, and coastal/marine natural resource base.

Figure 64 highlights the various landcover classes and vegetation types that comprise the YP, indicating the diversity of the abovementioned resource base that supports livelihood activities.

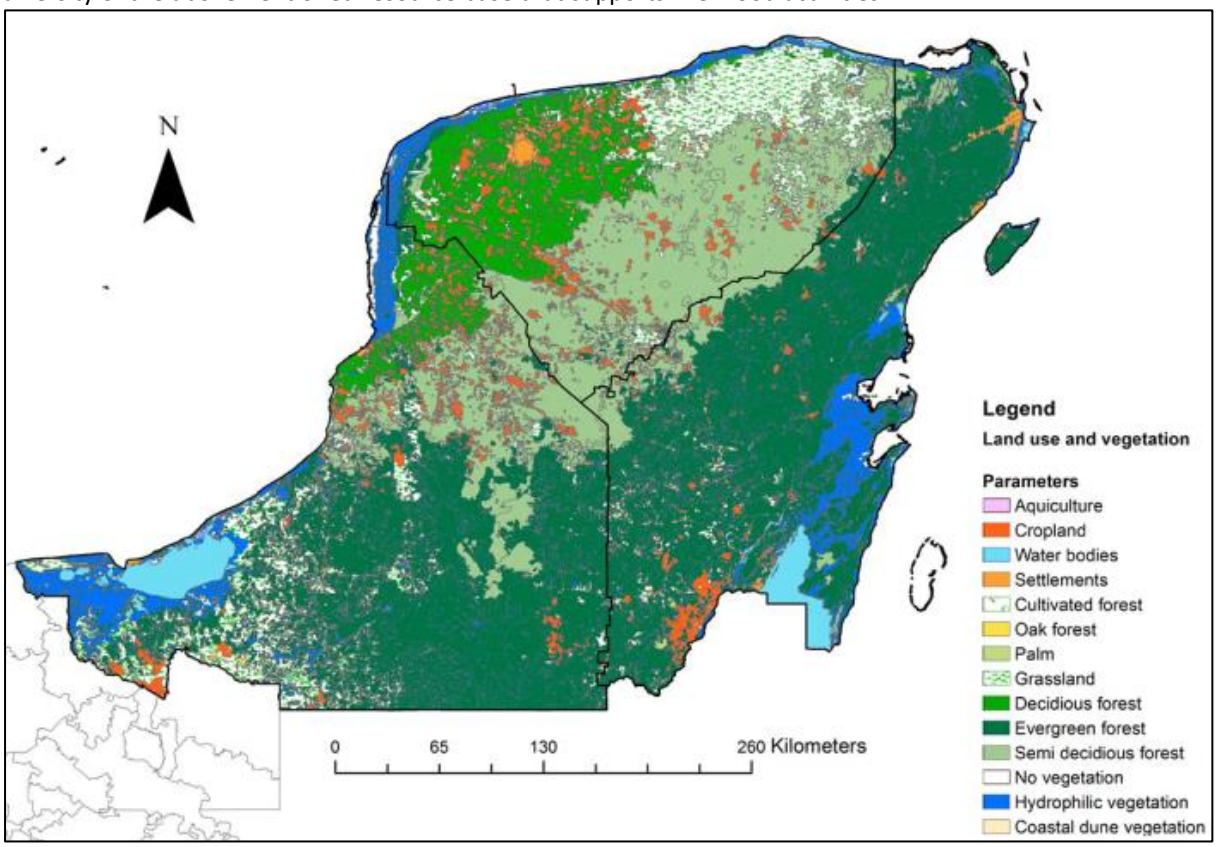


Figure 64. Landcover classes and vegetation types of the Yucatán Peninsula in 2015[163]

The predominant natural vegetation types of Yucatán are short and tall tropical jungle plants. Like the climate zones, the vegetation zones are in transition in the study area, from evergreen forest in the east to semideciduous forest in the west. The natural vegetation in the dryer climate consists of tropical dry forests, which can reach a height of 18-25 m. In the mid-20th century, commercially important forests (such as cedar and mahogany) and hardwoods dominated in that area, but these are increasingly scarce[164].

In rural areas of the YP, communities adopt a variety of livelihood strategies that are closely linked to the prevailing land tenure and social organization structures of the region. Tenure and organization are based largely on the *ejido*[165] system where members are given usufruct[166] rights to plots of agricultural land and communal rights to non-agricultural land, i.e., forest and pasture. Sub-structures of land tenure under the *ejido* system include — among others — *avecindados*, *posesionarios* or *comuneros*, *ejidatarios*, the leaders of *ejido* committees or rural cooperatives and private landowners[167]. Figure 65 shows the interrelationship of the abovementioned tenure systems and livelihood profiles, including capital and asset accumulation.

[163] Based on INEGI Series V (2015) and excerpted from: Balderas Torres, A., Skutsch, M., and de los Rios Ibarra, E. 2020. *Pro-poor analysis of REDD+ activities in the Yucatan Peninsula, Mexico*. Technical Series: Forest Governance and Economics, No. 8. San Jose, Costa Rica: IUCN and CIGA. [Online]. Available: https://doi.org/10.2305/IUCN.CH.2020.19.en

[164] Schneider, M.A.L., and Haller, T. 2017. *A Region Under Threat? Climate Change Impacts, Institutional Change and Response of Local Communities in Coastal Yucatán*. In Filho, W.L., and Keenan, J.M. (eds). Climate Change Adaptation in North America, Climate Change Management, p. 161-177. [Online]. Available: https://doi.org/10.1007/978-3-319-53742-9_10

[165] The structure of the *ejido* is democratic and members are either signatories to the act of establishment (*certificados*) or are their descendants (*usufructuarios*).

[166] A usufruct is a legal right accorded to a person or party that confers the temporary right to use and derive income or benefit from someone else's property.

[167] Balderas Torres, A., Skutsch, M., and de los Rios Ibarra, E. 2020. *Pro-poor analysis of REDD+ activities in the Yucatan Peninsula, Mexico*. Technical Series: Forest Governance and Economics, No. 8. San Jose, Costa Rica: IUCN and CIGA. [Online]. Available: https://doi.org/10.2305/IUCN.CH.2020.19.en

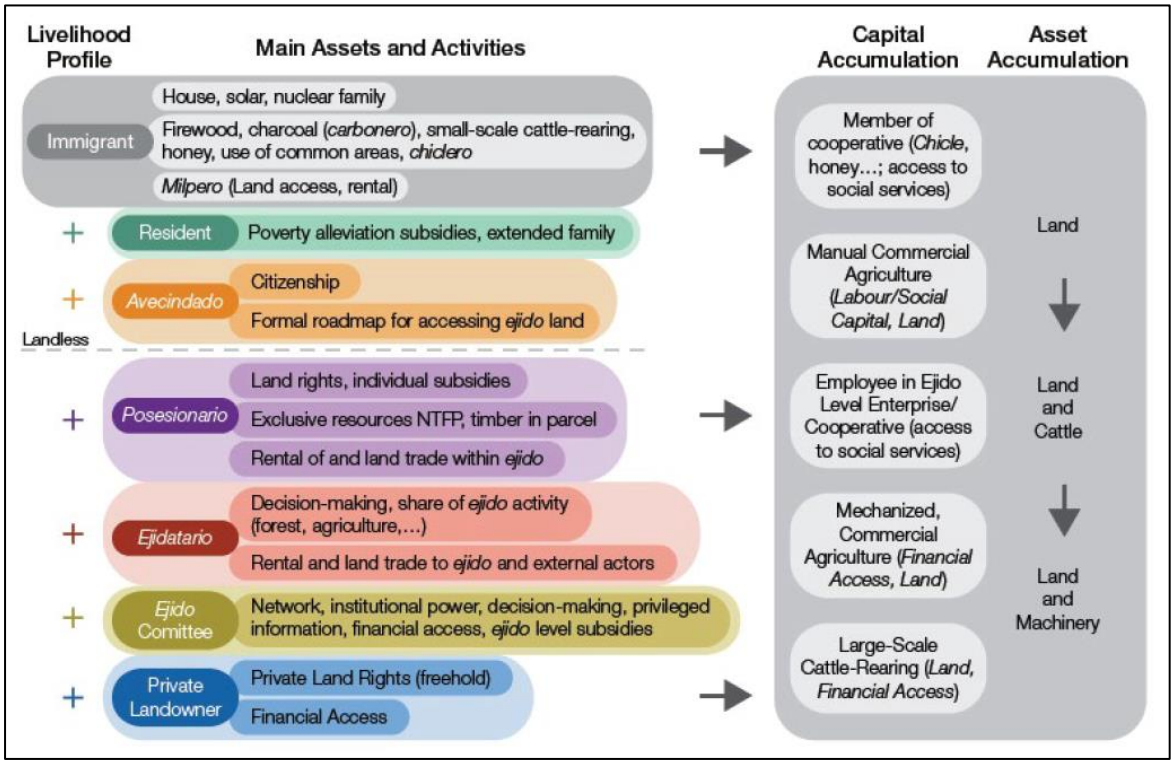


Figure 65. Different livelihood profiles, activities, and assets in the Yucatán Peninsula[168]

The following sections, grouped thematically, provide a succinct description of the main activities that underpin livelihoods in the YP.

Agriculture and agroforestry

Small-scale agriculture and agroforestry, dating back to at least 2000 B.C.[169], play significant roles in the Yucatán Peninsula, contributing to local food production, livelihoods, and the preservation of traditional farming practices. While the region's fertile soils, favourable climate, and diverse ecosystems support a range of agricultural activities, small-scale and subsistence farmers are considered particularly vulnerable to climate change impacts in the region as they are experiencing intensification of climate variability, in combination with non-climatic forces which negatively impact the production of maize and other staple crops[170].

The indigenous Maya people practised extensively rather than intensive agroforestry by hunting and gathering in combination with *milpa* horticulture[171] (a form of agroforestry with high cultural significance[172]). *Milpa* is a rotational farming system that involves the cultivation of multiple annual crops, including maize, beans, squash, and chilli peppers in a single plot and can also include the integration of fruit trees into a fallow forest, beekeeping, and maintenance of forest corridors for hunting, wood, and conservation of native species[173]. The cultivation of these annual crops is complemented by a series of managed and enriched intermediate stages of short-term perennial shrubs and trees, culminating in the re-establishment of mature closed forest on the once-cultivated plot[174,175]. The establishment of tree species like mahogany, cedar, or *ramón* alongside food crops, provides shade, improves soil fertility, and diversifies income sources through the sale of timber and/or non-timber forest products[176]. Increasingly lucrative beef and timber markets and the resultant deforestation pressures in the 20th and 21st centuries have threatened the viability of the *milpa* cultural landscape and tropical

[168] Excerpted from: Balderas Torres, A., Skutsch, M., and de los Rios Ibarra, E. 2020. *Pro-poor analysis of REDD+ activities in the Yucatan Peninsula, Mexico*. Technical Series: Forest Governance and Economics, No. 8. San Jose, Costa Rica: IUCN and CIGA. [Online]. Available: https://doi.org/10.2305/IUCN.CH.2020.19.en
[169] Pool, N., Gauthier, R., and Mizrahi, A. 2007. Rural poverty in Mexico: assets and livelihood strategies among the Mayas of Yucatán. *International Journal of Agricultural Sustainability*, 5(4) p.315-330. [Online]. Available: https://doi.org/10.1080/14735903.2007.9684831
[170] Mardero, S., Schmook, B., Lopez-Matinez, J.O., Cicero, L., Radel, C., and Christman, Z. 2018. The Uneven Influence of Climate Trends and Agricultural Policies on Maize Production in the Yucatan Peninsula, Mexico. *Land*, 7(80): p.1-20. [Online]. Available: https://doi.org/10.3390/land7030080
[171] Schneider, M.A.L., and Haller, T. 2017. *A Region Under Threat? Climate Change Impacts, Institutional Change and Response of Local Communities in Coastal Yucatán*. In Filho, W.L., and Keenan, J.M. (eds). Climate Change Adaptation in North America, Climate Change Management, p. 161-177. [Online]. Available: https://doi.org/10.1007/978-3-319-53742-9_10
[172] Pool, N., Gauthier, R., and Mizrahi, A. 2007. Rural poverty in Mexico: assets and livelihood strategies among the Mayas of Yucatán. *International Journal of Agricultural Sustainability*, 5(4) p.315-330. [Online]. Available: https://doi.org/10.1080/14735903.2007.9684831
[173] Varns, T., Cortez, R., Hovani, L., and Kingsbury, P. 2018. Yucatán Peninsula, Mexico: A Jurisdictional Approach to Conserving the Maya Forest. The Nature Conservancy, Arlington, VA, USA. [Online]. Available: https://www.researchgate.net/publication/327656009_Yucatan_Peninsula_Mexico_A_Jurisdictional_Approach_to_Conserving_the_Maya_Forest
[174] Meso-American Research Center. (2010). *Milpa Cycle*. [Online]. Available: https://www.marc.ucsb.edu/research/maya-forest-is-a-garden/maya-forest-gardens/milpa-cycle
[175] Food and Agriculture Organization of the United Nations (FAO). (2022). *Globally Important Agricultural Heritage Systems: Mayan milpa of the Yucatán Peninsula, Mexico*. [Online]. Available: https://www.fao.org/giahs/giahsaroundtheworld/designated-sites/latin-america-and-the-caribbean/milpa-maya-peninsular/en/
[176] Schneider, M.A.L., and Haller, T. 2017. *A Region Under Threat? Climate Change Impacts, Institutional Change and Response of Local Communities in Coastal Yucatán*. In Filho, W.L., and Keenan, J.M. (eds). Climate Change Adaptation in North America, Climate Change Management, p. 161-177. [Online]. Available: https://doi.org/10.1007/978-3-319-53742-9_10

ecosystem, which would be more resilient to fires, storms, and soil degradation than the current land use system[177].

More recently, alongside *milpa*, home gardens are still prevalent in the region. Home gardens are small-scale agricultural systems that incorporate diverse plant species, including fruit trees, vegetables, medicinal plants, and herbs. In this context, home gardens are socio-ecological agricultural production systems that involve diversified management of plants and animals for subsistence farming. Home gardens supply farmers with essential goods such as food, medicinal herbs, and timber, as well as occasional income from selling home garden products. The home gardens' contribution to the farmers' livelihoods is critical for marginalized communities[178]. Communities in the YP lowlands maintain a high diversity of plant species in their home gardens within a complex vertical and horizontal structure that mimics the natural ecosystem and often contains 300 to 500 species of plants and animals, where farmers combine practices for soil management, nutrient conservation, and water and crop protection[179].

Agricultural and agro-forestry livelihood activities hinge on the prevailing land tenure[180]. Five distinct land tenure arrangements are recognised in the YP: i) the home garden, or *solar*, is private land and produce can be sold without constraint; ii) the *milpa* is *ejido* land, primarily for maize cultivation[181], *milpa* is effectively private land; iii) *caña* (or *cañada*) is *milpa* but only after one year of cultivation and is, therefore, less productive[182], iv) *parcela*, where communities set aside private land for agroforestry; and v) communal forest land, where fuelwood, timber and non-timber forest products (NTFPs) can be collected for private use but the community assembly must agree to the commercial use of any forest products[183].

Beekeeping

Beekeeping, also known as apiculture, has been and remains an important activity in Mexico and especially the Yucatán Peninsula (YP), dating back to the indigenous Mayan civilization[184]. The use of honey in the Mayan culture extended to medicine, where remedies for ear-, eye-, and throat-related illnesses were treated using honey and honey by-products[185]. Nationally, beekeeping is practised by more than 40,000 producers in Mexico, who have around two million hives in apiaries distributed in the country's five beekeeping regions[186]. The average annual demand per apiary is approximately USD 125,000 of labour in its primary production phase, representing an important source of jobs and income from salary payments in rural areas[187].

The YP is arguably the apicultural heartland of Mexico as the region's diverse ecosystems — including tropical forests, savannas, and agricultural areas — provide an ideal environment for beekeeping and support a variety of bee species. The YP's bees have access to a variety of flowering plants, including tropical fruit trees, wildflowers, and *Melipona beecheii's*[188] preferred food source, the *nance* tree (*Byrsonima spp*., Figure 66), contributing to the distinct flavours and characteristics of the region's honey. Beekeeping not only supports community livelihoods but also provides important ecosystem services. Bees are key pollinators that facilitate the reproduction of many plant species, including agricultural crops and wild plants. Their pollination services support biodiversity and enhance agricultural productivity.

[177] *Ibid.*
[178] Neulinger, K., Vogl, C.R., and Alayõn-Gamboa, J.A. 2013. Plant species and their uses in home gardens of migrant Maya and mestizo smallholder farmers in Calakmul, Campeche, Mexico. *Journal of Ethnobiology*, 33 (1): p. 105-124. [Online]. Available: https://doi.org/10.2993/0278-0771-33.1.105
[179] *Ibid.*
[180] Refer also to Figure 65 for a detailed overview of the land tenure-livelihood nexus in the region.
[181] For which there is a government subsidy of about ~USD 650 per hectare per year.
[182] *Caña* attracts a slightly lower per hectare government subsidy of ~USD 550 per hectare per year.
[183] Pool, N., Gauthier, R., and Mizrahi, A. 2007. Rural poverty in Mexico: assets and livelihood strategies among the Mayas of Yucatán. *International Journal of Agricultural Sustainability*, 5(4) p.315-330. [Online]. Available: https://doi.org/10.1080/14735903.2007.9684831
[184] Echazarreta, C.M., Quezada-Euán, J.J.G, Medina, L.M., and Pasteur, K.L. 1997. Beekeeping in the Yucatan peninsula: development and current status. *Bee World*, 78 (3), p. 115-127. [Online]. Available: https://doi.org/10.1080/0005772X.1997.11099346
[185] *Ibid.*
[186] That is, the North, Centre and Altiplano, Pacific, Gulf, and the Yucatán Peninsula.
[187] Pool, N., Gauthier, R., and Mizrahi, A. 2007. Rural poverty in Mexico: assets and livelihood strategies among the Mayas of Yucatán. *International Journal of Agricultural Sustainability*, 5(4) p.315-330. [Online]. Available: https://doi.org/10.1080/14735903.2007.9684831
[188] Commonly known as stingless bees.

Figure 66. Melipona beecheii (A)[189] and Byrsonima crassiflora (B)[190]

There are over 130 species of native bees in the YP, however, only a few are social and can be kept in traditional log hives. Amongst the most important of these is *Melipona beecheii* which build blister-like sacks of honey, and comb inside hollow trunks, which can be cut from the tree and sealed at either end with a wooden disc and mud, to be kept domestically[191]. These traditional log hives are placed in natural settings, allowing bees to forage in the surrounding areas and collect nectar from a wide range of floral sources. Managed hives, including Langstroth and top-bar hives, are also used for European honeybees[192]. While relatively small quantities of honey are harvested in this way (around 0.25–1 litre per colony per year)[193], the YP region is nationally significant since it contributes ~95% of Mexico's honey exports, while accounting for only 30 to 35% of the total number of Mexican bee colonies[194].

Following World War II, Yucatan's honey export market boomed based largely on the efforts of a New York-based trading company which was actively pursuing honey as a means to compensate for the sugar shortages in the United States of America[195]. This injection of foreign capital alongside the initiatives of local entrepreneurs established honey production as a major economic activity in Yucatán during this period where large-scale, capital-intensive apicultural enterprises of the elite gave way to a proliferation of small-scale, labour-intensive peasant operations. This scenario prevailed to the extent that commercial honey production in the YP is now largely controlled by peasant farmers[196].
Beekeepers in the YP are socioeconomically stratified with two main groups emergent: i) one that represents 95% of the producers and is made up of low-income peasants (mostly indigenous) who own 80% of the apiaries; and ii) the second group comprised of medium-sized beekeepers and fully integrated businessmen, who have modern technology and market honey products as their main economic activity[197].

Fishing

The waters of the Maya region, i.e., the Yucatán Peninsula (YP), are characterised by the presence of a high biological diversity of fish species, including commercially important species such as snapper, grouper, tarpon, snook, and many others. Mangroves, lagoons, and estuaries are particularly important habitats for subsistence fishing in the region, especially in the northern coastal parts of the region which are characterised by the presence of marshland and flood lands, especially during the rainy season from June to October[198]. These areas provide nursery grounds for many fish species and support the overall health of the marine ecosystem.

Like beekeeping, agriculture and agroforestry, subsistence fishing in the YP is deeply rooted in the cultural heritage of the region. Fish were undoubtedly important for the region's ancient coastal societies, with fish

[189] Mexico Ambiental. 2020. *The Mayan sacred bee, endemic to Yucatan*. [Online]. Available: https://www.mexicoambiental.com/abeja-melipona-melipona-beecheii-la-abeja-sagrada-maya-endemicas-de-yucatan/
[190] Trade Winds Fruit. 2013. *Fruit Database*. [Online]. Available: https://www.tradewindsfruit.com/content/nance.htm
[191] Echazarreta, C.M., Quezada-Euán, J.J.G, Medina, L.M., and Pasteur, K.L. 1997. Beekeeping in the Yucatan peninsula: development and current status. *Bee World*, 78 (3), p. 115-127. [Online]. Available: https://doi.org/10.1080/0005772X.1997.11099346
[192] *Ibid.*
[193] *Ibid.*
[194] Martínez-Puc, J.F., Cetzal-Ix, W., González-Valdivia, N.A., Casanova-Lugo, F., and Saikat-Kumar, B. (2018). Characterization of beekeeping activity in the main municipalities of honey production in Campeche, Mexico. *Journal of the Selva Andina Animal Science*, 5 (1): p.44-53. [Online]. Available: http://www.scielo.org.bo/scielo.php?pid=S2311-25812018000100006&script=sci_abstract&tlng=en
[195] Echazarreta, C.M., Quezada-Euán, J.J.G, Medina, L.M., and Pasteur, K.L. 1997. Beekeeping in the Yucatan peninsula: development and current status. *Bee World*, 78 (3), p. 115-127. [Online]. Available: https://doi.org/10.1080/0005772X.1997.11099346
[196] *Ibid.*
[197] Martínez-Puc, J.F., Cetzal-Ix, W., González-Valdivia, N.A., Casanova-Lugo, F., and Saikat-Kumar, B. (2018). Characterization of beekeeping activity in the main municipalities of honey production in Campeche, Mexico. *Journal of the Selva Andina Animal Science*, 5 (1) p.44-53. [Online]. Available: http://www.scielo.org.bo/scielo.php?pid=S2311-25812018000100006&script=sci_abstract&tlng=en
[198] Jiménez Cano, N.G., and Sosa, T.S. 2015. Fishing in the northern Maya lowlands AD 250–750: preliminary analysis of fish remains from Xcambo, Yucatan, Mexico. *Environmental Archaeology*, 21(2), p.172-181. [Online]. Available: https://doi.org/10.1080/14614103.2015.1118176

remains consistently found in excavations of several pre-Hispanic Maya settlements, where fishing was a local subsistence activity that helped to meet the dietary needs of the ancient villagers[199].

Campeche has an old fisheries tradition with 3,904 boats, of these 96.89% constitute the artisanal fleet with about 12,100 formal and informal fishers. In the coastal zone, there are eight primary fishery sites: Isla Arena, Campeche, Lerma, Seybaplaya, Champoton, Sabancuy, Isla Aguada, and Ciudad del Carmen, reporting 7,428 formal fishers in 2015, with a total catch of 55,664 tons that year[200].
At the national level, Campeche's fisheries are eighth by volume and value and represent 2.73% of the national production. Yucatan's fisheries tradition is more recent, dating from the mid-1940s. The state has a semi-industrial fleet with 549 ships or boats and an artisanal fleet with 4,654 boats, 14,955 formal fishers and about 50% more informal fishers. Yucatan's fisheries are in 13th place by volume and sixth by economic value on the national level, with 48,213 tons per year representing 2.24% of national production[201].

Regarding economically important species, Mexico has the third-largest octopus fishery in the world. The octopus fishery yields between 9 000 and 21 700 metric tons per year in the Yucatán Peninsula alone, making it arguably the most economically important marine livelihood activity in the region, particularly from a commercial perspective [202]. The fishery consists of two primary species, the Maya octopus *(Octopus maya)* and the common octopus *(Octopus vulgaris)*. The non-migratory Maya octopus (Figure *67*) lives exclusively on the seafloor off the coastal states of Yucatán, Quintana Roo, and Campeche, so all Maya octopus sold in the world comes from this fishery[203]. In 2018, Mexico exported more than 11,700 metric tons of octopus, worth USD 94 million.

Figure 67. Mexican Four-eyed Octopus (Octopus maya)[204].

Around 90% of the fishers in the states of Yucatán and Campeche — about 15,000 in total — fish for Maya octopus[205]. Fishers in Quintana Roo also target the Maya octopus, though to a lesser extent than in Yucatán and Campeche. A total of 3,225 small-scale vessels and 344 large vessels are permitted to fish for octopus in these three states. Underpinning the fishery are infrastructural investments in warehouses, ice factories, and dedicated octopus processing facilities that provide employment beyond fishing. In addition to bringing in revenue, the Maya octopus is also a highly valued food for locals.

To a lesser extent, inland fishing is also practised in the YP. Inland fishing is artisanal and subsistence in nature with handlines being the main gear utilized, primarily through barefoot fishing along the shores of limestone-based water bodies, or with the aid of rafts and canoes[206]. In addition to the subsistence benefits of inland fishing, this activity also plays an important cultural and recreational role as part of social reciprocity networks in communally owned land (*ejidos*)[207], beliefs that reflect the close relationship between these communities and the natural environment. Much like many coastal regions around the world, subsistence fishing in the YP faces challenges and pressures. The rapid growth of tourism and commercial fishing, as well as environmental issues

[199] *Ibid.*
[200] Pedroza-Gutiérrez, C., Vidal-Hernández, L., and Rivera-Arriaga, E. 2021. Adaptive governance and coping strategies in the Yucatan Peninsula coasts facing COVID-19. *Ocean and Coastal Management* 212 (1), p. 1-11. [Online]. Available: https://doi.org/10.1016/j.ocecoaman.2021.105814
[201] *Ibid.*
[202] Porterfield, E., Valentine, M., Mustain, P., and Lowell, B. 2022. *Fishing for Trouble: Loopholes put illegally caught seafood on American's plates*. Oceana. [Online]. Available: https://usa.oceana.org/wp-content/uploads/sites/4/IUU-21-0013-SIMP-Report_m1_DIGITAL_SPREADS84.pdf
[203] *Ibid.*
[204] Octolab.tv. 2023. Mexican Four-Eyed Octopus Facts. [Online]. Available: https://octolab.tv/mexican-four-eyed-octopus/
[205] Porterfield, E., Valentine, M., Mustain, P., and Lowell, B. 2022. *Fishing for Trouble: Loopholes put illegally caught seafood on American's plates*. Oceana. [Online]. Available: https://usa.oceana.org/wp-content/uploads/sites/4/IUU-21-0013-SIMP-Report_m1_DIGITAL_SPREADS84.pdf
[206] Arce-Ibarra, A.M., and Charles. A. 2008. Non-management of Natural Resources: The Case of Inland Fisheries in the Mayan Zone, Quintana Roo, México. *Human Ecology*, 36, p.853-860. [Online]. Available: https://doi.org/10.1016/j.fishres.2007.11.015
[207] *Ibid.*

such as overfishing and habitat degradation, have had an impact on marine resources and ecosystems. These factors can affect the availability of fish and disrupt the delicate balance of the local ecosystem, potentially threatening the livelihoods of subsistence fishermen[208].

Tourism

The Yucatan Peninsula is renowned for its cultural and historical attractions — a tourist field survey undertaken in Quintana Roo by the World Bank in 2020 found that more than 80 percent of tourists were interested in visiting archaeological sites and carrying out activities related to them[209].
The ancient Mayan ruins of Chichen Itza, Tulum, Uxmal, and many others attract visitors interested in exploring the region's rich archaeological heritage. The colonial cities of Merida and Campeche offer well-preserved architecture, vibrant markets, and traditional festivals that provide insights into the region's colonial history and indigenous cultures.

In Campeche, impressive architectural relics from the Mayan culture remain, dating back to the Late Pre-Classic (200 B.C.) and the Late Classic (A.D. 800) periods when the region was probably densely populated[210]. Although Yucatan and Campeche are internationally known for their tourist attractions related to the Mayan archaeological zones and colonial sites, both states have developed some common coastal attractions, including beachside holiday houses for local families that use them during holiday periods and alternative tourism businesses of small and medium size within coastal areas (e.g. hotels and restaurants, ecotourism or nature tourism, recreational fisheries and sport fishing); both as a result of local, national and international public policies to highlight the importance of their use and conservation[211].

In quantitative terms, tourism represents 8.7% of the national gross domestic product (GDP) mainly through the use of coastal areas where almost half of Mexico's population lives[212]. The tourist sector is critically important for livelihoods in the Yucatán Peninsula, representing 10.1% of the state's GDP, while 13.4% of the economically active population of the state and 10.5% of its companies are engaged in tourism[213]. Campeche's reliance on tourism mirrors the national ratio and provides 8.7% of the state's GDP.

There is a growing emphasis on sustainable and community-based tourism in the Yucatan Peninsula. Initiatives focus on promoting responsible tourism practices, supporting local communities, and preserving the region's natural and cultural heritage. A priority challenge for the Yucatán Peninsula's coastal areas is the lack of sustainability of the tourism model that has driven economic growth, particularly in Quintana Roo[214]. This represents an important case of an economy whose development has been led by the expansion of the tourist industry organized around the traditional model of the tourist enclave and beach resort concentration. Deteriorating environmental conditions and changing international trends combined with climate change threats have made this tradition obsolete as a model of industrial organization, and increasingly unreliable as an engine of sustainable development. Moreover, the model has excluded local populations, particularly indigenous households, from its economic benefits[215]. Encouraging the indigenous community's involvement in the various segments of the tourism supply chain, including agriculture, transportation, lodging, and tourism operations is seen as a critical measure to improve the sustainability of the tourism sector[216].

5.2.3. Social

Demography and population growth

The Yucatán Peninsula has a population of approximately 5.1 million (2020), with 2.3 million people living in Yucatán State, 1.8 million in Quintana Roo and 0.9 million in Campeche[217]. There is considerable regional variation in the population density of the peninsula[218]. The most densely populated area is in Yucatán State — specifically in Mérida municipality and its surrounding areas[219]. The least densely populated areas are in Quintana Roo, on the eastern side of the peninsula. The Yucatán Peninsula's population has grown steadily over

[208] Arce-Ibarra, A.M., and Charles. A. 2008. Non-management of Natural Resources: The Case of Inland Fisheries in the Mayan Zone, Quintana Roo, México. *Human Ecology*, 36, p.853-860. [Online]. Available: https://doi.org/10.1016/j.fishres.2007.11.015
[209] *Ibid.*
[210] Neulinger, K., Vogl, C.R., and Alayõn-Gamboa, J.A. 2013. Plant species and their uses in home gardens of migrant Maya and mestizo smallholder farmers in Calakmul, Campeche, Mexico. *Journal of Ethnobiology*, 33 (1), p. 105-124. [Online]. Available: https://doi.org/10.2993/0278-0771-33.1.105
[211] Pedroza-Gutiérrez, C., Vidal-Hernández, L., and Rivera-Arriaga, E. 2021. Adaptive governance and coping strategies in the Yucatan Peninsula coasts facing COVID-19. *Ocean and Coastal Management* 212 (1), p. 1-11. [Online]. Available: https://doi.org/10.1016/j.ocecoaman.2021.105814
[212] *Ibid.*
[213] *Ibid.*
[214] The World Bank Group. (2020). *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. [Online]. Available: https://openknowledge.worldbank.org/entities/publication/06495366-f675-5692-8272-587b3a93d538
[215] *Ibid*
[216] *Ibid.*
[217] DataMexico. Yucatán. Available here.
[218] Britannica. No date. Yucatán Peninsula. Available here.
[219] Britannica. No date. Yucatán Peninsula. Available here.

the past decades. Since 2010, the population of the three states has increased at different rates, by nearly 13% and 19% in Campeche and the Yucatán States, respectively[220]. During this period, Quintana Roo experienced the highest population growth rate in Mexico, with its population increasing by more than 40%[221]. Since the 1980s, the Yucatán Peninsula has experienced an increase in its total population of more than 100%, which is much higher than the national average of 77%[222].

Poverty and inequality

Although poverty exists across Mexico, the southern parts of the country have higher rates of poverty than those in the north[223]. The states of Chiapas, Guerrero and Qaxaca have an average poverty rate of nearly 70%, which is considerably higher than the national average[224]. In the Yucatán Peninsula, poverty rates are lower than the aforementioned states, but still among the highest in the country. For example, Campeche is one of the 10 poorest states in Mexico and has a poverty rate of 46.2% (2018)[225]. Yucatán State had a poverty rate of 48.9% in the same year[226]. Unemployment, however, is low and currently just below ~2% in all three states[227].

The low unemployment rate and relatively high population rate coincide with a high rate of informality in the peninsula, at approximately 60% of the workforce[228]. The high poverty rate in the region is also directly related to the fact that indigenous people in Mexico tend to be poorer than those Mexicans of non-indigenous decent. In terms of its ethnic composition, the Yucatán Peninsula has the largest indigenous population in North America and the highest percentage of indigenous language speakers in Mexico[229]. Most of the people living in the peninsula are of Mayan decent, or those with mixed Mayan and Spanish ancestry (referred to as *mestizo*)[230]. Indigenous Mexicans have often been marginalised politically, largely because many are monolingual and do not speak Spanish, Mexico's official language. However, not all Mayans are poor as some have benefited from social mobility over the past 20 years[231]. Poverty among the Maya, however, remains acute. In addition to cultural and linguistic factors, poverty in southern parts of Mexico is also influenced by the country's topography. In these areas, communities are often small (with fewer than 2,500 people) and isolated by mountain ranges[232]. This has led to limited investment in these areas, high expenses in service payments, low demand for goods and services, high cost of raw materials, and high taxation rates[233].

Food security

Alongside the large proportion of the population of the Yucatán Peninsula living in poverty, the challenge of food insecurity is also present across the peninsula. In Yucatán State, approximately 27% of households are moderate to severely food insecure, and only 6% of households can fully cover their needs from production exclusively under the *milpa* system[234]. As noted above, the *milpa* is swidden agriculture based on maize, beans and squash as main crops[235]. In areas where there are low average crop yields, the *milpa* system is particularly important for crop diversity and productivity compared to monocrops of beans or maize[236]. Overall, the commodification of food systems and decreased *milpa* production have increased the dependence on non-traditional and store-bought foods[237]. Although there has been an increase in the availability and diversity of many foodstuffs, a large proportion of the population is unable to afford these foods and ends up consuming a less diverse diet[238].

In many households, the staples grown through the *milpa* are complemented by home gardens, and in urban areas where other livelihood activities are practised, they contribute significantly to household food consumption where people often tend to consume a diet that is less diverse and nutritious[239]. Home gardens and traditional cropping systems such as *milpa* are important for improving food security and the nutritional diversity of food consumed by the population of the peninsula. Given that the production of diversified food is

[220] DataMexico. Yucatán. Available here.
[221] DataMexico. Yucatán. Available here.
[222] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[223] WorldAtlas. Available here.
[224] WorldAtlas. Available here.
[225] WorldAtlas. Available here.
[226] Castañeda-Navarrete, J., 2021. Home garden diversity and food security in southern Mexico. *Food Security*, *13*(3), pp.669-683.
[227] DataMexico. Yucatán. Available here.
[228] DataMexico. Yucatán. Available here.
[229] History.com. 2018. Yucatán. Available here.
[230] Britannica. No date. Yucatán Peninsula. Available here.
[231] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[232] DataMexico. Yucatán. Available here.
[233] DataMexico. Yucatán. Available here.
[234] Novotny, I.P., Tittonell, P., Fuentes-Ponce, M.H., López-Ridaura, S. and Rossing, W.A., 2021. The importance of the traditional milpa in food security and nutritional self-sufficiency in the highlands of Oaxaca, Mexico. *PloS one*, *16*(2), p.e0246281. Available here.
[235] Castañeda-Navarrete, J., 2021. Home garden diversity and food security in southern Mexico. *Food Security*, *13*(3), pp.669-683.
[236] Novotny, I.P., Tittonell, P., Fuentes-Ponce, M.H., López-Ridaura, S. and Rossing, W.A., 2021. The importance of the traditional milpa in food security and nutritional self-sufficiency in the highlands of Oaxaca, Mexico. *PloS one*, *16*(2), p.e0246281. Available here.
[237] Castañeda-Navarrete, J., 2021. Home garden diversity and food security in southern Mexico. *Food Security*, *13*(3), pp.669-683.
[238] Leatherman, T., Goodman, A.H. and Stillman, J.T., 2020. A critical biocultural perspective on tourism and the nutrition transition in the Yucatan. *Culture, Environment and Health in the Yucatan Peninsula: A Human Ecology Perspective*, pp.97-120.
[239] Castañeda-Navarrete, J., 2021. Home garden diversity and food security in southern Mexico. *Food Security*, *13*(3), pp.669-683.

already not sufficient at meeting the nutritional demands of the population, it is necessary to stimulate household production of diversified cropping systems and to increase crop yields[240]. In terms of food systems, there is a marked difference between the coastal and inland areas of the peninsula. In most coastal areas, foods are predominantly purchased from stores and vendors, while communities in inland areas depend more on *milpa.* The latter communities already supplement their diets with food bought at a market, and the trend in the commercialisation of foods is also prevalent in these inland areas[241].

