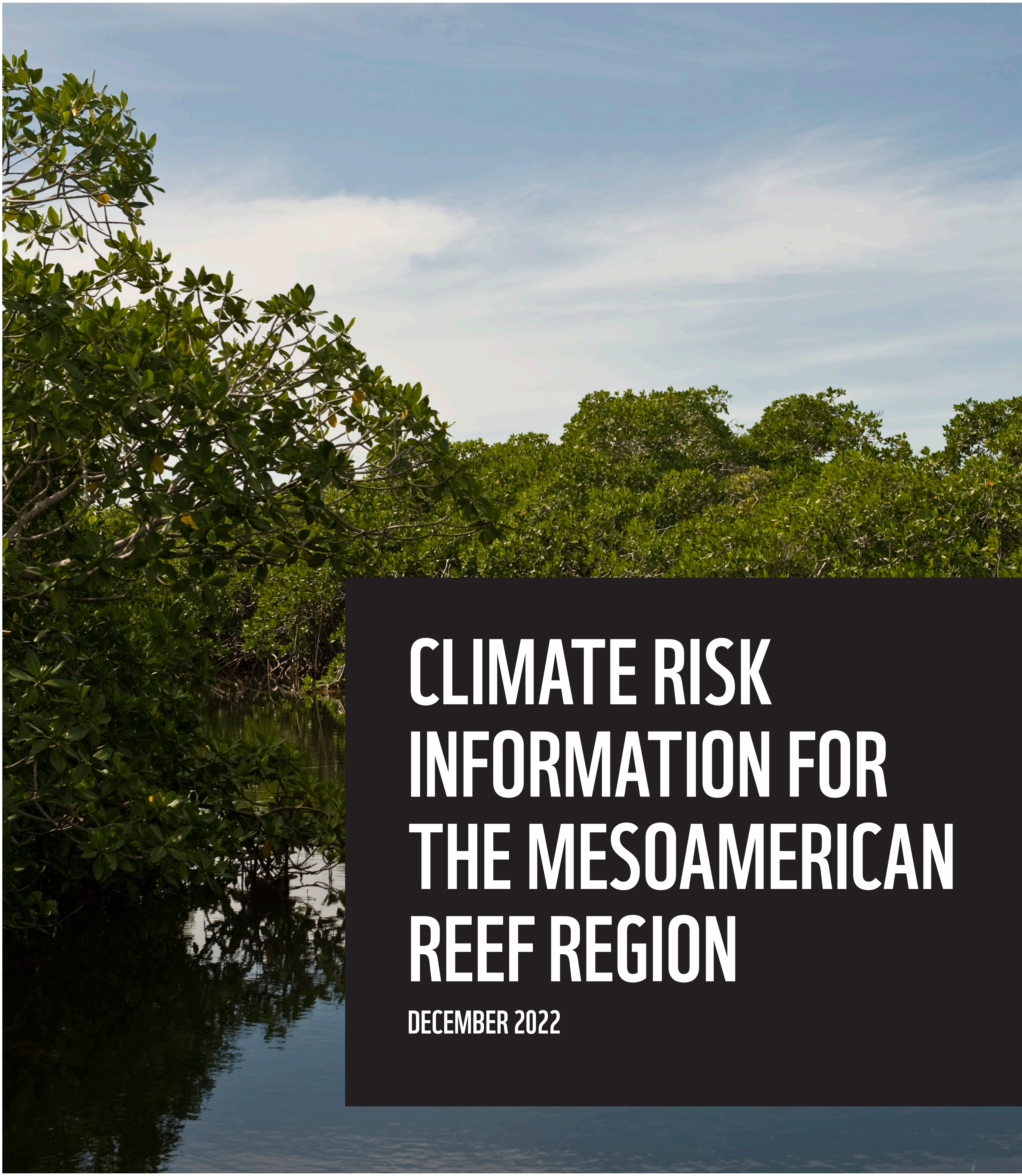


CLIMATE RISK INFORMATION FOR THE MESOAMERICAN REEF REGION

DECEMBER 2022

PROYECTO COSTAS LISTAS / SMART COASTS

WWF

IKI INTERNATIONAL CLIMATE INITIATIVE

Center for Climate Systems Research
Earth Institute | Columbia University

ABOUT THE INSTITUTIONS

WWF

For more than 50 years, WWF has been protecting the future of nature. The world's leading conservation organization, WWF works in 100 countries and is supported by 1.1 million members in the United States and close to 5 million globally. WWF's unique way of working combines global reach with a foundation in science, involves action at every level from local to global, and ensures the delivery of innovative solutions that meet the needs of both people and nature.

Columbia University Center for Climate Systems Research

The Center for Climate Systems Research (CCSR) is the home of the cooperative relationship between Columbia University and the National Aeronautics and Space Administration Goddard Institute for Space Studies (NASA GISS) and a research center of The Earth Institute at Columbia University. CCSR was established with the objective of providing enhanced understanding of the Earth's climate and its impacts on key sectors and systems. The GISS Climate Impacts Group develops innovative methods to apply climate information to aid in impact forewarning, risk reduction and resilience building for climate hazards around the world. CCSR also plays a large role in the dissemination of climate change research and information to governments, local and international organizations, educational institutions, and stakeholders.

ADVANCE Partnership

ADVANCE is a partnership between World Wildlife Fund (WWF) and the Columbia University Center for Climate Systems Research (CCSR) at The Earth Institute. Launched in 2015, ADVANCE facilitates adaptation by providing new ways of generating and integrating climate risk information into conservation and development planning, policies, and practice. ADVANCE envisions a future where the world is using co-generated climate risk information based on the best-available science to guide conservation, development, and disaster risk reduction to benefit human well-being and ecosystem health.

Citation: De Mel, M., Phillips, M., Bartlett, R., Porta. M. A., Calzada, A., Bood., N., Velasquez, P., Chevez, L., Kadam, S., Bader, D., Evans, J., Longobardi, K., Rohe, J., and Rosenzweig, C. 2021. Climate Risk Information for the Mesoamerican Reef Region. New York, NY, USA: Center for Climate Systems Research at Columbia University, WWF-US and WWF-Mesoamerica.


© Antonio Busiello / WWF Mesoamerica

CONTENTS

© Antonio Busiello / WWF Mesoamerica

© 2023
Paper 100% recycled

WWF® and ©1986 Panda Symbol are owned by WWF. All rights reserved.

WWF Mesoamerica, 15 Avenida 13-45, Zona 10, Colonia Oakland, Ciudad de Guatemala, Guatemala. Tel. +502 2366-5856

For contact details and further information, please visit our website at **wwfca.org**

Cover photography: © Antonio Busiello / WWF Mesoamerica

ABBREVIATIONS

CCSR	Center for Climate Systems Research
CMIP5	Coupled Model Intercomparison Project Phase 5
GCM	General Circulation Model
IKI	International Climate Initiative
IPCC	Intergovernmental Panel on Climate Change
MAR	Mesoamerican Reef
NASA	National Aeronautics and Space Administration
NASA GISS	NASA Goddard Institute for Space Studies
NASA NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
RCP	Representative Concentration Pathway
WWF	World Wildlife Fund

Note: Like all future projections, climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system, and limited understanding of some physical processes. In this publication, the levels of uncertainty are characterized using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations, and recent peer-reviewed literature. The projections are not true probabilities, and scenario-planning methods should be used to manage the risks inherent in future climate.


© Antonio Busiello / WWF Mesoamerica

KEY MESSAGES

Coastal and marine resources in the Mesoamerican Reef region provide essential ecosystem services, sustain key economic sectors, support livelihoods, and provide resilience to coastal communities. The Caribbean coastlines of Mexico, Belize, Guatemala and Honduras are among the most vulnerable regions worldwide to climate change impacts. Through the support of the International Climate Initiative (IKI) of Germany's Ministry of Economic Affairs and Climate Action, the Smart Coasts project aims to mainstream climate-smart principles into protected area management and coastal development policies with a view to improve the adaptive capacities of coastal communities in the region.

The Columbia University Center for Climate Systems Research (CCSR) developed climate risk information to support planning and decision making in the Mesoamerican Reef region. Projections were developed for RCP 4.5 and 8.5 and all results presented in this report (unless stated otherwise) are for RCP 8.5.[1] The key messages from the assessment are highlighted here.

1 RCP 8.5 was selected as the high-end scenario based on project team and stakeholder consultations in 2018. Since then, scientific literature indicates that warming associated with RCP 8.5 may be unlikely due to unrealistically high fossil fuel emissions associated with RCP8.5 (Hausfather and Peters, 2020). The climate risk assessment done by CCSR also includes results for RCP 4.5 and data for both scenarios are available from WWF Mesoamerica or CCSR.

REGIONAL CLIMATE PROJECTIONS

- Mean temperature is increasing across the regions, with inland areas seeing more warming. Under RCP 8.5, the region sees increases of ~1.5-2°C (low estimate) and ~2-3°C (high estimate) by midcentury (2041-2070) under high-end climate change.
- Many regions see a high number of total extreme heat days (>35°C) in a year by midcentury under high-end climate change. Mexico and northwestern Guatemala see larger numbers of extreme heat days than other areas, for both low and high estimates. Under the high estimate, coastal regions reach 100-200 days, depending on location with large parts of the region exceeding 150 days and some inland areas seeing nearly 200 days where temperatures exceed 35°C.
- Precipitation change is more complex, with a more pronounced drying trend in the low estimate by midcentury, despite minor increases in some regions under the high estimate. The low estimate shows projected decreases in precipitation across the region, ranging from -5% to -25%, while the high estimate shows minor increases of 5-10% in many of the project areas. Some parts of inland Mexico, Guatemala and Honduras (outside coastal protected areas) show small declines in precipitation even under the high estimate.
- Rainy days are projected to decline in many areas by midcentury under high-end climate change. Under the low estimate, the number of rainy days per year is projected to decrease in all areas, with very little change (fewer than 5 days in either direction) across the region even under the high estimate.
- Sea levels are increasing across the entire region, with the increase ranging from ~40-45cm for the high-end climate scenario by mid-century.
- Sea surface temperatures are increasing across the ocean areas in the Mesoamerican Reef region, increasing by ~1.5˚C to over 2˚C by midcentury under high-end climate change. The increase by the end of the century ranges from over 2˚C to almost 4˚C by end of the century.
- Over time, the pH levels decline by -0.14 to -0.16 with increasing ocean acidification under high-end climate change by midcentury and a decline ranging from -0.25 to -0.27 by end of century. The pH scale is logarithmic, so this change represents a large increase in acidity as a 0.1 decrease in pH is approximately a 30% increase in acidity. This can have impacts on coral reefs and other calcifying organisms.


© Antonio Busiello / WWF Mesoamerica

- Climate change impacts coastal communities as well as a range of sectors in the Mesoamerican Reef region. Climate projections can help decision-makers across several sectors and levels incorporate climate change risks into planning and investment decisions.

MEXICO PROJECT REGION

- Mean temperature is increasing across the entire Yucatan peninsula with inland areas seeing more warming. Under RCP 8.5, the region seeing increases of ~1.00-1.5°C in many areas and reaching ~2°C in more inland areas (low estimate). Under the high estimate, most areas in the peninsula see increases of at least 2°C, with some inland areas exceeding 2.5°C.
- Many areas see a high number of extreme heat days (>35°C) in a year by midcentury under high-end climate change with extreme heat days exceeding 100 in many areas, with some inland areas seeing over 150 days of extreme heat under the low estimate. Under the high estimate, large parts of the region exceed 150 days and some inland areas see ~200 days (or more) of total days over 35°C.
- Precipitation is projected to decrease significantly with the possibility of a slight increase across parts of the Yucatan peninsula. The low estimate shows projected precipitation declines of around -10-15%, as opposed to possible increases of less than 10% under high estimate.
- There is a projected decline in the number of rainy days compared to the baseline under high-end climate change. The low estimate projects decreases of 5-20 rainy days per year, while the high estimate shows very little change (fewer than 5 days in either direction) in the project region.
- Sea levels are increasing in the Mesoamerican Reef region, increase rates depending on the location. In the Yucatan peninsula sea level rise in the 2050s ranges from ~20-25cm under the low estimate and ~40-45cm for the high estimate.

BELIZE PROJECT REGION

- Mean temperature is increasing across Belize and the project regions. Under RCP 8.5, the areas of interest in Belize see increases of ~1.5-2.0°C (low estimate) and ~2.5-3°C (high estimate) by midcentury.w
- The total number of days over 35°C in the project area are projected to reach up to ~100 per year under the low estimate with some areas along the coastal region experiencing lower numbers. Under the high estimate, the distribution of extreme heat days remains similar. The total number of days over 35°C in the project area under the high estimate ranges from ~50-150 days per year.
- Precipitation is projected to decrease significantly under the low estimate with the possibility of smaller increases in northern zones under the high estimate. The low estimate shows projected precipitation declines of around -10-25% for all zones, as opposed to possible increases of 5-10% in northern zones and smaller mixed changes in the southern zone under the high estimate.
- There is a projected decline in the number of rainy days compared to the baseline under high-end climate change. The low estimate projects decreases of 15-30 rainy days per year, while the high estimate shows very little change (fewer than 5 days in either direction) across all zones in Belize.
- Sea levels are increasing in the Mesoamerican Reef region. In Belize, sea level rise in the 2050s is ~20cm under the low estimate and just over 40cm for the high estimate.

GUATEMALA PROJECT REGION

- Mean temperature is increasing across Guatemala. This increase is ~2°C in many areas under the low estimate (25^{th} percentile), with the central regions of the country projected to warm slightly more. Under the high estimate, most areas see increases of at least 2.5°C, with many areas reaching 3°C warming.
- The number of extreme heat days (>35°C) per year varies across Guatemala, with some of the inner/central regions seeing the highest number of extreme heat days. The total number of days over 35°C in a year range from ~50 to over 150 under the low estimate for RCP 8.5 midcentury. Under the high estimate, many parts of the region exceeding 150 days and some inland areas in the north seeing ~200 days (or more) where temperatures exceed 35°C.