Water and sanitation

In the Yucatán Peninsula, access to piped water and sanitation services is generally at a high rate. In 2010, approximately 90% of the population had access to flush or pour-flush toilets connected to piped sewer systems or septic tanks[242]. Concurrently, 94% of households had access to piped water supply. Overall, the three states of the peninsula have relatively high levels of access to water and sanitation, but the threat of spreading pests and disease remains. While access is high, water quality is a larger problem in the peninsula, and exposure to environmental health risks related to pollution is a larger problem, and results in a loss of welfare, economic opportunities and quality of life. There remains a need to further improve access to water and sanitation, particularly in areas where flooding is expected to increase under future climate conditions.

Health and wellbeing

The Yucatán Peninsula has substantial biological and cultural resources, yet there is a high level of malnutrition and deprivation among the population[243]. This is evident from the fact that Yucatán State has the largest proportion of adults between 20 and 59 (70%) who are overweight or obese[244]. This is the result of a nutritionally poor diet and the consumption of "junk food" such as biscuits, snack foods and sugary drinks[245]. Women and children are particularly prone to poor diets, including inadequate intake of vitamin A, folates, heme iron, zinc and calcium[246]. In more urbanised communities in particular, there is a higher dependence on commercially produced crops, and the *milpa* is less commonly used. In these areas, deficiencies in key vitamins and minerals (vitamin A and C, and Zinc) has been recorded as a result of lower production under *milpa.* One study showed that children between 5 and 11 only received 81% of their total energy requirements and had deficient levels of the aforementioned elements[247]. In addition to nutrient deficiencies, local communities in the Yucatán Peninsula are also affected by episodic energy imbalances during growth that are caused by illness, food insecurity and working conditions[248]. These problems are compounded by the proliferation of globalised diets[249] and physical inactivity[250]. Overall, communities in Yucatán are faced with what is known as the 'double-edged sword of malnutrition' where undernutrition and overnutrition occur concurrently[251]. Collectively, poor diets are causing numerous physiological impacts on people, including decreased muscle and skeletal growth and increased fat gain, leading to childhood stunting, low height-for-age and obesity, and ultimately resulting in adults with short stature, obesity, hypertension and diabetes[252].

In addition to the health impacts of poor diets, the health and wellbeing of the population of the Yucatán Peninsula is also affected by the prevalence of infectious and vector-borne tropical diseases. The peninsula not only hosts a wide variety of domestic and endemic wild animals, but also numerous vectors such as ticks, mosquitos and other insects[253]. Given that the peninsula has favourable conditions for the proliferation of diseases, changing climatic conditions and the increasing human population will likely influence their spread[254]. This has already been demonstrated in some parts of the peninsula, where the prevalence of Chagas disease increased in the wake of Tropical Cyclone Isidore in 2002. In the six months after the occurrence of the cyclone, there was a large increase in the domestic abundance of *Triatoma dimidiate,* the parasite responsible for the

[240] Novotny, I.P., Tittonell, P., Fuentes-Ponce, M.H., López-Ridaura, S. and Rossing, W.A., 2021. The importance of the traditional milpa in food security and nutritional self-sufficiency in the highlands of Oaxaca, Mexico. *PloS one*, *16*(2), p.e0246281.
[241] Leatherman, T., Goodman, A.H. and Stillman, J.T., 2020. A critical biocultural perspective on tourism and the nutrition transition in the Yucatan. *Culture, Environment and Health in the Yucatan Peninsula: A Human Ecology Perspective*, pp.97-120.
[242] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[243] Castañeda-Navarrete, J., 2021. Homegarden diversity and food security in southern Mexico. *Food Security*, *13*(3), pp.669-683.
[244] Castañeda-Navarrete, J., 2021. Homegarden diversity and food security in southern Mexico. *Food Security*, *13*(3), pp.669-683.
[245] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[246] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[247] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[248] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[249] Including processed foods that are high in fat relative to carbohydrates, and high in sugars.
[250] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[251] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[252] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[253] Haro, P., Trasviña-Muñoz, E., May-Concha, I., López-Valencia, G., Monge-Navarro, F., Herrera-Ramírez, C., Mercado-Rodríguez, J.A., Villanueva-Alonzo, H. and Waleckx, E., 2021. Historical spatial distribution of zoonotic diseases in domestic, synanthropic, and wild animals in the Mexican territory of the Yucatan Peninsula. *Journal of Tropical Medicine*, *2021*, pp.1-12.
[254] Guzman-Tabia, Y. Et al. 2005. Effect Of Hurricane Isidore On *Triatoma Dimidiata* Distribution And Chagas Disease Transmission Risk In The Yucatán Peninsula Of Mexico. Available here.

disease. This implies that research into and the active control of diseases such as Chagas should be prioritised as part of any interventions related to reducing the impacts of tropical cyclones on the peninsula's population.

5.3. Exposure Indicators

The exposure index assesses the potential impacts associated with significant climatic parameter variations to which a system, community, ecosystem, or livelihoods may be subject. In the case of the Yucatan peninsula, these are Extreme temperatures, Extreme precipitation, Precipitation variability and drought, Tropical cyclones, and Ocean impacts and acidification.

5.3.1. Temperature extremes

The extreme temperature analysis considers the number of hot and extremely hot days, the warm spell duration, the highest monthly, and the peak day and lowest night-time temperatures. Both the average and extreme observed temperatures are highest to the west of the area, particularly from May to August. The projected future sees the largest increase in the southwest predominantly in Jul/Aug and an average increase of between 2.0 -4.5 °C for the different SSP scenarios. The changes in extreme variables see significantly lower warm spells and increases in the 99th percentile days along the coastal areas to the north and west of the area. These areas however have been noted to be cooler in the historical record. The noted changes see an increase in the number of days >35°C in all areas as well as warm spell duration changes. The threshold happens at 2043 where each year's warm spell is longer and more severe than the historical average plus one standard deviation. The peak maximum temperature threshold is also around this time and peaks will range between 38 and 45 depending on the location.

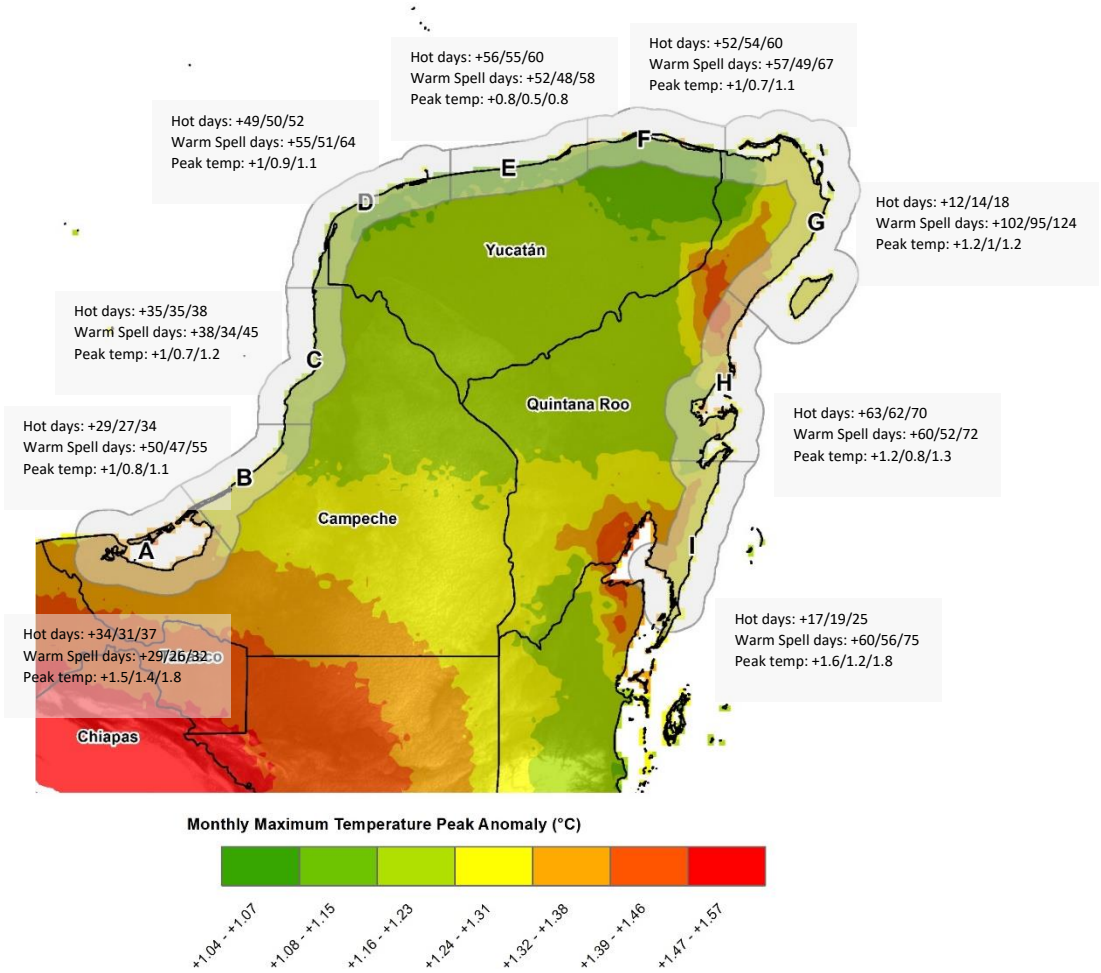


Figure 68. Monthly Maximum Temperature Peak Anomaly.

5.3.2. Precipitation variability

The annual rainfall and rainfall variability will have significant impacts on the environment and livelihoods that depend on regular rainfall. The majority of rainfall in the areas falls in the southern areas particularly from June to November. There is currently higher interannual rainfall variability to the west of the study area. Over time, however, there has been a long-term decrease in annual rainfall volumes, most notably to the west of the area. The projected future rainfall sees a continuation of this trend with most models agreeing on a decreased annual

rainfall. It is most notable in the months from Jun to Sep. This trend is enhanced later into the century and in the SSP370 and SSP585 scenarios (1). The decrease in total rainfall however varies at the monthly scale with the major decrease in the early season onset months of May to September. This is followed by increased rainfall volumes from October to December (2). However, the total decrease sees a leaning towards more drought-like conditions (3). Additionally, there are longer dry spells and shorter consecutive wet days (4). All of this leads to a noted increase in rainfall variability along the coastlines into the projected future.

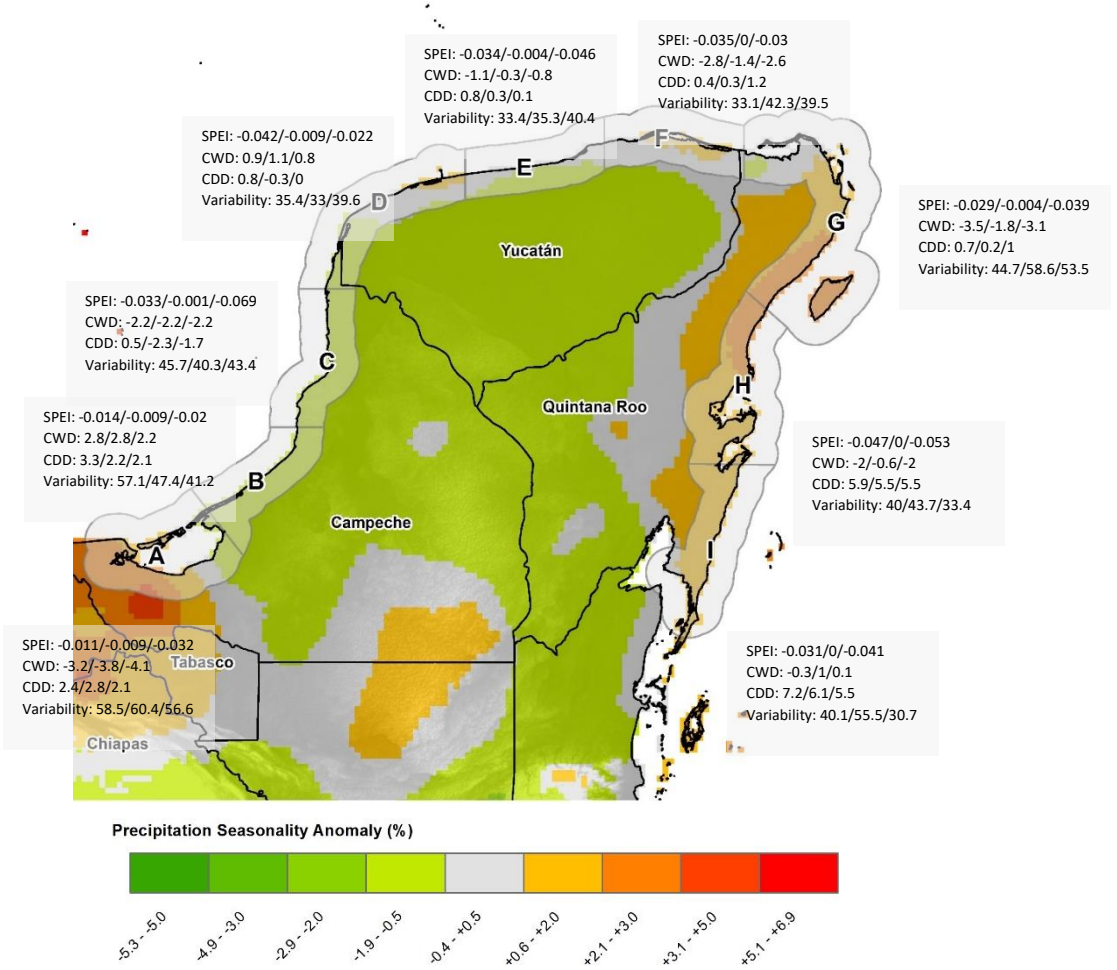


Figure 69. Precipitation seasonality anomaly.

5.3.3. Precipitation extremes

The peak rainfall is noted to the southwest of the study area, though there are however instances of notable high-magnitude events in the more northern areas. Despite the decrease in annual rainfall there is projected to be an increase in the peak monthly rainfall both to the southwest and the eastern coastline areas. There is also an increase in the extreme event magnitude and the peak 1- and 5-day event volume. There is however no notable change in the number of days with rainfall of 20mm or higher at an annual scale (1). In fact, after 2060, there are fewer days annually for both the SSP370 and SSP585 scenarios. However, on a seasonal scale (2) much like the changes in annual precipitation, we can note there is a focus on the extreme events in a shorter period from October to December and the extreme events decrease from January to September.

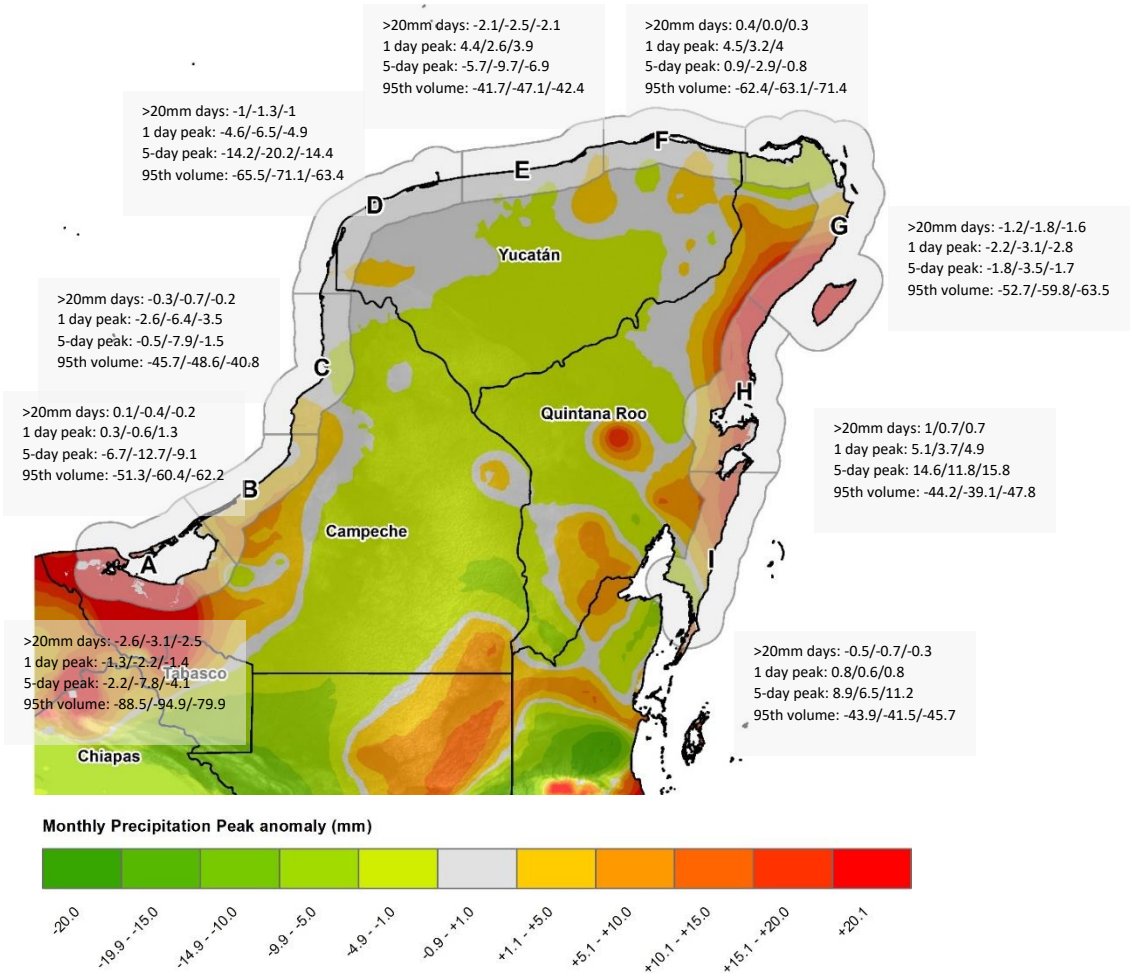


Figure 70. Monthly precipitation peak anomaly.

5.3.4. Tropical cyclones

Historically the eastern coast has been more exposed to tropical cyclone passage as well as significant wind speeds. The storm surges also peak in the north-eastern coastline as the cyclone events pass. The projection of tropical cyclone frequency and intensity is very challenging and even the IPCC is not clear on the direction of changes with any significant degree of certainty. They have however suggested that there is an expected decrease change overall in the number of events; but a likely increase in the frequency of category 4 and 5 events as well as an increase in the maximum intensity.

This study looks at anomalous sea surface temperature (SST) and the weakening of vertical wind shear (VWS) in the main development regions to infer the likely changes in tropical cyclone activity. The decrease in VWS and increased SST suggest an increase in cyclone formation. There is therefore a projected increase in cyclone activity on the west coast and a smaller increase along the west coast. The modelling of the storm surge however varies in magnitude.

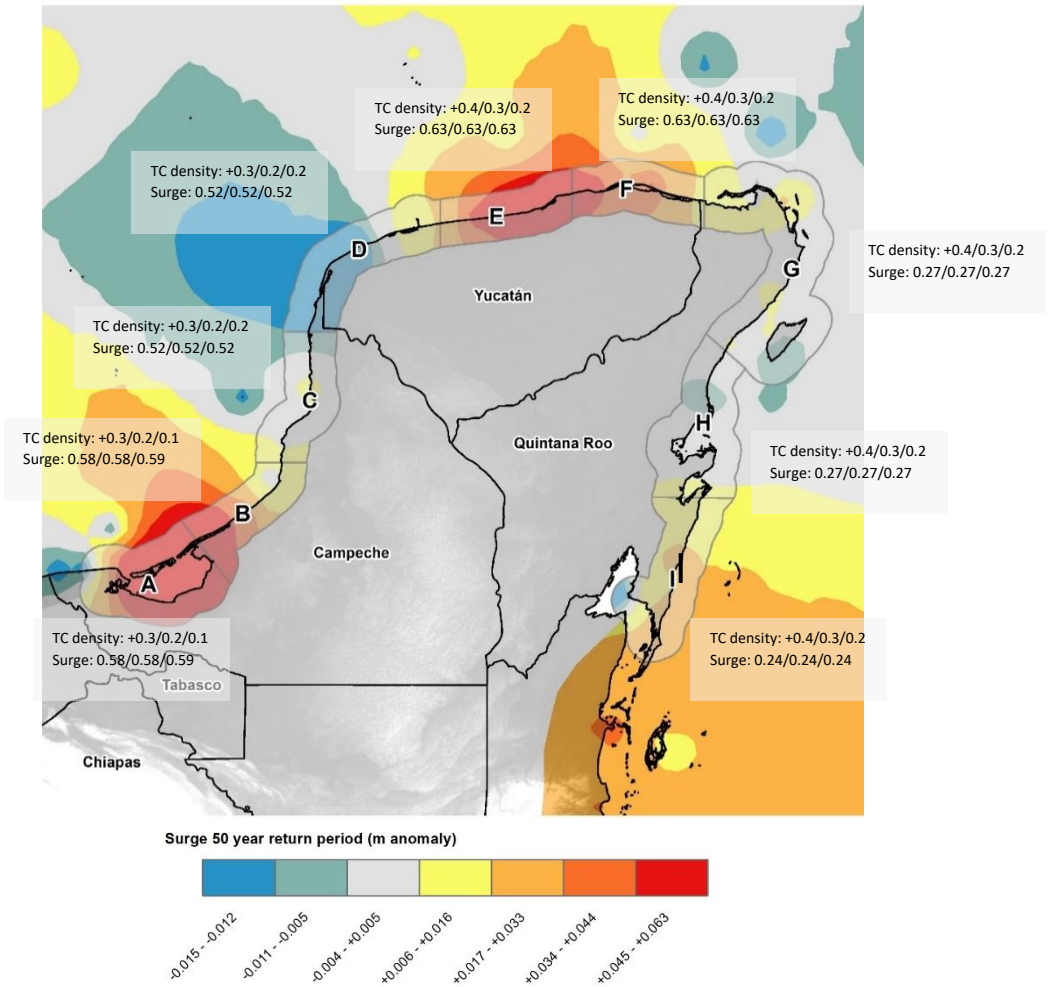


Figure 71. Surge 50-year return period (m anomaly).

5.3.5. Ocean characteristics

The ocean is warmer on the east coast, but the projected future sees an increase of up to 1 °C to the west and only 0.8 °C to the east. However, the projected increase in sea level is higher on the west coast. This will further enhance tropical cyclone storm surge impacts. The change in marine biodiversity and wellbeing is assessed through the projection of ocean acidification characteristics. This is done by projecting absolute changes in salinity, calcite, aragonite and pH. We can see an increase in salinity (limiting the growth of phytoplankton, more challenging for some marine organisms to regulate their internal water balance), but a decrease in calcite (more difficult for marine organisms to build and maintain their shells and skeletons), aragonite (more difficult for marine organisms to build and maintain their shells and skeletons), and pH (negative impacts on many marine species). The acidification of the ocean will likely negatively impact fish stock, health and shellfish.

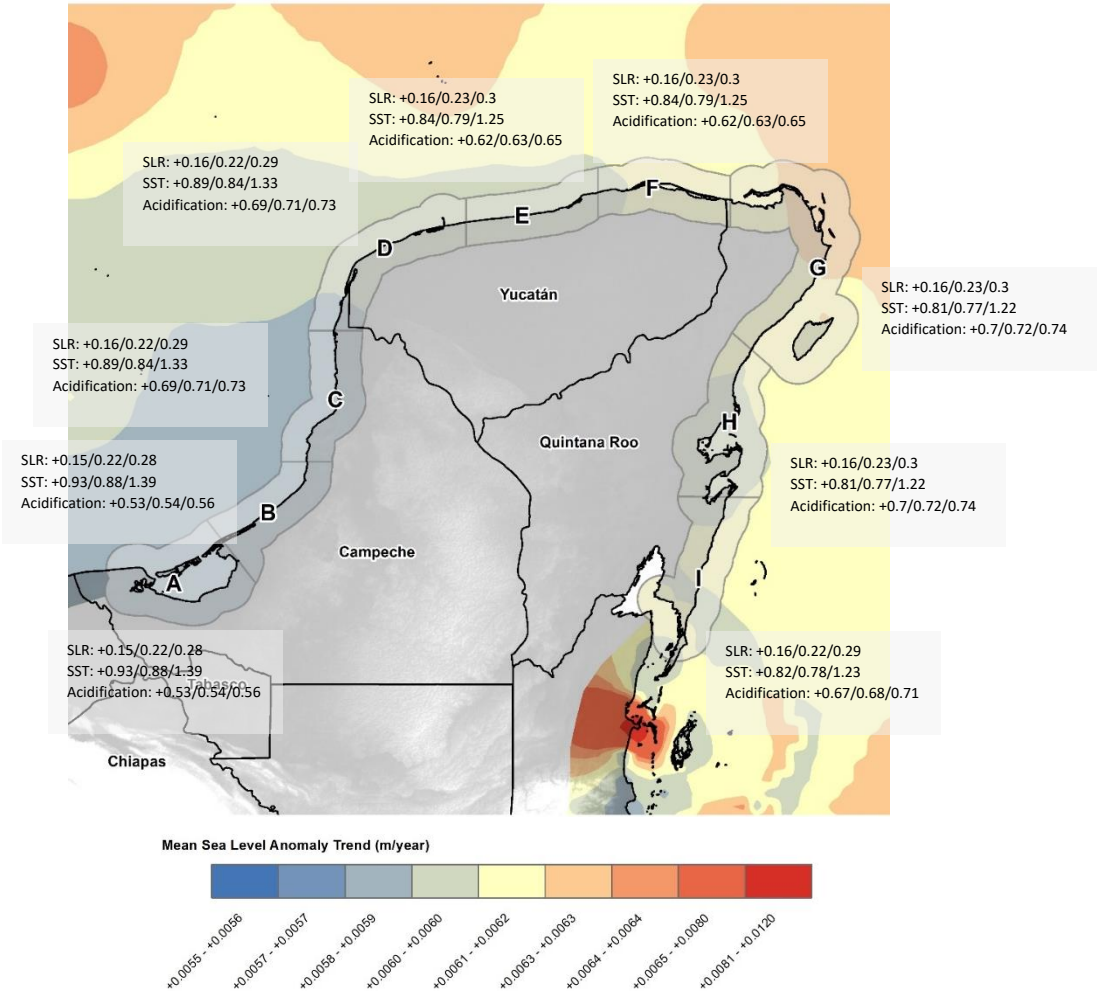


Figure 72. Mean sea level anomaly trend (m/year).

5.3.1. Exposure indicator summary

The exposure is highest generally for the hurricane/tropical cyclone hazards with several locations presenting a score of 9 or 10 for current and future scenarios. These locations are those to the northern and eastern coasts as these areas are more exposed to the higher density of cyclone events. While there is a lot of uncertainty regarding the changes in the number of cyclones and their intensity, the consensus is that there will be more extreme cyclones in the future and they will, with all likelihood hit the coast in a similar location as is noted historically. The projected future sees a limited increase in the storm surge height along the east coast but larger increases in the northern and western coastal areas.

The projected changes in extreme temperatures see increases mostly to the south western coastal areas with an increase in the number of days over 35 °C. There are some notable discrepancies in locations D, E, F and G with very high changes in the days above average plus one standard deviation in the SSP5-85 scenario. This indicates an increase in the general temperature profiles shifting towards more extreme events.

The number of extreme precipitation events is historically and projected to be highest in the south-eastern coastal area of location A. Above all other locations this area sees the greatest number of high-volume days, single and 5 consecutive day events and contribution of extreme events to total volume of annual rainfall. It should however be noted that this does not include the precipitation contribution of hurricanes as this was assessed separately.

The precipitation variability sees mixed exposure scores with the southwest location A seeing high values in the changes in the critical peak months impacting the high-volume months to be more extreme. The northern locations of D and E see high impacts of the changes in onset and cessation scores. This will impact the rainfed agriculture prevalent in the area.

The ocean impacts are quite similar in all areas as the dynamic mixing will smooth out much of the future anomalies. There are however increases in acidification noted to the east in locations G and H. Otherwise all the scores generally increase with increased severity of climate scenarios.

Table 5. Exposure scores over the study area per climate hazard

			A				B				C				D				E				F				G				H				I			
			1985-2015	2020-2050			1985-2015	2020-2050			1985-2015	2020-2050			1985-2015	2020-2050			1985-2015	2020-2050			1985-2015	2020-2050			1985-2015	2020-2050			1985-2015	2020-2050			1985-2015	2020-2050		
				SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85		SSP2-45	SSP3-70	SSP5-85
Climate exposure	Temperature extremes	Days above 35°C	8	9	9	9	8	9	9	10	9	9	10	10	5	6	6	6	6	8	8	8	4	6	6	7	1	2	2	3	5	6	7	7	2	2	3	4
		Nights > 26°C	3	5	7	9	2	2	2	4	2	2	2	3	2	3	4	6	2	2	2	2	1	1	2	2	1	1	2	2	2	2	2	2	1	2	2	2
		WSDI (days)	2	3	4	5	2	4	5	6	2	4	4	5	3	4	5	7	2	4	5	6	3	5	6	7	3	7	8	10	2	5	5	7	2	5	6	8
		Days above historical mean + standard deviation	3	5	6	7	4	5	6	8	4	5	7	8	6	7	8	10	5	6	7	9	4	6	7	9	5	7	8	10	3	5	6	8	3	5	6	8
	Precipitation Extremes	Number of days above 20mm	8	8	9	10	6	7	7	9	6	6	6	7	6	6	6	8	5	5	6	7	5	6	6	7	6	6	7	8	5	6	6	7	6	6	6	7
		1-Day Peak Precipitation	5	7	7	8	4	6	5	6	3	4	4	4	4	5	4	5	4	4	4	4	4	5	5	5	4	6	5	6	4	5	4	5	4	5	5	5
		5-Day Consecutive Peak Precipitation	7	9	8	9	5	7	6	7	4	5	4	5	4	5	5	5	4	5	4	5	4	6	5	5	5	6	6	7	4	6	5	5	5	6	6	6
		Total precipitation volume of the 95th percentile days	8	9	9	10	4	6	5	6	3	4	3	4	3	4	3	3	3	4	3	4	4	5	4	4	5	6	6	6	4	5	5	4	4	5	5	5
	Precipitation variability	Changes in critical onset/cessation months	1	2	2	2	4	5	5	5	6	6	6	6	7	7	7	7	6	7	7	7	6	6	6	6	5	5	5	5	5	6	5	5	4	5	5	5
		Changes in critical Peak months	9	10	10	10	7	8	8	8	6	6	6	6	5	6	6	6	5	5	5	5	5	6	6	6	6	7	7	7	6	6	6	6	7	7	7	7
		SPEI average	2	6	7	9	2	6	7	8	2	6	6	7	2	5	5	7	2	6	6	7	2	6	6	8	2	5	5	7	2	6	5	8	2	6	4	7
		Year on year variability range	7	8	8	8	5	8	6	5	6	6	5	5	5	4	4	5	5	4	4	5	4	4	5	5	7	6	8	7	6	5	5	4	5	5	7	3
		Change in CDD and CWD	1	5	9	8	5	5	8	9	7	8	10	9	4	7	8	9	5	7	8	9	5	6	6	9	3	5	2	6	3	5	5	7	4	7	7	8
	Hurricanes	Potential TC density based on VWS & SST changes	6	7	6	6	6	7	6	6	7	8	8	8	7	8	8	8	8	9	9	9	8	9	9	9	9	10	10	10	9	10	10	10	8	9	9	9
		Average Surge height (m)	9	9	9	9	9	9	9	9	8	8	8	8	8	8	8	8	9	10	10	10	9	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5
	Oceanic impacts	Average local SLR (mm)	1	5	7	8	1	5	7	8	1	5	7	9	1	5	7	9	1	6	7	9	1	6	7	9	1	6	7	9	1	6	7	9	1	5	7	9
		Average local SST (°C)	4	7	6	8	4	7	6	8	2	4	4	5	2	4	4	5	3	5	5	6	3	5	5	6	4	6	6	7	4	6	6	7	4	6	6	7
		Ocean acidification changes	1	7	7	7	1	7	7	7	1	8	9	9	1	8	9	9	1	8	8	8	1	8	8	8	1	9	9	9	1	9	9	9	1	8	8	9

5.4. Sensitivity indicators

Climate sensitivity is the degree to which a system can be affected either adversely or beneficially, by current and projected climate-related stimuli. These tend to be functions of an area that either currently or historically make an area impacted harder or have particular interdependencies that may be compromised in the event of an acute climate hazard or even a prolonged chronic change to an environment.

5.4.1. Environment

The factors considered for the environmental sensitivity were forest loss, NDVI trend, ground water vulnerability (based on the unique hydrological situation in the area), and coastal mangrove trends.

The forest loss score assesses the ratio of change in area under forest between 1996 and 2020 and the current forested area. This methodology highlights hotspot loss areas relative to the remaining forested areas, indicating potential ecosystem collapse. The areas to the north E and F have the highest ratio of forested areas losses. Area B also has significant losses. There are however some smaller locations of significant loss such as in the southern areas of Location H.

The NDVI trend measures the greenness of the vegetation over time and acts as a proxy for ecosystem health. There are significant decreases to the southwest of the area, though these are largely outside of the 20km coastal buffer area. Areas that include significant NDVI sensitivity are locations B, E, F, and H. Generally, the interior of the Yucatan sees positive NDVI trends but over time their coastal area has seen a clearing of vegetation and negative NDVI trends.

The ground water in the Yucatan is very complex due to the highly permeable limestone geology and the lack of surface water and surface runoff. Fresh water is accessed through “cenotes” or water holes in the surface. The highly permeable nature of the surface leads to enhanced exposure to the impacts of flooding as well as precipitation variability and drought. This is most prevalent in the north of the Yucatan where areas are classified as high vulnerability to floods and droughts. In the central areas, this is reduced to moderate vulnerability to floods and droughts, and in the south, this is classified as moderate vulnerability to floods and low vulnerability to droughts.

The mangrove trends area is an assessment of the ratio of mangrove losses to remaining intact mangroves. The areas of E and F see the greatest ratio of loss, there are however some small areas between them where loss ratios are low, and in some cases, restoration has been noted.

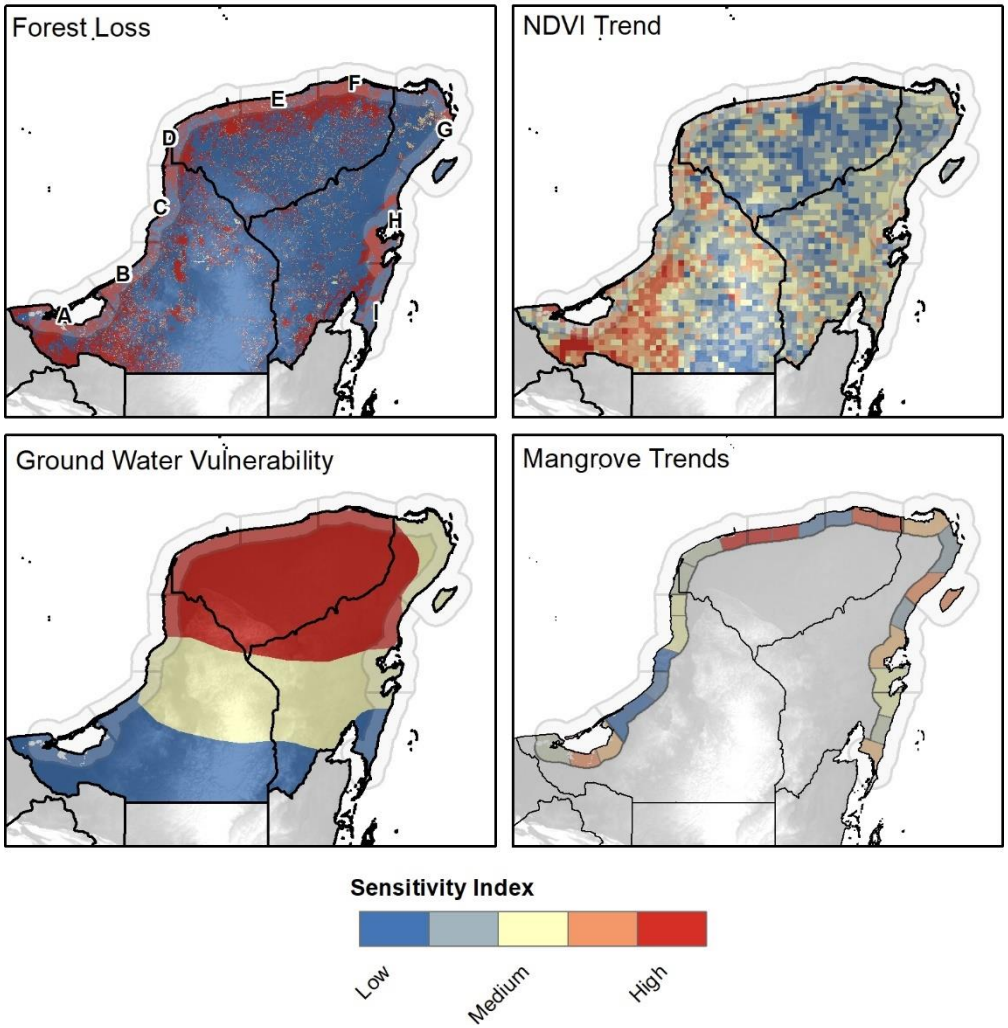


Figure 73. Environmental sensitivity indicators.

5.4.2. Livelihoods

The factors considered for the livelihood sensitivity were based on the spatial footprint indicating changes. Some factors such as beekeeping have a very small foot print which would not be noticed on a higher scale. The indicators included were climate-sensitive agriculture, agriculture yield gap, water crowding and fishing density. Climate-sensitive agriculture in areas that rely on consistent and predictable rainfall in the onset, peak and cessation of rains to sustain the crop. Areas that rely heavily on rainfall will be more sensitive to changes in precipitation patterns. These areas are the north in locations E and F as well as to the south west inland of location A.