- Precipitation is projected to decrease significantly under the low estimate across Guatemala with the possibility of a smaller increase in the coastal protected area under the high estimate. The low estimate shows projected precipitation declines of around -10-25% across the region, as opposed to slight increases of less than 10% in coastal Guatemala and even potential drying in northern (inland) Guatemala under the high estimate.

- There is a projected decline in the number of rainy days compared to the baseline under high-end climate change. The low estimate projects decreases of 10-20 rainy days per year inside the coastal region, while the high estimate shows very little change and potentially even a decline of several days per year in the same protected area.

- Sea levels are increasing in the Mesoamerican Reef region. In Guatemala sea level rise in the 2050s ranges from ~20cm under the low estimate and just over 40cm for the high estimate.

HONDURAS PROJECT REGION

- Mean temperature is increasing across Honduras. Under RCP 8.5, Honduras sees increases of ~1.5-2.0°C (low estimate) and ~2.5-3.0°C (high estimate) by midcentury.

- The number of extreme heat days (>35°C) per year varies across the region and in Honduras. The total number of days over 35°C in the project area are projected to reach ~50 per year under the low estimate with some areas along the northern coastal region of Honduras experiencing close to 100 days per year. Under the high estimate, the total number of days over 35°C in the project area could reach ~100-175 days per year in some areas along the northern coastal region of Honduras. Most inland areas in Honduras see a range of about 10-100 days under both the low and high estimates.

- Precipitation is projected to decrease significantly under the low estimate across Honduras with the possibility of a slight increases in the coastal protected area under the high estimate. The low estimate shows projected precipitation declines of around -5-20% across the region, as opposed to slight increases of less than 10% in coastal Honduras, with greater increases in the western side of the protected area. Even under the high estimate, precipitation is projected to decline very slightly across central (inland) Honduras.

- There is a projected decline in the number of rainy days compared to the baseline under high-end climate change. The low estimate projects decreases of 15-30 rainy days per year inside the coastal region, while the high estimate shows very little change and potentially even a decline of up to 5 days per year in the same protected area.

- Sea levels are increasing in the Mesoamerican Reef region. In Caribbean side of Honduras sea level rise in the 2050s ranges about 20cm under the low estimate and just over 40cm for the high estimate.

1. CONTEXT

1.1 INTRODUCTION TO THE REPORT

This report is developed by the Columbia University Center for Climate Systems Research (CCSR), in collaboration with WWF for the International Climate Initiative (IKI) funded project 'Climate-Smarting Protected Areas and Coastal Management in the Mesoamerican Reef Region.'- Smart Coasts. The document provides an overview of regional climate projections. This project builds on the ADVANCE partnership between CCSR and WWF, established in 2015.

The objective of CCSR's collaboration in this project was to provide climate projections and integrate this information into marine and coastal risk assessments and activities and guide planners on managing and minimizing the negative impacts of climate change on these ecosystems, as well as on people depending on them. By understanding the local impacts that climate change will have on these ecosystems, the resilience of the marine and coastal ecosystems can be improved when implementing adequate measures.

CCSRs main activities included:

1. Provision of localized climate projections to support natural capital assessments in the project region
2. Provision of climate projections for marine and coastal protected areas to support adaptation activities
3. Co-leadership of two workshops to co-generate climate risk information with project stakeholders
4. Guidance on using climate risk information for project activities

1.2. About the Smart Coasts Project

Coastal and marine resources in the Mesoamerican Reef region provide essential ecosystem services, sustain key economic sectors (e.g., fisheries and tourism), support the livelihoods of more than two million people and contribute to the protection of coastal communities against adverse effects of climate change. At the same time, the Caribbean coastlines of Mexico, Belize, Guatemala and Honduras are among the most vulnerable regions worldwide to climate change impacts. The management of these resources, including through protected areas and overarching coastal development frameworks, does not yet adequately take into account adaptation principles and options.

There is a need to strengthen capacities in coastal communities and government institutions to integrate climate change scenarios and adaptation options into a participatory decision-making process that can inform protected area as well as coastal zone management and development policies. Through the support of the International Climate Initiative, the Smart Coasts project aims to mainstream climate-smart principles into protected area management and coastal development policies in countries bordering the Mesoamerican Reef with a view to improve the adaptive capacities of coastal communities in the region.

To address these gaps, ecosystem-based adaptation options were determined in a cross-sector and stakeholder-driven decision-making process applying science-based tools. These tools include ecological risk assessments that integrate climate change and social development scenarios and ecosystem services modelling. While informing relevant policy and management frameworks, adaptation measures identified will be implemented in selected coastal areas in Mexico, Belize, Guatemala and Honduras. The project is helping to enhance knowledge and capacities at local and national levels, contribute to national and local adaptation policies and action plans and making best practices available at relevant national and international fora.

The project builds on various strategies to multiply its direct impact. Key representatives of coastal communities, government institutions and nongovernmental organizations were systematically trained on methods and tools to identify and assess appropriate solutions for adapting to the effects of climate change. By integrating climate-smart principles into relevant local, sub-national and national policy and management frameworks, strategies to better adapt to climate change will be fostered in the region over space and time. In addition, best practices on integrating climate change considerations into policies and management of coastal and marine resources will be compiled and shared at relevant national, regional and global fora.

The project thereby aims to allow for institutionalization of climate-smart policy and management frameworks for coastal and marine resources and replication of activities beyond the geographical scope and duration of the project.

The expected outcomes of the project included the following:

i. A portfolio of climate change adaptation options has been identified through a participatory process that considers local community needs and environment conservation.

ii. Local populations and decision makers have strengthened their capacity to identify and prioritize climate change adaptation options.

iii. Government authorities have recommendations to integrate climate change adaptation aspects and criteria in spatial planning instruments.

iv. Adaptation measures are implemented with the participation of local stakeholders.

v. A working group is established to promote better practices on the identification, integration and implementation of adaptation measures in coastal zones and marine protected areas.

1.3 Project Partners

The project, 'Climate-Smarting Protected Areas and Coastal Management in the Mesoamerican Reef Region' (Smart Coasts) is part of the investment portfolio of the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) of Germany. It is executed by WWF Germany, in collaboration with WWF Guatemala/ Mesoamerica, WWF Mexico and WWF US in partnership with Stanford University's Natural Capital Project and Columbia University.

Within each country, project activities are executed in collaboration with local and political partners.

Political partners include:

- Mexico: National Commission for Natural Protected Areas (CONANP), Government of Yucatan and Government of Quintana Roo
- Belize: Ministry of Agriculture, Fisheries, Forestry, the Environment and Sustainable Development via the Coastal Zone Management Authority and Institute (CZMAI)
- Guatemala: Ministry of the Environment and Natural Resources (MARN) via the
- Department of Ecosystems
- National Council of Protected Areas (CONAP)
- Honduras: Ministry Natural Resources and Environment (MiAmbiente+) National Institute of Forest Conservation, Protected Areas and Wildlife (ICF).

1.4. Location

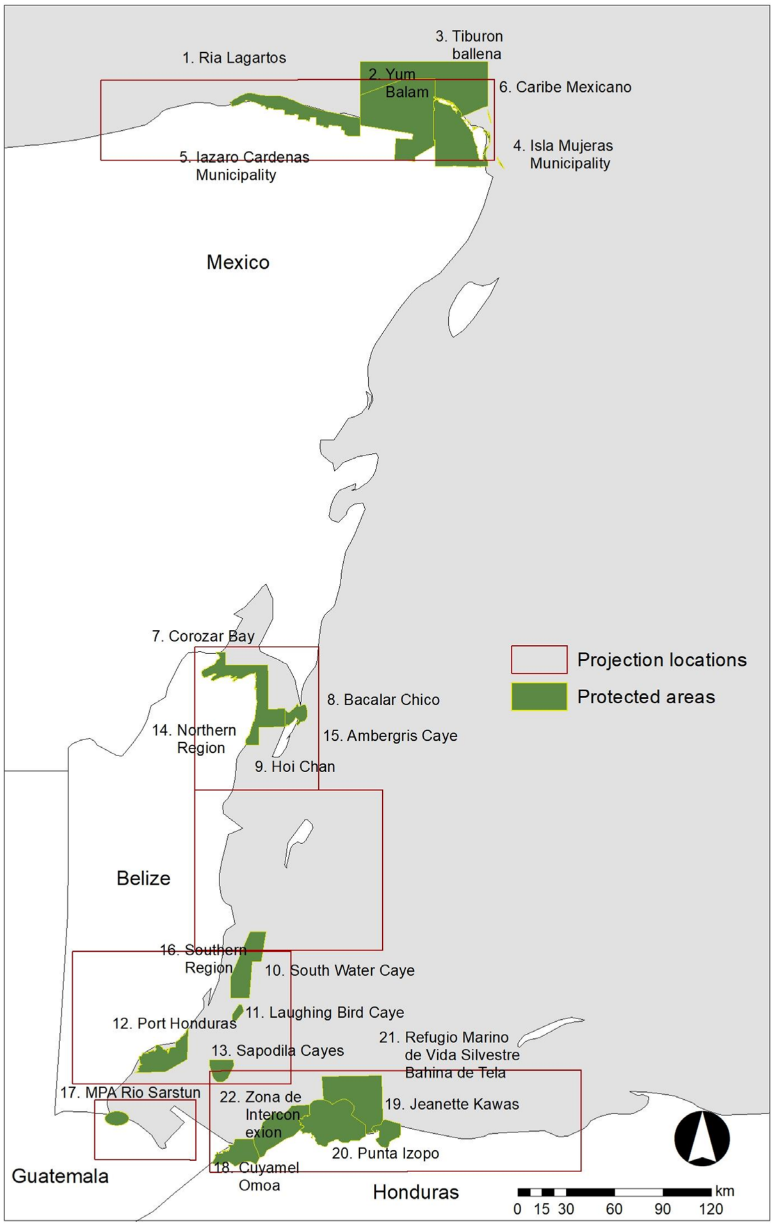
The Mesoamerican reef (MAR) is the largest transboundary reef system in the world and contains the world's second longest barrier reef. The system stretches across four countries: Mexico, Belize, Guatemala and Honduras, along more than 1,000 km of coastline and is a hotspot for biodiversity including endangered marine turtles, more than 60 types of corals and more than 500 fish species.

The project is being implemented in the four countries that conform the Mesoamerican Reef System. Project sites were chosen due to their importance for biodiversity conservation and the perceived level of vulnerability and exposure of populations within the area to climate change.

- Mexico: the target sites are the Dzilam State Reserve, Ria Lagartos Biosphere Reserve (Yucatan), and the Flora and Fauna Protection Area of Yum Balam (Quintana Roo).
- Belize: the target sites were identified in accordance with the national Integrated Coastal Zone Management Plan; specifically the Northern Regional Planning Zone (Zone 1), the Ambergris Caye Regional Planning Zone (Zone 2), and the Southern Regional Planning Zone (Zone 3).
- Guatemala: Rio Sarstún Multiple Use Area is the target site.
- Honduras: The focus is on four protected areas: Cuyamel-Omoa Protected Areas Subsystem, Jeannette Kawas National Park, Punta Izopo National Park, and Bahía de Tela Marine Wildlife Refuge and an 11,700 ha large connecting zone between two of the protected areas.

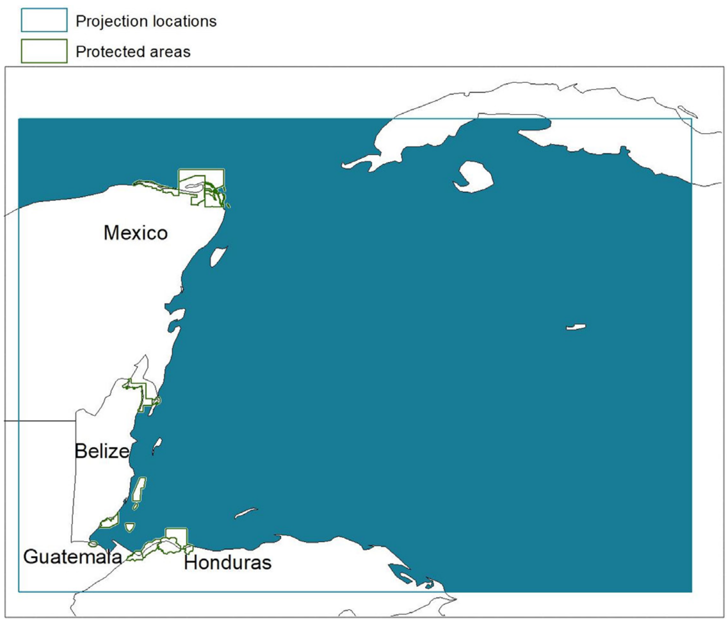
Projections were carried out for the entire Mesoamerican Reef project region, including the adjacent ocean regions where relevant. Annual projections were carried out for the entire region and seasonal projections were carried out for project specific regions in each country. The localized projections were carried out for smaller regions that roughly encompass the regions listed above, with the engagement of project partners and stakeholders.

Figure 1. Map of protected areas, coastal-marine zones, and climate projection locations



Note: The projection locations mapped here represent the approximate regions for which area-averaged climate projections were carried out for each of the four countries. This included one region each in Mexico, Guatemala and Honduras, while in Belize projections were carried out for the country's three coastal management zones.

Figure 2. Climate projection area for ocean variables



1.5 Stakeholder engagement process

Stakeholder engagement has been a key process from the start of the project. CCSR engaged with stakeholders during the initial workshop in Belize in November 2018, attended by implementing organizations and key partners from each country. Feedback on useful climate variables, appropriate seasons, and locations for climate projections were identified and discussed. Project partners were also consulted after the workshop to get feedback for projections. Near final projections were presented at two workshops in August 2019 in Mexico (attended by stakeholders from Belize and Mexico) and in Honduras (attended by stakeholders from Guatemala and Honduras).

Stakeholders have been engaged on all aspects of the project, including the ecosystem services analyses by Stanford University. Participatory decision making led to the identification of ecosystem-based adaptation options of which a few will be piloted under the next phase of the project.