The agriculture gap yield is "defined as the difference between actual farm yield and the yield potential with good management that minimizes yield losses from biotic and abiotic stresses, is a key biophysical indicator of the available room for a crop production increase with current land and water resources"[255]. Poor or non-ideal farming practices can lead to diminished yields in areas where higher and more sustainable yields are possible. These areas are considered more sensitive as these livelihoods are more impacted by climatic conditions and impacts. These are highest in the inland areas but there are high sensitivities in location I as well as in the southern areas of location B. The areas in the north are roughly middle of the range, neither showing any high sensitivity or enhanced capacity based on agriculture practices.

Water crowding is the competition agriculture has with local populations for water resources. In areas where the ground water is reduced or is highly susceptible to flood and drought, the local populations will have a greater representative demand for the limited water resources, thus placing strain on agrarian livelihoods. The highest sensitivity is in areas near the population hubs near Locations D and G.

The fishing hotspots area is estimated by using vessel density. While these may not all be fishing vessels, they are competing for space in these waters. The areas of the highest density are unsurprisingly those correlating to the highest population density of locations A, E and G.

[255] Rattalino Edreira, J.I., Andrade, J.F., Cassman, K.G. et al. Spatial frameworks for robust estimation of yield gaps. Nat Food 2, 773–779 (2021). https://doi.org/10.1038/s43016-021-00365-y

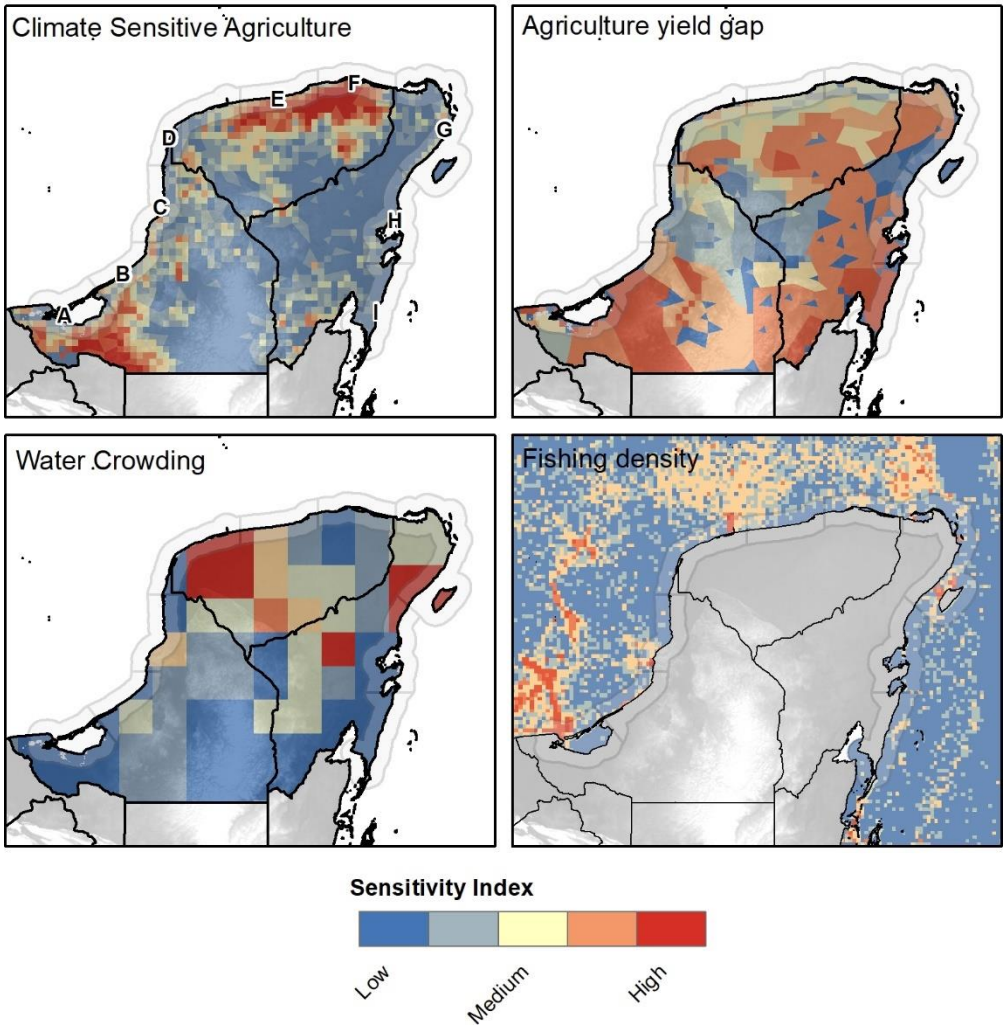


Figure 74. Livelihood sensitivity indicators.

5.4.3. Social

The factors considered for social sensitivity were the deprivation trend[256], the population density, the child dependency ratio and the Infant mortality rate. The deprivation trend is built from sociodemographic data and includes among others the subnational Human Development Index (SHDI), Night-time Lights, access, and the built environment. These data are largely focused on areas of higher populations; however, the lower population areas are also represented. The deprivation trend is highest in areas outside of the main population hubs in the more remote communities particularly in the northern areas around location F.

Population density is a standard metric for social sensitivity as an increased number of people in an area will result in more people being impacted by a climate hazard and will result in greater competition for limited resources. The highest sensitivities are noted in the population clusters of Mérida and Cancún. The child dependency ratio is the number of children under the age of 14 per 100 persons aged 15-64. This is an indicator of the breadwinner stress of the adults as well as the theoretical proportion of the population not in a position to look after themselves. The major population hubs of Mérida and Cancún have lower dependency ratios but more rural and agrarian areas of Tizimín have higher dependencies.

The Infant mortality rate is the number of deaths per 1,000 live births of children under one year of age. It serves as a good proxy for health services in communities. The data is segregated by province and sees Campeche as having the highest infant mortality rate.

[256] Center for International Earth Science Information Network - CIESIN - Columbia University. 2022. Global Gridded Relative Deprivation Index (GRDI), Version 1. Palisades, New York: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/3xxe-ap97.

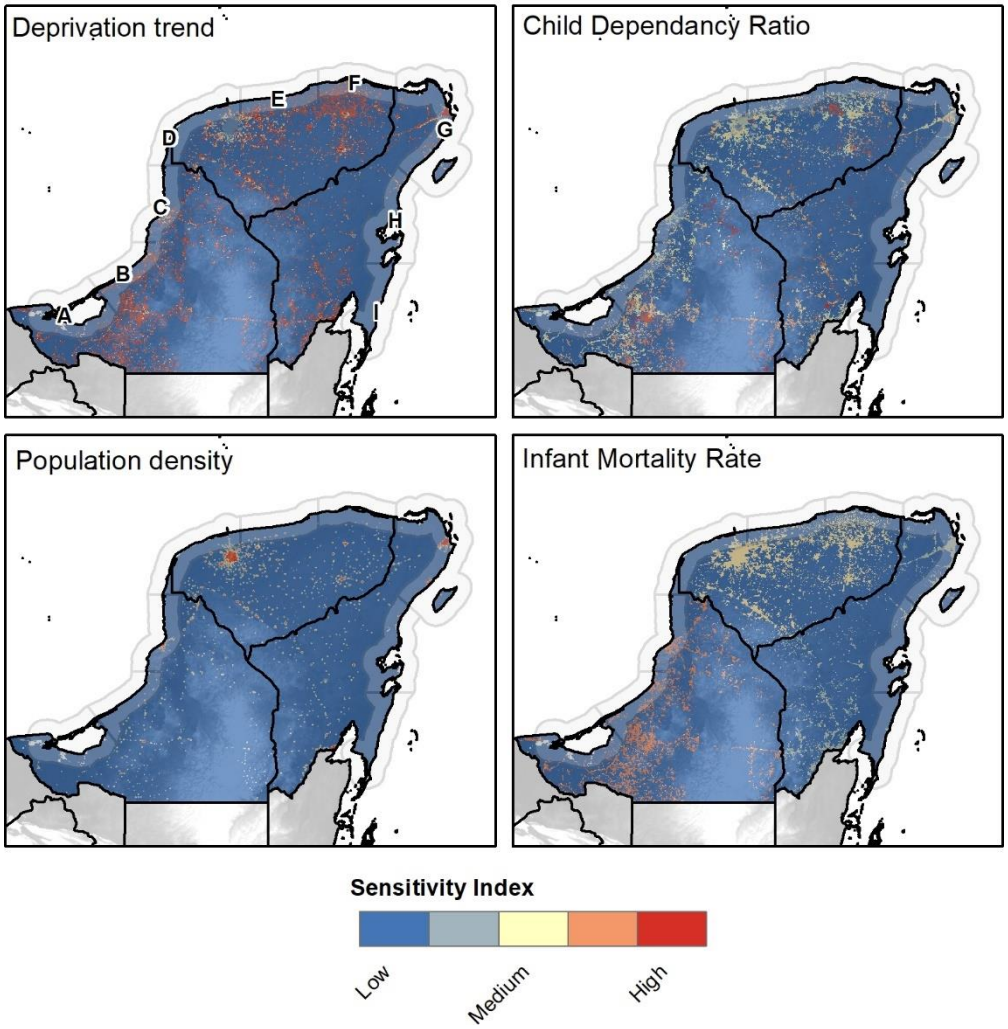


Figure 75. Social sensitivity indicators.

5.4.4. Sensitivity indicator summary

The social sensitivities tended to follow areas of the higher population as well as rural areas where health care is more limited. Locations B, D and F had the highest social sensitivity. Livelihood sensitivity is largely dependent on rainfed agriculture and the density of fishing. This sensitivity was highest in the western locations of A, B, D, E, and F. The environmental sensitivity was dictated by the forest and mangrove loss trends, as well as the health of ecosystems as noted by the NDVI analysis. The inland areas were noted to be less sensitive with the coastal area where forest and mangroves tend to have significant historical losses having a higher sensitivity. This is highest in locations B, D, E, F and H.

Table 6. Sensitivity scores over the study area per climate hazard

		A	B	C	D	E	F	G	H	I
Sensitivity	**Environmental**	1.5	6.8	2.8	5.9	6.4	6.8	2.4	5.9	3.3
	Livelihood	6.3	6.0	3.5	5.6	7.0	6.3	4.2	1.4	1.4
	Social	2.8	7.1	5	3.5	7.8	6.4	5.0	2.1	2.1

5.5. Adaptive capacity indicators

Adaptive Capacity is the ability of a system or community to recover from/adapt to, changes in baseline climate variables due to beneficial factors that will moderate potential damages/consequences. These tend to be factors that help in the recovery, so much more post-impact rather than sensitivities which tend to be pre-climate impact indicators.

5.5.1. Environment

The factors considered for the environmental adaptive capacity were current biomass density and forest integrity.

Both biomass density and forest integrity are indications of vegetation density and edge effects. Where there is increased density and minimal breaks in vegetation in the form of roads and tracks, ecosystems are generally healthier and are more able to recover from acute climate hazards. Additionally, these areas are able to maintain their microclimates and are thus less susceptible to external impacts. The highest capacities are further inland in the Yucatan and away from long connecting road networks. The more limited vegetation in the coastal areas sees lower adaptive capacity in these areas.

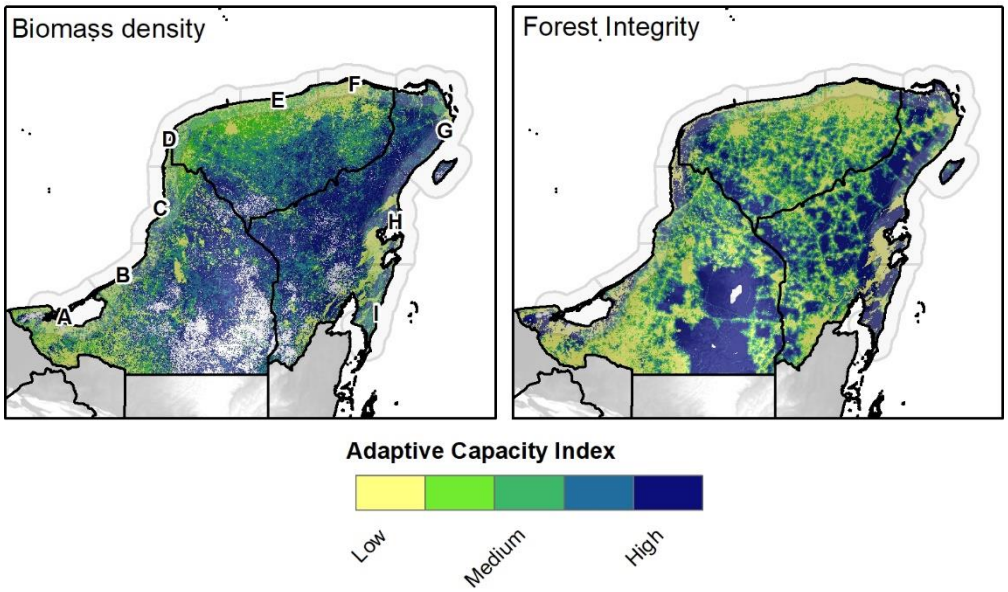


Figure 76. Environmental adaptive capacity indicators.

5.5.2. Livelihoods

The factors considered for the livelihood adaptive capacity were land productivity, accessibility and net primary productivity of the area. Accessibility is a measure of the distance required to travel between areas to get to areas of goods and services, this is also a proxy for the distance to get to markets and customers. The greater the distance the lower the capacity for farmers, fishers, or beekeepers to sell or trade goods. The areas with the highest capacity are those with the largest population densities. In the event of a climatic hazard occurring, being in close proximity to alternative livelihoods and other services may help to recover from these impacts. Net primary productivity is a measure of human intervention into the biosphere, or a modification of the natural habitat in order to create a livelihood. This is similar to the accessibility indicator with the highest interventions noted in the higher population areas. The productivity of the land is based on soil organic carbon trends. In the event of a climate hazard, crop farms located in areas with high productivity will be able to better recover crops.

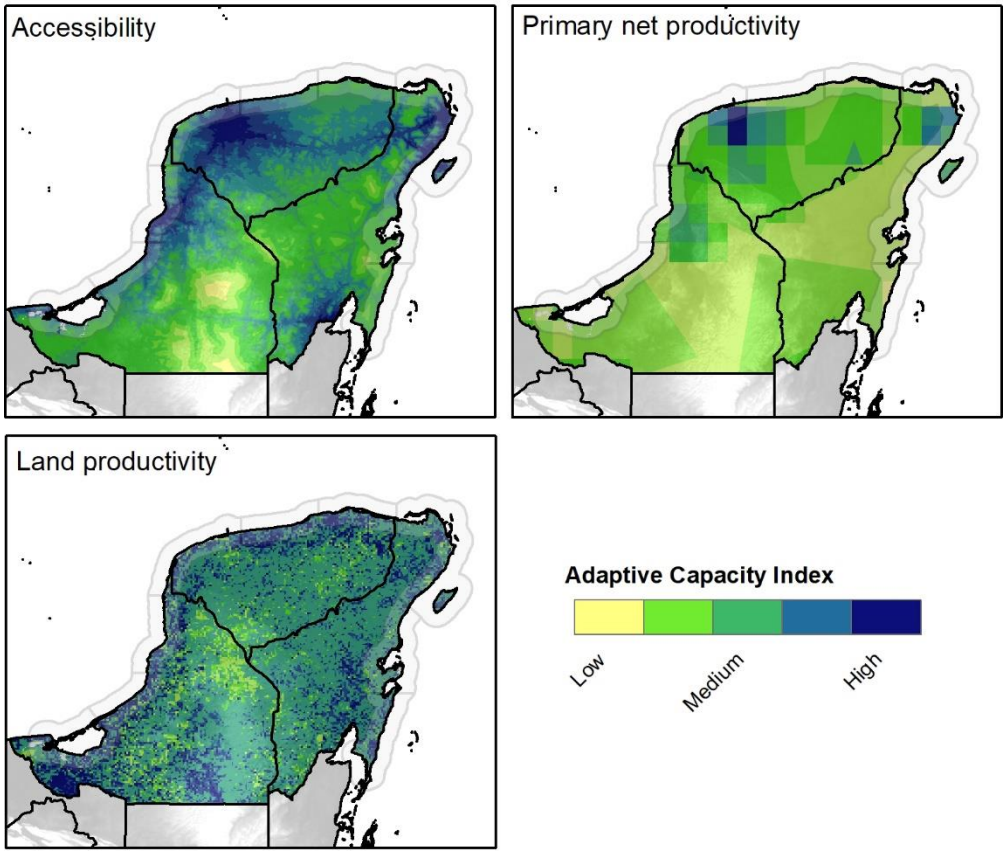


Figure 77. Livelihood adaptive capacity indicators.

5.5.3. Social

The factors considered for the social adaptive capacity were accessibility and the presence of various community services necessary in the event of an extreme event. These services are emergency services such as fire or police, community services such as halls, centres and shelters, and medical facilities such as clinics and hospitals. As before, higher accessibility means communities will have more evacuation routes if necessary as well as other goods necessary to recover from climate hazards. The locations of critical services will help communities impacted by climate hazards respond to and recover from the hazards. These tend to be located closer to higher population hubs.

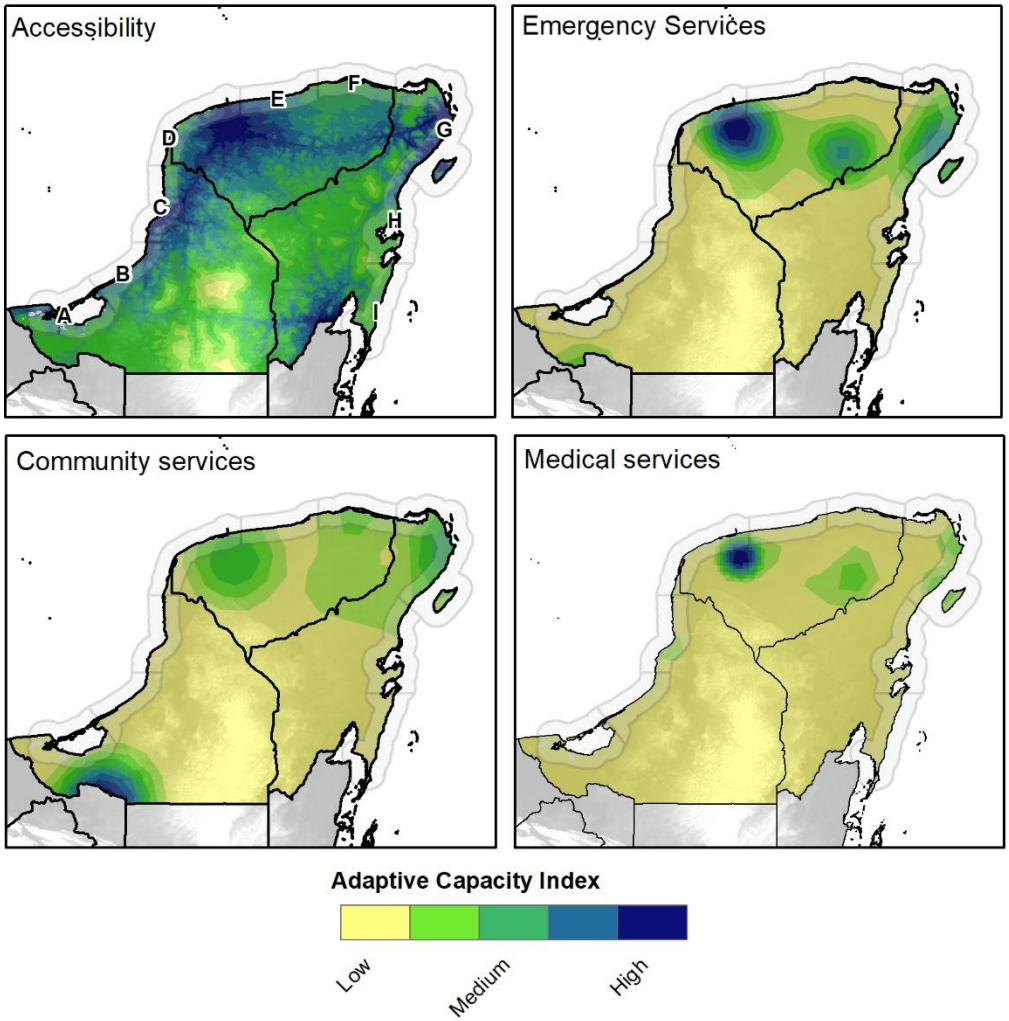


Figure 78. Social adaptive capacity indicators.

5.5.4. Adaptive Capacity indicator summary

The adaptive capacity indicators show a lower environmental adaptive capacity in the northern areas of E and F as these are degraded and have limited forest integrity. The highest adaptive capacity scores are noted on the eastern coastline in areas of G, H, and I.

The livelihood adaptive capacity is strongly influenced by the land productivity and accessibility of the north eastern coast in areas C, D and E. Conversely, locations H and I have very low adaptive capacity and these areas are very isolated and have limited net primary productivity.

The social adaptive capacity is focused in the higher density areas D (Mérida) and G (Cancún) as these have a prevalence of critical services required in the event of an acute climate hazard.

Table 7. Adaptive Capacity scores over the study area per climate hazard

		A	B	C	D	E	F	G	H	I
Adaptive Capacity	**Environmental**	4.1	3.7	5.8	4.9	1.7	1.5	7.4	5.6	7.2
	Livelihood	3.9	4.4	6.7	7.5	6.4	3.9	5.8	1.4	1.9
	Social	3.7	3.7	4.3	7.5	5.5	3.7	8.4	2.9	2.0

5.6. Vulnerability analysis results

The climate change vulnerability assessment combined the five climate exposures of Extreme temperatures, Extreme precipitation, Precipitation variability, Tropical cyclones, and Ocean impacts with the three critical key elements of social, livelihoods, and environmental sensitivities and adaptive capacities.

This resulted in 15 CCVAs for each of the climate hazard impacts and for the three critical key elements. This is useful for developing targeted interventions to address particular climate issues within a particular mandate.

These were combined to make critical key element-specific CCVAs to inform sectoral-level planning, allowing general mandate intervention targeting.

These three CCVAs were combined again to present the overall CCVA to allow for high-level strategic planning. The primary map presented is for the SSP2-45 scenarios, but the SSP3-70 and the SSP5-85 scenarios are also presented.

The CCVA results are as follows:

- *The CCVAs per climate hazard type and critical key elements highlight location F as the area that has the highest general vulnerability. This is a combination of being exposed to the greatest increase in tropical cyclone density, and increased ocean hazards such as acidification and varied precipitation. The variables of extreme temperatures and extreme precipitation are not very high here. Area F also has increased livelihood and environmental sensitivity and reduced capacities as it is further away from the larger population hubs.*
- *The locations of A and B to the southwest have high CCVA for the extreme precipitation and temperatures. There is also high livelihood and environmental sensitivity in these areas as well as reduced adaptive capacity for all the critical key elements. These areas have medium to high vulnerability.*
- *Location E to the east of Mérida is somewhat in the middle of all the CCVAs as it is in the interface between the high cyclone and ocean impact to the east and the higher precipitation and temperature exposures to the southwest. This area has a medium vulnerability.*
- *Locations G, H and I to the west coast have high exposure to the ocean and tropical cyclone impacts but also have lower sensitivities than the northern areas and have generally medium to good adaptive capacities. These areas' CCVAs are all similar and are medium to lower vulnerability.*
- *Locations C and D are far enough away from the enhanced impacts of the extreme precipitation and temperatures and also have limited sensitives but also low adaptive capacities. These areas seemingly have the lowest overall climate vulnerability.*

Table 8. Vulnerability by climate hazard type and critical key elements

CCVA per hazard and per key critical element			A	B	C	D	E	F	G	H	I
	Temperature extremes	Environmental	6.0	5.3	4.0	3.1	6.2	8.2	1.2	5.0	2.7
		Livelihood	6.8	6.5	0.3	2.2	5.8	4.8	4.5	5.2	5.8
		Social	4.4	7.9	4.4	2.2	6.5	7.4	3.0	2.6	3.5
	Precipitation Extremes	Environmental	7.4	5.4	3.7	2.8	5.6	7.2	1.2	5.8	2.8
		Livelihood	8.0	6.5	1.0	2.3	5.0	4.3	4.0	6.0	4.8
		Social	4.9	8.3	4.1	2.0	6.2	7.0	2.8	3.2	3.2
	Precipitation variability	Environmental	6.0	2.3	2.5	4.1	5.1	9.0	2.9	5.9	4.1
		Livelihood	6.7	2.4	0.9	3.1	4.3	5.5	5.7	7.1	6.2
		Social	5.5	4.1	2.6	1.9	6.2	9.1	4.1	4.1	4.1
	Hurricanes	Environmental	2.3	3.2	3.9	4.0	6.5	9.1	3.4	6.0	3.5
		Livelihood	1.5	3.3	1.8	3.7	6.4	6.9	6.6	6.4	5.2
		Social	2.2	5.4	4.2	2.8	7.1	8.8	4.2	3.6	3.6
	Oceanic impacts	Environmental	3.3	3.8	3.5	4.0	6.9	8.9	2.8	5.8	2.8
		Livelihood	3.2	4.3	0.3	3.5	7.1	6.9	6.1	5.3	5.1
		Social	3.1	6.2	3.8	2.7	7.3	8.5	3.8	3.1	3.4

Table 9. Vulnerability by critical key elements

CCVA per key critical		A	B	C	D	E	F	G	H	I
	Environmental	5	4.2	3.5	2.6	6	6.2	5.8	6.5	5.5
	Livelihood	3.7	6.6	3.9	2.2	6.8	8.5	3.6	3.1	3.4
	Social	4.6	4.2	3.7	3.1	6.4	9.2	2.1	5.3	3.3

Table 10. Overall combined vulnerability

	A	B	C	D	E	F	G	H	I

Cumulative combined relative climate change vulnerability assessment	4.6	5.6	3.7	2.8	6.4	8.3	3.8	4.6	4.0

Climate Exposure

Extreme Temperature (ET)

Extreme Precipitation (EP)

Precipitation Variability (PV)

Tropical Cyclone Density (TC)

Ocean Hazards (OH)

Exposure rating

Low Medium High

Sensitivitiy Index

Social Sensitivity

Livelihood Sensitivity

Environmental Sensitivity

Sensitivity rating

Low Medium High

Adaptive Capacity Index

Social Adaptive Capacity

Livelihood Adaptive Capacity

Environmental Adaptive Capacity

Adaptive Capacity rating

Low Medium High

Inervention planning level

Social CCVAs

Livelihood CCVAs

Environmental CCVAs

ET EP PV TC OH

Sector Planning level

Relative Climate vulnerability by critical key elements

Average Social CCVA

Average Livelihood CCVA

Average Environmental CCVA

Strategic Planning

Average overall relative climate vulnerability

SSP2-45 - 2020-2050

SSP3-70 - 2020-2050

SSP5-85 - 2020-2050

A B C D E F G H I

Climate vulnerability Assessment Score

Very Low Low Medium High Very High

N

0 25 50 100 150 Kilometers

Figure 79. Components of the Climate Change Vulnerability Assessment (CCVA). Exposure indicators (1st row), Sensitivity indicators (2nd row), and adaptive capacity indicators (3rd row) per critical key elements, CCVA outputs at Targeted Intervention Planning scale with relative Vulnerability by climate hazard type and critical key elements (4th row), CCVA per critical key elements (5th row), combined CCVA (6th row - left) and SSP3-70 and SSP5-85 (right panel)

6. Intervention planning

The GCF investment framework highlights the requirements and interventions that need to be met before funding can be considered.

- *Impact potential: Interventions to reduce the current and future impacts of climate change need to have a significant potential to reduce the loss of life, value of assets, livelihoods, environmental damages, and social losses, and increase the resilience both directly and indirectly of vulnerable communities and areas.*
- *Paradigm shift: Interventions should also catalyse positive change beyond the scope of a single project or local area thereby enabling replication or scaling up of the project results to create a paradigm shift towards long-term resilience.*
- *Sustainable development potential: Interventions are also measured against economic, social, environmental and gender sustainability parameters so that co-benefits of the project and the associated paradigm shifts enhance steps toward the achievement of the Sustainable Development Goals.*
- *Needs of the recipient: Interventions should be designed to address the most vulnerable areas and communities but should also indicate how potential recipients may respond to this, as well as include considerations for longer-term capacity development.*
- *Country ownership: project interventions and proposed activities should align with the country's NDC and other relevant national plans. Additionally, motivation should be given for how the funding proposal will help to achieve these plans.*
- *Efficiency and effectiveness: projects need to consider the economic and financial soundness of interventions by looking at the expected rate of return, the ratio of co-financing and how projects are developed along the line of best sector practices.*

6.1. Potential ACCIÓN interventions

Interventions of the ACCIÓN project are aligned along the social, livelihood and environmental critical elements. Interventions should therefore address i) climate challenges that threaten food/water security and reduce poverty, ii) promote livelihood resilience to cope with and recover from chronic stresses and acute climate shocks, while maintaining or enhancing its capabilities and assets, and not undermining the natural resource base, iii) ecosystems security to maintain resilience, functionality, and ecosystem services under conditions of climate change.

High-level interventions that are based on best practices and have been implemented successfully in the Latin American context are as follows:

Table 11. High-level potential interventions

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
Climate-smart agriculture (CSA)[258]			
Agroforestry[259,260]	• *The cultivation of crops and or the keeping of livestock (silvopastoral) in conjunction with trees or shrubs.* • *Fruit, timber, meat, milk and crops are produced according to season and harvest.*	• *Improve soil retention during flooding.* • *Water source protection and increase water availability.* • *Reduce the impacts of landslides and soil erosion.* • *Increase household income due to livelihood diversification.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.* • *Increase livestock productivity and fodder production during drought and flooding.* • *Enhance crop productivity during drought and flooding.* • *This agricultural system allows for the introduction of improved crop varieties which are adapted to rising temperatures and rainfall, and more resistant to pests and diseases, with higher productivity and high organoleptic quality.* • *The presence of shade trees in agroforestry systems reduces high temperatures and maintains soil moisture which results in a reduction of the average annual temperatures and extreme heat impacts.* • *The relative humidity is increased, and evapotranspiration is reduced, aiding in enhanced productivity of crops and pastures during drought.* • *Silvopastoral systems can be managed intensively, reducing the need to extend grazing areas into critical ecosystems and improving livestock productivity under conditions of climate change.*	**Environmental** **Livelihood**

[257] Interventions may address the following key critical elements
[258] CSA is an integrated approach to managing landscapes—cropland, livestock, forests and fisheries—that addresses the interlinked challenges of food security and accelerating climate change. CSA aims to simultaneously achieve three outcomes: increased productivity, enhanced resilience and reduced emissions.
[259] Soto-Pinto, L., Anzueto, M., Mendoza, J., Ferrer, G.J. and de Jong, B., 2010. Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. *Agroforestry Systems*, *78*, pp. 39-51.
[260] Nahed-Toral, J., Valdivieso-Pérez, A., Aguilar-Jiménez, R., Cámara-Cordova, J. and Grande-Cano, D., 2013. Silvopastoral systems with traditional management in southeastern Mexico: a prototype of livestock agroforestry for cleaner production. *Journal of cleaner production*, *57*, pp. 266-279.

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
Terraces[261]	• *Terraces form a range from step-like horizontal planting surfaces (treads) to supporting vertical walls (risers).* • *Parallel rows of plants slightly modify the hillslope gradient and follow the hillside contour.* • *Zanja-bordo terraces in Middle America, are commonly used of which popular variations are metepantle or metepantli.* • *Zanjas are most often positioned immediately downslope from the bordos and serve as reservoirs that capture runoff and allow water to penetrate the soil.* • *An additional option is agave terraces, which are fringes or bands of densely planted agave (incl. A. cupreata, A. augustifolia and others) established along the contour lines, followed up-hill with fringes of naturally regenerated forests of native tree species such as Tepeguaje, Encino, and Chiquil.*	As above, including: • *The production of non-timber forestry products such as agave syrup, fibres, and artisanal mezcal, which aid in improving local incomes and increase adaptive capacities amongst vulnerable rural communities.* • *Timber and firewood produced in the naturally regenerated and sustainably managed forest fringes are important for household use.*	**Environmental** **Livelihood** **Social**
Reduced tillage[262]	• *Minimum mechanical disturbance of soil is encouraged.* • *Agricultural land is not left fallow, and tillage occurs at a shallower depth with reduced intensity.*	• *As indicated for agroforestry.*	**Environmental** **Livelihood**
Cover crops and mulching[263]	• *Mulching describes the use of crop residues or organic matter to nourish the soil.* • *Residues cover the soil and are not removed during land preparation or harvesting.* • *Cover crops perform a similar function, where soil is not left fallow.* • *Soil coverage is promoted by seasonal crops such as legumes.*	• *As indicated for agroforestry.*	**Environmental** **Livelihood**

[261] LaFevor, M.C., 2014. *Conservation engineering and agricultural terracing in Tlaxcala, Mexico* (Doctoral dissertation).
[262][262] Ochoa-Noriega, C.A., Velasco-Muñoz, J.F., Aznar-Sánchez, J.A. and Mesa-Vázquez, E., 2021. Overview of Research on Sustainable Agriculture in Developing Countries. The Case of Mexico. *Sustainability*, *13*(15), p.8563.
[263] Ochoa-Noriega, C.A., Velasco-Muñoz, J.F., Aznar-Sánchez, J.A. and Mesa-Vázquez, E., 2021. Overview of Research on Sustainable Agriculture in Developing Countries. The Case of Mexico. *Sustainability*, *13*(15), p.8563.

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
Indigenous crops and livestock[264]	• *Indigenous crops such as tobacco, sugar cane, maize, coconut palms, bananas, citrus, pineapples, sesame seeds, chilli peppers, or rubber are cultivated.* • *Other indigenous crops such as coffee or cacao are planted in conjunction with native tree species.* • *A diversity of traditional crops is cultivated instead of promoting monoculture production.* • *Livestock are kept on a subsistence or small-scale basis for meat and milk production and rotatory grazing is utilised.* • *Potreros are small traditional grazing areas that include pastures, leguminous trees, and shrubs, that are grazed by livestock.* • *Managed and unmanaged forests are also included in the management system.*	• *Indigenous crops and livestock show increased resilience to climate change impacts such as flooding and drought.* • *Enhance livestock and crop production during drought and flooding.* • *Non-timber forestry products provide alternative income sources to local communities.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Environmental** **Livelihood**
Milpas intercropping system[265]	• *The milpa is a traditional Mesoamerican intercropping system in which maize is grown simultaneously with other crop species, such as common beans, fava beans, squash or potatoes.* • *Crops are planted in alternate rows.* • *Fruit trees and other trees could be interspersed with crops along contour lines, to generate the successive formation of natural terraces.*	• *As indicated for agroforestry*	**Environmental** **Livelihood**
Ecosystem-based adaptation (EbA)[266]			
Forest restoration and rehabilitation[267,268]	• *Planting indigenous trees in degraded riparian and dryland forest ecosystems allows for a natural balance of biodiversity and the re-establishment of ecosystem services.*	• *Improvement of water availability and water quality.* • *Promote integrated water catchment management.* • *Reduce downstream sedimentation.* • *Increase water infiltration.* • *Reduce riverbank erosion.*	**Environmental** **Livelihood**

[264] Toledo, V.M., Ortiz-Espejel, B., Cortés, L., Moguel, P. and de Jesús Ordoñez, M., 2003. The multiple use of tropical forests by indigenous peoples in Mexico: a case of adaptive management. *Conservation Ecology*, *7*(3).
[265] Nature: Maize intercropping in the milpa system. Diversity, extent and importance for nutritional security in the Western Highlands of Guatemala. Online Available: https://www.nature.com/articles/s41598-021-82784-2#:~:text=The%20milpa%20is%20a%20traditional,great%20diversity%20of%20crop%20combinations.
[266] EbA is a nature-based solution that harnesses biodiversity and ecosystem services to reduce vulnerability and build resilience to climate change.
[267] Mexal, J.G., Cuevas Rangel, R.A. and Landis, T.D., 2008. Reforestation success in central Mexico: factors determining survival and early growth. *Tree planters' notes.*
[268] García-Barrios, L., Galván-Miyoshi, Y.M., Valsieso-Pérez, I.A., Masera, O.R., Bocco, G. and Vandermeer, J., 2009. Neotropical forest conservation, agricultural intensification, and rural out-migration: the Mexican experience. *BioScience*, *59*(10), pp.863-873.

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
		• *Promote water recharge.* • *Replenish groundwater tables.* • *Alternative livelihoods such as non-timber forest products.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Social**
Wetland rehabilitation[269,270,271]	• *The re-establishment of ecosystem services and biodiversity through the planting of seedlings or mature wetland plants into degraded wetland ecosystems.* • *Site preparation is required beforehand which includes soil preparation and removal of invasive plant species.* • *Utilising live plants, and organic and inorganic materials, to promote functioning ecosystems, prevent erosion, control sediment and re-establish a habitat.*	• *As above, including enhanced fisheries productivity because fish nursing grounds are re-established.* • *Reduction of saltwater intrusion into coastal aquifers.* • *Enhance water availability and quality.* • *Improve coastal protection against hurricanes, sea level rise and storm surges.* • *Reduce coastal erosion.* • *Reduce damage to coastal infrastructure resulting from flooding, storm surges and sea level rise.* • *Promote tourism and livelihoods from tourist activities.* • *Promote sustainable livelihoods from products such as fruit, wood and herbal remedies.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.* • *Promote integrated coastal zone management.*	**Environmental** **Livelihood**
Coastal mangrove rehabilitation[272,273,274]	• *Collect plant propagules, such as cuttings, seeds or spores, and prepare the restoration site for planting.* • *Directly plant propagules at regular intervals at an appropriate time of year.*	• *As above*	**Environmental**

[269] Climate Technology Centre and Network: Wetland restoration and rehabilitation. Online available: https://www.ctc-n.org/technologies/wetland-restoration-and-rehabilitation
[270] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[271] United States Environmental Protection Agency: Wetland restoration. Online available: http://water.epa.gov/type/wetlands/upload/2006_11_29_wetlands_restdocfinal.pdf
[272] Climate Technology Centre and Network: Wetland restoration and rehabilitation. Online available: https://www.ctc-n.org/technologies/wetland-restoration-and-rehabilitation
[273] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[274] Laulikitnont. 2014. Evaluating mangrove restoration success. Online available: repository.usfca.edu/cgi/viewcontent.cgi?article=1011&context=capstone

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
	• *In re-establishing mangroves, establishing nurseries to stockpile seedlings for future planting could be advantageous.* • *Mangrove re-establishment is also achieved by planting dune grasses to allow for mangrove re-establishment.* • *Mangroves that show minimal degradation could also be left to re-establish without additional intervention.* • *The Ecological Mangrove Restoration method focuses on evaluating and creating the right hydrology in restoration sites first, which then allows for the establishment of plants instead of relying on the manual planting of individual mangrove species.*		**Livelihood**
Dune and beach rehabilitation [275,276]	• *Reduce disturbance to beaches and coastal dunes by introducing physical barriers that trap sand, mechanically stabilizing dune ridges, and planting schemes using species adapted to the ecosystem to biologically fix or reforest the dune ridge.* • *Beach nourishment could also be utilised where beach sand is introduced to regions where coastal erosion is extensive.* • *Sand is transferred from a region of coastline where sand has been deposited, from quarries or offshore.*	• *As indicated for wetland rehabilitation.*	**Environmental** **Livelihood**
Coastal realignment and setback[277]	• *Managed realignment is the deliberate altering of flood defences to allow planned flooding of a presently defended coastal area.* • *The realignment includes EbA interventions such as wetland re-establishment.* • *Coastal setback is a planning tool that identifies a zone next to the existing shoreline which is targeted as a buffer zone.* • *Buffer zones could also include mangroves and or wetlands, which provide protection against climate change impacts.* • *Distances from the shoreline or elevations from sea level are predefined and infrastructure development in these high hazard risk regions is restricted.*	• *As indicated for wetland rehabilitation.*	**Environmental** **Livelihood**
			Environmental

[275] Ruiz-Martínez, G., Mariño-Tapia, I., Baldwin, E.G.M., Casarín, R.S. and Ortiz, C.E.E., 2016. Identifying coastal defence schemes through morphodynamic numerical simulations along the northern coast of Yucatan, Mexico. *Journal of Coastal Research*, *32*(3), pp.651-669.
[276] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[277] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
Seagrass rehabilitation[278]	• *Rehabilitation of seagrass ecosystems includes harvesting plants from nurseries or undegraded ecosystems and transplanting seagrass plants into degraded ecosystems.* • *Subsequent management and monitoring of sites are required.*	• *As indicated for wetland rehabilitation, excluding non-timber forestry products.*	**Livelihood**
Coral reef rehabilitation 279,280,281	• *Transfer of nursery-grown coral fragments to degraded coral ecosystems.* • *Reattaching broken corals into rock crevices or using coral cement.* • *Coral nurseries are usually located in mid-water, away from natural reefs, where the fragments are free from predation and anthropogenic stressors.* • *Habitat is prepared for coral introduction by reducing external stressors such as fishing and invasive algae.*	• *Nursery-grown coral show increased resilience to climate change impacts such as bleaching.* • *Coastal erosion is reduced because coral reefs provide protection against the impacts of storm surges and sea level rise.* • *The adverse impacts on fisheries infrastructure because of climate change impacts are reduced and hence livelihoods are protected.* • *Promote tourism and livelihoods from tourist activities.* • *Establish fish nursing grounds and hence promote fisheries productivity and livelihoods from the fisheries sector.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Environmental** **Livelihood**
Living breakwaters[282,283]	• *Natural materials such as bamboo, rocks, wood and shells are utilised as off-shore, barriers between the sea and the land.* • *These structures are deliberately constructed to provide a habitat for species and to aid the restoration of coastal reef ecosystems while supporting the services these ecosystems provide.* • *These structures could also incorporate grey engineering and aim to mimic some of the characteristics of natural coral reefs.*	• *As above*	**Environmental** **Livelihood**

[278] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[279] Nature: Coral conservation in the Caribbean. Online available: https://www.nature.org/en-us/about-us/where-we-work/caribbean/stories-in-caribbean/caribbean-a-revolution-in-coral-conservation/
[280] National Oceanic and Atmospheric Administration: Restoring coral reefs. Online available: https://www.fisheries.noaa.gov/national/habitat-conservation/restoring-coral-reefs
[281] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[282] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[283] Marine Sanctuaries Conservation Series: Science review of artificial reefs. Online available: http://sanctuaries.noaa.gov/science/conservation/pdfs/artificial_reef.pdf

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
Expansion and establishment of marine protected areas[284]	• *Marine Protected Areas (MPAs) are areas set aside to protect marine ecosystems.* • *MPAs have a clearly defined geographical space, which is recognised, dedicated, and managed through sustainable interventions such as EbA.* • *The main objective is to achieve long-term conservation of marine and coastal ecosystems, along with associated ecosystem services.*	• *As for wetland rehabilitation, including the conservation of culturally important sites.* • *Promote livelihoods from ecotourism.* • *Greater participation in natural resource management.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Environmental** **Livelihood**
Green infrastructure[285]			
Urban wetlands[286,287]	• *These wetlands lie within the boundaries of cities.* • *Wetlands are natural or newly established with a combination of green and grey engineering interventions.*	• *Enhance water availability during drought and variable rainfall events.* • *Promote water and air quality in cities.* • *Reduce impacts of urban flooding.* • *Increase water infiltration and reduce runoff.* • *Replenish groundwater tables.* • *Reduce erosion and landslide impacts in urban settlements.*	**Environmental** **Social**
Other interventions			
Ecotourism[288]	• *Tourism activities are centred around the forest and coastal ecosystems, including diving, hiking, and visiting culturally important sites, nature reserves and protected areas.*	• *Provide alternative and diversified livelihoods among local communities.* • *Enhance planning of coastal and forest management.* • *Promote entrepreneurship and economic development among coastal communities.*	**Environmental** **Social**
Coral reef insurance[289,290]	• *Coral reefs are viewed as assets that are naturally exposed to hazards such as hurricanes and tropical storms.*	• *As indicated for coral reef rehabilitation, as well as the rapid re-establishment of coastal protection against storm surges and sea level rise.*	**Environmental**

[284] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[285] Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services, while also enhancing biodiversity.
[286] Ramsar: Urban wetlands. Online available: https://www.ramsar.org/sites/default/files/documents/library/wwd18_handouts_eng.pdf
[287] Torres-Lima, P., Conway-Gómez, K. and Buentello-Sánchez, R., 2018. Socio-environmental perception of an urban wetland and sustainability scenarios: A case study in Mexico City. *Wetlands*, *38*(1), pp.169-181.
[288] The World Bank: Opportunities for environmentally healthy and resilient growth in Mexico's Yucatan Peninsula. Online available: https://documents1.worldbank.org/curated/en/958161577478303830/pdf/Opportunities-for-Environmentally-Healthy-Inclusive-and-Resilient-Growth-in-Mexicos-Yucatan-Peninsula.pdf
[289] Nature.org: Insuring nature to ensure a resilient future. Online available: https://www.nature.org/en-us/what-we-do/our-insights/perspectives/insuring-nature-to-ensure-a-resilient-future/
[290] Green economy coalition: Insuring coral reefs in Mexico. Online available: https://www.greeneconomycoalition.org/news-and-resources/insuring-coral-reefs-in-mexico

Intervention	Description	Adaptation benefits	Critical key element impact area[257]
	• *Coral reef insurance provides an effective tool that can provide immediate funding to repair coral reefs damaged by hurricanes or tropical storms.*		**Livelihood**
Ecosystem-based approach to fisheries management[291]	• *These interventions aim to promote marine and coastal ecosystem conservation and the preservation of ecosystem services through regulatory and legislative changes, centred on an ecosystem-based approach.* • *These initiatives include land-use planning, promoting traditional fisheries practices, the establishment of MPAs, restricting and regulating fishing equipment as well as harvest quotas.*	• *Promote the development of sustainable and alternative livelihoods.* • *Enhance the resilience of women and children to climate change impacts due to the diversification of livelihoods.* • *Promote diversified livelihoods within the fisheries sector despite climate change impacts due to enhanced ecosystem resilience.*	**Environmental** **Livelihood**
Traditional knowledge sharing[292,293]	• *Indigenous knowledge is prominent in fields such as agroforestry, traditional medicine, biodiversity conservation, customary resource management, impact assessment, and natural disaster preparedness and response.* • *Indigenous knowledge sharing relies on the observation of natural environments.* • *Traditional knowledge has often resulted in the establishment of agricultural practices and natural resource utilisation that have reduced ecosystem impacts.* • *Indigenous responses to climate variation typically involve changes to livelihood practices and other socio-economic adjustments.*	• *Indigenous observations and interpretations of meteorological phenomena focus on elements of significance for local livelihoods, security and well-being, and are essential for climate change adaptation.* • *Indigenous peoples' observations contribute to advancing climate science, by ensuring that assessments of climate change impacts and policies for climate change adaptation are relevant at the local level.* • *The ability to sustainably access multiple resources and rely on different modalities of land use enhances the management of local-level climate change impacts.* • *Traditional systems of governance and social networks improve the ability to collectively manage diversity and share resources while dissipating shocks and reinforcing innovative capacities to adapt to climate change impacts.*	**Environmental** **Social** **Livelihood**

[291] FAO: A ecosystem-based approach to fisheries. Online available: https://www.fao.org/publications/card/en/c/6de19f1f-6abb-5c87-a091-3cc6e89c3a88/
[292] Toledo, V.M., Ortiz-Espejel, B., Cortés, L., Moguel, P. and de Jesús Ordoñez, M., 2003. The multiple use of tropical forests by indigenous peoples in Mexico: a case of adaptive management. *Conservation Ecology*, *7*(3).
[293] United Nations University. Traditional knowledge holds the key to climate change. Online available: https://unu.edu/publications/articles/why-traditional-knowledge-holds-the-key-to-climate-change.html

6.2. Stakeholder perception of the local vulnerability

Local expert stakeholders from various agencies working in the Yucatan Peninsula were polled in terms of their perception of the impacts that current and future climate changes will have on the ground for communities, livelihoods and the environment. Additionally, they highlighted “wish list” projects to increase climate resilience.

The stakeholder identified by a wide margin terrestrial ecosystem destruction as the most severe potential future impact of climate change. Other impacts in the top 5 impacts include marine ecosystem damage, livelihoods destroyed, impact on fisheries and deforestation resulting from livelihood losses. These impacts are all interrelated as damage/destruction of terrestrial ecosystems will have a significant impact on local fishery, tourism, and natural resource-based livelihoods. Other impacts noted further inland are stress to agriculture and agri-tourism and enhanced wildfire severity. It is clear, along the coastal areas that ecosystems, fisheries, and tourism are the major livelihoods and the most exposed to the future climate changes.

When asked what interventions they would propose to meet the future adaption needs of communities, livelihoods and the environment, there was an overwhelming preference for mangrove rehabilitation as this single intervention directly helps safeguard coastal areas and communities from tropical cyclone storm surge, protects fish species and breeding areas, preserves the natural beauty of coastal areas, and indirectly promotes fishery livelihoods and tourism. The second most promoted intervention was EbA approaches to fishery management which also has significant multi-faceted benefits to livelihoods, environment and tourism.

The next 10 interventions that had between 4% and 8% preference were; climate-smart agriculture, wetland rehabilitation, forest restoration/rehabilitation, coral reef rehabilitation, enhancing marine protected areas, promoting traditional knowledge sharing, enhancing ecotourism, promoting agroforestry, dune and beach rehabilitation and seagrass rehabilitation. The majority of these are focused on building ecosystem resilience. Promoting interventions of this nature will have indirect benefits for livelihoods and communities as these are so intertwined in the coastal areas.

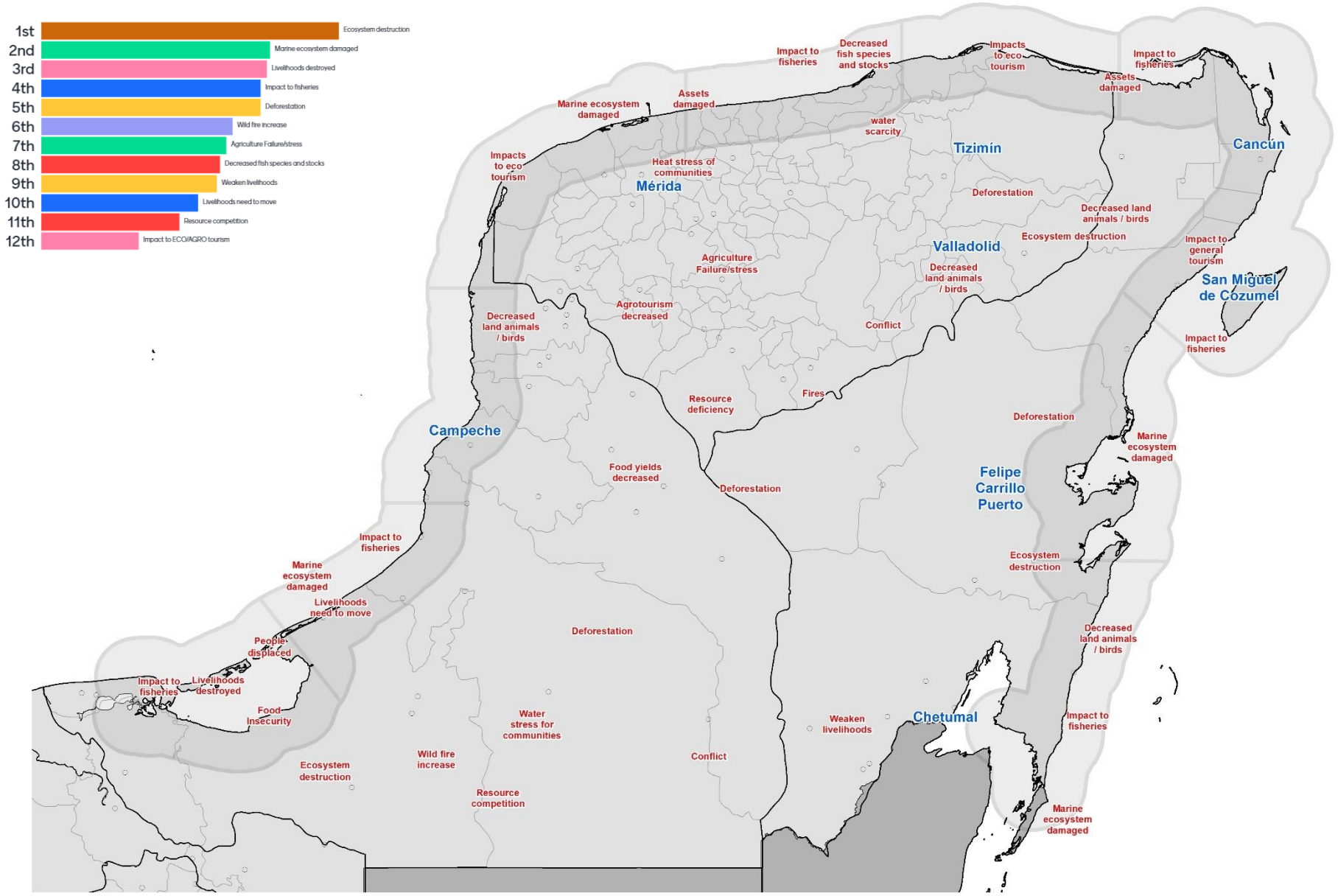


Figure 80. Stakeholders identified projected climate impacts on social, livelihood and environmental criteria and perception of the most severe future impacts

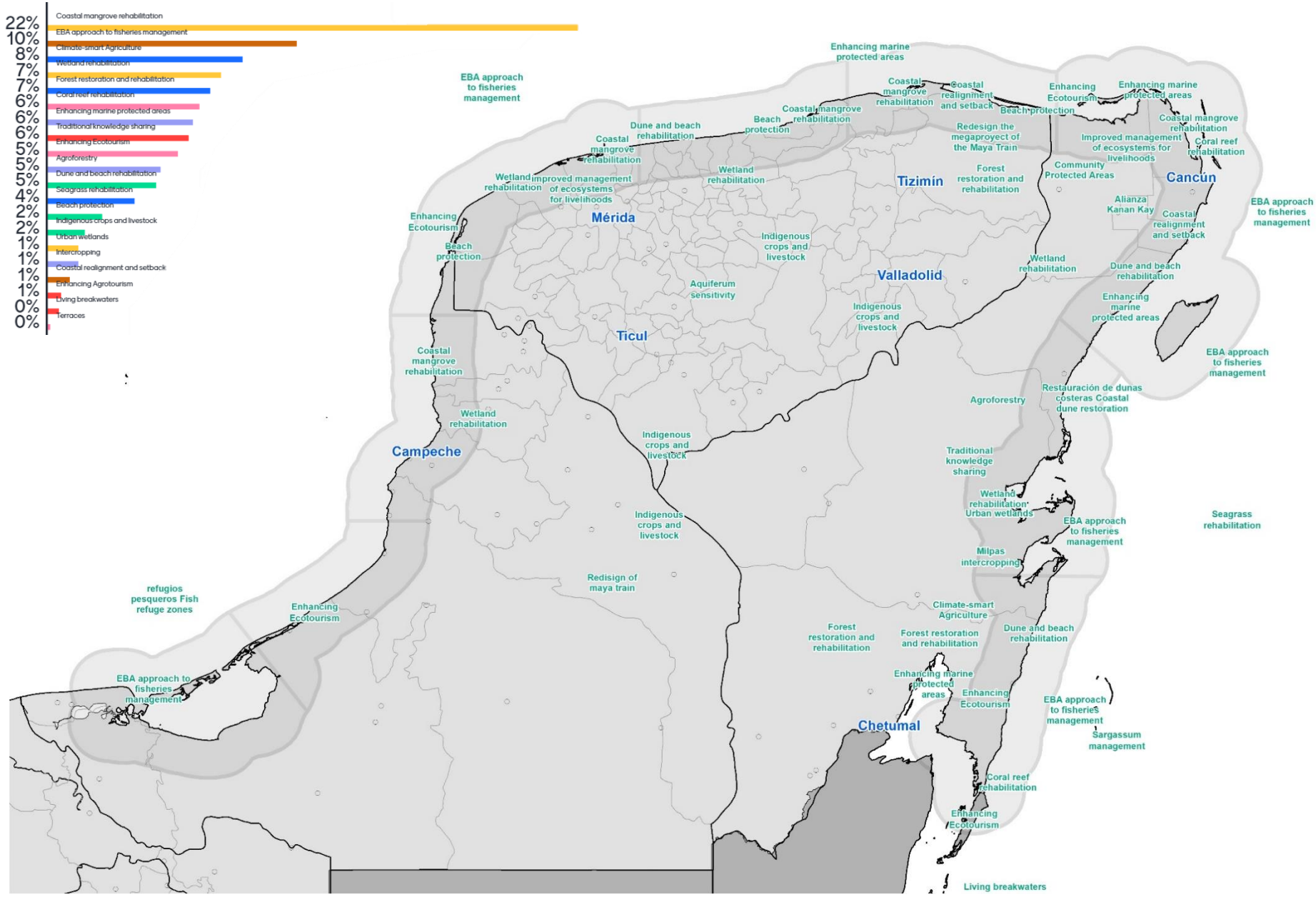


Figure 81. Stakeholders identified a wish list of project interventions and perception of the most important potential interventions

6.3. Location-specific intervention considerations

Each section of the coastline will be differentially exposed and have varying sensitivities and adaptive capacities. Additionally, the demographic profile, livelihoods and environmental landscape will vary along the coast. This assessment considers each of these factors individually and cumulatively through the climate change vulnerability assessment to suggest a non-exhaustive list of interventions that may be suitable in these areas. Local environment, livelihood, social and gender assessments as well as community inputs should however be used to finalise interventions.

6.3.1. Location A: Ciudad del Carmen

This area is to the southwest of the Yucatan peninsula and has the Laguna de Términos (a large estuary-lagoon). This area is projected to see a large increase in temperatures, extreme temperature events and warm spells. There is also projected to be more varied year-on-year precipitation and a moderate long-term tendency towards more drought events. The change in extreme rainfall events is decreased over the course of a year, but this is increased in the months from Oct-Jan. The impacts of tropical cyclones are projected to increase with high storm surges projected as well as moderate increases in tropical cyclone density. The changes in sea level and acidification are moderate here but increases to surface temperatures are high.

The area around this location has seen significant forest losses and a general negative trend in ecosystem health. There is also a medium/high trend in mangrove losses along the coast. This area has a large amount of rainfed agriculture enhancing the climate sensitivity of the area. The agriculture gap yield is also medium-high, so yields are not as high as the local climate can support. There is also significant fishing occurring from this location as a major livelihood. There is however low water crowding as water stress here should be lower than in other areas. Socially there is a generally lower population density, but a medium child dependency ratio and deprivation trend and a moderate to high infant mortality rate.

This location has low medium biomass density and forest integrity meaning ecosystems are only somewhat sheltered. The area has low to moderate accessibility to other communities but has low net primary productivity meaning economic activity here is more limited. There is however medium to high land productivity. There are limited services in the area and social adaptive capacity is generally low.

Stakeholders have indicated that there are currently and will likely be impacts on fisheries, food insecurity and potential livelihoods and communities severely compromised. They have indicated that EBA approaches to fisher management and fish shelters in this area will have significant benefits to the local communities.

The key critical elements of social, livelihoods and environment are roughly equivalent in their climate vulnerability and this area has an average medium over all vulnerability. Interventions that would benefit this area include the following:

Table 12. Potential interventions in Location A

Social interventions	Livelihoods interventions	Environmental interventions
• *Livelihood and environmental interventions have social co-benefits*	• *CSA: Reduced tillage* • *CSA: Cover crops and mulching* • *CSA: Indigenous crops and livestock* • *CSA: intercropping* • *Living breakwaters* • *Ecosystem-based approach to fisheries management*	• *Coastal mangrove rehabilitation* • *Living breakwaters* • *Ecosystem-based approach to fisheries management*

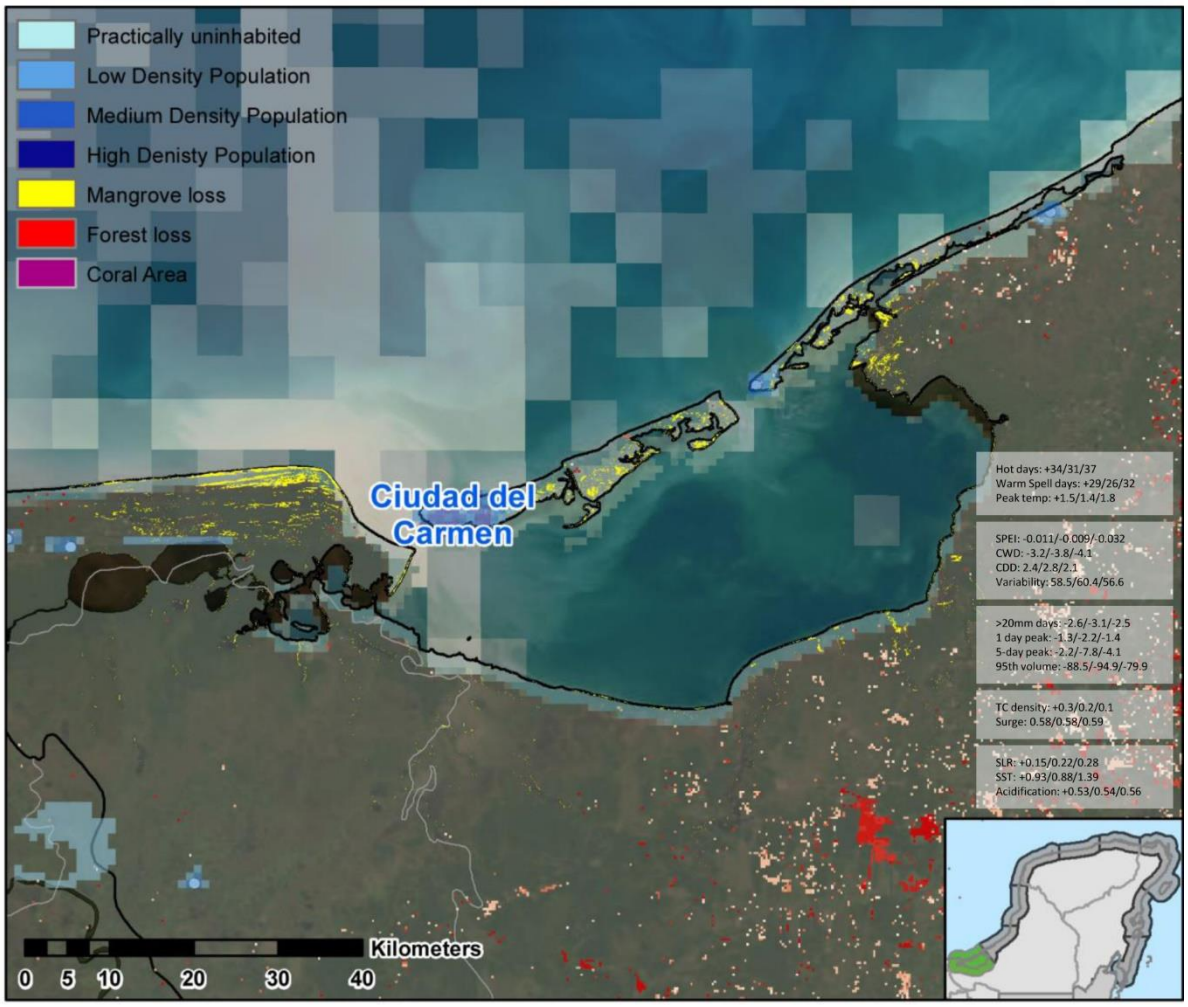


Figure 82. Characteristic of area A

6.3.2. Location B: Sabancuy

This area is on the southwest of the Yucatan, but north of the Laguna de Términos. There are projected increases in temperatures, heat waves and temperature extremes. The projected changes to rainfall variability here are less severe and the tendency towards more severe drought is lower. There is a decrease in the volume of extreme rainfall days other than Oct to Dec. Like the location to the south, this area projects the impacts of tropical cyclones to increase with high storm surges projected as well as moderate increases is tropical cyclone density. The changes in sea level and acidification are moderate here but increases to surface temperatures are high.

This area has extensive forest losses close to the coastal areas as well as a highly negative ecosystem help trend. The mangrove losses however are very low compared to the rest of the coastline. There is low to medium ground water vulnerability. This area has some rain-fed agriculture, but it is not significant, what there is, does have a high gap yield meaning the yield is not as high as it could be. Water crowding here is again low and there is a more limited fishing industry. Despite the low population in this area, there are high deprivation trends and infant mortality rates and a medium child dependency ratio.

The adaptive capacity of this area is relatively low medium as both the biomass density and forest integrity are compromised with many areas exposed. This area also has medium accessibility and land productivity but low economic activity. There is however lower access to goods and critical services

Stakeholders have indicated that marine ecosystems and fisheries are likely to be impacted by climate changes with some compromise to livelihoods. They however have proposed only enhancing ecotourism as a future intervention to diversity livelihoods in the area.

The key critical elements of social and the environment are roughly equivalent in their medium climate vulnerability. Livelihoods, while few in this area have medium-high vulnerability as the economic state is low. Interventions that would benefit this area include the following:

Table 13. Potential interventions in Location B

Social interventions	Livelihoods interventions	Environmental interventions
• *Traditional knowledge sharing*	• *Agroforestry* • *Ecosystem-based approach to fisheries management* • *Traditional knowledge sharing*	• *Agroforestry* • *Forest restoration and rehabilitation* • *Ecosystem-based approach to fisheries management*

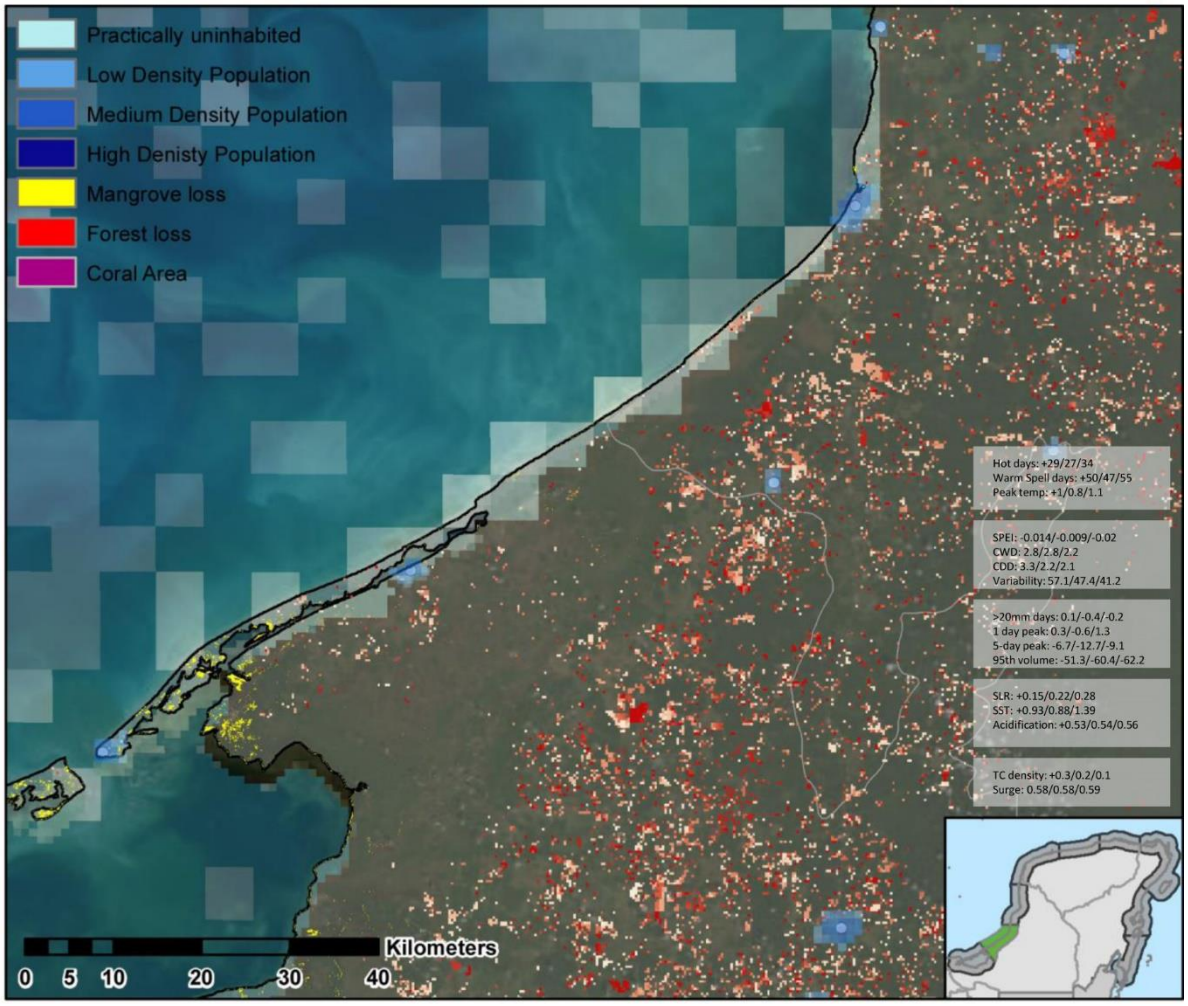


Figure 83. Characteristics of Area B

6.3.3. Location C: Campeche

This area is to the west of Yucatan. Projected increases in temperature are milder here, as are the changes in warm spell durations. This area does however have the highest projected drought severity, but only moderate year-on-year variability is projected. The changes in extreme rainfall here are relatively low with only Oct to Nov seeing an increase in extreme events and decreases in other extreme rainfall parameters. Being closer to the east and with the passage of tropical cyclones, there is a projected moderate increase in tropical cyclone density here. The changes in acidification are the highest here but surface temperature here is the highest noted change along the peninsula. This area does have some deforestation, but this is further inland away from the coast. The coastal ecosystems seem to have a moderate health trend with most areas faring well. The mangrove trend here is low (particularly in the southern areas) and medium in the more northern areas. There are some rainfed agriculture areas but this isn't a high-density area. Additionally, the yield gap here is not significant. There is some measure of water stress, particularly in the southern areas. There seems to be little in the way of fishing in these areas. There is moderate population density around Campeche but is very limited elsewhere, there is also moderate to higher infant mortality rate and deprivation trends. There is a medium child dependency ratio. The biomass and forest integrity in this area are moderately high. Additionally, there Is good accessibility and land productivity and medium economic activity in the area. There are however limited goods and services in the area in the event of a climate emergency. The stakeholders did not indicate significant impacts in this area and highlighted a decrease in avian and fauna species. Likewise, they proposed only a few interventions here; mangrove restoration and wetland rehabilitation.

The key critical elements of social, livelihood and environment are roughly equivalent in their low medium climate vulnerability. Interventions here should seek to retain much of the low vulnerability and should be minimally invasive. Interventions that would benefit this area include the following:

Table 14. Potential interventions in Location C

Social interventions	Livelihoods interventions	Environmental interventions
• *Traditional knowledge sharing*	• *General water-efficient CSA practices* • *CSA: Cover crops and mulching* • *Indigenous crops and livestock* • *Fish stock nurseries*	• *Forest restoration and rehabilitation* • *Coastal mangrove rehabilitation particularly to the north* • *Fish stock nurseries*

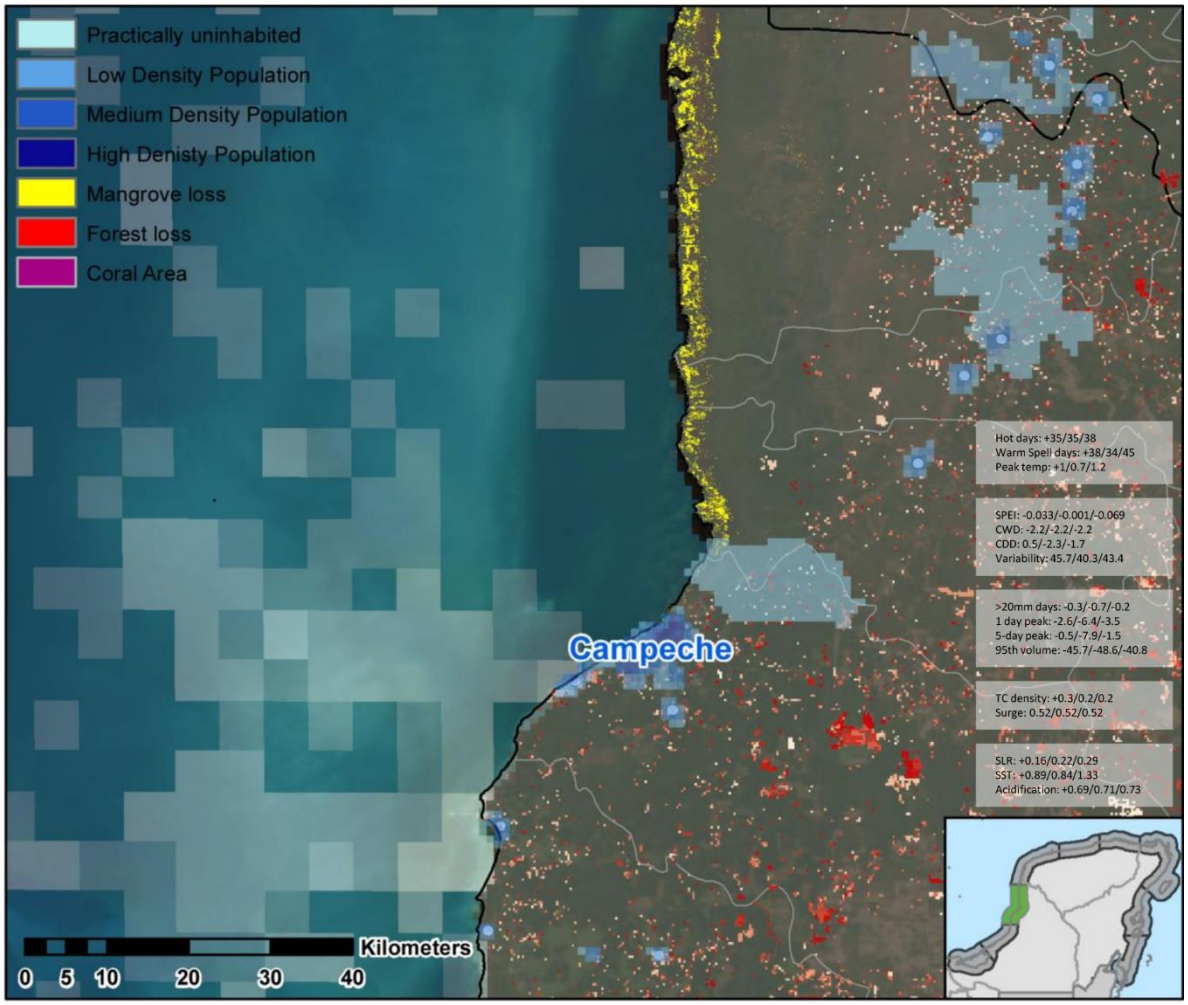


Figure 84. Characteristic of area C

6.3.4. Location D: Mérida West

This area is in the north west of the Yucatan peninsula. There is a moderate increase in the number of hot days and warm spell days annually. There is lower precipitation variability and the drought tendency here is also low, as is the change in consecutive wet and dry days. The changes in the extreme rainfall see annual decreases in volume occurring, but an increase in the magnitude of single-day events in Oct to Dec. Projected change in Topical cyclone density is moderate as is the change in storm surge. The acidification and surface temperature of the oceans here are high but the sea level rise is moderate.