1.6 Ecosystem service analyses and the integration of climate risk information

Stanford University's Natural Capital Project team carried out modeling to support the identification of critical ecosystem services, how these services change with climate change and supported the prioritization of key locations for maintaining ecosystem services. Climate change variables developed through this assessment were integrated into several natural capital models.

Sea level rise was integrated into the coastal risk reduction model

Precipitation (monthly, seasonal) was integrated into the sediment export/retention model

Mean temperature, extreme heat (days over 35°C), precipitation (annual total), were integrated into the tourism and recreation model

Sea surface temperature was integrated into the target coral reef fish biomass and lobster fishery production

The analyses were carried out for the 2050s time slice for RCP8.5 (high-end climate change) low (25^{th} percentile) and high estimates (75^{th} percentile).

2. METHODS

Climate projections were developed using the NASA Earth Exchange Global Daily Downscaled (NEX-GDDP) dataset with 21 CMIP5 climate models for most variables. The methods and models used for some variables differ and are detailed in Table 1 and the following sections. Projections for the Mesoamerican Reef region shown below were developed for Representative Concentration Pathway (RCP) 8.5[2] and two estimates are given low (25^{th} percentile) and high (75^{th} percentile) to provide a range of future possibilities and capture uncertainties. This risk-based approach to decision-making is critical to appropriately account for uncertainty in adaptation planning across a range of sectors and applications.

There is a degree of uncertainty associated with predicting future climate conditions as they have yet to occur (Horton et al., 2015), but this uncertainty should not be a reason for inaction or for not using projections to inform decision-making. One of the reasons for this uncertainty is that natural variability of the climate system is largely unpredictable (e.g., randomness in ocean dynamics, storm events).

A second source of uncertainty is human behavior. The effectiveness of international climate agreements to reduce greenhouse gas emissions, the development of new technologies and cultural and behavioral patterns will direct the trajectory of greenhouse gas emissions over time and determine the magnitude and rate of climate change.

A third source of uncertainty lies in the global climate models that project future climate patterns. Each of these mathematical models simulates the climate system, how that system will respond to increased greenhouse gas emissions and feedback loops from the interconnected systems that govern weather and climate. These models incorporate these various aspects in slightly different ways, resulting in different outputs for temperature, precipitation, sea level rise and other variables.

See note on low (25^{th} percentile) and high (75^{th} percentile) estimates in the Methods section.

Table 1 summarizes the projected climate variables that were examined in this assessment. See Annex 1 for detailed methods used to develop the climate projections developed for this assessment.

2 RCP 8.5 was selected as the high-end scenario based on project team and stakeholder consultations in 2018. Since then, scientific literature indicates that warming associated with RCP 8.5 may be unlikely due to unrealistically high fossil fuel emissions associated with RCP8.5 (Hausfather and Peters, 2020). The climate risk assessment done by CCSR also includes results for RCP 4.5 and data for both scenarios are available from WWF Mesoamerica or CCSR.

Table 1. Summary of projected essential climate variables influencing climate-induced hazards within this report

Variables influencing hazards	Seasons	Time slices	Future emissions scenarios	Datasets and Resolution	Regions
Temperature • Change Extreme heat • Days over 35°C Precipitation • Change • Rainy days (days over 1mm)	Annual Seasonal projections developed for project regions* Seasons vary by region **See regional section for projections*	Climate model Baseline (1980-2005) 2020s (2011-2040)** 2050s (2041-2070) (presented in report) 2080s (2071-2100)** ***Projections available by request*	RCP 8.5 (presented in report) RCP 4.5*** ****Projections available by request*	NASA NEX GDDP 21 climate model outputs derived from CMIP5 0.25 degrees (~25km)	Overall region Project locations in - Mexico - Belize - Guatemala - Honduras See Figure 1
Sea level rise • Change	Annual	Climate model baseline (2000-2004) 2020s (2020-2029) 2050s (2050-2059) 2080s (2080-2089)	RCP 4.5 and 8.5 combined	24 CMIP5 models and other datasets (see methodology)	Entire coastline spanning project area
Sea surface temperature • Change	Annual Summer (August to October)	Climate model Baseline (1980-2005) 2020s (2011-2040) 2050s (2041-2070) 2080s (2071-2100)	RCP 8.5 (presented in report) RCP 4.5*** ****Projections available by request*	5 CMIP5 models	Mesoamerican ocean region See Figure 2
pH	Annual			2 CMIP5 models	

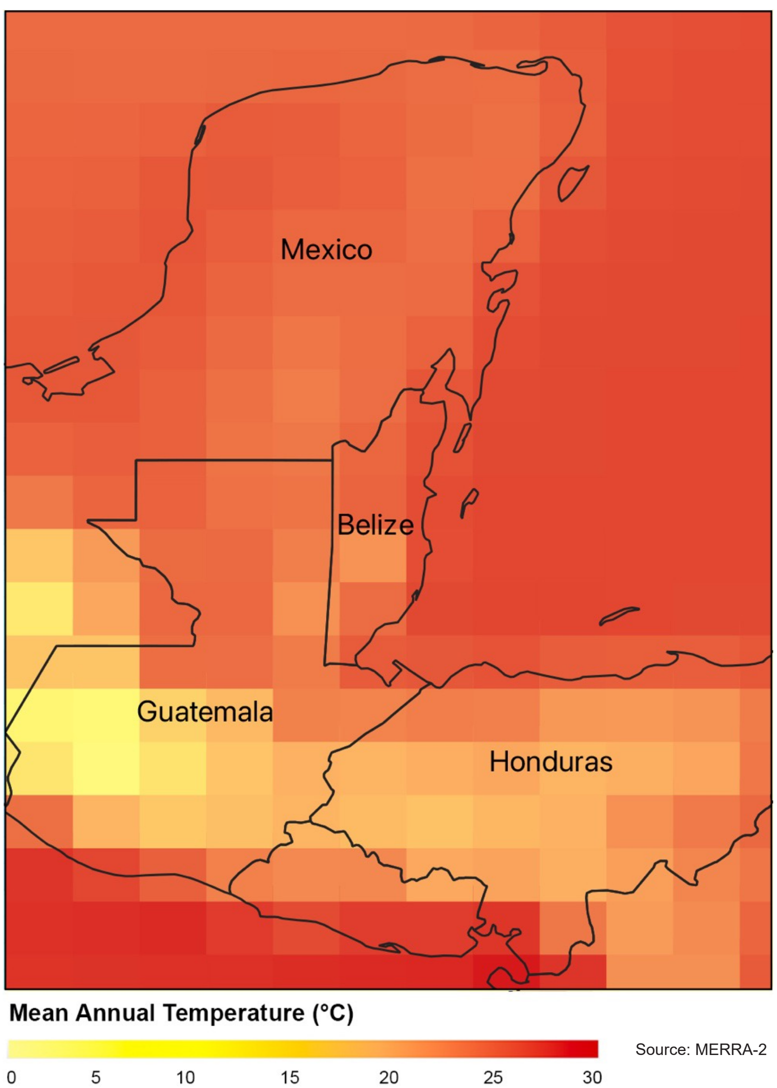
3. CLIMATE RISK INFORMATION – REGIONAL OVERVIEW

3.1 Observed Climate

3.1.1 Observed temperature

Observed climate for the region shows warmer temperatures in coastal areas compared to inland areas, with mean annual temperatures up to 30°C in the Caribbean coastal regions of Belize, Guatemala and Honduras.

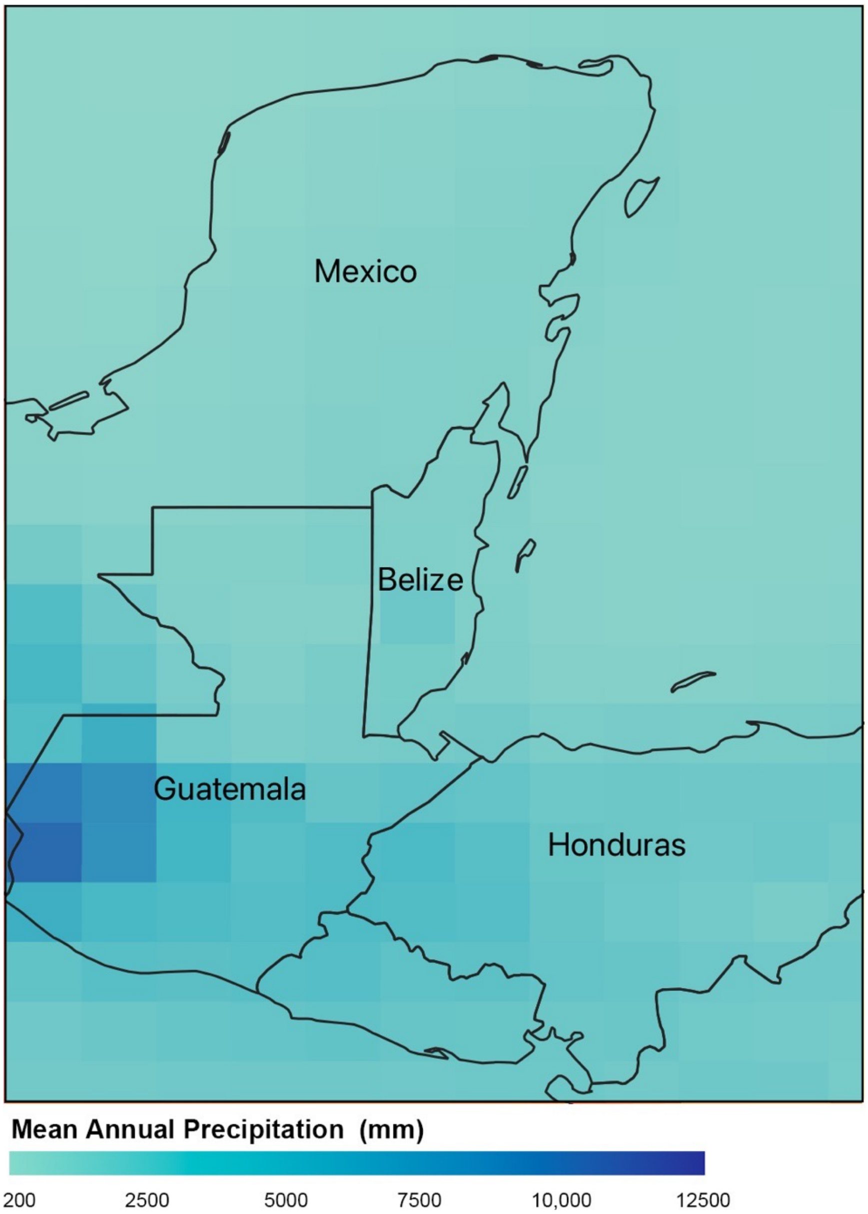
Figure 3. Observed mean annual temperature



3.1.2 Observed precipitation

Observed climate for the region shows more precipitation in inland areas compared to the coastline. On average, the Yucatan peninsula of Mexico and Belize receive less annual rainfall than inland regions in Guatemala and Honduras.

Figure 4. Observed total annual precipitation



Note: These observed climate maps have been developed using the NASA Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) dataset (about 50km in resolution). Please note that these observed data will likely differ from the climate model baselines.

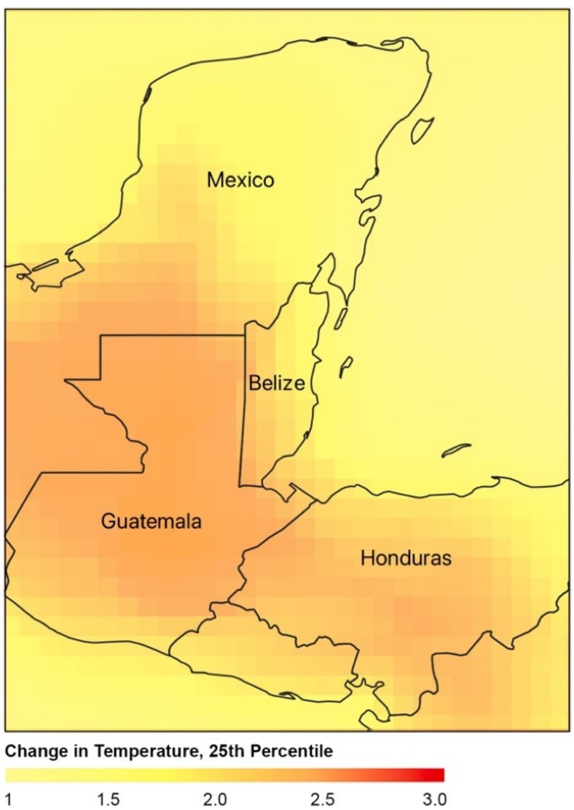
Source: MERRA-2

3.2 Projected Climate

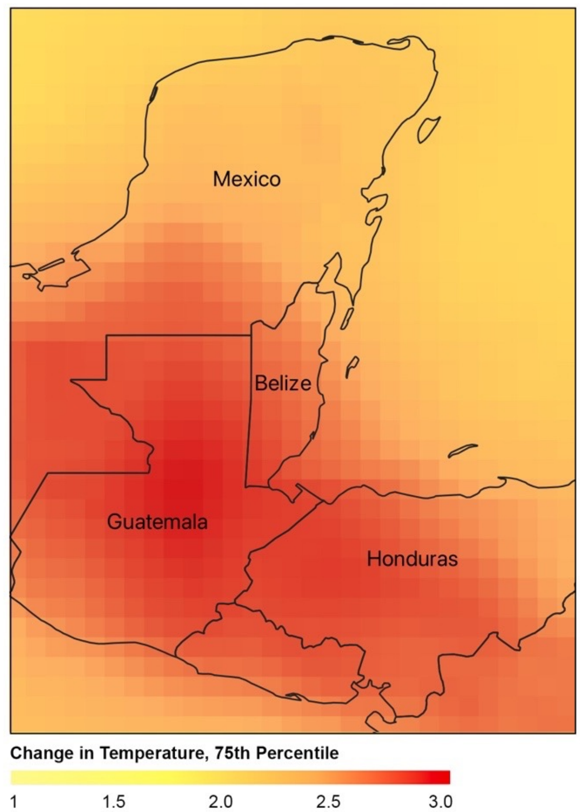
3.2.1 Mean annual temperature

Mean temperature is increasing across the entire Mesoamerican Reef region by the 2050s. This increase is at least 1.5°C in many areas and reaching about 2°C in more inland areas under the low estimate (25th percentile). Under the high estimate (75th percentile), most areas see increases of at least 2°C, with some inland areas reaching up to 3°C.