There are some notable areas of deforestation in this location as well as negative ecosystem health present along the coastal areas. This area is noted to have high vulnerability for ground water to flood and drought events. There are isolated but consistent mangrove loss areas along the coast. There is very little rainfed agriculture in the area and the gap yield is only medium. There is however high-water crowding indicating potential water stress for communities. There is also higher fishing density in the norther part of this area by Progreso. There is low population density along the coastal area as well as low deprivation, child dependency and infant mortality rates in this area

The biomass in this area is generally low, however, there is good forest integrity protecting the natural areas. This area also has good accessibility to local areas and generally good economic activity. This area also has access to good and essential services in the event of a climate emergency.

The stakeholders have indicated that future climate impacts are likely to be heat stress in the city area, damage to ecosystems and coastal assets and impact to ecosystems. Their wish list interventions focused predominantly along the coast with mangrove rehabilitation, beach protection, and fishery management, as well as other interventions of wetland rehabilitation and improved management of ecosystems for livelihoods.

The key critical elements of social, livelihoods and environment are roughly equivalent in their climate vulnerability and this area has a low over all vulnerability, driven primarily by high adaptive capacity in the area. Interventions that would benefit this area include the following:

Table 15. Potential interventions in Location D

Social interventions	Livelihoods interventions	Environmental interventions
• *Ecosystem-based approach to fisheries management* • *Forest restoration and rehabilitation*	• *Ecosystem-based approach to fisheries management* • *Coastal mangrove rehabilitation* • *Agroforestry* • *Forest restoration and rehabilitation*	• *Expansion and establishment of marine protected areas* • *Living breakwaters* • *Coastal mangrove rehabilitation* • *Forest restoration and rehabilitation*

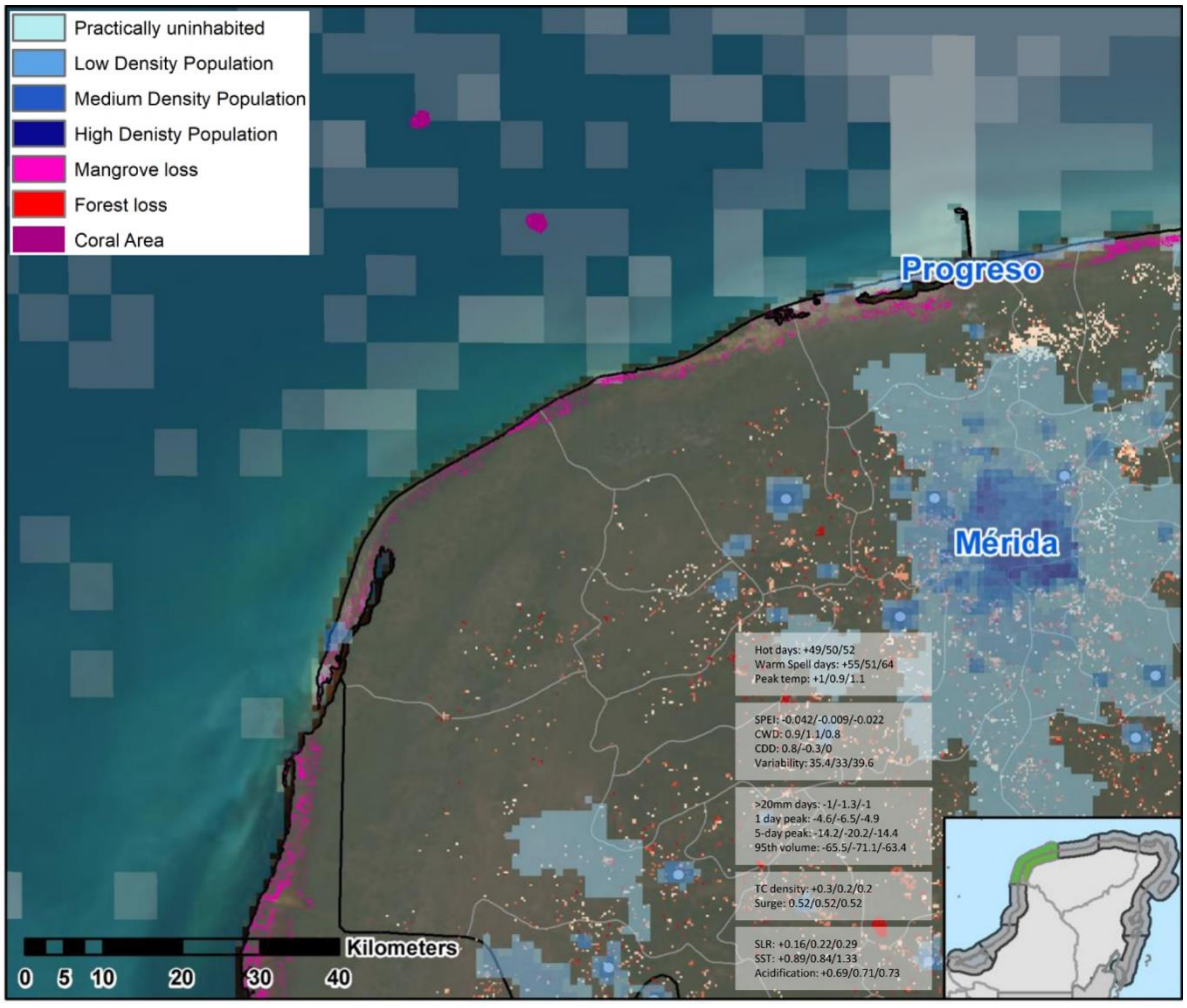


Figure 85. Characteristic of area D

6.3.5. Location E: Mérida East

This area is to the north of the Yucatan Peninsula. Projected temperatures here are set to increase but the peak temperature change is the lowest in the area, there are however large increases in the number of hot days and the warm spell duration.

The year-on-year rainfall variability here is moderate but the change in drought tendency is high. There is an annual increase in the volume of single-day events, particularly in October. The projected change in storm surge is highest in this location and the change in tropical cyclone density is tied with all locations to the east. Sea surface temperature and change in acidification are moderate here, however, the change in sea level rise is highest here and tied with the other areas to the east.
This area has clusters of deforestation close to the coast and a general negative ecosystem health trend. Additionally, there are clusters of high-density mangrove losses. This location also has a lot of rainfed agriculture in the area with medium gap yields and medium high-water crowding. There are also some significant fishing areas in the location. This area has higher deprivation trends and medium child dependency ratio and infant mortality rates. There is a moderate population density further inland.

This area has very low environmental adaptive capacity with both the biomass density and forest integrity being very low in this area. There is relatively good accessibility and medium economic activity in the western part of this area and moderate to good land productivity. This area also has medium access to the goods and services in the main city of Merida to the west. The major impacts in this area are damage to fish stocks and fishing livelihoods as noted by the local stakeholders. The proposed interventions are highly focused on ecosystem restoration with dune and beach restoration, coastal mangrove rehabilitation and wetland rehabilitation.

Environmental adaptive capacity in this area is low, while social sensitivity is high and the key critical elements of social, livelihoods and environment come out with a similar climate vulnerability of medium-high overall vulnerability. Interventions that would benefit this area include the following:

Table 16. Potential interventions in Location E

Social interventions	Livelihoods interventions	Environmental interventions
• *Forest restoration and rehabilitation* • *Traditional knowledge sharing*	• *Reduced tillage* • *Cover crops and mulching* • *Indigenous crops and livestock intercropping* • *Ecosystem-based approach to fisheries management*	• *Forest restoration and rehabilitation* • *Wetland rehabilitation* • *Coastal mangrove rehabilitation* • *Dune and beach rehabilitation*

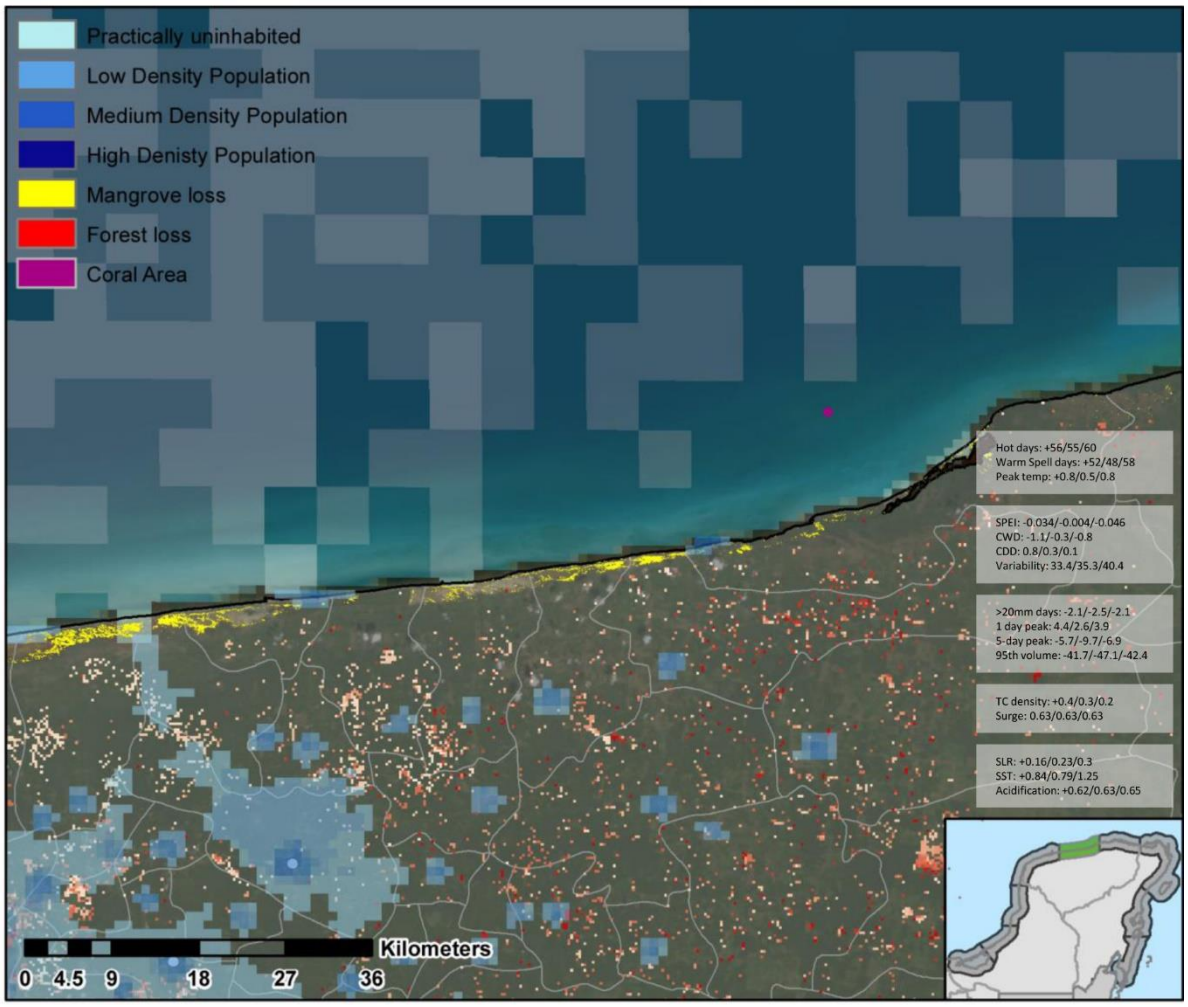


Figure 86. Characteristic of area E

6.3.6. Location F: Rio Lagartos

This area is near the north eastern part of the Yucatan. The temperatures here show a projected future of high change in hot days, but only moderate changes in warm spell duration and peak temperature. The year-on-year variability here is low as is the tendency for future drought. There is however moderate change in consecutive wet and dry days in this area. There is an increase in the number and severity of extreme rainfall events in this location particularly in Oct/Nov. This area also has the highest change in tropical cyclone density and very high projected storm surge changes. This area also has the highest sea level rise and surface temperature and moderate to high acidification.

There are several large clusters of deforestation and a negative ecosystem health trend. This area also has high-density mangrove losses. This area also has a very high rainfed density and medium gap yields, this is more severe further inland. There are also several high-density fishing locations in this location. There are high deprivation trends in this location but there are medium-high child dependency ratios and infant mortality rates with lower population density.

The biomass and forest integrity in this area are very low and there is little adaptive capacity gained from this. This area also has low accessibility and economic activity but the land productivity in relatively high. This area has limited access to goods and critical services in the event of a climate disaster.

Stakeholders indicated that major impacts in this area are deforestation and damage to eco-tourism. They have proposed several interventions to enhance marine protected areas, mangrove rehabilitation, beach protection, forest restoration and redesign of the Maya train to promote tourism.

The key critical elements of social, livelihood have very high climate vulnerability. Climate vulnerability of the environment is less severe but still medium mainly because there ecosystem health and mangrove loss trends are not too severe. Interventions that would benefit this area include the following:

Table 17. Potential interventions in Location F

Social interventions	Livelihoods interventions	Environmental interventions

• *Forest restoration and rehabilitation* • *Traditional knowledge sharing*	• *Reduced tillage* • *Cover crops and mulching* • *Indigenous crops and livestock intercropping* • *Ecosystem-based approach to fisheries management* • *Ecotourism*	• *Forest restoration and rehabilitation* • *Wetland rehabilitation* • *Coastal mangrove rehabilitation* • *Dune and beach rehabilitation*

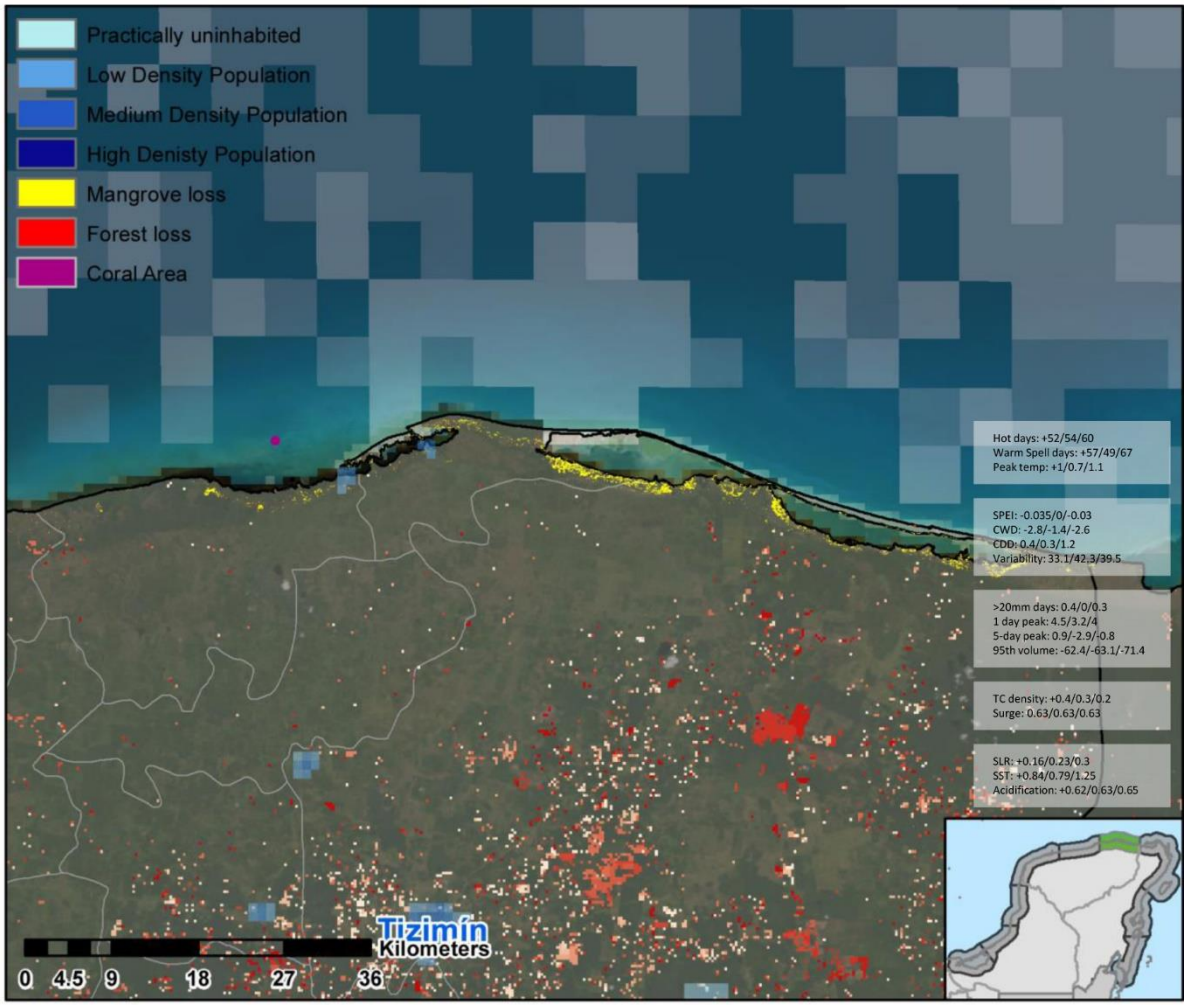


Figure 87. Characteristic of area F.

6.3.7. Location G: Cancun

This area is to the north east of the Yucatan peninsula. There is a very large increase in the duration of the warm spells. There is also a moderate increase in peak temperatures. There is a significant increase in the year-on-year rainfall variability, a moderate projected drought tendency, and a high decrease in the number of consecutive wet days. Annually, there is an average decrease in extreme event occurrence and magnitude, however, there are several months that see an increase in peak single-day rainfall volume, these are Oct to Dec, May and Aug. There is a large change in the tropical cyclone density but a low change in the storm surge height. Acidification and sea level rises are high here and surface temperature changes are moderate. The deforestation trends in recent years here seem to be very more limited than in some other areas. Additionally, the ecosystem health trends in this area seem to be mostly positive. This area along has medium ground water vulnerability. The mangrove losses here are very low. There are also noted areas of coral reefs close to the shore. There is very limited climate-sensitive rainfed agriculture in the area and the gap yield therefore doesn't strongly apply. There is significant fishing boat density in this location and medium to high water crowding. There is high population density in the city of Cancun but is lower elsewhere in the area. The child dependency ratio and infant mortality rates are medium but the deprivation trend in the build-up area is high.

Adaptive capacities in this area are all relatively high with forest integrity and biomass having high capacity, accessibility being very high and economic activity and land productivity also being high. This area is close to a major city and has access to critical goods and services necessary in the event of a climate emergency.

The stakeholder has indicated that this area will likely suffer from impacts to fisheries and tourism as the major economic activity in the area. Proposed interventions in this area suggested were the protection of mangroves and marine areas, dune and beach rehabilitation and EbA approaches to fisheries and further enhancing eco-tourism.

The environment is the key critical element with the highest climate vulnerability with a medium score. The high livelihood and social adaptive capacities lower the overall climate vulnerabilities of these elements, but these are incredibly important to this area and shouldn't be discarded for intervention. Neither should the area as an important economic driver for the whole region. Interventions that would benefit this area include the following:

Table 18. Potential interventions in Location G

Social interventions	Livelihoods interventions	Environmental interventions
• *Coastal realignment and setback* • *Urban wetlands*	• *Coral reef rehabilitation* • *Coastal realignment and setback* • *Living breakwaters* • *Ecotourism* • *Coral reef insurance* • *Ecosystem-based approach to fisheries management*	• *Dune and beach rehabilitation* • *Seagrass rehabilitation* • *Coral reef rehabilitation* • *Living breakwaters* • *Ecotourism* • *Coral reef insurance*

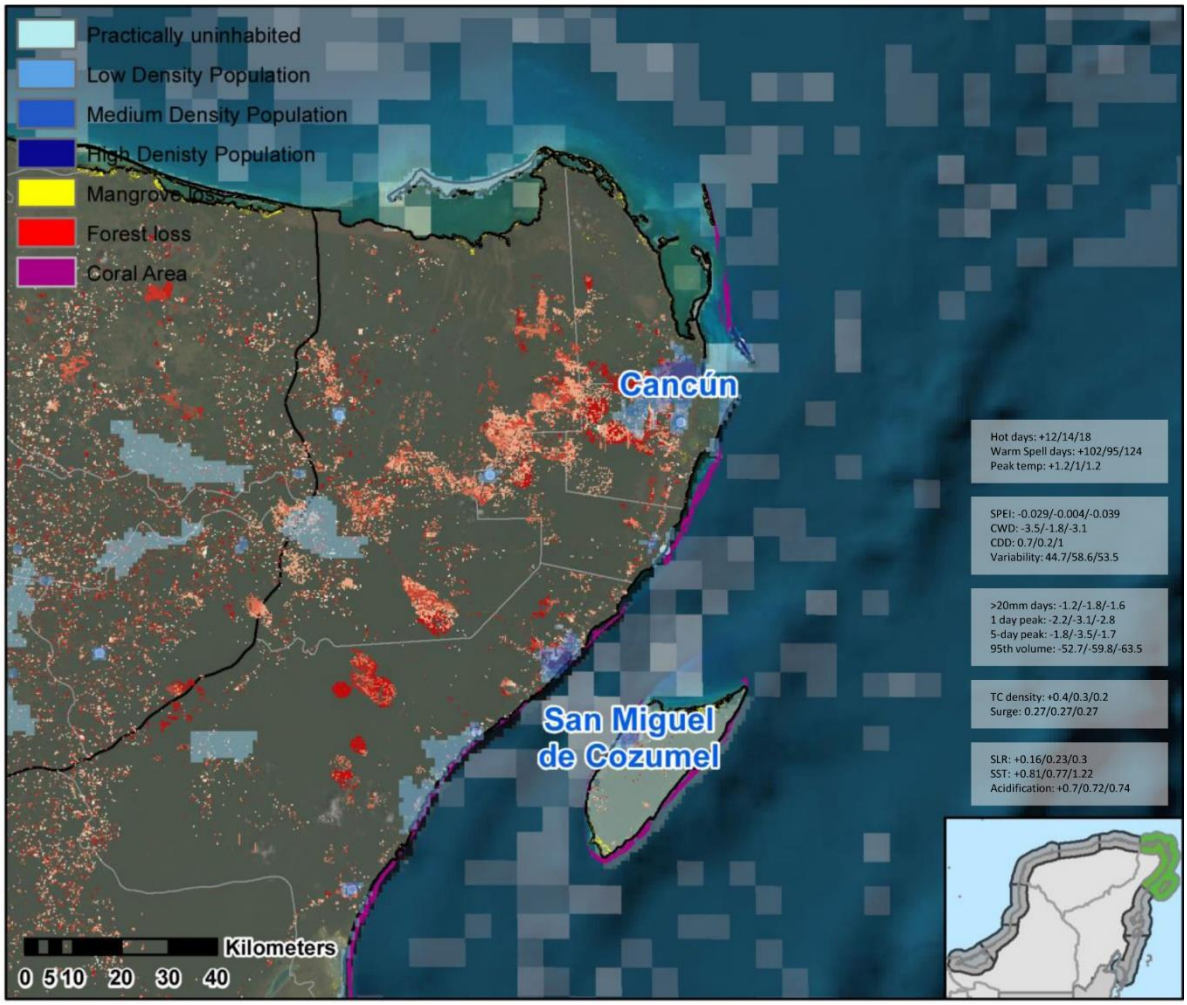


Figure 88. Characteristic of area G

6.3.8. Location H: Tulum

This location is to the east of the Yucatan peninsula. This area has the highest increase in the number of hot days and peak temperatures and a moderate increase in the number of warm spell days. There is also a strong drought tendency in this area and a large increase in the number of consecutive dry days. There are strong increases is the number and magnitude of extreme rainfall events with the largest changes noted in May and October. The change in tropical cyclone storm surge here is low but the increase in tropical cyclone occurrence here is the highest as this area is the most exposed to cyclone events. Acidification, surface temperature and sea level rise are all high here.

There are some notable deforested areas inland in this area and the ecosystem health trend is medium or negative. There are however only medium mangrove losses in the area. There also seems to be a long coral reef close to the shore. There is practically no rainfed agriculture in this area and there is lower sensitivity from this. There is also low water crowding in this area and fishing in this area is more limited. This area is very sparsely populated and there are minimal indications of infant mortality, child dependency ratio and deprivation trends.

The adaptive capacity here is quite mixed. Biomass and forest integrity are highly clustered and range from very high to very low over short distances. There is very limited accessibility and economic activity in this area and land productivity here is medium. This area is also far away from critical goods and services in the event of a climate disaster.

Stakeholders indicate that major impacts in the future may be damage to marine ecosystems and terrestrial ecosystem destruction. Proposed interventions in this area were the restoration of dunes, and EbA approaches to fishery management, sea grass rehabilitation, wetland management., as well as enhancing traditional knowledge sharing.

The environment is the key critical element with the highest vulnerability of a medium-high score. Social vulnerability is medium and livelihood vulnerability is low. Interventions that would benefit this area include the following:

Table 19. Potential interventions in Location H

Social interventions	Livelihoods interventions	Environmental interventions
• *Traditional knowledge sharing*	• *n/a*	• *Forest restoration and rehabilitation* • *Coastal mangrove rehabilitation* • *Coral reef rehabilitation* • *Living breakwaters* • *Coral reef insurance*

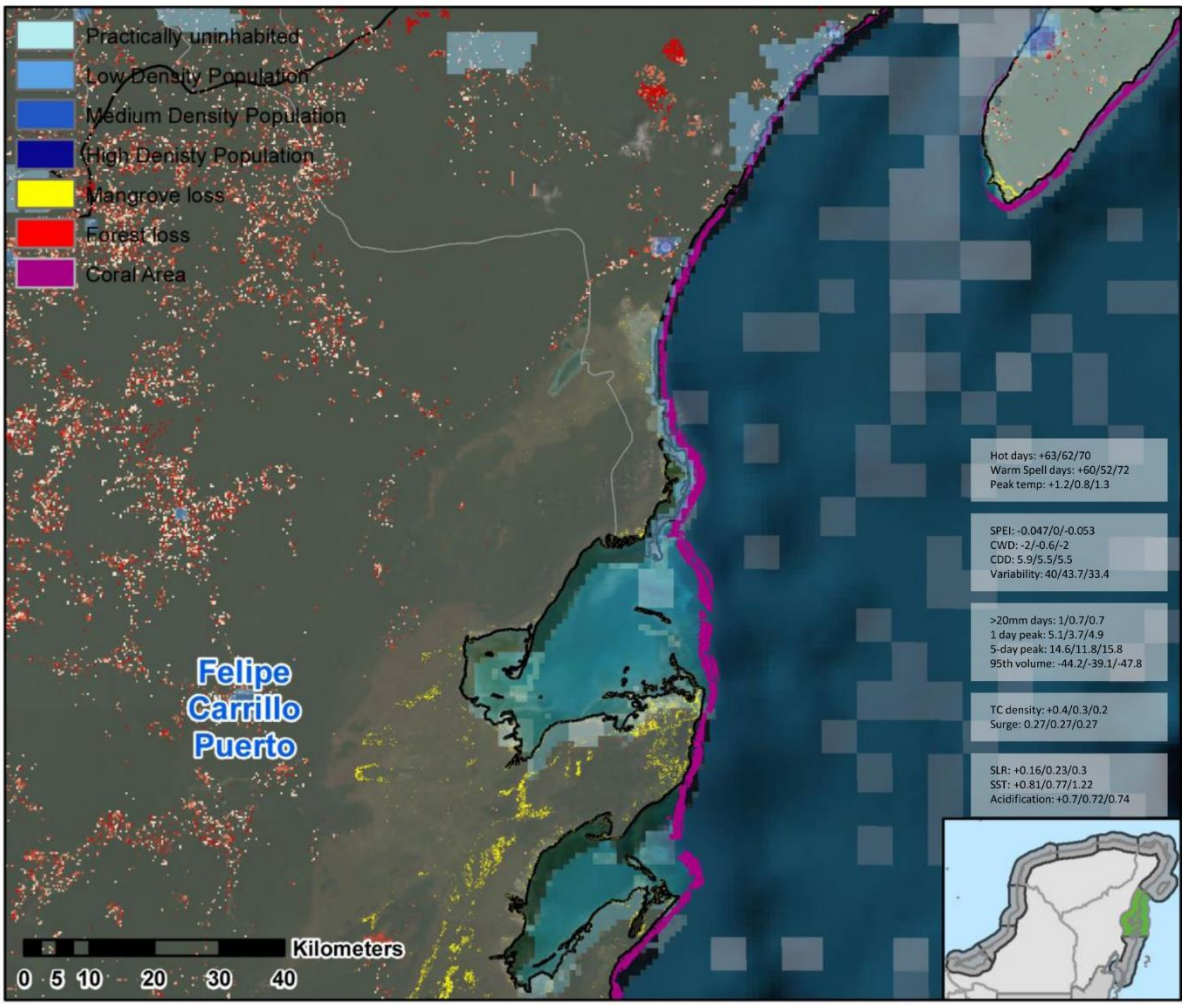


Figure 89. Characteristic of area H

6.3.9. Location I: Mahahual

This area is to the south east of the Yucatan peninsula. This area has the peak highest temperature increases and a moderate increase in hot day occurrence and warm spell duration. There is a significant increase in the consecutive dry days and a moderate increase in the drought tendency. The extreme events here see an increase in the volume of the 1- and 5-day peak rainfall events, particularly in May and October. Tropical cyclone occurrence here is expected to be high along with the other locations on the east and northern coast, but changes in storm surge are projected to be low. Changes in acidification, surface temperature and sea level rise are all high here.

There is a large cluster of recent deforestation in the area. The ecosystem health in the area is medium and there is a long stretch of corals. The mangrove losses in this area are moderate. There is again very limited rainfed agriculture in the area and low water crowding, There is also some fishing density in the area, but this is more limited than in some other locations. The population density in this area is low as is the deprivation trend, infant mortality rate and the child dependency ratio

While there are clusters of low biomass density and forest integrity, these clusters are small and there are more areas how high capacity. This area has very low accessibility and very low economic productivity. This area has medium land productivity. This area is also very far away from goods and services in the event of a climate emergency.

Stakeholders identified threats to this area of impact on fisheries, damages to the marine environment and decrease in avian/fauna species. They proposed enhancing ecotourism in this area and rehabilitating coral reefs, beaches, and dunes. They also suggested EbA approaches to fishery management.

The limited population and subsequent livelihoods result in these vulnerabilities being lower. The environment is the key critical element with the highest vulnerability of a medium score. Interventions that would benefit this area include the following:

Table 20. Potential interventions in Location I

Social interventions	Livelihoods interventions	Environmental interventions

• *Traditional knowledge sharing*	• *Ecosystem-based approach to fisheries management*	• *Forest restoration and rehabilitation* • *Coastal mangrove rehabilitation* • *Coral reef rehabilitation* • *Living breakwaters* • *Coral reef insurance*

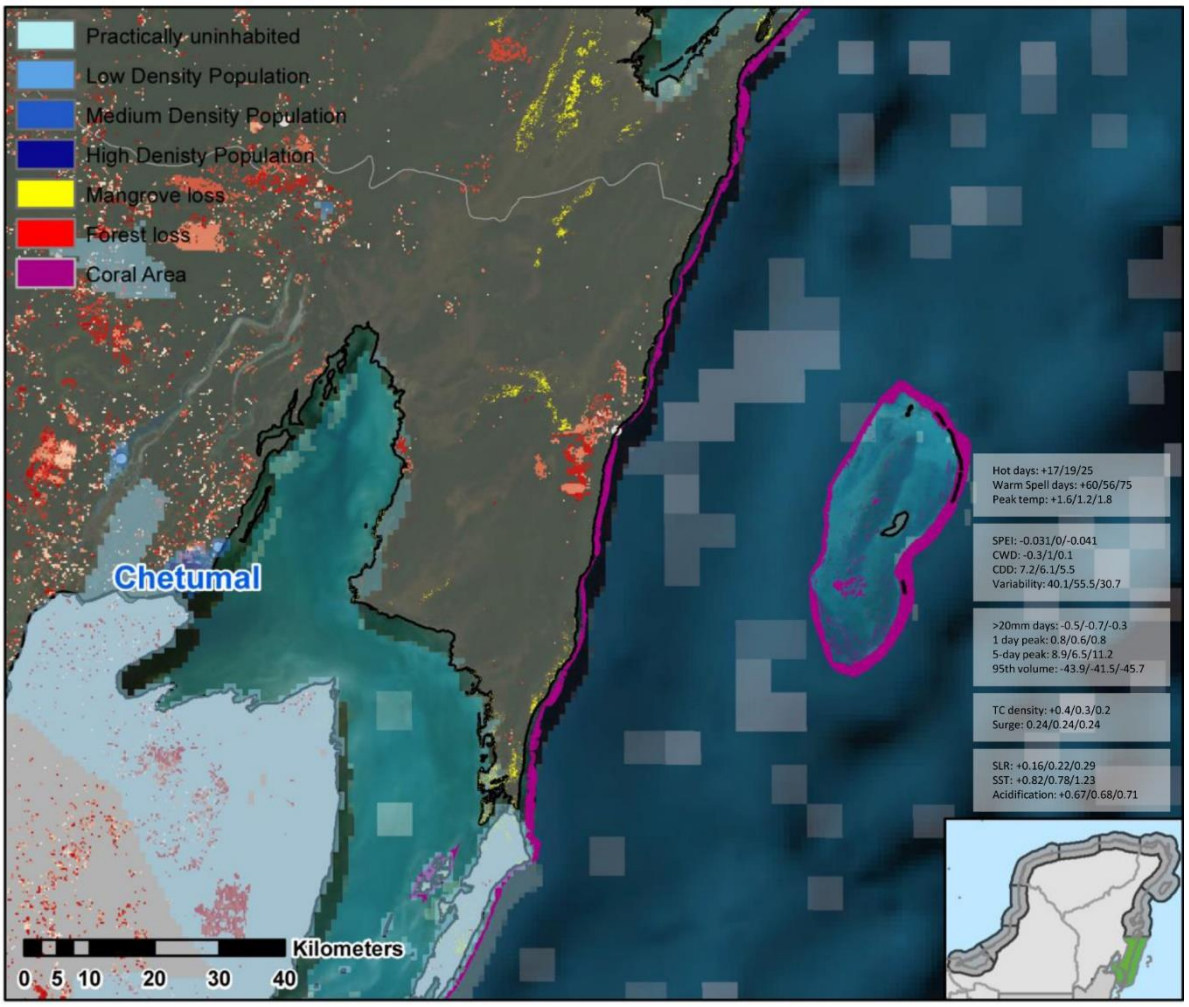


Figure 90. Characteristics of area I

6.3.10. Small island locations

These islands will all be subject to future climate impacts and have minimal adaptive capacity to cope. Strengthening the local marine and terrestrial environment will help not only increase physical resilience but also enhance livelihoods that rely on these environmental assets.

- *Cayo Arcas: This island sees large changes to temperatures and some increase in warm spell duration. Precipitation here is highly varied and there is a moderate tendency for drought in the future. Extreme rainfall here is mostly decreased other than in October. This island will have high exposure to future storm surges and moderate future exposure to tropical cyclone occurrence. Acidification around the island is high as is the change in ocean surface temperatures. But there is a relatively lower sea level rise potential.*
- *Alcranes Reef: This island has medium-high changes to temperatures with an increase in warm spell duration. There is a moderate leaning towards future drought occurrence. There is also a change in extreme events which see increased magnitude in October, but generally lower in other months. The island is in the area most likely to be in the pathway of the tropical cyclone and as such has a high future impact potential, there is also an increase in the potential storm surge magnitude. There is a high sea level rise potential on this island and moderate sea surface temperature changes. Changes in acidification here are moderate.*
- *Cozumel: a large island located on the eastern side of the Yucatan peninsula, it has a moderate increase in peak temperatures. There is a significant increase in the year-on-year rainfall variability. There are several months (Oct to Dec, and May) that see an increase in peak single-day rainfall volume. There is a large change in the tropical cyclone*

density but a low change in the storm surge height. Acidification and sea level rise are high here and surface temperature changes are moderate. The projected increase in sea level rise here is high but this island is large, so the impacts are less severe. The projected changes in sea surface temperatures and acidification here are relatively low.

- *Chinchorro: this island will see large increases in peak temperatures and significantly increased consecutive dry days with moderate drought potential. There is a projected increase in the occurrence and magnitude of extreme rainfall events on this island. There is also medium to high exposure to tropical cyclone occurrence but lower surge anomaly. The sea level rise here is moderate as are the changes in sea surface temperatures and acidification changes.*

Table 21. Potential interventions in the islands

Social interventions	Livelihoods interventions	Environmental interventions
• *Coastal realignment and setback* • *Ecotourism* • *Ecosystem-based approach to fisheries management*	• *Dune and beach rehabilitation* • *Coastal realignment and setback* • *Seagrass rehabilitation* • *Coral reef rehabilitation* • *Living breakwaters* • *Ecotourism* • *Coral reef insurance* • *Ecosystem-based approach to fisheries management*	• *Forest restoration and rehabilitation* • *Coastal mangrove rehabilitation* • *Dune and beach rehabilitation* • *Coastal realignment and setback* • *Seagrass rehabilitation* • *Coral reef rehabilitation* • *Living breakwaters* • *Expansion and establishment of marine protected areas* • *Coral reef insurance* • *Ecosystem-based approach to fisheries management*

Figure 91. Critical islands surrounding the Yucatan peninsula exposed to future climate changes.