Figure 5. Annual mean temperature change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



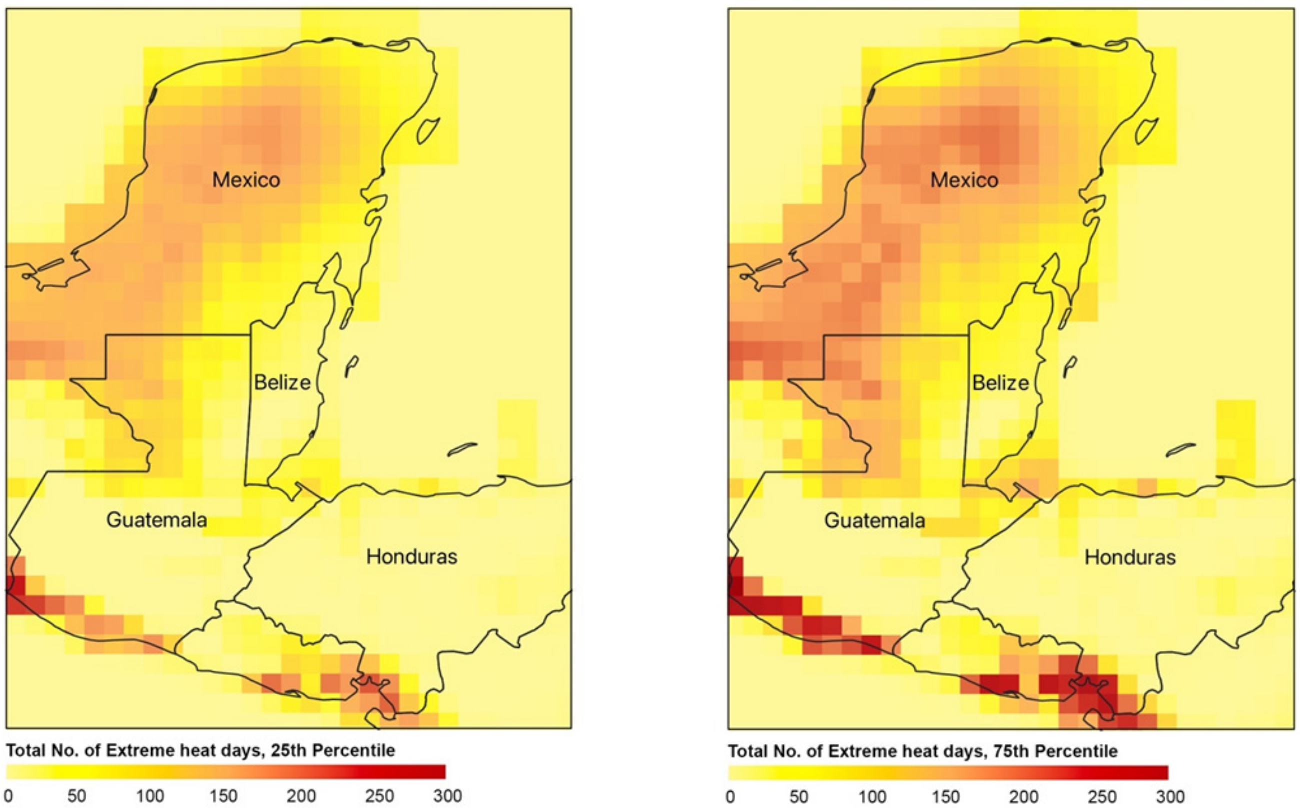
High estimate (75th percentile)

Data source: NASA NEX-GDDP

3.2.2 Extreme heat days

Many regions across the Mesoamerican reef region see a high number of extreme heat days (>35°C) in a year. The number of extreme heat days is particularly high in the Yucatan peninsula of Mexico and northern Guatemala where the total number of days over 35°C in a year exceeds 150 in many areas, with some inland areas seeing ~200 days of extreme heat under the low estimate. In coastal areas the number is lower (~50 or more). Under the high estimate, the number of extreme heat days is higher in Mexico and northern Guatemala. Coastal regions reach 100-200 days, depending on location, with large parts of the region exceeding 150 days and some inland areas seeing over 200 days where temperatures exceed 35°C. In some coastal parts of southern Guatemala and Honduras extreme heat days reach ~300 per year.

Figure 6. Total number of extreme heat days (>35°C) in the 2050s (2041-2070) under RCP 8.5

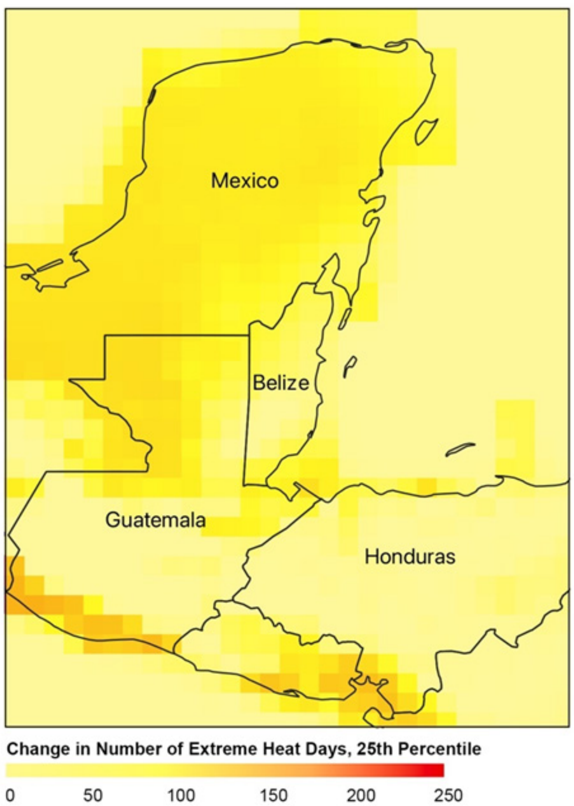


Low estimate (25th percentile) **High estimate (75th percentile)**

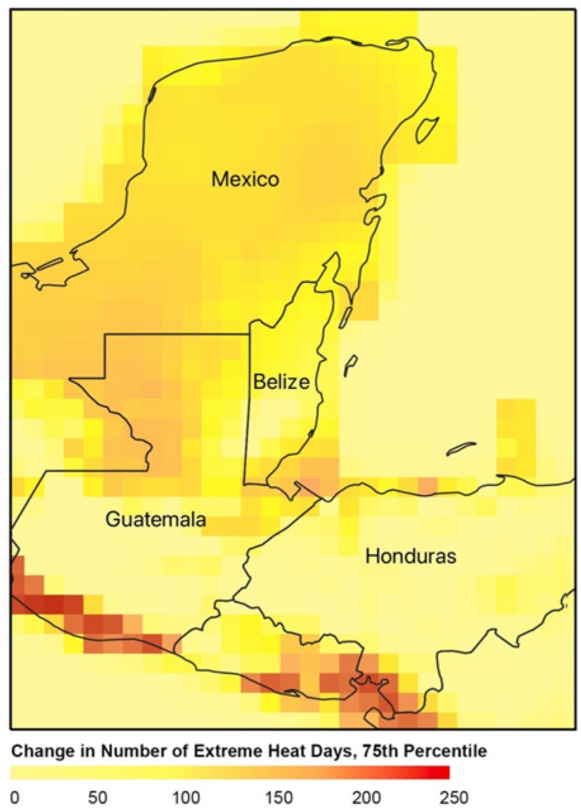
Data source: NASA NEX-GDDP

When looking at the change in the number of extreme heat days (>35°C), most regions see a large increase as seen in the maps below, which show how many additional days over 35°C a location will experience, compared to the baseline. The north of Guatemala and the Yucatan peninsula, especially the inland regions, are projected to experience many more days of extreme heat, increasing by as much as 150 days per year, depending on the estimate. The patterns are similar across the low and high estimates. Under the low estimate, the northern coastal regions experience ~50 additional extreme heat days while that number exceeds 100 in some inland areas. Under the high estimate, many areas experience increases of over 100 days where the temperature exceeds 35°C. Inland areas in Guatemala (excluding the northern and southern coastlines) and inland Honduras see smaller increases in extreme heat days under both estimates (up to ~50).

Figure 7. Change in the number of extreme heat days (>35°C) in the 2050s (2041-2070) under RCP 8.5



Low estimate (25th percentile)



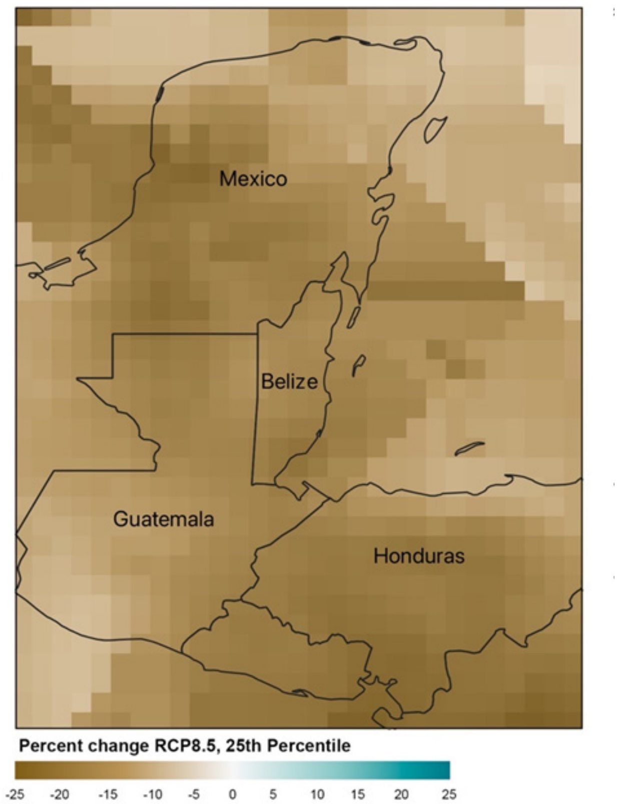
High estimate (75th percentile)

Data source: NASA NEX-GDDP

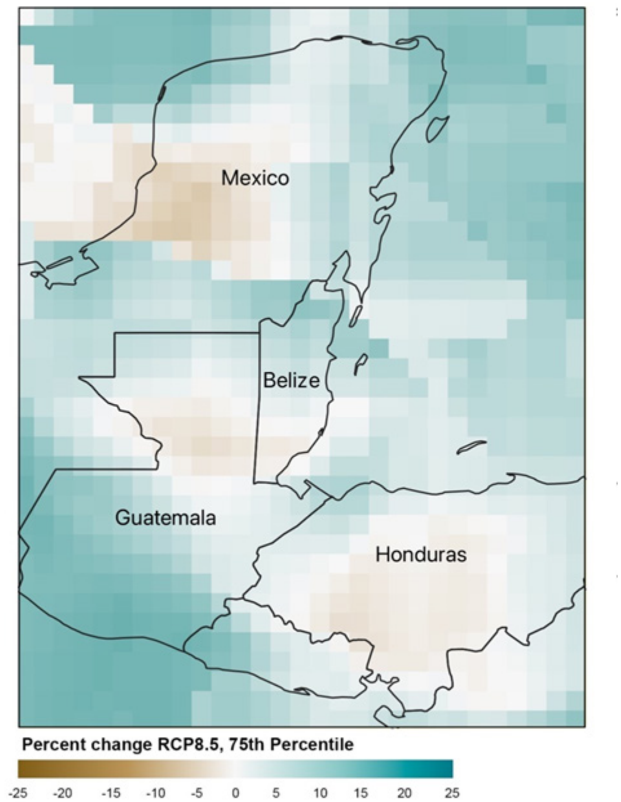
3.2.3 Precipitation

Under the low estimate, a decline in precipitation occurs across the entire Mesoamerican Reef region, with declines of as much as -25%. The drying is slightly more pronounced in inland areas. Under the high estimate, many of the coastal and ocean regions see slight increases in rainfall, while some inland areas see a slight decline in precipitation. The low estimate shows a more significant drying trend as opposed to little change or possible increase in precipitation (~5-10%) under the high estimate.

Figure 8. Annual mean precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



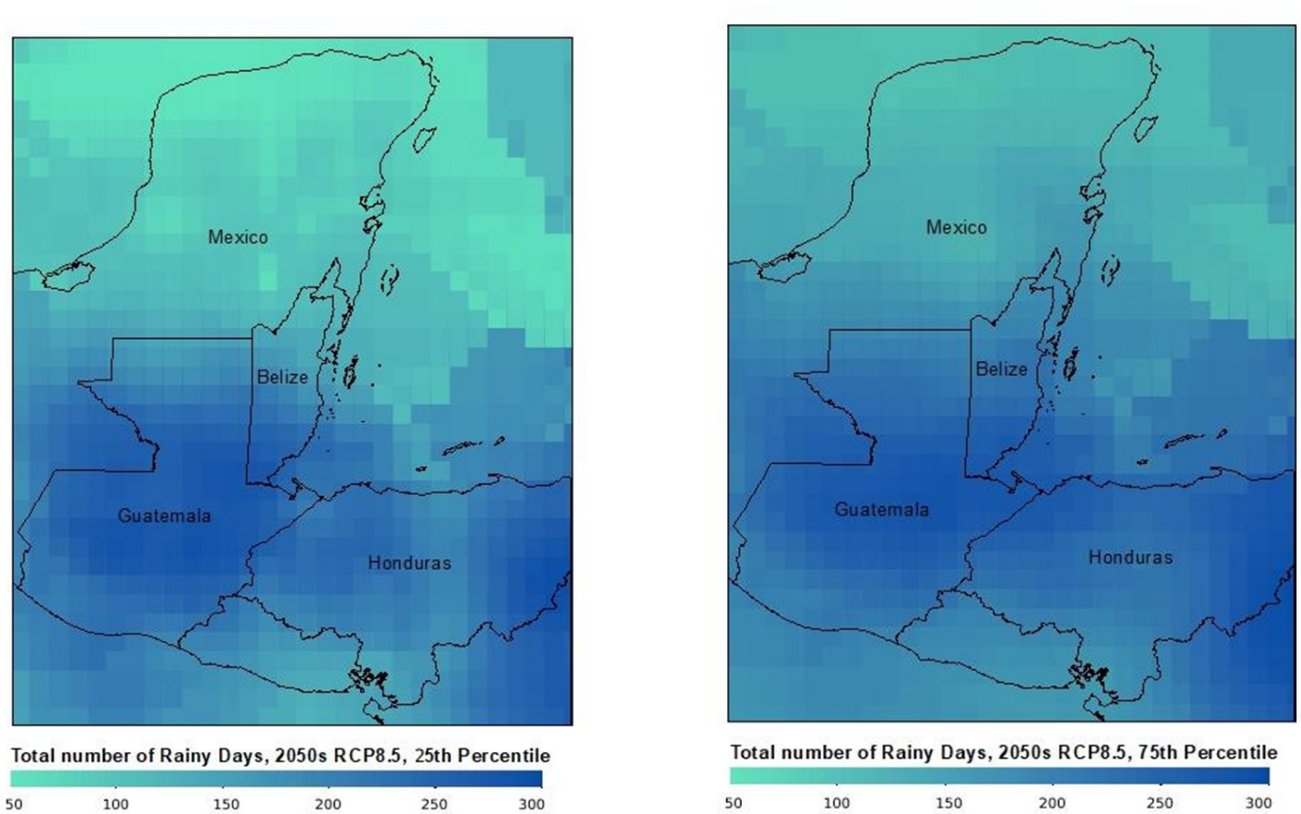
High estimate (75th percentile)

Data source: NASA NEX-GDDP

3.2.4 Rainy days

Many regions in the Mesoamerican reef region see a high number of rainy days (days per year with more than 1mm of rainfall). Guatemala in particular experiences a high number of rainy days (many areas with >200 by midcentury under both estimates), especially in its highland areas. Honduras and southern Belize also see between 150-250 rainy days per year under both estimates. In the Yucatan peninsula the total number of rainy days under the low estimate is lower than other regions, with ~100 rainy days a year in the northern region, while the southern region sees slightly higher numbers of total rainy days. Under the high estimate, the projected total number of rainy days by midcentury is projected to follow a similar spatial pattern as the low estimate across the region.

Figure 9. Total number of rainy days (>1mm) in 2050s (2041-2070) under RCP 8.5

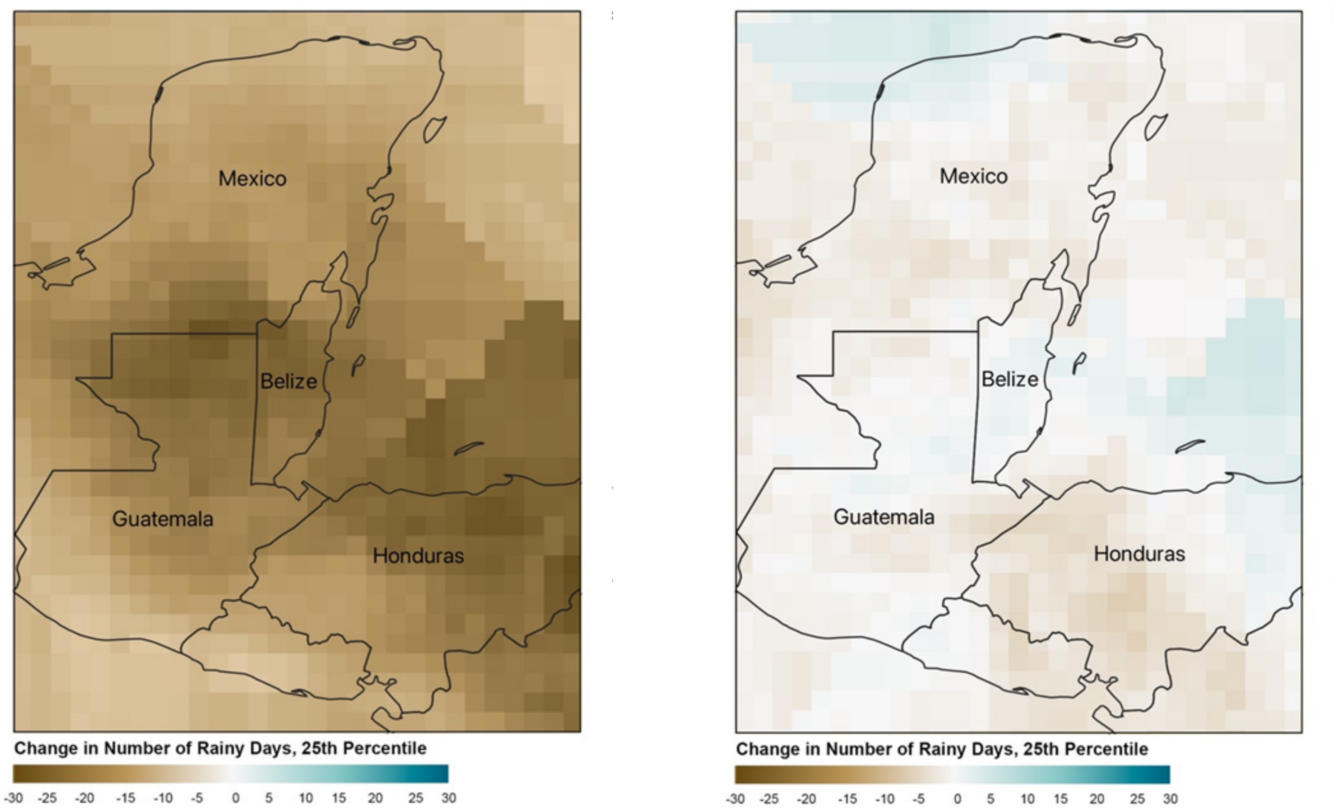


Low estimate (25th percentile) **High estimate (75th percentile)**

Data source: NASA NEX-GDDP

There is a decline in the number of rainy days compared to the baseline under the low estimate across the entire Mesoamerican Reef region. Coastal and northern areas of the Yucatan peninsula experience a smaller decline in rainy days, in comparison to other regions. Even under the high estimate, many areas experience a very slight decline in the number of rainy days per year, with a few regions seeing small increases, but most areas experiencing changes of less than 5 days per year on average in either direction. In the western side of the Yucatan peninsula, a slight decline in rainfall is expected even under the high estimate (Figure 8), with increases scattered across the northern region of the peninsula. Slight increases are seen in several areas in northern Belize, central Guatemala and coastal Honduras. The strong agreement on either declines or little change in the number of rainy days across the region indicates that total rainfall in the future may be spread over fewer days.

Figure 10. Change in number of rainy days (>1mm) in 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)

High estimate (75th percentile)

Data source: NASA NEX-GDDP

3.2.5 Sea level rise

Sea level is projected to increase in the Mesoamerican Reef region. Depending on the location, sea level rise in the 2050s is just over 20cm for the low estimate (25th percentile) to ~40-45cm under the high estimate (75th percentile), based on the combined RCP 4.5 and 8.5 scenarios.[3]

Figure 11. Sea level rise in 2050s (2050-2059) compared to the baseline (2000-2004) under the combined RCP 4.5 and 8.5 scenario

Low estimate (25th percentile)

High estimate (75th percentile)

Data source: NASA NEX-GDDP

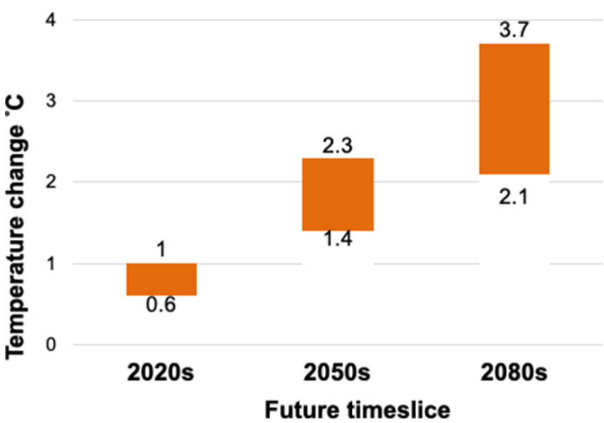
3 The sea level rise method was developed by the Climate Impacts Group during the CMIP5 era, which is a combined approach using both RCP 4.5 and 8.5. In addition to results from 24 CMIP5 climate models, the database and projections include several other sea level change components (see methods section for details). Since then, CCSR presents results of RCPs separately to communicate trajectories of change associated with different levels of climate mitigation.

3.2.6 Sea surface temperature

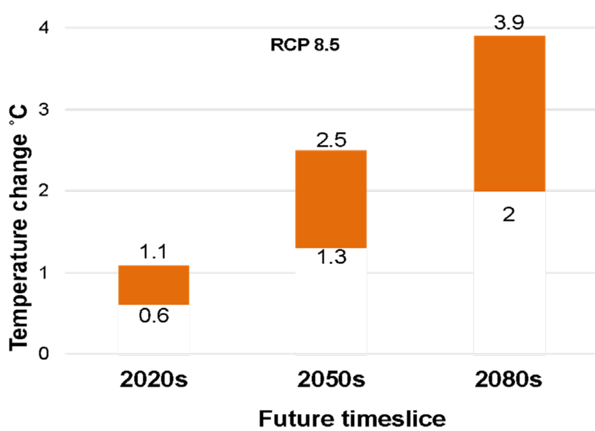
Annual sea surface temperature projections for the Mesoamerican reef ocean region indicate an increase of about ~1.5˚C to over 2˚C by the 2050s for RCP 8.5 (see Figure 2 for region and Figure 12 for projections). This range exceeds 2˚C and reaches almost 4˚C by end of the century. The summer, the warmest period in the region, spanning from August to October, sees slightly higher increases in sea surface temperatures, with high estimates of these increases roughly 0.1˚C to 0.2˚C larger than the annual change.

Figure 12. Sea Surface Temperatures in the Mesoamerican Reef Region

Annual



Summer (August to October)



3.2.7 pH

pH projections carried out for the region (see Figure 2), show a decreasing trend over time, compared to the baseline levels in each of two models. The baseline pH level in the HadGEM2 model is slightly lower (8.07), compared to the CanESM2 level (8.10).

CanESM2 pH level under RCP 8.5

Model	Baseline Mean	RCP8.5 2020s	RCP8.5 2050s	RCP8.5 2080s
pH value	8.10	8.05	7.95	7.95
Change		-0.05	-0.14	-0.26

HadGEM2 pH level under RCP 8.5

Model	Baseline Mean	RCP8.5 2020s	RCP8.5 2050s	RCP8.5 2080s
pH value	8.07	8.00	7.90	7.79
Change		-0.07	-0.16	-0.27

Over time, the pH levels decline with increasing acidification of the oceans under RCP 8.5. The HadGEM2 (-0.16) sees a slightly sharper decline than the CanESM2 model (-0.14) by mid century. The HadGEM2 model sees a decline of -0.27 by the end of the century, with the CanESM2 model projecting a decline of -0.25. This increasing acidity (lowering of pH) is consistent with projected increases in ocean acidification as a result of carbon dioxide dissolving in ocean water. Although this increase in acidity corresponding to decreasing pH might not seem high, the pH scale is logarithmic, so this change represents a large increase in acidity. For example, a 0.1 decrease in pH is approximately a 30% increase in acidity.

4. CLIMATE RISK INFORMATION – MEXICO PROJECT REGION

4.1 Introduction to the Mexico project region results

In addition to the regional observations and projections, this section focuses on the results for the Mexico project area focused on the Yucatan peninsula. Projections are provided for the entire peninsula and also the specific project area. The target protected area sites are Dzilam State Reserve, the Ria Lagartos Biosphere Reserve (Yucatan) and in the Flora and Fauna Protection Area of Yum Balam (Quintana Roo).

Projections were developed for mean annual temperature, extreme heat days, precipitation change, rainy days and sea level rise. The methods used for projections are described in the methods section of the report.

4.2 Context

In Mexico, the project focuses on the Northeast region of the Yucatan Peninsula, covering three protected areas: Dzilam State Reserve, Ria Lagartos Biosphere Reserve and Yum Balam Flora and Fauna Protection Area. Roughly, 12,000 people live in this area, distributed in 7 local communities.

Climate hazards identified by the local population include a change in the timing of seasons, decreased rainfall, heat waves and hotter days, and drought. In 2020, the area received precipitation 70% above average and a historic hurricane season was registered, with 5 hurricanes directly impacting the area. Thousands of people were displaced, many communities were flooded and there were important disruptions.

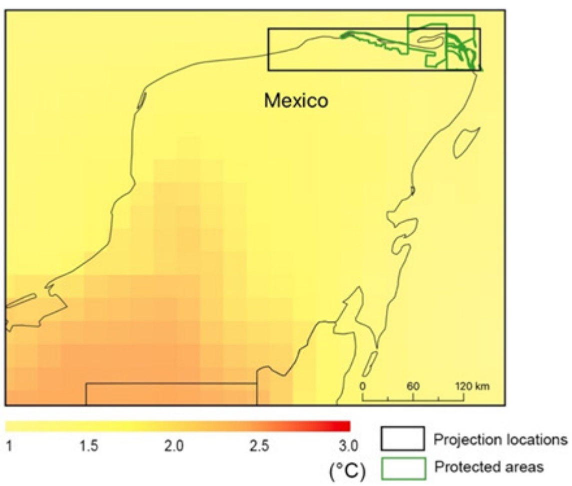
In terms of vegetation cover, coastal habitats include mangroves, seagrass beds and coastal dunes. These provide important ecosystem services to the local population, including protection from coastal hazards (erosion, flood, sea level rise) and are important support for fisheries and tourism, but face different sources of pressure, primarily degradation due to infrastructure development and land use change.