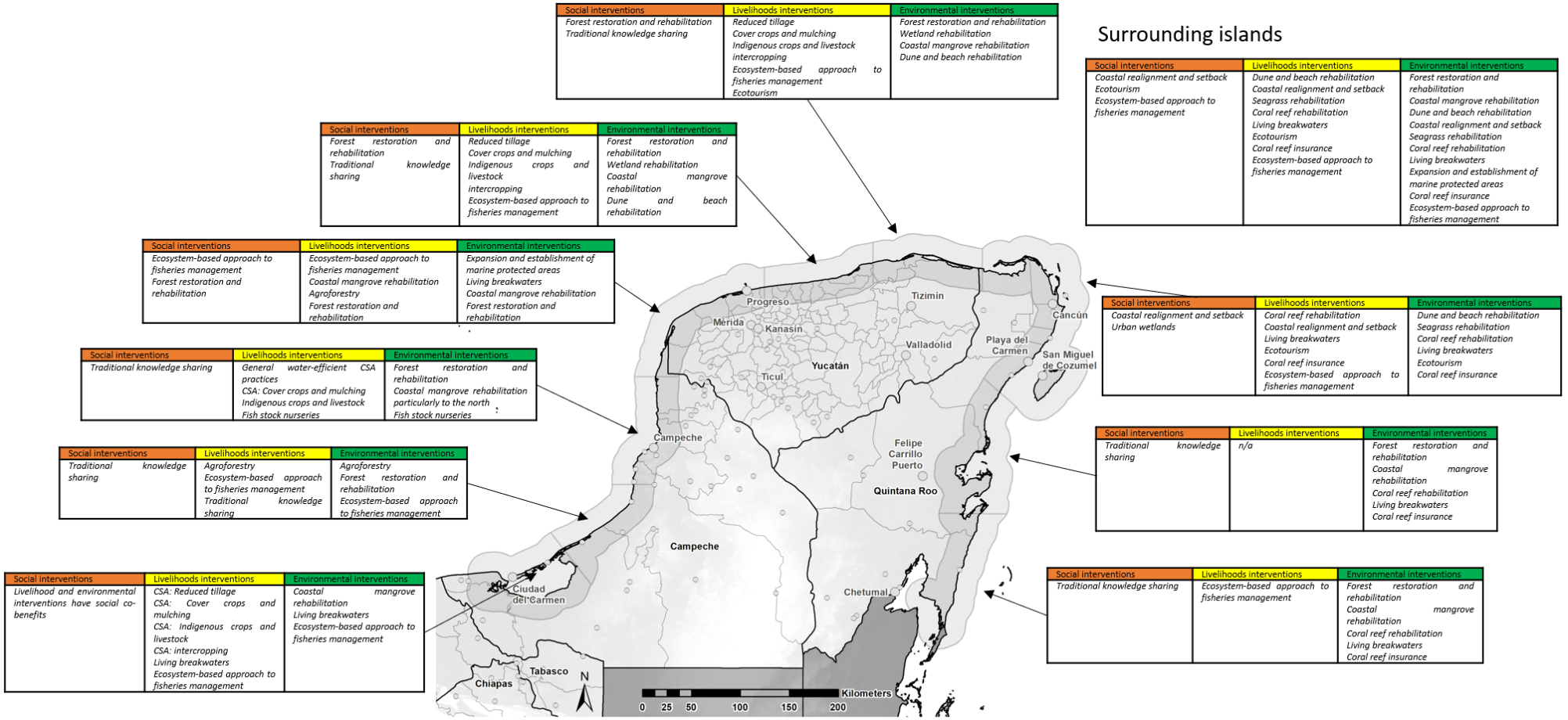


Figure 92. Distribution of potential interventions

7. B.1. Climate rationale and context

7.1. B.1.1. Local context

Mexico is located in the southern part of North America and is bordered in the north by the United States of America, in the south by Guatemala and Belize, and by the Pacific Ocean to the west, the Gulf of Mexico and the Caribbean Sea to the east. The country comprises two distinct climatic zones, namely: i) a temperate zone in the north that is generally arid, with moderate rainfall, mild to warm summers and cool to cold winters; and ii) a tropical zone in the south, which is mostly rainy and hot[294]. The project's target area, namely the Yucatán Peninsula, is located in the southern region, at Mexico's border with Guatemala and Belize, between the Gulf of Mexico and the Caribbean Sea. In most of the central part of the peninsula, the climate is predominantly classified as tropical, savannah (Aw[295]), with temperatures and humidity that are generally high, and heavy rainfall and tropical storms occur during the summer months[296]. The peninsula receives a relatively low annual rainfall of approximately 600–1600 mm, and the southern parts of the region receive more rainfall overall than the northern parts[297]. The Yucatán Peninsula is composed predominantly of coralline and porous limestone rock beds which form a landscape that rises gradually from north to south, and there are numerous sinkholes and caverns across the landscape[298]. It has a wide variety of diverse ecosystems, including tropical rainforests, tropical reefs, mangroves (including *petenes*), dunes, *cenotes*[299] and other ecosystems related to its limestone geography (including caves and subterranean rivers)[300]. The peninsula has one of the largest karst aquifer systems in the world, with a total area of permeable limestone covering approximately 165,000 km^2.[301] There are no significant natural lakes or surface-level rivers flowing overland in most parts of the peninsula (with the exception of some southern areas), and most of the water is located in subterranean rivers and lagoons. The peninsula's water supply is dependent predominantly on this system, and underground water is the main source of water (90%) for domestic and agricultural use[302].

The Yucatán Peninsula has a population of approximately 5.1 million (2020)[303]. In the past few decades, the total population of the peninsula has grown steadily. Since the 1980s, the Yucatán Peninsula has experienced an increase in its total population of more than 100%, which is much higher than the national average of 77%[304]. As a result of the rapidly growing population, ecosystems across the Yucatán Peninsula have deteriorated in recent decades as a result of anthropogenic pressures and climate change. In the past 30 years, coastal areas (including mangrove forests) have been adversely impacted by tourism and urban development through the construction of buildings, roads, ports and harbours[305]. At present, 80% of the rainforests are degraded, and only 22% of the peninsula's total area contains mature vegetation. Poverty rates In the Yucatán Peninsula are lower than that of its neighbouring southern states, but still among the highest in the country. The targeted communities for this project will be those who are most vulnerable to the impacts of climate change – particularly low-income groups who are dependent on the dwindling natural resource base of the peninsula.

7.2. B.1.2. Climate change problem

The Yucatán Peninsula has experienced several significant climatic changes in recent decades. These changes, as well as projected future climate changes for the region, are summarised in Table 22 below. A brief description of each of these climatic changes is presented in the sections below the table, and a detailed analysis is available in Chapter 2 Projected future climate.

*Table **22**. Observed and projected future climate changes in the Yucatán Peninsula.*

Climatic change	Observed trend	Projected future
Precipitation	• *Declining average precipitation trend* • *Increasing extreme rainfall/peak rainfall trend* • *Increasing drought conditions*	• *Annual precipitation will decline across much of the Yucatán Peninsula* • *Most severe declines: south-eastern parts of Quintana Roo (15.0–19.8 mm per decade)*

[294] CMCC. G20 Climate Risk Atlas: Mexico. Available here
[295] According to the Köppen-Geiger climate classification system
[296] Worlddata. Available at: here
[297] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[298] Britannica. No date. Yucatán Peninsula. Available here.
[299] water-filled sink holes
[300] Panorama. 2022. Harnessing the power of AI and community centred approaches to monitor Jaguars in the Yucatan Peninsula. Available: here.
[301] Adame, M.F., Santini, N.S., Torres-Talamante, O. and Rogers, K., 2021. Mangrove sinkholes (cenotes) of the Yucatan Peninsula, a global hotspot of carbon sequestration. *Biology letters*, *17*(5), p.20210037.
[302] Rodríguez-Huerta, E., Rosas-Casals, M. and Hernández-Terrones, L.M., 2020. A water balance model to estimate climate change impact on groundwater recharge in Yucatan Peninsula, Mexico. *Hydrological Sciences Journal*, *65*(3), pp.470-486. Available here.
[303] DataMexico. Yucatán. Available here.
[304] Azcorra, H. and Dickinson, F., 2020. *Culture, environment and health in the Yucatán peninsula*. Springer International Publishing.
[305] Sampedro, E.B., The Mangroves: Characterisation and environmental services. Available here.

Climatic change	Observed trend	Projected future
		• *An increasing trend in average precipitation is projected for central and south-western areas (parts of south-western Campeche up to 10 mm per decade)* • *Extreme rainfall will become more common on the east coast* • *The number of consecutive dry days is also projected to increase* • *Periods between rainfall will become longer, drought conditions will intensify, and rainfall periods will become more intense.*
Temperature	• *Rising mean annual temperatures* • *Increasing maximum temperatures* • *Increasing minimum temperatures*	• ***Mean temperature:*** *northern and eastern coastal areas are predicted to experience increases of between 0.24–0.26°C per decade* • *Southern Yucatán State and the western part of Quintana Roo, temperature increases of up to 0.29°C per decade are predicted* • ***Peak temperature:*** *North-eastern coastal region of the peninsula, maximum temperatures are expected to rise by 0.26–0.27°C per decade* • *South-western Campeche will experience increases in* ***average maximum temperatures*** *by up to 0.32°C per decade* • ***Average decadal minimum temperature****: 0.23–0.24°C per decade in north-eastern Quintana Roo; up to 0.31°C per decade in the southwest of Campeche*
Tropical cyclones	• *Unclear trend in tropical cyclone activity* • *Tropical cyclones and storm/ depressions: increase from 1950 to present of ~0.2 events over 5 years*	• *Highly variable into the future with a likely (67% confidence) ~50% to -50% range on either side of current occurrence.* • *Expected decrease change overall in the number of events.* • *Category 4 and 5: likely expected to increase by 50%* • *Slight increase in the maximum intensity per tropical cyclone event* • *Increase in the precipitation rate associated with tropical cyclone events* • *Storm surges will become increasingly common and severe*
Ocean characteristics	• *Sea level rise of ~2 mm/year since 1990* • *Rising sea surface temperatures* • *Clear trend in ocean acidification*	• ***SLR:*** *north-eastern areas of the Yucatan peninsula of up to +0.17m between 2020 and 2050.* • *Areas to the west are projected to see a lower increase of up to +0.15m* • ***SST:*** *Areas to the west and east of the peninsula will show a rise in SST of up to 0.94 and 0.86, respectively* • *Ocean acidification: Continued projected trend*

Observed climate trends

Precipitation

The Yucatán Peninsula is experiencing decreasing average precipitation, as well as an increase in extreme rainfall and drought conditions (Figure 5 and Figure 7). Between 1971 and 2020, the Yucatan peninsula saw a decrease in average precipitation. Except for some parts of Quintana Roo, all subregions experienced a 1-2.9 mm decline in annual rainfall. Some areas, especially in the western parts, witnessed reductions of 8-16.2 mm per decade. Climate change has contributed to this trend, causing rainfall patterns to become more variable, with heavy precipitation becoming more common, and periods between rainfall becoming longer. Extreme rainfall and drought occurrences have increased across the region, with the north-western areas experiencing abnormally dry conditions since the 1980s, intensifying since 2010.

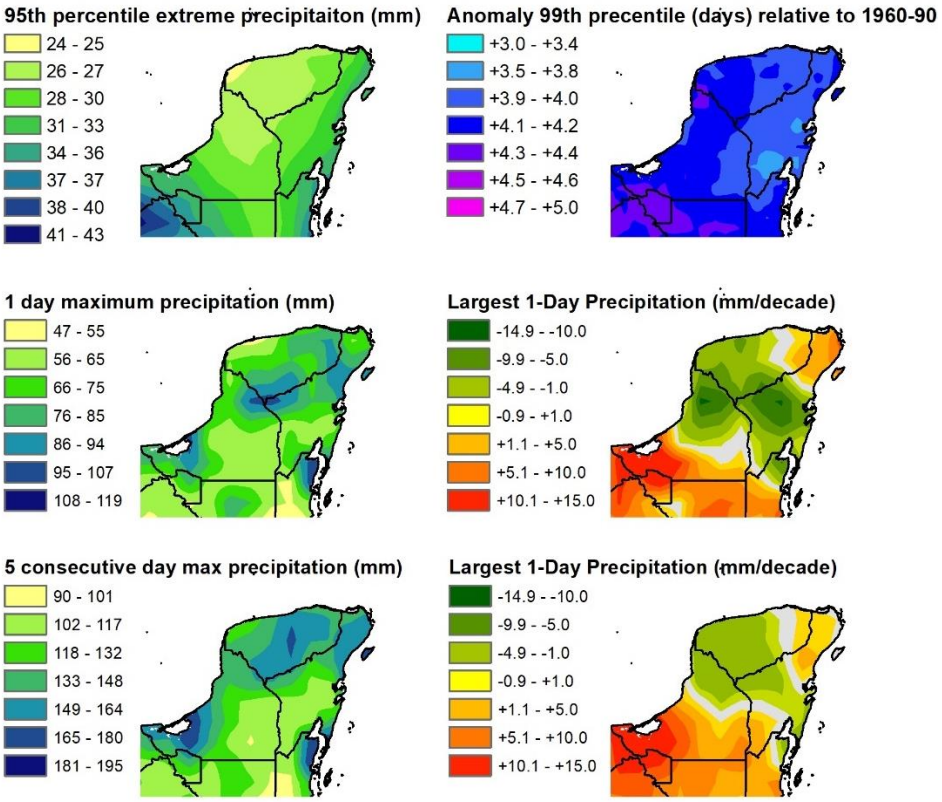


Figure 93. Current change in peak rainfall distribution and trends of extreme rainfall parameters

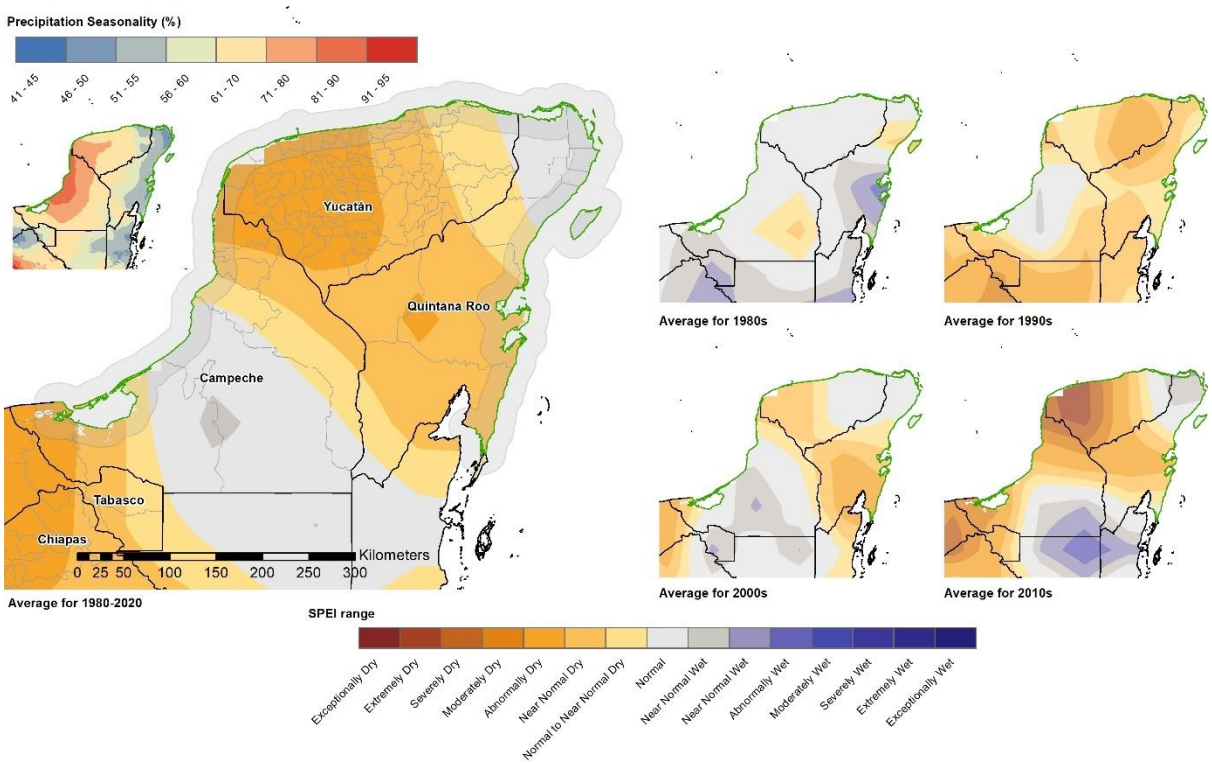


Figure 94. Current SPEI drought classification (A); and Decadal SPEI drought conditions over time (B); Current rainfall trend and precipitation seasonality

Temperature

Long-term temperature trends for the Yucatán Peninsula indicated that increases in average temperatures are largest on the south and east coast of the region (Figure 8). This trend is in contrast to some central areas of the west coast of the peninsula, such as in the coastal areas between Yucatán and Campeche states, where temperatures show a decreasing trend. Concurrent with the increasing average temperature trend, a rise in the occurrence and duration of heat waves has also been observed. Between 1960

and 1990, there was a significant increase in warm spell duration, particularly in the coastal areas on the east and northeast coast of the peninsula.

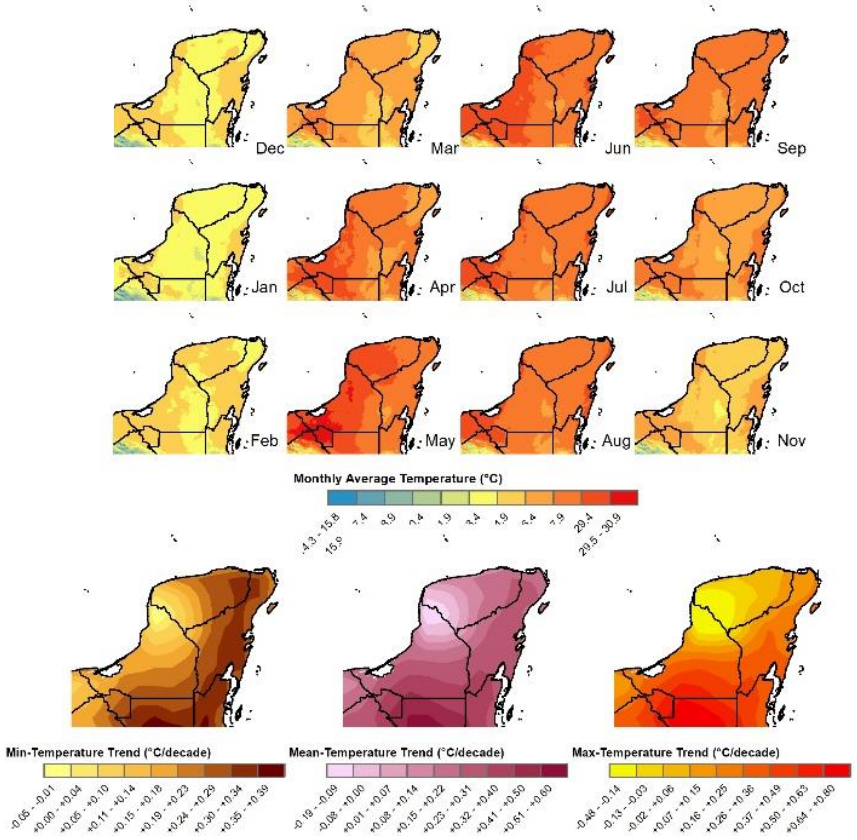


Figure 95. Current temperature trends (B)

Tropical cyclones

The Yucatán Peninsula is particularly prone to the occurrence of tropical cyclones, owing to its location between two oceans as well as the Gulf of Mexico which is generally an area of high tropical cyclone density and has experienced numerous of these events in recent decades. The change over time in tropical cyclones and storms/depressions shows an increase from 1950 to the present of ~0.2 events over a 5-year period. This trend is however not statistically significant due to the generally varied nature of these events. While a clearly discernible trend is not evident, there does appear to be a greater occurrence of tropical cyclone events in more recent times. The Yucatán's vulnerability to tropical cyclones means that it is also exposed to storm surges and high wind speeds.

Ocean characteristics

During the past 100 years, Mexico has experienced sea level rise (SLR) above the global average, reaching more than 2 mm/year since 1990. In the waters surrounding the Yucatán Peninsula, sea levels have also been observed. Sea levels along the eastern coast of the peninsula have risen comparatively more than areas to the west of the peninsula, corresponding to the higher sea surface temperatures which have been observed in this area. Alongside rising sea levels, a clear trend in ocean acidification has been observed in the waters surrounding the Yucatán.

Projected future climate

Precipitation

Under future climate conditions, projections for the Yucatán Peninsula indicate that extreme rainfall will become more common while drier conditions will become more prevalent. Projections, however, indicate variation as a result of the geography of the region. Rainfall is expected to decrease by 15.0–19.8 mm/decade in south-eastern Quintana Roo, while it is expected to increase by up to 10 mm/decade in south-western Campeche. Peak precipitation changes are also projected. In eastern coastal areas, increases in monthly precipitation peaks are predicted to be as much as 20.1 mm (Figure 25A), with this trend diminishing further inland, and becoming positive in the interior areas. In south-central parts of Yucatán State, central and eastern Campeche and western Quintana Roo, monthly mean precipitation peaks are predicted to decline by between 1.0–4.9 mm, along with a number of hotspot areas where projections show an increase in peak precipitation. Most parts of the peninsula — particularly southern parts of Quintana Roo and most of Campeche — will experience an increase in the average largest 1-day precipitation anomaly and 1-day precipitation per

decade. An increase in both the average largest 5-day cumulative precipitation anomaly and precipitation trend is predicted, with the west coast of the peninsula most severely affected. Drought conditions are projected to increase, by 1.1–2.0 days per year and up to 3 days in large parts of Quintana Roo state. The number of consecutive dry days is also projected to increase, particularly in the uplands of the peninsula and towards the south-eastern coast. This indicates that periods between rainfall will become longer, with intensifying drought conditions, while rainfall periods will become longer and more intense.

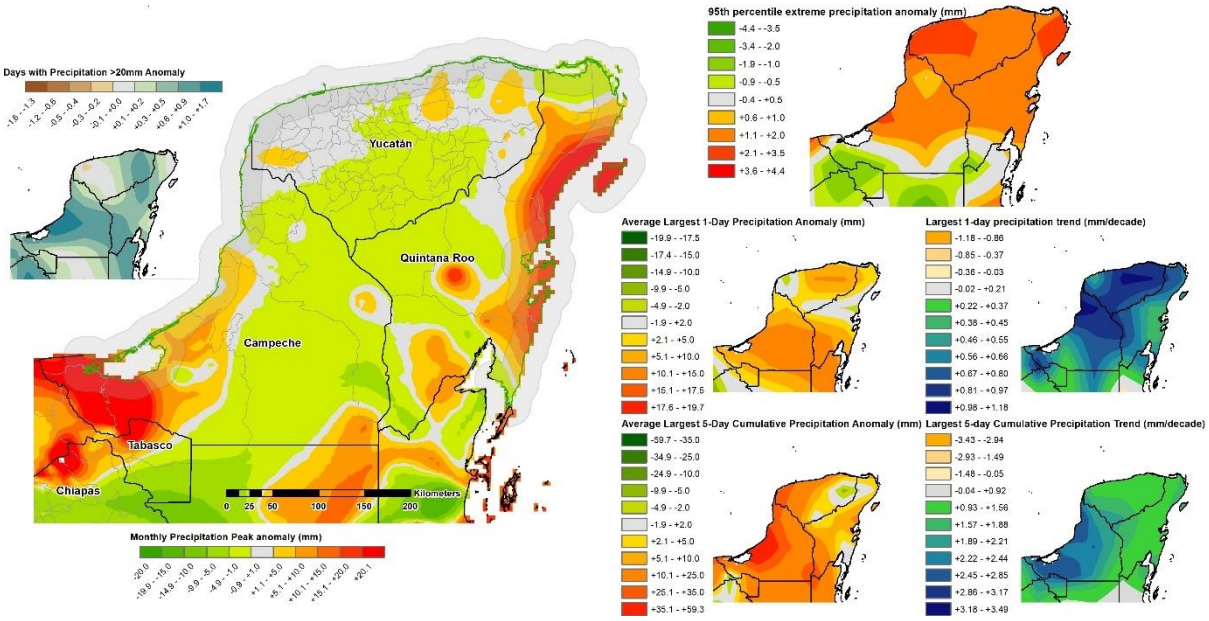


Figure 96. Projected peak rainfall distribution and distribution of extreme rainfall parameters; and Projected trend of extreme rainfall parameters.

Temperature

Under future climate conditions, mean temperature increases are projected for the entire Yucatán Peninsula, with the northern and eastern coastal areas predicted to experience increases of between 0.24–0.26°C per decade (Figure 30). In the south of the Yucatán State and the western part of Quintana Roo, temperature increases of up to 0.29°C per decade are predicted. Concurrently, the average decadal minimum temperatures in the peninsula will increase along the same axis as for maximum temperature — between 0.23–0.24°C per decade in north-eastern Quintana Roo, and up to 0.31°C per decade in the southwest of Campeche. A rise in the occurrence of heatwaves is also projected for the Yucatán Peninsula. The analysis indicates an increase in monthly maximum temperature peaks across the entire peninsula, as well as an increase in the duration of warm spells — particularly in coastal areas. Since increases in temperature and increases in the occurrence of dry spells result in an enhanced drying of vegetation and increased susceptibility of ignitions to be more severe, an increase in the duration of the fire weather season is expected in all locations around the Yucatan peninsula.

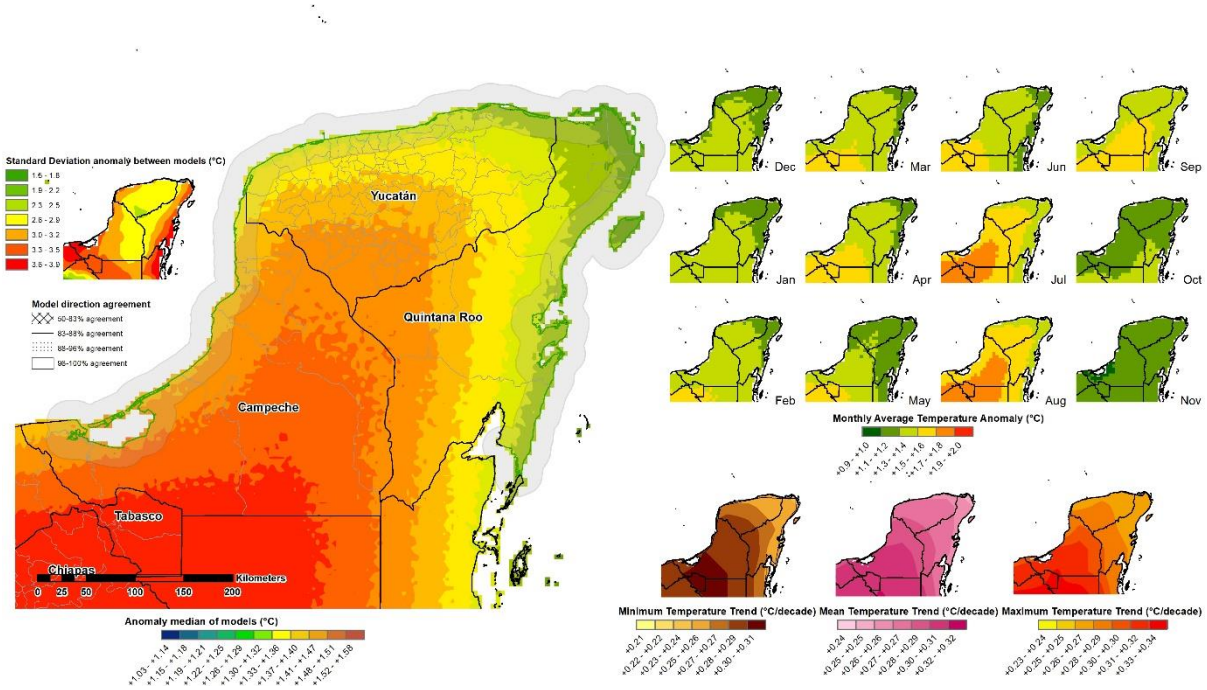


Figure 97. Median future average temperature, standard deviation between ensemble models, model agreement, and monthly temperature anomalies; and Projected temperature trends and 10th to 90th percentile ranges.

Tropical cyclones

Projections for tropical cyclone activity under future climate conditions are highly variable, with a likely (67% confidence) ~50% to -50% range on either side of the current occurrence. There is however an expected decrease change overall in the number of events expected, as well as a likely increase in more severe Category 4 and 5 (by 50%). Overall, a slight increase in the maximum intensity per tropical cyclone event is expected, as well as an increase in the precipitation rate associated with tropical cyclone events. The frequency and intensity of tropical cyclones are strongly related to anomalous sea surface temperature (SST) in the main development region, the weakening of vertical wind shear (VWS) in the mid-troposphere during depression development, and the La Nina phase of the El Nino Southern Oscillation (ENSO). Each of these factors may change because of future climate change, influencing the characteristics of tropical cyclones. ENSO and wind-shear characteristics are highly dynamic and will change on synoptic and annual time scales in response to current conditions. SST changes, on the other hand, will be more linear and while they will exhibit a seasonal cycle, the baseline trend will not likely revert to oscillations around current SST means.

Ocean characteristics

Projections show that SST will rise by 1.5°C by mid-century, and by 2.0°C towards the end of the century, with a trend of 0.16°C/decade. As with the rest of Mexico, the waters around the Yucatán Peninsula are also projected to increase under future climate conditions, Figure 44. This includes a projected increase in average sea surface temperatures (SST) to up to 28.1°C. Areas to the west and east of the peninsula will show SST anomalies of up to 0.94 and 0.86, respectively. Along with increasing SST, the Yucatán Peninsula will also experience a significant rise in sea levels. Projected increases in sea level see the largest change in the northeastern areas of the Yucatan peninsula of up to +0.17m between 2020 and 2050. Areas to the west are projected to see a lower increase of up to +0.15m. SST and SLR will occur alongside the gradual acidification of oceans. The ocean surrounding the Yucatan is projected to see an increase in salinity of up to +0.3 with the largest increase noted to the west.

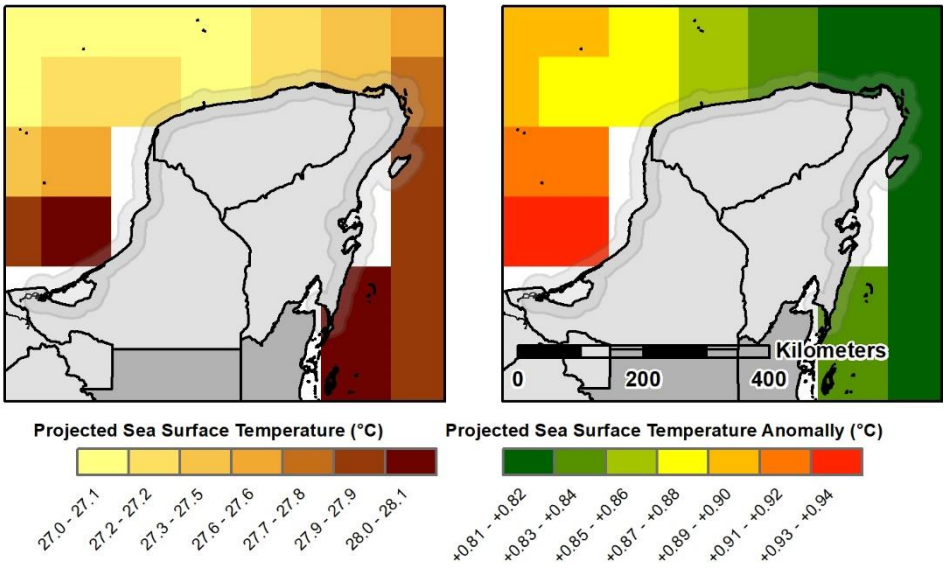


Figure 98. Projected sea surface temperatures and sea surface temperature anomaly.

Climate change impacts

The described climatic changes are directly affecting vulnerable communities and ecosystems in the Yucatán Peninsula. Under future climate conditions, these communities will increasingly face vulnerability to climate change, especially the intensifying tropical cyclones already observed[306]. The costs associated with historical climate and hydro-meteorological impacts in Mexico have risen over time (Figure 99). In 2005, storms affected up to 3 million people, while in 2011, storms, floods, extreme temperatures, and droughts impacted 3.5 million people. Damage costs have also escalated, peaking between 2004 and 2015, with fewer reported impacts earlier in the record. While the higher reported rates of damage are likely related to reporting bias, climate change is nonetheless directly affecting the occurrence of hydro-meteorological impacts in Mexico as a whole, as well as in the Yucatán Peninsula. A summary of specific observed and projected impacts of climate change in Mexico and the Yucatán Peninsula is presented below.

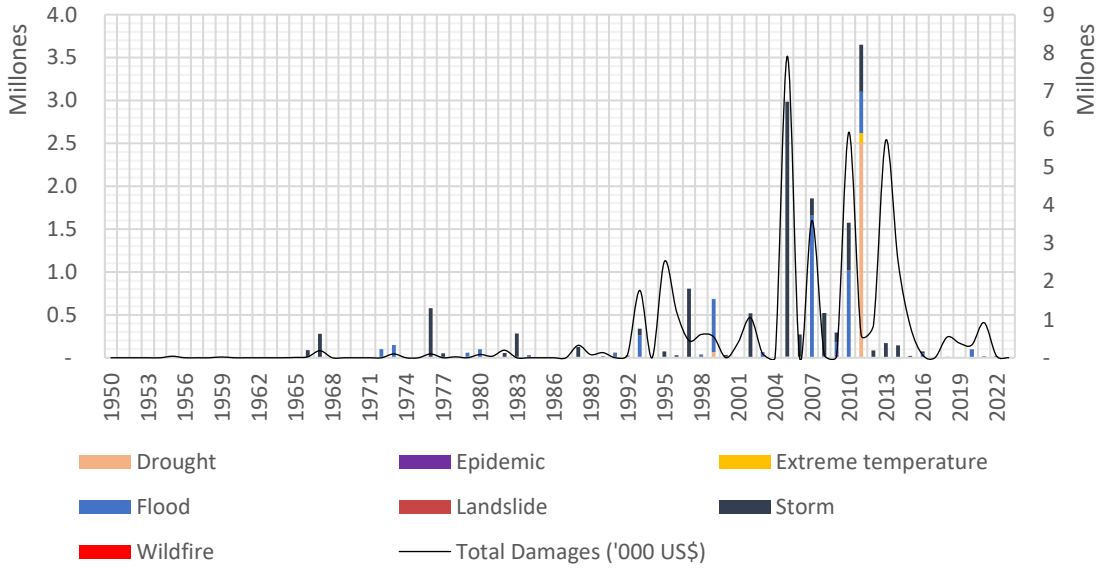


Figure 99. Changes over time in people affected by climate and hydro-meteorological events and estimated damage costs[307]

Impacts on coastal areas

The coastline of Mexico (and particularly the Yucatán Peninsula) is highly vulnerable to the impacts of climate change. The effects of rising sea levels are increasingly threatening infrastructure and investments, while tropical cyclones and extreme weather threaten the lives and livelihoods of local communities that depend on coastal zones for their survival[308]. As coastal ecosystems continue to be affected by climate change, projections indicate that an overall

[306] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[307] D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: The CRED/OFDA International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.
[308] NDC Partnership. 2018. Impacts of Climate Change on the Coastal Zone of Mexico: An Integrated Ecosystem Approach in the Gulf of Mexico to Support Coastal Zone Management Legislation. Available here.

negative impact can be expected on Mexico's fisheries[309]. Under low and high emissions scenarios, fish catch potential will decrease by 6.8% and 17%, respectively by 2050[310]. Along the coastline of the Yucatán Peninsula, climate change is already causing numerous impacts. These include the spread of invasive aquatic plants such as sargassum which reduces the tourism value of the beaches as well as coastal erosion caused by SLR and storm surges. Climate change is also affecting ecosystems in coastal areas which local communities depend on for their livelihoods. This includes more than 350,000 fishers that depend on fisheries around the country's coastal areas. Climate change is exacerbating the impacts of already unsustainable fishing practices that threaten the sustainability of these community's livelihoods.

Impacts on water

As with Mexico as a whole, groundwater is also a critical natural resource in the Yucatán Peninsula. a high dependence of local communities on groundwater, particularly during the dry season[311]. In the Yucatán Peninsula, changing precipitation patterns will likely impact surface water availability, but groundwater is overall of more importance than surface water, with the exception of areas in the south of the peninsula[312]. Projections indicate that as annual precipitation declines in most of the eastern parts of the Yucatán Peninsula, important areas for groundwater infiltration will become increasingly arid. By some estimates, groundwater recharge will decrease by up to 23% by 2030[313]. Some parts of the peninsula will likely see rising demand for water while supply will become diminished as a result of climate change. Along with changes in water availability for domestic and agricultural use, climate change is also affecting vulnerable local communities through intensifying floods. In the Yucatán Peninsula, there is currently a high level of risk of flooding. Under future climate conditions, floods will become more frequent and intense as tropical cyclones become more regular. Tropical cyclone activity in the Caribbean Sea and the Gulf of Mexico is expected to increase while drought conditions across the peninsula are expected to intensify. Flooding will be particularly severe in coastal areas.