Historically, the population in this area depended on fisheries as a main livelihood. However, more recently, communities have identified alternative sources of income, focusing largely on tourism-based activities. Degradation of natural resources and climate hazards couple to increase the vulnerability of local communities, their livelihoods and infrastructure.

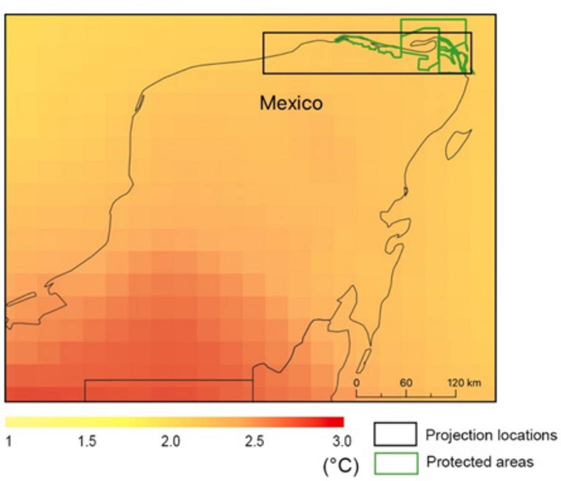
4.3 Mean annual temperature

Mean temperature is increasing across the entire Yucatan peninsula by the 2050s. This increase ranges from 1.0-1.5°C in many areas and reaching about 2°C in more inland areas under the low estimate (25th percentile). Under the high estimate, most areas in the peninsula see increases of at least 2°C, with some inland areas exceeding 2.5°C.

Figure 13. Annual mean temperature change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



High estimate (75th percentile)

Data source: NASA NEX-GDDP

Mean temperature in the project region

In the project region, mean temperature change ranges from ~1.5 to 2.0˚C by mid century under RCP 8.5. The increase in temperature differs slightly across seasons. The difference between the low (25th percentile) and high (75th percentile) is ~0.5-0.8˚C. The warming in the Nortes season is slightly less, with the wet season warming a little higher than other seasons under the high estimate. In the model baseline, the wet season is also the warmest season in the project region.

Focal region in Mexico

Coordinates

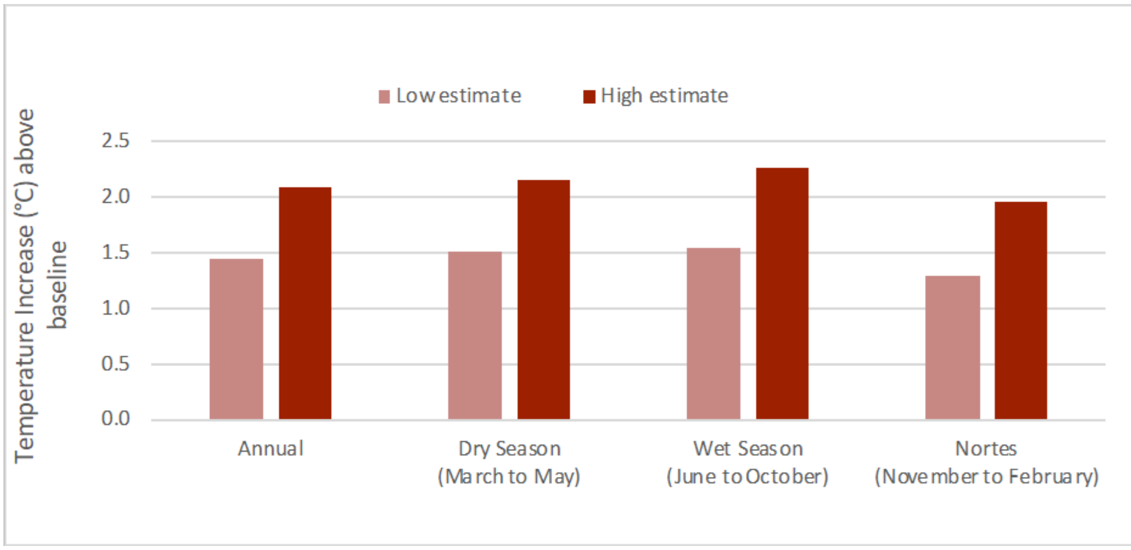
North = 21.60

South = 21.16

East = -86.77

West = -88.97

Figure 14. Annual mean temperature change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Annual mean temperature change under RCP 8.5 for 2050s (2041-2070) compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

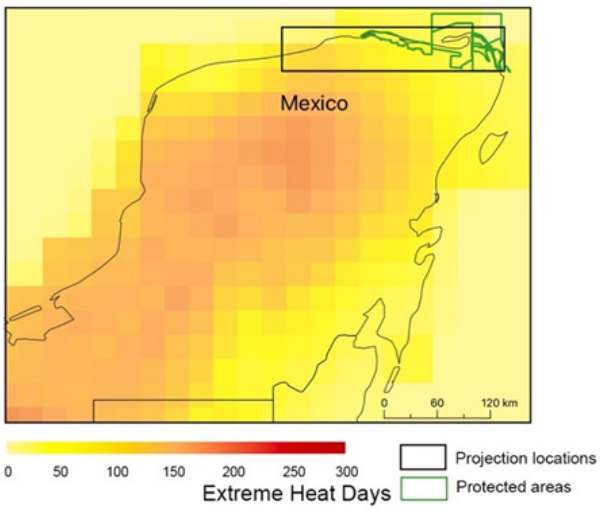
Seasons	Baseline	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Annual	25.4	0.5	0.9	1.4	2.1	2.5	3.5
Dry (March to May)	25.9	0.6	1.0	1.5	2.1	2.4	3.6
Wet (June to October)	27.3	0.6	1.0	1.5	2.3	2.6	3.9
Nortes (November to February)	23.2	0.4	0.9	1.3	2.0	2.3	3.3

Data source: NASA NEX-GDDP

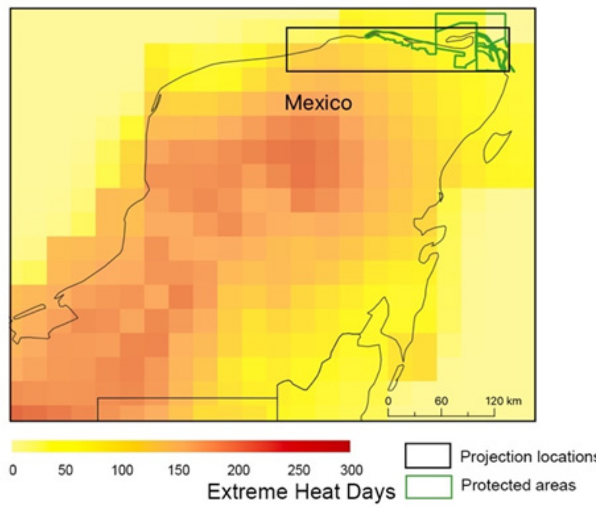
4.4 Extreme heat days

The projected number of extreme heat days per year (>35°C) is particularly high in the Yucatan peninsula of Mexico by midcentury even under the low estimate, where the total number of days over 35°C exceeds 100 in many areas, with some inland areas seeing over 150 days of extreme heat and lower numbers in some coastal areas. Under the high estimate, the number of extreme heat days exceeds 150 days across large parts of the region, with some inland areas seeing ~200 days (or more) per year where temperatures exceed 35°C.

Figure 15. Total number of extreme heat days (>35°C) in the 2050s (2041-2070) under RCP 8.5



Low estimate (25th percentile)

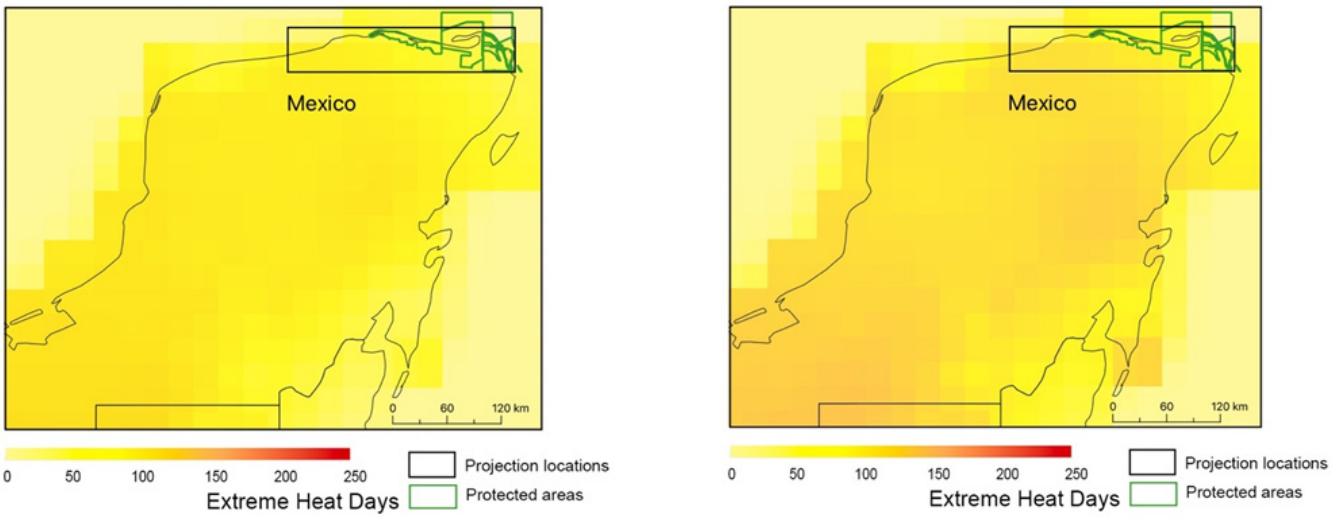


High estimate (75th percentile)

Data source: NASA NEX-GDDP

When looking at the change in number of extreme heat days (>35°C), most regions see a large increase as seen in the maps below, which show how many additional days over 35°C a location will experience, compared to the baseline. The Yucatan peninsula, especially the inland regions experience many more days of extreme heat. The patterns are similar across the low and high estimates. Under the low estimate, the northern coastal region experiences ~50-100 additional extreme heat days per year, while that number exceeds 100 in some inland areas. Under the high estimate, most internal areas in the Yucatan and even parts of the coastal region experience an increase of ~100-150 days per year where the temperature exceeds 35°C.

Figure 16. Change in the number of extreme heat days (>35°C) in the 2050s (2041-2070) under RCP 8.5



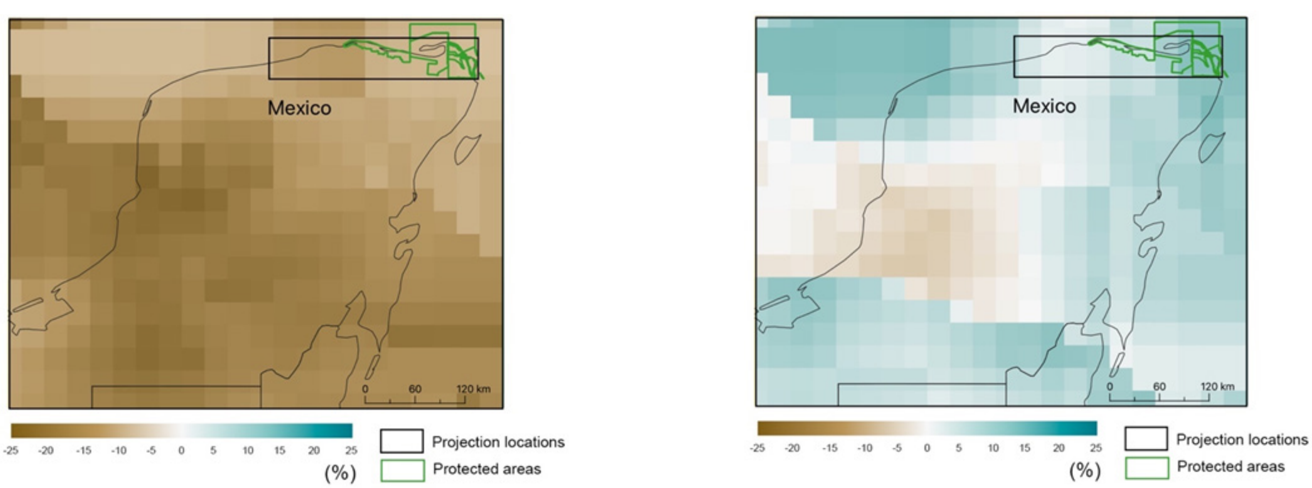
Low estimate (25th percentile) | High estimate (75th percentile)

Data source: NASA NEX-GDDP

4.5 Precipitation

Under the low estimate, a decline in precipitation occurs across the entire Yucatan peninsula. The drying is more pronounced along the western side of the peninsula. The northern coastal region sees a smaller decline in precipitation in comparison to inland areas. Under the high estimate, coastal regions and the surrounding areas see small increases in precipitation (generally less than 10%), while the western side of the peninsula is still projected to experience a very slight decline in precipitation. The low estimate shows a more significant drying trend as opposed to some inland declines and overall coastal increases in precipitation under the high estimate.

Figure 17. Annual mean precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile) | High estimate (75th percentile)

Data source: NASA NEX-GDDP

Precipitation in the project region

In the model baseline, models project total annual rainfall of 1056 mm in the project region. The vast majority of this precipitation is received during wet season (745mm), followed by much lower levels in the Nortes season (162mm) and dry season (148mm). By midcentury, annual precipitation change ranges from -14% to 4%, indicating high model agreement the region will experience some level of drying. All seasons, other than the Nortes season, are projected to experience more drying under the low estimate than possible increased precipitation under the high estimate by midcentury. There is a significant likelihood of drying in the dry season, with the low estimate projecting a decrease of 26% by midcentury.

Focal region in Mexico

Coordinates

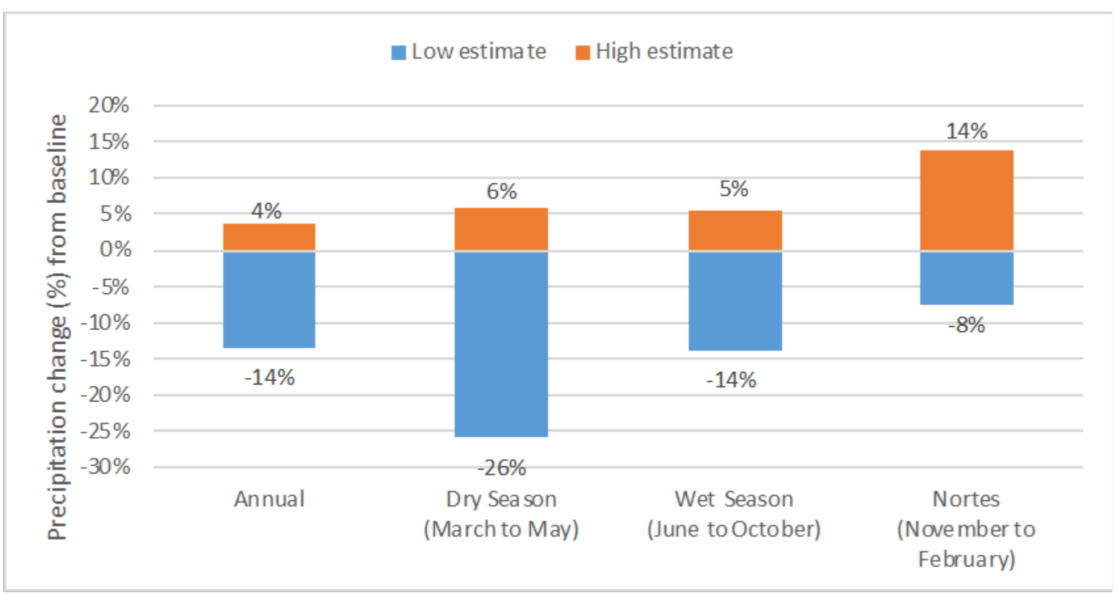
North = 21.60

South = 21.16

East = -86.77

West = -88.97

Figure 18. Annual precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Annual precipitation change (%) under RCP 8.5 for 2050s compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

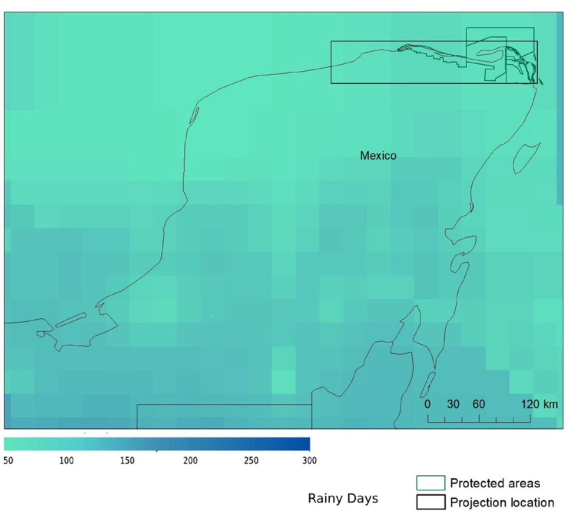
Seasons	Baseline (mm)	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Annual	1055.9	-6%	5%	-14%	4%	-29%	5%
Dry (March to May)	147.8	-7%	12%	-26%	6%	-43%	-12%
Wet (June to October)	745.2	-5%	7%	-14%	5%	-31%	12%
Nortes (November to February)	162.1	-6%	10%	-8%	14%	-18%	9%

Data source: NASA NEX-GDDP

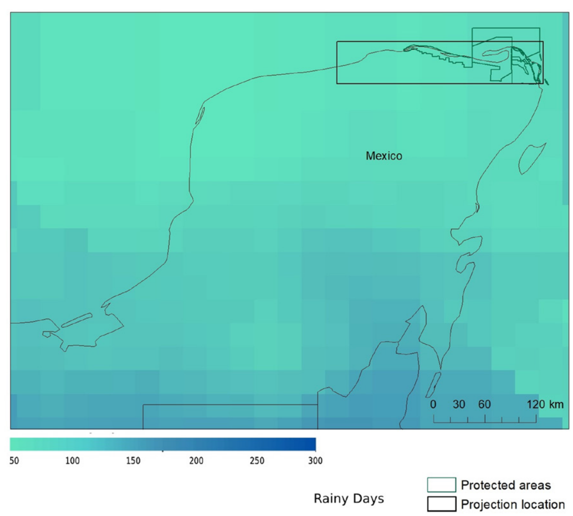
4.6 Rainy days

In the Yucatan peninsula the projected total number of rainy days per year (days over 1mm of rainfall) ranges from ~50-150 by midcentury, with the southern region seeing slightly higher numbers of total rainy days. Under the high estimate, the total rainy days is slightly higher than the low estimate, especially in the central and southern areas. In much of the Yucatan peninsula, the number of rainy days ranges from ~100-150 per year, with a few areas seeing more than 150 rainy days per year.

Figure 19. Total number of rainy days (>1mm) in 2050s (2041-2070) under RCP 8.5



Low estimate (25th percentile)

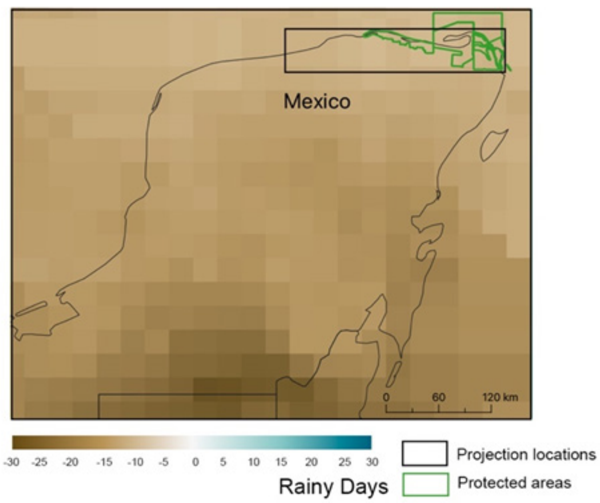


High estimate (75th percentile)

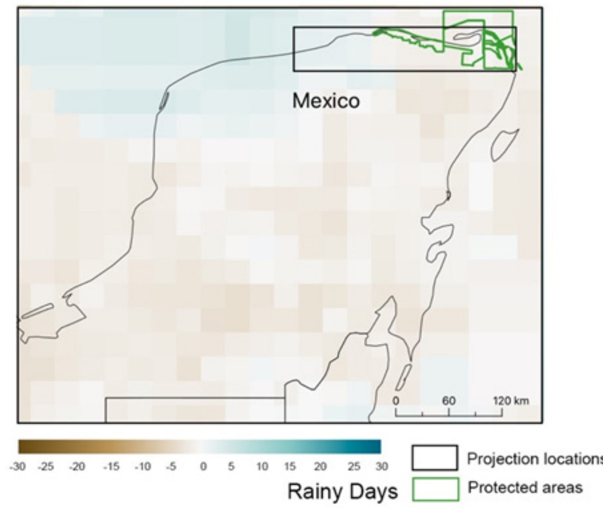
Data source: NASA NEX-GDDP

There is a decline in the number of rainy days compared to the baseline under the low estimate. Coastal and northern areas of the Yucatan peninsula experience a smaller decline in rainy days, in comparison to other regions. Even under the high estimate, many areas experience very small declines in the number of rainy days with a few regions seeing a slight increase, but most areas see very little change under the high estimate (changes of less than 5 days per year in either direction). In the Yucatan peninsula, a slight decline in rainfall is expected even under the high estimate (Figure 17), with increases scattered across the northern region of the peninsula. The strong agreement on either declines or little change in the number of rainy days across the region indicates that total rainfall in the future may be spread over fewer days, which could result in more extreme precipitation events.

Figure 20. Change in number of rainy days (>1mm) in 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



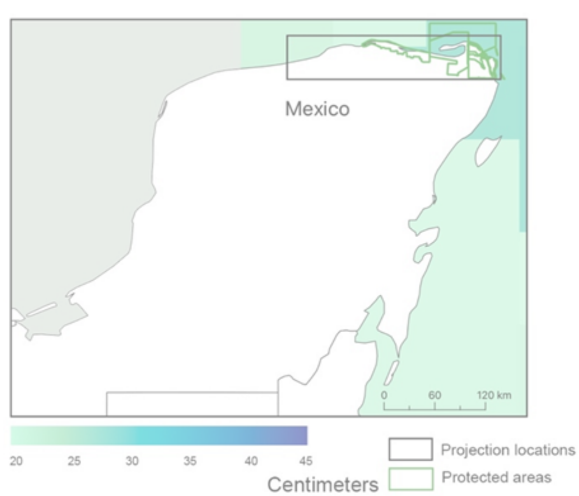
High estimate (75th percentile)

Data source: NASA NEX-GDDP

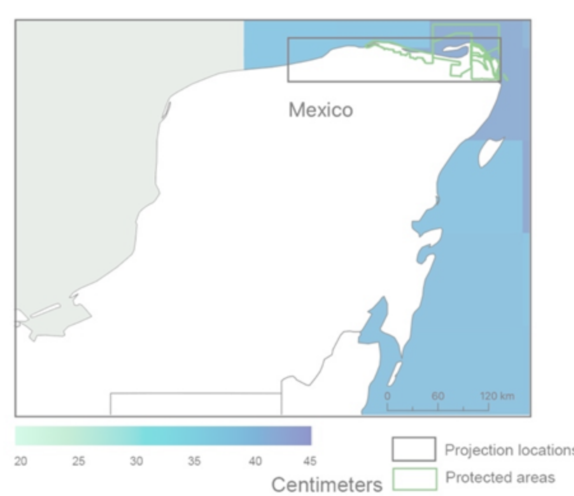
4.7 Sea level rise

Sea level is projected to increase in the Yucatan peninsula. Depending on the location, sea level rise in the 2050s ranges from 20-25cm under the low estimate and 40-45cm for the high estimate.

Figure 21. Sea level rise in 2050s (2050-2059) compared to the baseline (2000-2004) under the combined RCP 4.5 and 8.5 scenario



Low estimate (25th percentile)



High estimate (75th percentile)

Data source: Several datasets, including 24 CMIP5 climate models

5. CLIMATE RISK INFORMATION – BELIZE PROJECT REGION

5.1 Introduction to the Belize project region results

In addition to the regional observations and projections, this section focuses on the results for the Belize project areas. Projections are provided for the region and the specific project areas. The target protected area sites in Belize are based on the country's Coastal Zone Management plan: the Northern Regional Planning Zone (Zone 1), the Ambergris Caye Regional Planning Zone (Zone 2), and the Southern Regional Planning Zone (Zone 3).

Projections were developed for mean annual temperature, extreme heat days, precipitation change, rainy days and sea level rise. The methods used for projections are described in the methods section of the report.

5.2 Context

In Belize, the project focuses on two distinct areas of the country's national integrated coastal zone management plan (ICZM); the Northern and Southern Regions. The Northern Region covers 233,600ha of land and sea and approximately 118 km of coastline. There are four MPAs within the region: the Corozal Bay Wildlife Sanctuary (71,600 ha), Bacalar Chico Forest and Marine Reserves (6,200 ha), Caye Caulker Marine Reserve (3,913 ha) and Hol Chan Marine Reserve (401,700 ha). There are seven coastal communities buffering the MPAs whose populations depend heavily on the MPAs' marine resources for livelihoods and sustenance. This region is predominantly flat terrain of 0-1 m above sea level. The barrier reef is located a short distance off the coast with a narrow continental shelf lagoon separating the reef from the coastline. Mangroves, coral reefs, and seagrass beds are the predominant ecosystem types.

This region is of great social and economic importance, with key livelihoods strongly tied to fishing and tourism and dependent on the coastal and marine ecosystems including those within MPAs. Key perceived threats to this region are sea level rise which could result in loss of up to 75% of coastal beaches with just a 0.5m increase in sea level. This region has already experienced erosion of coastal property due to loss of mangrove cover and increased land conversion for tourism and urban expansion. Seventy-three percent of major tourism properties are already thought to be at risk and up to 50% reductions in coral cover have been measured, due to the combined effects of mass coral bleaching (from increased sea surface temperature), storm events, pollution and overfishing.

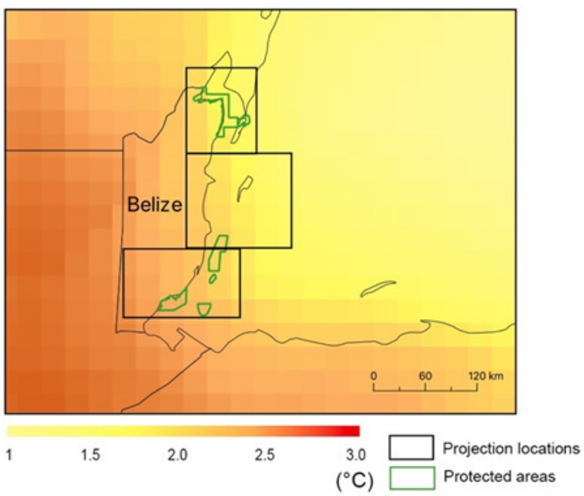
The Southern Region encompasses 1,923,814 ha of land and sea, 145 km of coastline, and four MPAs: - South Water Marine Reserve (47,000 ha), Laughing Bird Caye National Park (4,100 ha), Port Honduras Marine Reserve (39,700 ha) and Sapodilla Caye Marine Reserve (15,600 ha). There are fourteen coastal communities buffering the MPAs whose populations depend heavily on the natural resources within the MPAs. This region has an elevation of 1-3 m above sea level along the mainland coast and 0-1 m on outer cayes. Mangroves, coral reefs, and seagrass beds are the predominant ecosystem types. Key livelihoods are tied to fishing, tourism, and agriculture all of which exist within the coastal zone. Southern Belize has been significantly impacted by torrential rains and flooding events that resulted in loss of lives and property, including in the agriculture sector. Pollutant run-offs from storm events have caused loss of live coral and seagrass cover on southern reefs over time.