Impacts on agriculture

In the Yucatán Peninsula, water stress caused by droughts is already directly impacting vulnerable local communities through impacts on agriculture. These communities (many of which lack piped water) have reported shortages of water for human use, as well as impacts on agricultural production[314]. In many communities, high temperatures and water stress have already caused crop damage, particularly where they are dependent on rain-fed agriculture. Even in areas where irrigation infrastructure is better developed, droughts have reduced the availability of irrigation water, and where water is still available, the quality is often lower as a result of higher salinity due to increased evaporation caused by temperature rise[315]. Along with impacts on crop production, livestock productivity in the Yucatán Peninsula has also been adversely affected by climate change in recent decades. Droughts have already caused a decrease in grazing, a decline in the fertility of cattle and a drying of water holes and wells across the peninsula, with adverse impacts on food security[316]. Secondary agricultural activity has also been affected by climate change, including a reported loss in honey production because of reduced flowering of key species being impacted by dry conditions[317]. In addition, dry conditions have also caused an increase in damage to crops by wild animals and pests, with some smallholders reporting losses of up to 50%[318]. Under future climate conditions, as temperatures continue to rise and climate hazards such as floods and droughts become more common, these impacts are expected to intensify. Along with the direct impacts of climate change on agricultural productivity, projections also indicate a likely increase in agricultural water demand as a result of increased rates of evapotranspiration. Under a low and medium emissions scenario, water demand will likely increase by 21.6% and 18.9%, respectively[319].

Impacts on forests

Forest productivity in the Yucatán Peninsula has shown a weak increase in recent decades as a result of the fertilising effect of higher atmospheric CO_2 levels. Because of this effect, an increase in forest productivity is expected for the Yucatán Peninsula under future climate conditions[320]. Regardless of this potential positive effect, however, sea level

[309] Cisneros-Mata, M.A., Mangin, T., Bone, J., Rodriguez, L., Smith, S.L. and Gaines, S.D., 2019. Fisheries governance in the face of climate change: Assessment of policy reform implications for Mexican fisheries. *PloS one*, *14*(10), p.e0222317.
[310] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[311] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[312] Rodríguez-Huerta, E., Rosas Casals, M. and Hernández Terrones, L.M., 2019. Climate change effects on groundwater recharge in Yucatan Peninsula. Application of water balance models to GCMs.
[313] Rodríguez-Huerta, E., Rosas-Casals, M. and Hernandez-Terrones, L.M., 2019. Water societal metabolism in the Yucatan Peninsula. The impact of climate change on the recharge of groundwater by 2030. *Journal of cleaner production*, *235*, pp.272-287.
[314] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[315] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[316] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[317] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[318] Metcalfe, S.E., et al., 2020. Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula, Mexico. Regional Environmental Change, 20, pp.1-15.ather in the Yucatan Peninsula, Mexico. *Regional Environmental Change*, *20*, pp.1-15.
[319] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[320] CMCC. G20 Climate Risk Atlas: Mexico. Available here.

rise is posing a severe threat to coastal mangrove forests along the coastline of the Yucatán Peninsula, which impacts the capacity of these areas to buffer coastal areas against tropical cyclones and associated storm surges[321]. As the population of the peninsula continues to grow and sea level rise continues to affect coastal ecosystems, mangrove forests will become increasingly degraded due to coastal development and their capacity to provide ecosystem services under future climate conditions will become diminished.

Impacts on health

Climate change has already, directly and indirectly, affected the health and well-being of the Yucatán Peninsula's population. This includes impacts related to the increase in temperatures, as well as those related to flooding caused by extreme rainfall and the direct effects of extreme climate events such as tropical cyclones. Rising average and maximum temperatures and flooding are increasing the prevalence of infectious and vector-borne diseases such as zika, dengue and malaria, reducing agricultural productivity and therefore also affecting food security. Moreover, higher temperatures — particularly when heatwaves occur — directly affect labour productivity by reducing the number of hours that a person can work, as well as the productivity of workers during active work hours[322]. Under future climate conditions, these trends are projected to intensify. For example, the prevalence of infectious and vector-borne diseases will increase significantly. Estimates show that by 2050, under a medium emissions scenario, approximately 74% of the country's population will be at risk of dengue and 73.3% under a high emissions scenario. For zika, the percentage of the population at risk by 2050 will be 51.7% and 52.5% under a medium and high emissions scenario, respectively[323]. Under a low and high emissions scenario, the percentage of the population at risk of Malaria will be 53.8% and 57%, respectively[324]. While these figures are for Mexico as a whole, the high vulnerability of local communities to climate change in the Yucatán means that they will likely be disproportionately impacted.

Impacts on the economy

The climate impacts described above will, directly and indirectly, affect the economy of Mexico, as well as that of the three states comprising the Yucatán Peninsula. Aggregate damages from climate change will reach approximately 5.54% of Mexico's GDP by 2100[325]. Agriculture is predicted to be the most severely affected sector. In the Yucatán Peninsula, tourism will be severely affected by climate change in the absence of intervention. Coastal zones in the region, particularly along the east coast, will be directly impacted by sea level rise, increased tropical cyclone activity, higher temperatures, and more intense rainfall, all of which will affect ecosystems and infrastructure upon which the sector is dependent. Overall, climate change is projected to strongly influence the economy of all three states in the Yucatán Peninsula and will potentially increase the poverty rate in the region from approximately 15% to 18.8% by 2030[326].

7.3. B.1.3. Adaptation needs and solutions

To respond to the impacts of increasing temperatures, rainfall variability, extreme rainfall events, tropical cyclones and changing ocean characteristics on and address the adaptation needs of vulnerable communities and ecosystems (terrestrial and marine) in Mexico's Yucatan Peninsula, an integrated adaptation approach is required. Such an approach should respond to the critical social, livelihood and environmental vulnerabilities to climate change touched on above (see Annex 2 for more detail). As such, adaptation interventions need to: i) address climate impacts that threaten food and water security, and enhance poverty; ii) promote the resilience of livelihoods (coping and recovery) to climate shocks and chronic stresses, while maintaining or enhancing productivity and promoting the sustainable use of natural resources; and iii) support ecosystem resilience (health and functionality) to changing climatic conditions to maintain critical ecosystem service flows.

Given the above, an integrated adaptation approach that has at its foundation ecosystem-based adaptation (EbA) and also integrates climate-smart agriculture, green infrastructure and other nature-based solutions (NbS) has been identified by the proposed project. This approach is aimed at protecting local communities, their livelihoods and infrastructure from the direct impacts of floods, droughts, tropical cyclones and sea-level rise, resulting in an avoidance of losses. In addition, adaptation activities will support livelihood productivity and build adaptive capacity under climate change conditions, including by enhancing the resilience of terrestrial and marine ecosystems on which local communities rely. This includes securing the maintained supply of vital ecosystem services, including amongst others, coastal protection and flood reduction, temperature regulation, fresh water supplies, maintenance of nutrient and hydrological cycles, fish stock maintenance, as well as habitat and biodiversity conservation.

[321] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[322] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[323] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[324] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[325] CMCC. G20 Climate Risk Atlas: Mexico. Available here.
[326] Sánchez-Triana, E., Ruitenbeek, J., Enriquez, S. and Siegmann, K. eds., 2019. *Opportunities for Environmentally Healthy, Inclusive, and Resilient Growth in Mexico's Yucatán Peninsula*. World Bank Publications. Available here.

With EbA as the foundation of the project's adaptation solution, a variety of climate risks will be addressed effectively in a cost-effective manner (relative to a hard infrastructure approach). For example, the natural infrastructure provided by EbA, such as restoring coastal and marine ecosystems, is less costly to maintain over the long term when compared to hard infrastructure alternatives such as seawalls and bulkheads. Moreover, EbA will provide multiple social and economic co-benefits (such as improved fish stocks and ecotourism sites), which increase its profitability[327]. Prioritising the use of EbA in combination with and parallel to climate-smart agriculture, green infrastructure and other NbS options above the current paradigm of using grey interventions will contribute to proactively rather than reactively addressing the impacts of climate change on vulnerable communities and ecosystems in the Yucatan Peninsula. Feasible and effective interventions under the proposed adaptation solution that will address past, present and expected future behaviour of the climate indicators described above are presented in Table XX below (more details are provided in Annex 2). Barriers to the proposed adaptation solution and the project's approach to addressing them are presented in Section B.2.

[Please note that this table will need to be updated based on the final set of interventions included in the project design.]

Table XX. Interventions under the proposed adaptation solution will address the identified climate indicators and vulnerabilities.

Climate hazard	Intervention	Adaptation benefits	Critical key element impact area[328]
Climate-smart agriculture (CSA)[329]			
Extreme temperatures Extreme precipitation Precipitation variability	Agroforestry[330,331]	• *Improve soil retention during flooding.* • *Water source protection and increase water availability.* • *Reduce the impacts of landslides and soil erosion.* • *Increase household income due to livelihood diversification.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.* • *Increase livestock productivity and fodder production during drought and flooding.* • *Enhance crop productivity during drought and flooding.* • *This agricultural system allows for the introduction of improved crop varieties which are adapted to rising temperatures and rainfall, and more resistant to pests and diseases, with higher productivity and high organoleptic quality.* • *The presence of shade trees in agroforestry systems reduces high temperatures and maintains soil moisture which results in a reduction of the average annual temperatures and extreme heat impacts.* • *Relative humidity is increased, and evapotranspiration is reduced, aiding in enhanced productivity of crops and pastures during drought.* • *Silvopastoral systems can be managed in an intensive manner, reducing the need to extend grazing areas into critical ecosystems and improving livestock productivity under conditions of climate change.*	**Environmental** **Livelihood**
	Terraces[332]	As above, including: • *The production of non-timber forestry products such as agave syrup, fibres, and artisanal mezcal, which aid in improving local incomes and increase adaptive capacities amongst vulnerable rural communities.* • *Timber and firewood produced in the naturally regenerated and sustainably managed forest fringes are important for household use.*	**Environmental** **Livelihood** **Social**
	Reduced tillage[333]	• *As indicated for agroforestry.*	**Environmental** **Livelihood**
	Cover crops and mulching[334]	• *As indicated for agroforestry.*	**Environmental** **Livelihood**

[327] USAID. 2018.
[328] Interventions may address the following key critical elements
[329] CSA is an integrated approach to managing landscapes—cropland, livestock, forests and fisheries—that addresses the interlinked challenges of food security and accelerating climate change. CSA aims to simultaneously achieve three outcomes: increased productivity, enhanced resilience and reduced emissions.
[330] Soto-Pinto, L., Anzueto, M., Mendoza, J., Ferrer, G.J. and de Jong, B., 2010. Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. *Agroforestry Systems*, *78*, pp. 39-51.
[331] Nahed-Toral, J., Valdivieso-Pérez, A., Aguilar-Jiménez, R., Cámara-Cordova, J. and Grande-Cano, D., 2013. Silvopastoral systems with traditional management in southeastern Mexico: a prototype of livestock agroforestry for cleaner production. *Journal of cleaner production*, *57*, pp. 266-279.
[332] LaFevor, M.C., 2014. *Conservation engineering and agricultural terracing in Tlaxcala, Mexico* (Doctoral dissertation).
[333][333] Ochoa-Noriega, C.A., Velasco-Muñoz, J.F., Aznar-Sánchez, J.A. and Mesa-Vázquez, E., 2021. Overview of Research on Sustainable Agriculture in Developing Countries. The Case of Mexico. *Sustainability*, *13*(15), p.8563.
[334] Ochoa-Noriega, C.A., Velasco-Muñoz, J.F., Aznar-Sánchez, J.A. and Mesa-Vázquez, E., 2021. Overview of Research on Sustainable Agriculture in Developing Countries. The Case of Mexico. *Sustainability*, *13*(15), p.8563.

Climate hazard	Intervention	Adaptation benefits	Critical key element impact area[328]
	Indigenous crops and livestock[335]	• *Indigenous crops and livestock show increased resilience to climate change impacts such as flooding and drought.* • *Enhance livestock and crop production during drought and flooding.* • *Non-timber forestry products provide alternative income sources to local communities.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Environmental** **Livelihood**
	Milpas intercropping system[336]	• *As indicated for agroforestry*	**Environmental** **Livelihood**
Ecosystem-based adaptation (EbA)[337]			
Extreme temperatures Extreme precipitation Precipitation variability Tropical cyclones	Forest restoration and rehabilitation[338,339]	• *Improvement of water availability and water quality.* • *Promote integrated water catchment management.* • *Reduce downstream sedimentation.* • *Increase water infiltration.* • *Reduce riverbank erosion.* • *Promote water recharge.* • *Replenish groundwater tables.* • *Alternative livelihoods such as non-timber forest products.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Environmental** **Livelihood** **Social**
	Wetland rehabilitation[340,341,342]	• *As above, including enhanced fisheries productivity because fish nursing grounds are re-established.* • *Reduction of saltwater intrusion into coastal aquifers.* • *Enhance water availability and quality.* • *Improve coastal protection against hurricanes, sea level rise and storm surges.* • *Reduce coastal erosion.* • *Reduce damage to coastal infrastructure resulting from flooding, storm surges and sea level rise.* • *Promote tourism and livelihoods from tourist activities.* • *Promote sustainable livelihoods from products such as fruit, wood and herbal remedies.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.* • *Promote integrated coastal zone management.*	**Environmental** **Livelihood**
Tropical cyclones Increased sea-surface temperatures Sea-level rise	Coastal mangrove rehabilitation[343,344,345]	• *As above*	**Environmental** **Livelihood**
	Dune and beach rehabilitation [346,347]	• *As indicated for wetland rehabilitation.*	**Environmental** **Livelihood**
	Coastal realignment and setback[348]	• *As indicated for wetland rehabilitation.*	**Environmental** **Livelihood**

[335] Toledo, V.M., Ortiz-Espejel, B., Cortés, L., Moguel, P. and de Jesús Ordoñez, M., 2003. The multiple use of tropical forests by indigenous peoples in Mexico: a case of adaptive management. *Conservation Ecology*, *7*(3).
[336] Nature: Maize intercropping in the milpa system. Diversity, extent and importance for nutritional security in the Western Highlands of Guatemala. Online Available: https://www.nature.com/articles/s41598-021-82784-2#:~:text=The%20milpa%20is%20a%20traditional,great%20diversity%20of%20crop%20combinations.
[337] EbA is a nature-based solution that harnesses biodiversity and ecosystem services to reduce vulnerability and build resilience to climate change.
[338] Mexal, J.G., Cuevas Rangel, R.A. and Landis, T.D., 2008. Reforestation success in central Mexico: factors determining survival and early growth. *Tree planters' notes*.
[339] García-Barrios, L., Galván-Miyoshi, Y.M., Valsieso-Pérez, I.A., Masera, O.R., Bocco, G. and Vandermeer, J., 2009. Neotropical forest conservation, agricultural intensification, and rural out-migration: the Mexican experience. *BioScience*, *59*(10), pp.863-873.
[340] Climate Technology Centre and Network: Wetland restoration and rehabilitation. Online available: https://www.ctc-n.org/technologies/wetland-restoration-and-rehabilitation
[341] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[342] United States Environmental Protection Agency: Wetland restoration. Online available: http://water.epa.gov/type/wetlands/upload/2006_11_29_wetlands_restdocfinal.pdf
[343] Climate Technology Centre and Network: Wetland restoration and rehabilitation. Online available: https://www.ctc-n.org/technologies/wetland-restoration-and-rehabilitation
[344] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[345] Laulikitnont. 2014. Evaluating mangrove restoration success. Online available: repository.usfca.edu/cgi/viewcontent.cgi?article=1011&context=capstone
[346] Ruiz-Martínez, G., Mariño-Tapia, I., Baldwin, E.G.M., Casarín, R.S. and Ortiz, C.E.E., 2016. Identifying coastal defence schemes through morphodynamic numerical simulations along the northern coast of Yucatan, Mexico. *Journal of Coastal Research*, *32*(3), pp.651-669.
[347] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[348] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments

Climate hazard	Intervention	Adaptation benefits	Critical key element impact area[328]
	Seagrass rehabilitation[349]	• *As indicated for wetland rehabilitation, excluding non-timber forestry products.*	**Environmental** **Livelihood**
	Coral reef rehabilitation [350,351,352]	• *Nursery-grown coral show increased resilience to climate change impacts such as bleaching.* • *Coastal erosion is reduced because coral reefs provide protection against the impacts of storm surges and sea level rise.* • *The adverse impacts on fisheries infrastructure because of climate change impacts are reduced and hence livelihoods are protected.* • *Promote tourism and livelihoods from tourist activities.* • *Establish fish nursing grounds and hence promote fisheries productivity and livelihoods from the fisheries sector.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Environmental** **Livelihood**
	Living breakwaters[353,354]	• *As above*	**Environmental** **Livelihood**
	Expansion and establishment of marine protected areas[355]	• *As for wetland rehabilitation, including the conservation of culturally important sites.* • *Promote livelihoods from ecotourism.* • *Greater participation in natural resource management.* • *Enhance the resilience of women and children to climate change impacts due to diversified livelihoods.*	**Environmental** **Livelihood**
Green infrastructure[356]			
Extreme temperatures Extreme precipitation Precipitation variability Tropical cyclones	Urban wetlands[357,358]	• *Enhance water availability during drought and variable rainfall events.* • *Promote water and air quality in cities.* • *Reduce impacts of urban flooding.* • *Increase water infiltration and reduce runoff.* • *Replenish groundwater tables.* • *Reduce erosion and landslide impacts in urban settlements.*	**Environmental** **Social**
Other interventions			
Extreme temperatures Extreme precipitation Precipitation variability	Ecotourism[359]	• *Provide alternative and diversified livelihoods among local communities.* • *Enhance planning of coastal and forest management.* • *Promote entrepreneurship and economic development among coastal communities.*	**Environmental** **Social**
	Coral reef insurance[360,361]	As indicated for coral reef rehabilitation, as well as the: • *rapid re-establishment of coastal protection against storm surges and sea level rise.*	**Environmental** **Livelihood**

[349] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[350] Nature: Coral conservation in the Caribbean. Online available: https://www.nature.org/en-us/about-us/where-we-work/caribbean/stories-in-caribbean/caribbean-a-revolution-in-coral-conservation/
[351] National Oceanic and Atmospheric Administration: Restoring coral reefs. Online available: https://www.fisheries.noaa.gov/national/habitat-conservation/restoring-coral-reefs
[352] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[353] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[354] Marine Sanctuaries Conservation Series: Science review of artificial reefs. Online available: http://sanctuaries.noaa.gov/science/conservation/pdfs/artificial_reef.pdf
[355] UNEP: Ecosystem based adaptation in coastal environments. Online available: https://www.unep.org/gan/resources/toolkits-manuals-and-guides/options-ecosystem-based-adaptation-coastal-environments
[356] Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services, while also enhancing biodiversity.
[357] Ramsar: Urban wetlands. Online available: https://www.ramsar.org/sites/default/files/documents/library/wwd18_handouts_eng.pdf
[358] Torres-Lima, P., Conway-Gómez, K. and Buentello-Sánchez, R., 2018. Socio-environmental perception of an urban wetland and sustainability scenarios: A case study in Mexico City. *Wetlands*, *38*(1), pp.169-181.
[359] The World Bank: Opportunities for environmentally healthy and resilient growth in Mexico's Yucatan Peninsula. Online available: https://documents1.worldbank.org/curated/en/958161577478303830/pdf/Opportunities-for-Environmentally-Healthy-Inclusive-and-Resilient-Growth-in-Mexicos-Yucatan-Peninsula.pdf
[360] Nature.org: Insuring nature to ensure a resilient future. Online available: https://www.nature.org/en-us/what-we-do/our-insights/perspectives/insuring-nature-to-ensure-a-resilient-future/
[361] Green economy coalition: Insuring coral reefs in Mexico. Online available: https://www.greeneconomycoalition.org/news-and-resources/insuring-coral-reefs-in-mexico

Climate hazard	Intervention	Adaptation benefits	Critical key element impact area[328]
Tropical cyclones Increased sea-surface temperatures Sea-level rise	Ecosystem-based approach to fisheries management[362]	• *Promote the development of sustainable and alternative livelihoods.* • *Enhance the resilience of women and children to climate change impacts due to the diversification of livelihoods.* • *Promote diversified livelihoods within the fisheries sector despite climate change impacts due to enhanced ecosystem resilience.*	**Environmental** **Livelihood**

The integrated adaptation approach of EbA, climate-smart agriculture, green infrastructure and other NbS proposed by the project includes inherently 'no-regret' options, focusing on maximizing positive and minimizing negative aspects of adaptation to the climate change impacts described above. Such options will reduce vulnerabilities to climate change, increase adaptive capacities and have a positive impact on livelihoods and ecosystems regardless of how the climate changes. The project has been designed (see Section B.3. and Annex 2) to avoid environmental, sociocultural, and economic maladaptation. Environmental maladaptation is prevented by activities that: i) avoid the degradation that causes negative effects in situ; ii) avoid displacing pressures onto other environments (neighbouring areas or areas that are connected ecologically or socio-economically); iii) support the protective role of ecosystems against current and future climate-related hazards; iv) integrate uncertainties concerning climate change impacts and the reaction of an ecosystem; and v) set the primary purpose as being to promote adaptation to climate-related changes rather than to reduce greenhouse gas emissions. Sociocultural maladaptation will be prevented by activities that: i) start from local social characteristics and cultural values that could have an influence on risks and environmental dynamics; ii) consider and develop local skills and knowledge related to climate-related hazards and the environment; and iii) call on new skills that the community is capable of acquiring. Economic maladaptation will be prevented by activities that: i) promote the reduction of socio-economic inequalities; ii) support the relative diversification of economic and/or subsistence activities; and iii) integrate any potential changes in economic and subsistence activities resulting from climate change.

7.4. B.1.4. Related projects/interventions

Among the recently completed and ongoing projects that are in whole or in part active in the Yucatan Peninsula and Mexico as a whole and complementary to ACCION are presented in Table XX below.

[Please note that this table will need to be updated based on the final set of interventions included in the project design.]

Table XX. Overview of projects related to ACCION and potential complementarities.

Project details	Description	Complementarities with ACCION
GEF: Sustainable Production Systems and Biodiversity in the Yucatan Peninsula (2016-2021)[363]	Goal: The key objective of this initiative is to strengthen socio-ecological and economic resilience across Mexico's Yucatan region to climate change impacts such as drought and flooding. Objectives: This GEF-supported project promotes the conservation of biodiversity and ecosystem services by implementing ecosystem restoration and reforestation initiatives in the Yucatan region of Mexico. The target sectors include forestry, agriculture and other land-use practices. Enhanced sustainable land-use management, cultivating indigenous trees, establishing mahogany tree nurseries and promoting sustainable agricultural practices are key to the successful implementation of this project. Promoting the development of biodiversity corridors through enhanced sustainable land-use practices across these sectors is also an objective of this initiative.	

[362] FAO: A ecosystem-based approach to fisheries. Online available: https://www.fao.org/publications/card/en/c/6de19f1f-6abb-5c87-a091-3cc6e89c3a88/
[363] GEF: Forestry in the Yucatan. Available online: https://www.thegef.org/newsroom/news/forestry-yucatan-mainstreaming-biodiversity-and-promoting-development

GEF: Seventh Operational Phase of the GEF Small Grants Programme in Mexico (2021-2026)[364]	**Goal:** The key objective of this initiative is to strengthen socio-ecological and economic resilience to climate change impacts such as storm surges, sea level rise, flooding and drought, in seven landscapes and seascapes across Mexico. **Objectives:** These landscapes include the Agroforestry Landscape of Chiapas and Tabasco, the coastal seascape of the Yucatan Peninsula, the Grijalva-Usumacinta Lower Basin Landscape, the Sustainable Forestry Landscape of Campeche, Quintana Roo, and Yucatan, the Forest and Milpa Landscape of Campeche, Quintana Roo, and Yucatan, the Oaxaca Mountains Landscape, as well as the Mixteca Arid Landscape. Community-based activities are promoted and aim to promote sustainable development across the aforementioned landscapes. Climate change adaptation activities include the cooperative management of aquatic ecosystems; wetland and reef restoration; establishment of new community conservation areas and territories, as well as the promotion of inclusive ecosystem conservation through silvopastoral and agroforestry systems.	
World Bank: Integrating coastal watershed conservation in Mexico (since 2012)[365]	**Goal:** Promoting climate change resilience of coastal communities in Mexico by utilising ecosystem-based adaptation to conserve coastal watersheds. **Objectives:** Enhance the conservation and sustainable management of coastal watersheds in Mexico through ecosystem-based adaptation measures. Payment for ecosystem services is utilised to sustainably manage 35,000 ha of land within these watersheds. Such initiatives include local communities making use of agroforestry, silvopastoral systems, mangrove and coastal ecosystem restoration practices, as well as revegetation of riverbanks. Objectives of this project also include enhancing community resilience to the impacts of drought and flooding through sustainable management of 1.7 million ha of protected areas across the Gulf of California and the Gulf of Mexico. Finally, Mexico's National Institute of Ecology and Climate Change has developed and introduced Integrated Watershed Action Plans and monitoring in six coastal basins as part of this project. These basins include Tuxpan, Antigua, Jamapa, Baluarte, San Pedro, and Vallarta.	
GEF: Community-based ecotourism and biodiversity conservation in the Yucatan Peninsula[366]	**Goal:** Promote the climate change resilience of local Yucatan communities by encouraging ecotourism, ecosystem restoration and the conservation of ecosystem services. **Objectives:** Conserve biodiversity of the Yucatan Biosphere Reserve, by using the traditional knowledge of the Punta Allen and Muyil communities. The establishment of ecosystem-based practices such as indigenous farming, and forestry practices aid in enhancing the climate change resilience of local communities against impacts such as drought and flooding. In addition, sustainable livelihoods, food and water security are promoted through the conservation of ecosystem services. Ecotourism is encouraged as a means of enhancing the resilience of the local community to climate change impacts.	
WWF: Protecting and restoring mangroves along the northern coast of the Yucatan Peninsula[367]	**Goal:** Conserve and restore coastal ecosystems in the Yucatan Peninsula to enhance local biodiversity and the resilience of coastal communities to climate change impacts such as drought, storm surges and flooding. **Objectives:** Restore and revegetate mangrove ecosystems along the northern coast of the Yucatan Peninsula.	

[364] GEF: Seventh Operational Phase of the GEF Small Grants Programme in Mexico. Available online: https://www.thegef.org/projects-operations/projects/10504
[365] The World Bank: Integrating coastal watershed management in Mexico. Available online: https://www.worldbank.org/en/results/2020/05/06/integrating-coastal-watershed-conservation-in-mexico
[366] GEF: Community-based Biodiversity conservation in the Yucatan Peninsula. Available online: https://www.thegef.org/news/community-based-ecotourism-protects-biodiversity-yucatan-peninsula
[367] WWF: Restoring mangroves along the northern Yucatan Peninsula coast. Available online: https://www.worldwildlife.org/magazine/issues/winter-2022/articles/protecting-and-restoring-mangroves-along-the-northern-coast-of-the-yucatan-peninsula

Global Mangrove Alliance: Protecting and restoring free-flowing rivers in Mexico[368]	**Goal:** To enhance the resilience of coastal ecosystems to climate change impacts such as flooding, storm surges and drought. **Objectives:** The main project aims include the restoration of inland watersheds and wetlands so that coastal mangrove ecosystems can also be successfully rehabilitated. In so doing, ecosystem services are restored and the resilience of coastal communities to climate change impacts is enhanced.	

7.5. B.1.5 Consistency with national plans and strategies

National policy/legislation	Description	Proposed project alignment[369]
Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) 2022	In its updated NDC, Mexico has increased its mitigation targets, aiming for a 35% reduction in greenhouse gas (GHG) emissions by 2030, compared to a 22% reduction established in its previous submission in 2020. If external support is secured, Mexico commits to a GHG reduction of 40% by 2030, increasing its previous conditional target of 36%. The updated NDC also includes the implementation of the country's National Strategy for the Reduction of Emissions from Deforestation and Forest Degradation (ENAREDD+). The adaptation priority areas in Mexico's NDC are i) ecosystems and biodiversity; ii) food systems and food security; iii) human population and territory; iv) infrastructure and cultural heritage; and v) water. Several adaptation-related targets and objectives are defined by the NDC, including the protection of communities from adverse impacts of climate change, such as extreme hydrometeorological events related to global changes in temperature; as well as the increment in the resilience of strategic infrastructure and the ecosystems that host national biodiversity. In order to reach those priorities Mexico will, *inter alia*, strengthen the adaptive capacity by at least 50%, in the number of municipalities in the category of "most vulnerable", establish early warning systems and risk management at every level of government and reach a rate of 0% deforestation by the year 2030. Some of the adaptation actions presented foster positive synergies with mitigation actions.	The project will likely make a positive contribution to several adaptation targets such as the protection of ecosystems, strengthening the adaptative capacity of communities that are reliant on climate-sensitive livelihoods such as agriculture and fishing, as well as improving food and water security. Depending on the specific activities selected, mitigation co-benefits may also be realised. For example, reforestation efforts may result in avoided emissions through carbon sequestration and improvements in soil organic carbon levels.
General Law on Climate Change (LGCC) 2012	The LGCC law establishes the legal framework for addressing climate change in Mexico. It aims to reduce greenhouse gas emissions, promote sustainable development, and adapt to the impacts of climate change. The law mandates the creation of a National System for Climate Change, which coordinates climate policies and actions across different sectors. The law establishes the following institutions: i) the National Institute of Ecology and Climate Change; ii) the Climate Change Council; and iii) the Inter-secretariat Commission for Climate Change. The LGCC was amended in 2020 and in 2022, with additional wording in accordance with the Paris Agreement and the NDC (see above), as well as further clarification for the implementation of the Mexican Emission Trading System.	Where tangible, 'on the ground' project interventions are complemented by capacity development, strengthened governance structures, and improved knowledge management and learning (KML), the proposed project has the potential to support Mexico's legal and policy landscape. For instance, revisions and amendments to policy and legislation could draw from practical experience implementing the proposed project, as well as from stakeholder engagement outcomes.
Special Climate Change Program (PECC) 2021-2024	The PECC outlines Mexico's strategy for mitigating and adapting to climate change. It sets national targets and action plans for reducing emissions, promoting renewable energy, improving energy efficiency, and enhancing resilience to climate impacts. The PECC is aligned with the	From an emissions perspective, and depending on the specific activities selected, mitigation co-benefits may also be realised. For example, reforestation efforts may result in avoided emissions through carbon sequestration and improvements in soil organic carbon levels.

[368] Global Mangrove Alliance: restoring free-flowing rivers in Mexico. Available online: https://www.mangrovealliance.org/how-protection-of-mexicos-free-flowing-rivers-benefits-mangroves/

[369] Since project activities are currently in the ideation phase, project alignment has been determined based on the areas of action, general objectives, and results areas for GCF adaptation projects and interventions. This includes but is not necessarily limited to adaptation for/of: i) health, food and water security; ii) livelihoods of people and communities; iii) ecosystems and ecosystem services; and iv) infrastructure and the built environment.

National policy/legislation	Description	Proposed project alignment[369]
	National Development Plan and related programs, as well as to the Climate Change National Strategy: 10-20-40 Vision, and to the sector programs of the 14 Secretariats or Ministries. The adaptation section describes the objective of reducing the vulnerability of the populations and the productive sectors, as well as preserving and protecting ecosystems and environmental services and increasing resistance of the strategic infrastructure to the adverse impacts of climate change.	Concerning adaptation, the PECC contains ~70 adaptation targets in total, of which the proposed project could contribute positively to at least 10. For instance, the project could implement actions to reduce climate change risks in rural and urban populations (Strategy 1.2), as well as promote protection, conservation and restoration actions and schemes of terrestrial, marine, and coastal ecosystems and their biodiversity (Strategy 2.1).
National Strategy on Climate Change	This strategy, updated periodically, provides guidelines and priorities for climate change action in Mexico. It focuses on mitigation, adaptation, research and innovation, capacity-building, and international cooperation. The strategy sets out the main focal areas regarding cross-sectoral climate policy, adaptation to climate change and reduction of GHG emissions, presented as 'eight axes of action'. These are i) reduce vulnerability to climate change of Mexicans living at risk and strengthen their resilience; ii) reduce the vulnerability of production systems and strategic infrastructure against weather contingencies; iii) foster adaptability of ecosystems to the effects of global warming; iv) accelerate energy transition towards clean energy sources; v) reduce power consumption intensity through efficiency and rationality schemes; vi) transition to sustainable city models, with intelligent mobility systems, integrated waste management and buildings with a low carbon footprint; vii) encourage better agricultural and forestry practices, with schemes for Reducing Emissions from Deforestation and Degradation (REDD+); and viii) reduce short-lived pollutant emissions, such as black carbon and methane, to improve the health and welfare of Mexicans. The Strategy also reinforces Mexico's mitigation goals to reduce emissions by 30% by the year 2020 with respect to the business-as-usual scenario, and by 50% by 2050, as compared with emissions in 2000.	Concerning mitigation, depending on the specific activities selected, mitigation co-benefits may be realised through the implementation of the proposed project. Similarly, for adaptation targets and objectives under Mexico's Strategy on Climate Change, the project will likely make a positive contribution to several adaptation targets such as the protection of ecosystems, strengthening the adaptative capacity of communities that are reliant on climate-sensitive livelihoods such as agriculture and fishing, as well improving food and water security.
National Climate Change Information System (SINACC)	SINACC is a platform that collects, analyses, and disseminates data and information related to climate change. It supports decision-making processes and facilitates the monitoring of climate change policies and actions.	Through the practical experience implementing the proposed project and its stakeholder engagement outcomes — particularly where these activities are complemented by capacity development, and improved knowledge management and learning (KML) — the proposed project can generate value-adding data and information to support the SINACC.

8. Annexes

8.1. Annex 1: Past and ongoing projects

The Yucatan Peninsula is particularly rich in biodiversity with ecosystems including coastal forests, wetlands and mangroves. Anthropogenic stressors such as unsustainable agricultural practices, deforestation, mining, and urbanisation have exacerbated the impacts of climate change, in particular storm surges, flooding and droughts across this region. Numerous local and regional projects have thus implemented ecosystem-based adaptation (EbA) measures such as rehabilitation and restoration of watersheds, coastal mangroves, wetlands and forests to reduce the impacts of climate change on ecosystems and local communities. Stakeholder feedback indicated the locations of several adaptation projects currently underway in the Yucatan. Additionally, a high-level summary of other projects is provided below, with a more detailed description provided thereafter.

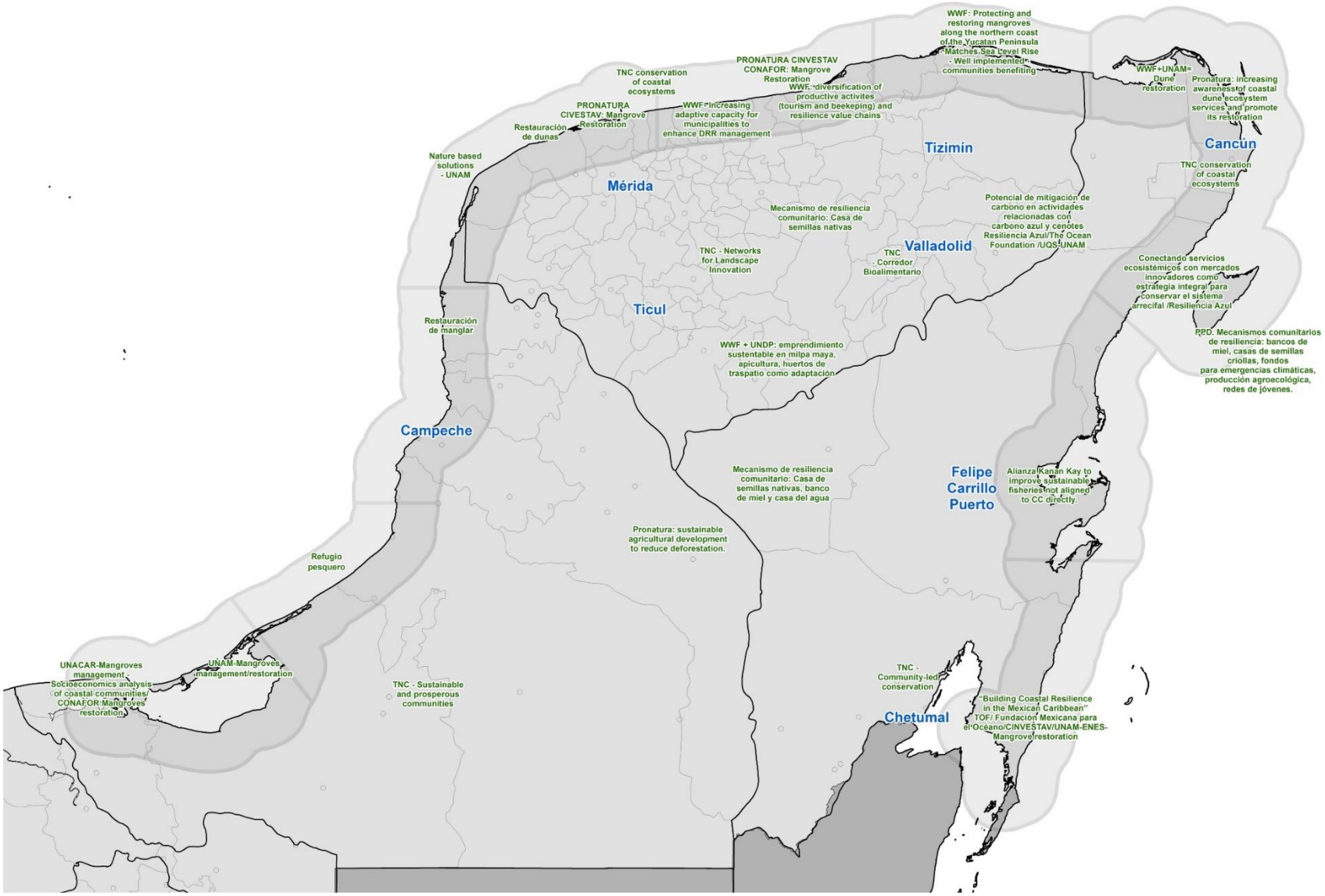


Figure 100. Stakeholders indicated locations of various adaptation projects currently underway in the Yucatan

8.1.1. High-level Past and ongoing EbA projects

Table 23. Past and ongoing EbA projects and initiatives relevant to Mexico, the Caribbean and Latin America

Project name	Geographic coverage	Funding	Project executing agency	General project description and key aspects
GEF: Sustainable Production Systems and Biodiversity in the Yucatan Peninsula (2016-2021)[370]	Mexico: Yucatan Peninsula	Co-financing total: US$ 21.48 million GEF grant: US$ 11.7 million.	National Commission for the Knowledge and Use of Biodiversity (CONABIO)	• *Conserve biodiversity and ecosystem services.* • *Ecosystem restoration and reforestation.* • *Target sectors include forestry, agriculture, and other land-use practices.* • *Enhance sustainable land-use management, cultivating indigenous trees, nurseries, and sustainable agricultural practices.*
GEF: Seventh Operational Phase of the GEF Small Grants Programme in Mexico (2021-2026)[371]	Mexico: Chiapas, Tabasco, Yucatan Peninsula, the Grijalva-Usumacinta Lower Basin, Campeche, Quintana Roo, Campeche, the Oaxaca Mountains, Mixteca Arid region	Co-financing Total: US$ 12.3 million GEF grant: US$ 4.5 million	United Nations Office for Project Services (UNOPS)	• *Community-based activities promote sustainable development and land use.* • *Cooperative management of aquatic ecosystems; wetland and reef restoration.* • *Promote inclusive ecosystem conservation through silvopastoral and agroforestry systems.*
GEF: Mesoamerican biological corridor (2000-2006)[372]	Mexico: Campeche, Chiapas, Qintana Roo, Tabasco, and Yucatan	Co-financing Total: US$ 75.2 million GEF grant: US$ 14.8 million	Secretariat of Environment and Natural Resources (SEMARNAP); Secretariat of Agriculture and Rural Development (SAGAR); Secretariat of Welfare (SEDESOL); Secretariat of Infrastructure, Communication and Transport (SCT); Secretariat of Agrarian Reform (SRA)	• *Establish new and restore existing ecosystem corridors.* • *Promote sustainable land and coastal management.* • *Restore forest and coastal ecosystems.*
GEF: Community-based ecotourism and biodiversity conservation in the Yucatan Peninsula[373]	Mexico: Yucatan	Not available	Not available	• *Promote indigenous farming and forestry practices.* • *Promote sustainable livelihoods and ecotourism.* • *Encourage community involvement in ecosystem restoration.*

[370] GEF: Forestry in the Yucatan. Available online: https://www.thegef.org/newsroom/news/forestry-yucatan-mainstreaming-biodiversity-and-promoting-development
[371] GEF: Seventh Operational Phase of the GEF Small Grants Programme in Mexico. Available online: https://www.thegef.org/projects-operations/projects/10504

[372] GEF: Mesoamerican biological corridor. Available online: https://www.thegef.org/projects-operations/projects/779

[373] GEF: Community-based Biodiversity conservation in the Yucatan Peninsula. Available online: https://www.thegef.org/news/community-based-ecotourism-protects-biodiversity-yucatan-peninsula

The World Bank: Integrating coastal watershed conservation in Mexico (since 2012)[374]	Mexico: Coastal basins in Tuxpan, Antigua, Jamapa, Baluarte, San Pedro, and Vallarta	GEF grant: US$ 39.5 million	National Commission of Protected Areas, the National Forestry Commission, the National Institute of Ecology and Climate Change, and the Mexican Fund for the Conservation of Nature	• *Enhance the conservation and sustainable management of coastal watersheds.* • *Integrated Watershed Management in important catchments.* • *Payment for ecosystem services to sustainably manage agricultural land within these watersheds.* • *Promote agroforestry, silvopastoral systems, mangrove and coastal ecosystem restoration and reforestation.*
WWF: Protecting and restoring mangroves along the northern coast of the Yucatan Peninsula[375]	Mexico: Yucatan Peninsula	Not available	Not available	• *Restore and revegetate mangrove ecosystems along the northern coast of the Yucatan Peninsula.*
Global Mangrove Alliance: Protecting and restoring free-flowing rivers in Mexico[376]	Mexico	Not available	Mexico's National Water Commission, and the national public ministry that manages terrestrial protected areas (CONANP)	• *Restore inland watersheds and wetlands.* • *Rehabilitate and revegetate coastal mangrove ecosystems.*
GEF: Building resilience across urban systems through ecosystem-based adaptation in Latin America and the Caribbean (2016-2021)[377]	El Salvador, Jamaica and Mexico	Co-financing Total: US$ 29.7 million GEF grant: US$ 6 million	Ministry of Environment and Natural Resources (El Salvador), Ministry of Land and Environment (Jamaica), Ministry of Planning and Environmental Policy (Mexico) with support from UNEP – Regional Office for Latin America and the Caribbean	• *Promote sustainable agricultural practices.* • *Restore degraded ecosystems across agricultural land, riparian forests, and aquatic ecosystems.* • *Restore water catchments across Jamaica by planting 44,000 trees and rehabilitating 2 ha of wetland.* • *Restore 3,6 km of riparian corridors in Mexico.* • *Construct urban wetlands and riparian parks, as well as permeable walkways to promote rainwater infiltration.*

[374] The World Bank: Integrating coastal watershed management in Mexico. Available online: https://www.worldbank.org/en/results/2020/05/06/integrating-coastal-watershed-conservation-in-mexico

[375] WWF: Restoring mangroves along the northern Yucatan Peninsula coast. Available online: https://www.worldwildlife.org/magazine/issues/winter-2022/articles/protecting-and-restoring-mangroves-along-the-northern-coast-of-the-yucatan-peninsula

[376] Global Mangrove Alliance: restoring free-flowing rivers in Mexico. Available online: https://www.mangrovealliance.org/how-protection-of-mexicos-free-flowing-rivers-benefits-mangroves/

[377] GEF: Building resilience of urban systems through EbA in Latin America and the Caribbean. Available online: https://www.thegef.org/projects-operations/projects/5681

Scaling ecosystem-based adaptation in rural Latin America (2021-2025)[378]	Costa Rica, Guatemala, Ecuador	GIZ funding: US$ 9 million	Tropical Agricultural Research and Higher Education Center (Costa Rica); Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; Ministry of Environment and Energy; Ministry of Environment and Natural Resources; Ministry of Foreign Affairs	• *Incorporate EbA interventions into Nationally Determined Contributions, sectoral plans, and National adaptation processes.* • *Upscale EbA measures through the development of innovative financial mechanisms, institutional strengthening, and knowledge sharing.*
Scaling up climate resilient water management practices for vulnerable communities and ecosystems in La Mojana, Colombia (2018-2026)[379]	Colombia	GCF grant: US$ 38.5 million	Ministry of Environment	• *Enhance the climate change resilience of more than 400,000 people.* • *Promote sustainable water management by using ecosystem-based adaptation interventions.* • *Restore 40,000 ha of forests and wetlands with the assistance of local communities.*
Reducing climate change vulnerability and flood risk in coastal cities and semi-urban areas in Latin America (2020-2025)[380]	Chile and Ecuador	Adaptation Fund grant amount: US$ 13.9 million	Ministry of Environment	• *Restore coastal mangrove ecosystems and revegetation of urban water catchment regions and slopes.* • *Enhance the partnership between coastal cities in Latin America and promote EbA interventions.*
REDD carbon project in the Emas-Taquari biodiversity corridor, Goias and Mato Grosso do Sul, Brazil (2010-2040)[381]	Brazil	Not available	Ministry of Environment; Ministry of Agriculture	• *Restore degraded forest ecosystems and the conservation of biodiversity.* • *Re-establish indigenous vegetation and use reforestation initiatives around Emas National Park, and the Nascentes do Rio Taquari State Park.* • *Restore 589 ha using native Cerrado tree species.* • *Enhance sustainable local livelihoods through the production of fruits, seeds, fibres, oils, and honey.*
REDD Paraguay forest conservation project in the	Paraguay	Not available	Ministry of Environment; Ministry of Agriculture	• *Co-ownership and management of agricultural land with local communities.* • *Introduce sustainable agricultural practices such as agroforestry and silvopastoral systems.* • *Promote reforestation of degraded agricultural land.*

[378] IUCN: Scaling EbA in rural Latin America. Available online: https://www.iucn.org/our-work/projects/scaling-ecosystem-based-adaptation-measures-rural-latin-america

[379] UNDP: GCF Colombia wetlands. Available online: https://undp-climate.exposure.co/gcf-colombia-wetlands

[380] Adaptation Fund: Reducing climate change vulnerability in coastal regions of Latin America. Available online: https://www.adaptation-fund.org/project/chile-ecuador-reducing-climate-vulnerability-flood-risk-coastal-urban-semi-urban-areas-cities-latin-america/

[381] REDD: Carbon Project in the Emas-Taquari Biodiversity Corridor, Goiás and Mato Grosso do Sul, Brazil. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=232

Chaco-Pantanal ecosystem (2011-2031)[382]				
REDD Paraguay forest conservation project in San Rafael (2010-2040)[383]	Paraguay	Not available	Ministry of Environment; Ministry of Agriculture	• *Conservation of forest ecosystems across the La Amistad region of San Rafael.* • *Encourage local community involvement in the reforestation and rehabilitation of degraded land.* • *Payments to community members are implemented for the protection of existing forests and reforestation initiatives.*
REDD Restoration of degraded areas and reforestation in Colombia (2002-2032)[384]	Colombia	Not available	Ministry of Environment; Ministry of Agriculture	• *Restore and revegetate degraded grasslands across Caceres and Cravo Norte.* • *Generate an increment in existing carbon stocks and will promote carbon sequestration.* • *Promote reforestation by using sustainable agricultural techniques such as silvopastoral and agroforestry.*
REDD Reduction of deforestation and degradation in Tambopata Nature Reserve and Bahuaja-Sonene National Park (2008-2028)[385]	Peru	Not available	Ministry of Environment; Ministry of Agriculture	• *Enhance the monitoring and conservation capacity of local authorities and communities in terms of natural resource utilisation in the Madre de Dios.* • *Promote sustainable land-use practices.* • *Restore ecosystems by using agroforestry practices, and reforestation initiatives.*
REDD Watershed Restoration in the Cantareira water system (2009-2039)[386]	Brazil	Not available	Ministry of Environment; Ministry of Agriculture	• *Restore indigenous vegetation to an area of 185.56 ha surrounding the Cachoeira Reservoir.* • *Utilise municipal funds from water users to pay farmers and ranchers who conserve and restore riparian forests on their agricultural land.*
REDD Restoration of the Pachijal and Mira River watersheds (2011-2041)[387]	Ecuador	Not available	Ministry of Environment; Ministry of Agriculture	• *Encourage private landowners to reforest agricultural land and catchment areas by using indigenous vegetation.*

[382] REDD: Paraguay forest conservation project. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=158

[383] REDD: Paraguay forest conservation project. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=175

[384] REDD: Restoration of degraded areas and reforestation in Colombia. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=135

[385] REDD: Reduction of deforestation and degradation in Madre de Dios, Peru. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=201

[386] REDD: Watershed Restoration in the Cantareira Water System. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=264

[387] REDD Restoration of the Pachijal and Mira river watersheds. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=177

				• *Rehabilitate 346 ha of degraded grasslands in the Andean mountains.* • *Utilise agroforestry as a reforestation intervention.*
IUCN Building livelihood resilience to climate change in Guatemala's Highlands (2020-2027)[388]	Guatemala	GCF funding: US$ 24.8 million	Ministry of Agriculture; Ministry of Environment and Natural Resources	• *Utilise integrated watershed management in the dry corridor of the Guatemalan highlands.* • *Promote water security among 132,000 people across an area of 146,500 ha of which 22,500 ha will be restored.* • *Community-led ecosystem revegetation and rehabilitation of water catchments.*
REDD Lacandon Forest for Life project (2012-2042)[389]	Guatemala	Not available	Ministry of Agriculture; Ministry of Environment and Natural Resources	• *Encourage local communities to participate in reforestation projects.* • *Utilise indigenous tree species for reforestation initiatives.* • *Generate alternative income sources for local communities and establish a carbon credit payment system.*
IFAD Inclusive Blue Economies Project (2021-2027)[390]	Haiti	Total Project Costs: US$ 20.84 million IFAD Financing: US$ 14 million Co-financiers: National Government US$ 2.51 million	Agency for national protected areas; National Department of Agriculture	• *Enhance sustainable natural and marine resource management among coastal communities. Women, youth, and children are prioritised in this project.* • *Restore mangrove forests and other coastal ecosystems around the Three Bays protected area.*
Adaptation Fund: Ecosystem-based adaptation for communities in the Central Forest corridor of Tegucigalpa (2019-2026)[391]	Honduras	Adaptation Fund grant: US$ 4.4 million	Ministry of Energy, Natural Resources and Environment	• *Establish EbA interventions in the central forest corridor.* • *Use reforestation initiatives within the green belt around Tegucigalpa.* • *Rehabilitate greenbelt watersheds and payment for ecosystem services.*
UNESCO: Mangrove restoration as a nature-based solution in	Seaflower (Colombia), Guanahacabibes Peninsula (Cuba), Macizo del Cajas	Not available	Ministry of Environment and Natural Resources	• *Restore and rehabilitate mangrove ecosystems across the Caribbean and Latin American biospheres.*

[388] IUCN: Building livelihoods and climate change resilience in the upper basins of Guatemala. Available online: https://www.iucn.org/our-work/projects/building-livelihood-resilience-climate-change-upper-basins-guatemalas-highlands

[389] REDD: Forest for Life Project. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=180

[390] IFAD: Inclusive Blue Economy Project. Available online: https://www.ifad.org/en/web/operations/-/project/2000002247

[391] Adaptation Fund: Using EbA in the central forest corridor of Honduras. Available online: https://www.adaptation-fund.org/project/ecosystem-based-adaptation-communities-central-forest-corridor-tegucigalpa/

biosphere reserves in Latin America and the Caribbean (2022-2025)[392]	(Ecuador), Xiriualtique-Jiquilisco (El Salvador), Darien (Panama), Noroeste Amotapes-Manglares (Peru) and La Encrucijada (Mexico)			
WWF and the Coca-Cola Company: Protecting and Restoring the Mesoamerican reef ecosystem (2007-2020)[393]	Mexico, Belize, Guatemala and Honduras	Not available	Ministry of Environment and Natural Resources	• *Conserve watersheds, support integrated water-conservation measures, and raise awareness among the local communities on the importance of conserving water resources.* • *Promote ecosystem-based adaptation interventions such as revegetation of water catchments, as well as reforestation of coastal forests and mangroves.*

[392] UNESCO: Mangrove conservation and restoration in Latin America and the Caribbean. Available online:

https://en.unesco.org/news/unesco-launches-mexico-new-project-conservation-and-restoration-mangroves-latin-america-and

[393] WWF: Restoring the Mesoamerican reef ecosystem. Available online: https://www.wwfca.org/en/conservation_sierra_de_las_minas/

8.1.2. Detailed Past and Ongoing Projects and initiatives related to ecosystem-based adaptation

Mexico and the Yucatan Peninsula

GEF: Sustainable Production Systems and Biodiversity in the Yucatan Peninsula (2016-2021)[394]

Budget: Co-financing Total: US$ 21.48 million; GEF grant: US$ 11.7 million
Location: Mexico
Goal: The key objective of this initiative is to strengthen socio-ecological and economic resilience across Mexico's Yucatan region to climate change impacts such as drought and flooding.
Objectives: This GEF-supported project promotes the conservation of biodiversity and ecosystem services by implementing ecosystem restoration and reforestation initiatives in the Yucatan region of Mexico. The target sectors include forestry, agriculture, and other land-use practices. Enhanced sustainable land-use management, cultivating indigenous trees, establishing mahogany tree nurseries, and promoting sustainable agricultural practices are key to the successful implementation of this project. Promoting the development of biodiversity corridors through enhanced sustainable land-use practices across these sectors is also an objective of this initiative.

GEF: Seventh Operational Phase of the GEF Small Grants Programme in Mexico (2021-2026)[395]

Budget: Co-financing Total: US$ 12.3 million; GEF grant: US$ 4.5 million
Location: Mexico
Goal: The key objective of this initiative is to strengthen socio-ecological and economic resilience to climate change impacts such as storm surges, sea level rise, flooding, and drought, in seven landscapes and seascapes across Mexico.
Objectives: These landscapes include the Agroforestry Landscape of Chiapas and Tabasco, the coastal seascape of the Yucatan Peninsula, the Grijalva-Usumacinta Lower Basin Landscape, the Sustainable Forestry Landscape of Campeche, Quintana Roo, and Yucatan, the Forest and Milpa Landscape of Campeche, Quintana Roo, and Yucatan, the Oaxaca Mountains Landscape, as well as the Mixteca Arid Landscape. Community-based activities are promoted and aim to promote sustainable development across the aforementioned landscapes. Climate change adaptation activities include the cooperative management of aquatic ecosystems; wetland and reef restoration; establishment of new community conservation areas and territories, as well as the promotion of inclusive ecosystem conservation through silvopastoral and agroforestry systems.

GEF: Mesoamerican biological corridor (2000-2006)[396]

Budget: Co-financing Total: US$ 75.2 million; GEF grant: US$ 14.8 million
Location: Mexico
Goal: The proposed project promotes the conservation of biodiversity and sustainable use of natural resources through the establishment of biological corridors in south-eastern Mexico (states of Campeche, Chiapas, Quintana Roo, Tabasco, and Yucatan). Such adaptation measures aim to increase the resilience of forest and coastal communities to climate change impacts such as storm surges, sea level rise, flooding, and drought.
Objectives: These corridors aim to foster the sustainable management of land and coastal ecosystems. In addition to promoting biodiversity, the proposed corridors are selected to optimise the connectivity among protected areas. Institutional coordination between federal and state agencies, non-government organisations (NGOs) and local communities and stakeholders are also prioritised. Additional climate change adaptation measures promoted in this initiative include the restoration of forest and coastal ecosystems, as well as discouraging deforestation.

GEF: Community-based ecotourism and biodiversity conservation in the Yucatan Peninsula[397]

Budget: Not available
Location: Mexico
Goal: Promote the climate change resilience of local Yucatan communities by encouraging ecotourism, ecosystem restoration and the conservation of ecosystem services.

[394] GEF: Forestry in the Yucatan. Available online: https://www.thegef.org/newsroom/news/forestry-yucatan-mainstreaming-biodiversity-and-promoting-development
[395] GEF: Seventh Operational Phase of the GEF Small Grants Programme in Mexico. Available online: https://www.thegef.org/projects-operations/projects/10504

[396] GEF: Mesoamerican biological corridor. Available online: https://www.thegef.org/projects-operations/projects/779

[397] GEF: Community-based Biodiversity conservation in the Yucatan Peninsula. Available online: https://www.thegef.org/news/community-based-ecotourism-protects-biodiversity-yucatan-peninsula

Objectives: Conserve biodiversity of the Yucatan Biosphere Reserve, by using the traditional knowledge of the Punta Allen and Muyil communities. The establishment of ecosystem-based practices such as indigenous farming, and forestry practices aid in enhancing the climate change resilience of local communities against impacts such as drought and flooding. In addition, sustainable livelihoods, food, and water security are promoted through the conservation of ecosystem services. Ecotourism is encouraged as a means of enhancing the resilience of the local community to climate change impacts. The GEF Small Grants Programme also supports Community Tours Sian Ka'an through several grants from the Community Management of Protected Areas Conservation initiative in partnership with the United Nations Foundation.

World Bank: Integrating coastal watershed conservation in Mexico (since 2012)[398]

Budget: US$ 39.5 million (GEF grant)
Location: Mexico
Goal: Promoting climate change resilience of coastal communities in Mexico by utilising ecosystem-based adaptation to conserve coastal watersheds.

Objectives: Enhance the conservation and sustainable management of coastal watersheds in Mexico through ecosystem-based adaptation measures. Payment for ecosystem services is utilised to sustainably manage 35,000 ha of land within these watersheds. Such initiatives include local communities making use of agroforestry, silvopastoral systems, mangrove, and coastal ecosystem restoration practices, as well as revegetation of riverbanks. Objectives of this project also include enhancing community resilience to the impacts of drought and flooding through sustainable management of 1.7 million ha of protected areas across the Gulf of California and the Gulf of Mexico. Finally, Mexico's National Institute of Ecology and Climate Change has developed and introduced Integrated Watershed Action Plans and monitoring in six coastal basins as part of this project. These basins include Tuxpan, Antigua, Jamapa, Baluarte, San Pedro, and Vallarta.

WWF: Protecting and restoring mangroves along the northern coast of the Yucatan Peninsula[399]

Budget: Not available
Location: Mexico
Goal: Conserve and restore coastal ecosystems in the Yucatan Peninsula to enhance local biodiversity and the resilience of coastal communities to climate change impacts such as drought, storm surges and flooding.

Objectives: Restore and revegetate mangrove ecosystems along the northern coast of the Yucatan Peninsula.

Global Mangrove Alliance: Protecting and restoring free-flowing rivers in Mexico[400]

Budget: Not available
Location: Mexico
Goal: To enhance the resilience of coastal ecosystems to climate change impacts such as flooding, storm surges and drought.

Objectives: The main project aims include the restoration of inland watersheds and wetlands so that coastal mangrove ecosystems can also be successfully rehabilitated. In so doing, ecosystem services are restored and the resilience of coastal communities to climate change impacts is enhanced.

Latin America and the Caribbean

GEF: Building resilience across urban systems through ecosystem-based adaptation in Latin America and the Caribbean (2016-2021)[401]

Budget: Co-financing Total: US$ 29.7 million; GEF grant: US$ 6 million
Location: El Salvador, Jamaica and Mexico

[398] The World Bank: Integrating coastal watershed management in Mexico. Available online: https://www.worldbank.org/en/results/2020/05/06/integrating-coastal-watershed-conservation-in-mexico

[399] WWF: Restoring mangroves along the northern Yucatan Peninsula coast. Available online: https://www.worldwildlife.org/magazine/issues/winter-2022/articles/protecting-and-restoring-mangroves-along-the-northern-coast-of-the-yucatan-peninsula

[400] Global Mangrove Alliance: restoring free-flowing rivers in Mexico. Available online: https://www.mangrovealliance.org/how-protection-of-mexicos-free-flowing-rivers-benefits-mangroves/

[401] GEF: Building resilience of urban systems through EbA in Latin America and the Caribbean. Available online: https://www.thegef.org/projects-operations/projects/5681

Goal: To reduce the vulnerability of communities living in three medium-sized Latin American and Caribbean cities to the effects of climate change through the integration of Ecosystem-based Adaptation (EbA) into urban planning in the medium- to long-term. Such measures aim to promote the resilience of urban communities to climate change impacts such as extreme heat, sea level rise, storm surges and flooding.

Objectives: The key objective of this initiative is to promote sustainable agricultural practices, restore degraded ecosystems and promote ecosystem services as well as biodiversity through EbA interventions. Across 1,000 ha of agricultural land that will be sustainably managed; 16 km of riparian forest and 150 ha of aquatic and forest ecosystems restored. The objective is to restore water catchments across Jamaica by planting 44,000 trees and rehabilitating 2 ha of wetland. In Mexico, EbA interventions include the restoration of 3,600 m of riparian corridors. At the urban landscape scale, permeable walkways will be constructed to promote rainwater infiltration, and an artificial wetland and a riparian park will be established. At the household scale, ecological sanitation plans will be developed, and rainwater harvesting systems constructed at schools and public buildings.

Scaling ecosystem-based adaptation (EbA) in rural Latin America (2021-2025)[402]

Budget: GIZ funding: US$ 9 million
Location: Costa Rica, Guatemala, Ecuador
Goal: Utilising EbA measures to enhance the climate change resilience of vulnerable communities and ecosystems in rural areas of Latin America to impacts such as flooding, storm surges, sea level rise and droughts.

Objectives: The initiative aims to strengthen the capacity of a diverse set of target groups, including national decision-makers and vulnerable rural communities to implement climate change adaptation measures successfully. Additional objectives include increasing the use of EbA practices in the target countries' adaptation planning, as well as incorporating these internationally Determined Contributions, sectoral plans, and National adaptation processes. Such initiatives aim to facilitate the meeting of national adaptation and sustainable development goals. Sustainability and upscaling of EbA measures are promoted through the development of innovative financial mechanisms, institutional strengthening, and knowledge sharing. Increasing the flow of financial resources for EbA measures and facilitating access to funding for EbA implementation is an additional objective of this project.

Scaling up climate resilient water management practices for vulnerable communities and ecosystems in La Mojana, Colombia[403]

Budget: GCF grant: US$ 38.5 million
Location: Colombia
Goal: Promote climate-resilient livelihoods and enhance sustainable water resource management across vulnerable communities in Colombia using ecosystem-based adaptation approaches. In so doing, the vulnerability of local communities to drought and erratic precipitation events is enhanced.

Objectives: The project aims to enhance the climate change resilience of more than 400,000 people by promoting sustainable water management, ecosystem-based adaptation approaches, early warning systems and climate-resilient livelihoods. The project plans to restore 40,000 ha of vulnerable forest and wetlands with the assistance of 50 local communities.

Reducing climate change vulnerability and flood risk in coastal cities and semi-urban areas in Latin America (2020-2025)[404]

Budget: Adaptation Fund grant amount: US$ 13.9 million
Location: Chile and Ecuador
Goal: Reduce the vulnerability of three coastal cities in Chile and Ecuador to climate change impacts such as flooding, storm surges, sea level rise, drought and landslides, by mainstreaming a risk-based approach to adaptation, building collaboration and networking, and developing a culture of adaptation.

Objectives: The project focuses on the climate change hazards which follow acute precipitation events and storm surges namely, flooding and landslides. Enhancing the capacities of these cities to adapt to climate change

[402] IUCN: Scaling EbA in rural Latin America. Available online: https://www.iucn.org/our-work/projects/scaling-ecosystem-based-adaptation-measures-rural-latin-america

[403] UNDP: GCF Colombia wetlands. Available online: https://undp-climate.exposure.co/gcf-colombia-wetlands

[404] Adaptation Fund: Reducing climate change vulnerability in coastal regions of Latin America. Available online: https://www.adaptation-fund.org/project/chile-ecuador-reducing-climate-vulnerability-flood-risk-coastal-urban-semi-urban-areas-cities-latin-america/

impacts, is a key objective. Restoring mangrove ecosystems and revegetation of urban water catchment regions and slopes, are adaptive measures aimed at reducing riverbank erosion and water flow, and are implemented in this project. The enhanced partnership between coastal cities in Latin America is an additional objective of this initiative.

REDD carbon project in the Emas-Taquari biodiversity corridor, Goias and Mato Grosso do Sul, Brazil (2010-2040)[405]

Budget: Not available
Location: Brazil
Goal: Conserve and restore the Cerrado-Pantanal biodiversity corridor and in so doing enhance the resilience of forest communities to climate change impacts such as flooding, landslides, and drought.

Objectives: The project's main objective is the restoration of degraded forest ecosystems and the conservation of biodiversity. The establishment of indigenous vegetation and reforestation initiatives aims to connect the corridors connecting the remaining Cerrado ecosystem fragments in the area surrounding the Emas National Park, and the Nascentes do Rio Taquari State Park. Reforestation of 589 ha using native Cerrado species, will also enhance sustainable local livelihoods through the production of fruits, seeds, fibres, oils, and honey.

REDD Paraguay forest conservation project in San Rafael (2010-2040)[406]

Budget: Not available
Location: Paraguay
Goal: Reduce greenhouse gas emissions from deforestation and forest degradation in the Parana Atlantic Ecosystem. The adaptive measures implemented aim to reduce the vulnerability of forest communities to climate change impacts such as flooding, drought, and landslides.

Objectives: Conservation of forest ecosystems across the La Amistad region of San Rafael is promoted by local community involvement in reforestation initiatives. Payments to community members of US$ 170/ha/year are implemented for the protection of existing forests and US$65/ha/year is paid to local communities for reforestation initiatives.

REDD Paraguay forest conservation project in the Chaco-Pantanal ecosystem (2011-2031)[407]

Budget: Not available
Location: Paraguay
Goal: The project goal is to conserve the natural and cultural qualities, including the stored carbon of forest lands in the Chaco-Pantanal transition zone of Alto Paraguay. The adaptive measures implemented aim to reduce the vulnerability of forest communities to climate change impacts such as flooding, drought, and landslides.

Objectives: The main objective of the initiative is to purchase available properties in partnership (co-ownership and management) with local communities, thus ensuring the permanence of a conservation management regime. Primary adaptive measures include the introduction of sustainable agricultural practices such as agroforestry to promote forest conservation and reforestation. The objective is to replicate this basic approach in other regions of Latin America where livestock production and related ecosystem degradation predominates.

REDD Restoration of degraded areas and reforestation in Colombia (2002-2032)[408]

Budget: Not available
Location: Colombia
Goal: The project goal is to conserve the natural and cultural qualities, including the stored carbon of grasslands in Caceres and Cravo Norte, by means of reforestation initiatives. These adaptive measures aim to reduce the vulnerability of communities to climate change impacts such as flooding, drought, and landslides.

[405] REDD: Carbon Project in the Emas-Taquari Biodiversity Corridor, Goiás and Mato Grosso do Sul, Brazil. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=232

[406] REDD: Paraguay forest conservation project. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=175

[407] REDD: Paraguay forest conservation project. Available online:https://www.reddprojectsdatabase.org/view/project.php?id=158

[408] REDD: Restoration of degraded areas and reforestation in Colombia. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=135

Objectives: The project has the primary aim of restoring degraded grasslands in Colombia. The project is expected to generate an increment in existing carbon stocks and will promote carbon sequestration. By promoting sustainable agricultural techniques such as silvopastoral and agroforestry systems, climate change adaptability will be enhanced across this region.

REDD Reduction of deforestation and degradation in Tambopata Nature Reserve and Bahuaja-Sonene National Park (2008-2028)[409]

Budget: Not available
Location: Peru
Goal: Reduce the pressure caused by land-use changes in the Natural Protected Areas' buffer zones in the Madre de Dios region, Peru. Adaptive measures implemented aim to enhance the resilience of local communities to climate change impacts such as flooding and drought.

Objectives: The project aims to enhance the monitoring and conservation capacity of local authorities and communities in terms of natural resource utilisation in the Madre de Dios region. Additionally, the control and surveillance system will be strengthened, and the project will provide technical support to regional forest authorities to promote sustainable land-use practices. Ecosystem degradation will be addressed through agroforestry practices and reforestation, and in so doing enhance the climate change resilience of local communities.

REDD Watershed Restoration in the Cantareira water system (2009-2039)[410]

Budget: Not available

Location: Brazil

Goal: Promote water security in the San Paulo region by using ecosystem-based adaptation. These adaptation measures aim to enhance the resilience of local communities to climate change impacts such as flooding and drought.

Objectives: The project will restore indigenous vegetation to an area of 185.56 ha surrounding the Cachoeira Reservoir, which supplies the city of Sao Paulo, Brazil. Municipalities utilise funds from water users to pay farmers and ranchers who conserve and restore riparian forests on their lands.

REDD Restoration of the Pachijal and Mira River watersheds (2011-2041)[411]

Budget: Not available

Location: Ecuador

Goal: Promote water security in Ecuador by using ecosystem-based adaptation. These adaptation measures aim to enhance the resilience of local communities to climate change impacts such as flooding, landslides, and drought.

Objectives: The main objective of this initiative is to encourage private landowners to reforest agricultural land and catchment areas by using indigenous vegetation. Such interventions will aid in rehabilitating 346 ha of degraded grasslands in the Andean mountains in Ecuador. Agroforestry is an additional ecosystem-based adaptation intervention implemented in this project, aimed at promoting the climate change resilience of Andean communities.

IUCN Building livelihood resilience to climate change in Guatemala's Highlands (2020-2027)[412]

Budget: GCF funding: US$ 24.8 million

[409] REDD: Reduction of deforestation and degradation in Madre de Dios, Peru. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=201

[410] REDD: Watershed Restoration in the Cantareira Water System. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=264

[411] REDD Restoration of the Pachijal and Mira river watersheds. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=177

[412] IUCN: Building live;lihoods and climare change resilience in the upper basins of Guatemala. Available online: https://www.iucn.org/our-work/projects/building-livelihood-resilience-climate-change-upper-basins-guatemalas-highlands

Location: Guatemala

Goal: Promote water security in Guatemala's highlands by using ecosystem-based adaptation. These adaptation measures aim to enhance the resilience of local communities to climate change impacts such as flooding, landslides, and drought.

Objective: The project has the key objective of utilising integrated watershed management in the dry corridor of the Guatemalan highlands. The project aims to benefit 132,000 people in an area of 146,500 ha of which 22,500 ha will be restored. Community-led ecosystem revegetation and rehabilitation of water catchment areas form part of this initiative. Such EbA interventions have the objective of promoting water and food security despite climate change impacts.

REDD Lacandon Forest for Life project (2012-2042)[413]

Budget: Not available

Location: Guatemala

Goal: Promoting climate change mitigation through reforestation and reduced ecosystem degradation in the Sierra del Lacandon National Park. Such adaptation interventions aim to promote the resilience of forest communities in the events of drought and flooding.

Objectives: The primary objective of this initiative is to encourage local communities to participate in reforestation projects. Indigenous tree species are utilised. Assessing the potential to generate alternative income sources for local communities as well as establishing a carbon credit payment system, are additional objectives of this project. Poverty reduction and biodiversity conservation are expected outcomes of such interventions.

IFAD Inclusive Blue Economies Project (2021-2027)[414]

Budget: US$ 20.8 million (total project costs)

Location: Haiti

Goal: Reduce poverty and enhance climate change resilience of coastal communities in the event of sea level rise, storm surges, drought, and floods by restoring coastal and marine ecosystems.

Objectives: Enhance sustainable natural and marine resource management among coastal communities in the northern and northeastern regions of the country. Women, youth, and children are prioritised in the project considering their vulnerability to climate change impacts. A key objective of this project is to promote the restoration of mangrove forests and other coastal ecosystems around the Three Bays protected area.

Adaptation Fund: Ecosystem-based adaptation for communities in the Central Forest corridor of Tegucigalpa (2019-2026)[415]

Budget: US$ 4.4 million (grant amount)

Location: Honduras

Goal: Using ecosystem-based adaptation initiatives to reduce poverty and enhance the resilience of coastal communities in the central forest corridor to the impacts of drought and floods.

Objectives: Ensuring the conservation of forest biodiversity and ecosystem services is a primary objective of this project. Food and water security is a key outcome in establishing EbA interventions in the central forest corridor. Reforestation initiatives within the green belt region surrounding Tegucigalpa are an example of such

[413] REDD: Forest for Life Project. Available online: https://www.reddprojectsdatabase.org/view/project.php?id=180

[414] IFAD: Inclusive Blue Economy Project. Available online: https://www.ifad.org/en/web/operations/-/project/2000002247

[415] Adaptation Fund: Using EbA in the central forest corridor of Honduras. Available online: https://www.adaptation-fund.org/project/ecosystem-based-adaptation-communities-central-forest-corridor-tegucigalpa/

interventions. Rehabilitation of greenbelt watersheds, conserving natural biodiversity and payment for ecosystem services are additional outcomes of this project.

UNESCO: Mangrove restoration as a nature-based solution in biosphere reserves in Latin America and the Caribbean[416]

Budget: Not available

Location: Colombia, Cuba, Ecuador, El Salvador, Panama, Mexico, Peru

Goal: To promote the resilience of coastal ecosystems in Latin America and the Caribbean to the impacts of storm surges, flooding, and drought by using nature-based interventions.

Objectives: The restoration and rehabilitation of mangrove ecosystems in the following biospheres: Seaflower (Colombia), Guanahacabibes Peninsula (Cuba), Macizo del Cajas (Ecuador), Xiriualtique-Jiquilisco (El Salvador), Darien (Panama), Noroeste Amotapes-Manglares (Peru) and La Encrucijada (Mexico). The resilience of these coastal regions to climate change impacts is enhanced by the restoration of mangroves and the services these ecosystems provide.

WWF and Coca-Cola Company: Protecting and Restoring the Mesoamerican reef ecosystem (2007-2020)[417]

Budget: Not available
Location: Mexico, Belize, Guatemala and Honduras
Goal: Promoting climate change resilience of coastal communities in the Caribbean and Latin America by utilising ecosystem-based adaptation to conserve coastal watersheds.

Objectives: The primary objective of this project is to protect watersheds, support integrated water-conservation measures, and raise awareness among communities on the importance of conserving water resources. Ecosystem-based adaptation interventions include the revegetation of water catchments, as well as the reforestation of coastal forests and mangroves.

[416] UNESCO: Mangrove conservation and restoration in Latin America and the Caribbean. Available online:

https://en.unesco.org/news/unesco-launches-mexico-new-project-conservation-and-restoration-mangroves-latin-america-and

[417] WWF: Restoring the Mesoamerican reef ecosystem. Available online: https://www.wwfca.org/en/conservation_sierra_de_las_minas/