The government of Belize has made advances in coastal and MPA management and recognizes the importance of ecosystem services to sustainable development and have a great desire to integrate ecosystem-based approaches to climate risk reduction, including within strategies, policies, plans and projects.

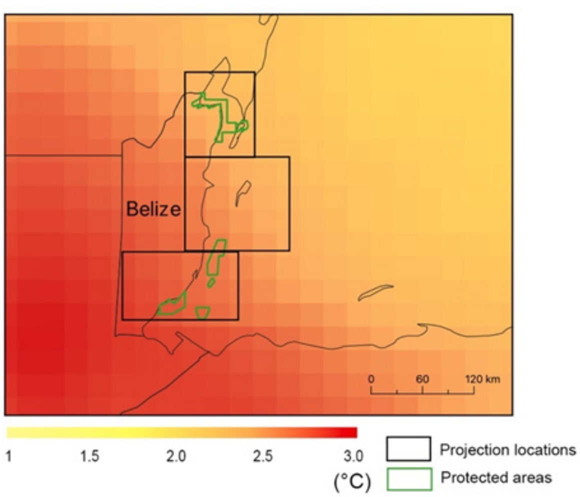
5.3 Mean annual temperature

Mean temperature is increasing across Belize and the region by the 2050s. This increase ranges from 1.5-2.0°C in Belize under the low estimate (25th percentile across climate models). Under the high estimate (75th percentile across climate models), most areas in Belize see increases of ~2.5°C, with some inland areas reaching 3°C warming. The southern region of Belize (Zone 3) warms more than the northern regions of Belize (Zones 1 and 2), with Zone 1 warming the least by midcentury under both estimates.

Figure 22. Annual mean temperature change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



High estimate (75th percentile)

Data source: NASA NEX-GDDP

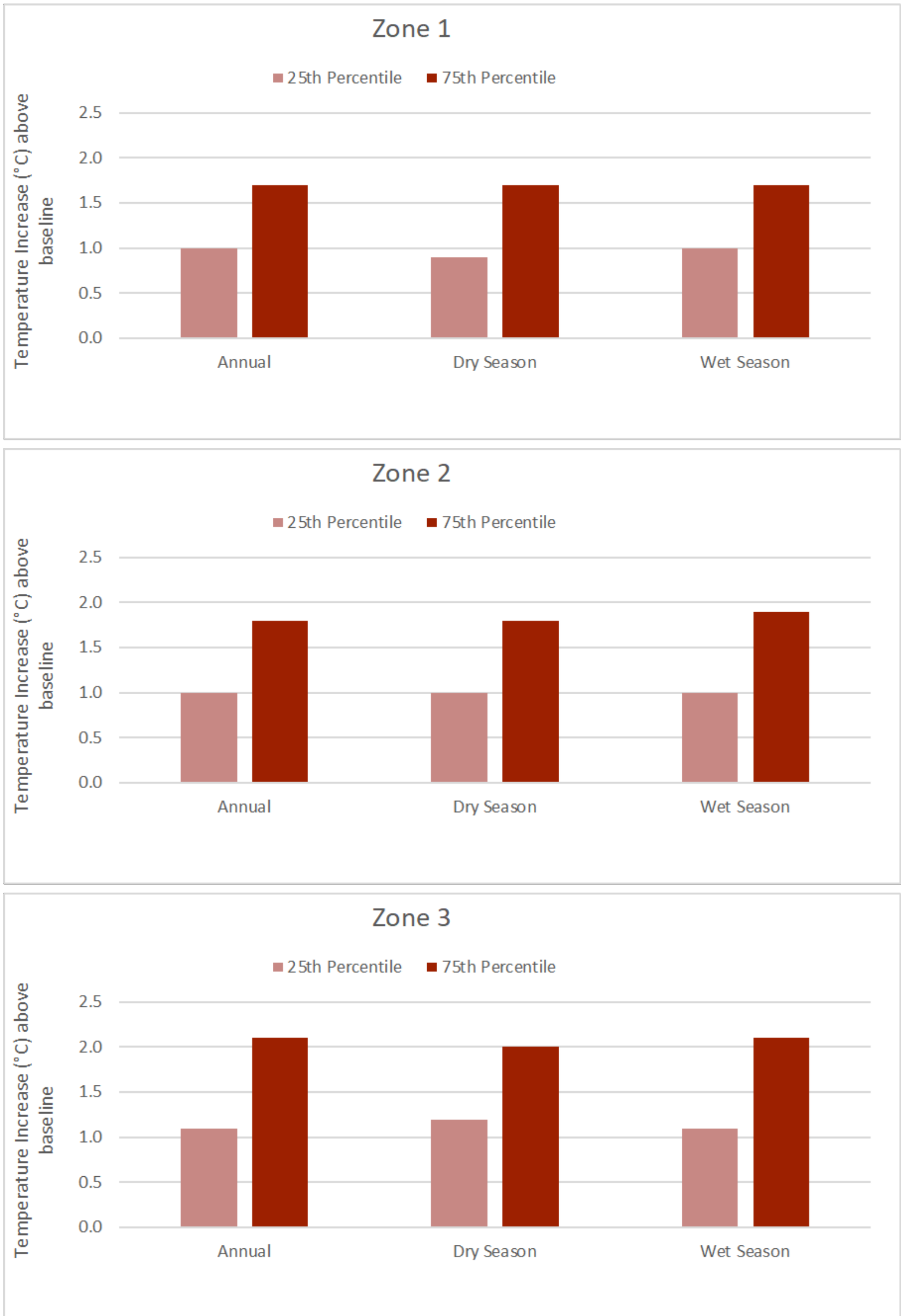
Mean temperature in the project region

Across the project regions, annual mean temperature change ranges from ~0.9 to 2.1˚C by midcentury under RCP 8.5. The increase in temperature is very similar across seasons. The difference between the low (25th percentile) and high (75th percentile) annual warming is ~0.7 to 0.9˚C, depending on the zone. The warming is slightly lower in Zone 1, with Zone 2 warming slightly more and Zone 3 warming the most. The largest difference of warming between zones is ~0.4 ˚C (annual, high estimate difference between Zones 1 and 3).

Focal regions in Belize

Coordinates	Coordinates	Coordinates
Zone 1 (north):	Zone 2 (middle):	Zone 3 (south):
North = 18.52	North = 17.71	North = 16.81
South = 17.70	South = 16.80	South = 15.94
West = -88.44	West = -88.44	West = -89.12
East = -87.73	East = -87.39	East = -87.90

Figure 23. Annual mean temperature change (˚C) 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Data source: NASA NEX-GDDP

Annual mean temperature change (°C) under RCP 8.5 for 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

Seasons	Model Baseline	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Zone 1							
Annual	26.1	0.5	0.9	1.0	1.7	1.2	2.2
Dry (December to May)	25.2	0.4	0.9	0.9	1.7	1.2	2.1
Wet (June to November)	26.9	0.5	0.9	1.0	1.7	1.2	2.3
Zone 2							
Annual	25.7	0.5	1.0	1.0	1.8	1.2	2.4
Dry (December to May)	25.0	0.5	0.9	1.0	1.8	1.2	2.2
Wet (June to November)	26.4	0.6	1.0	1.0	1.9	1.2	2.4
Zone 3							
Annual	25.3	0.6	1.0	1.1	2.1	1.4	2.6
Dry (December to May)	24.5	0.6	1.0	1.1	2.0	1.4	2.5
Wet (June to November)	26.1	0.6	1.1	1.2	2.1	1.4	2.7

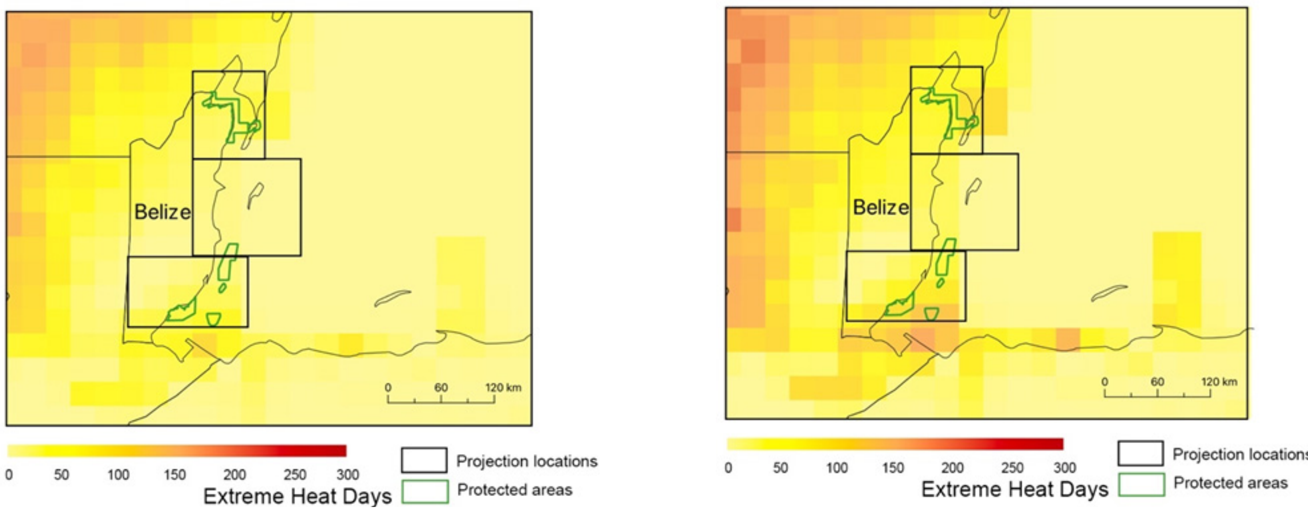
Data source: NASA NEX-GDDP

5.4 Extreme heat days

The number of extreme heat days (>35°C) per year varies across the region and Belize. The coastal region of interest is projected to experience a lower total number of extreme heat days per year during the mid-century period than the rest of the region under RCP8.5.

The total number of days over 35°C in the project area are projected to reach up to ~100 per year by midcentury under the low estimate with some areas along the coastal region experiencing lower numbers. The projections over the islands and some parts of the coast are lower than inland areas, as land areas in GCMs are generally relatively warmer than oceans and also experience a more rapid rate of warming than ocean areas, therefore seeing a higher number of extreme heat days in both the baseline and the future. Under the high estimate, the distribution of extreme heat days remains similar, with all areas experiencing more days over 35°C compared to the low estimate by midcentury. The total number of days over 35°C in the project area under the high estimate ranges from ~50-150 days per year.

Figure 24. Total number of extreme heat days per year (>35°C) in the 2050s (2041-2070) under RCP 8.5

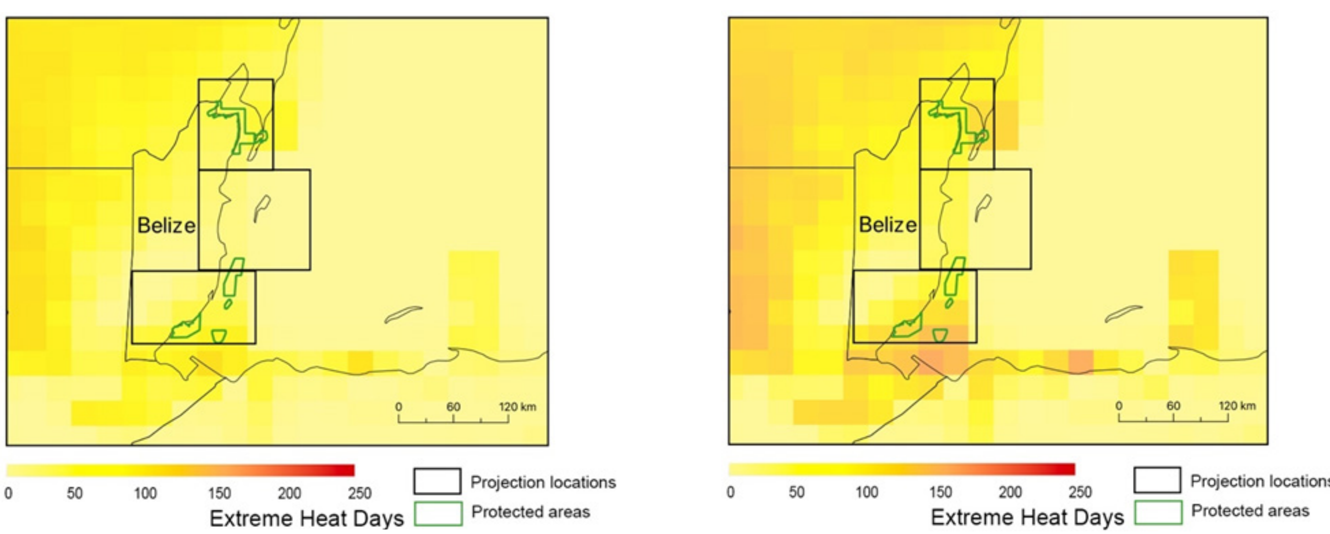


Low estimate (25th percentile) High estimate (75th percentile)

Data source: NASA NEX-GDDP

The change in number of extreme heat days (>35°C) per year varies across the region and Belize. The largest increases are seen along the coast and inland areas (except Zone 2, which also experiences lower numbers of extreme heat days in the baseline). Along the coast in Zones 1 and 3, the number of extreme heat days increases by ~50-70 days per year under the low estimate. The central area of Belize and the coastal Zone 2 area are projected to experience the smallest increase in the number of extreme heat days, with increases rarely exceeding 50 additional days per year. The spatial patterns of increases in extreme heat days are similar across the low and high estimates. Zone 3 could experience up to ~150 additional extreme heat days per year under the high estimate. In Zones 1 and 2 the projected increases range from ~50-120 additional days per year, with slightly smaller increases in Zone 2.

Figure 25. Change in the number of extreme heat days per year (>35°C) in the 2050s (2041-2070) under RCP 8.5



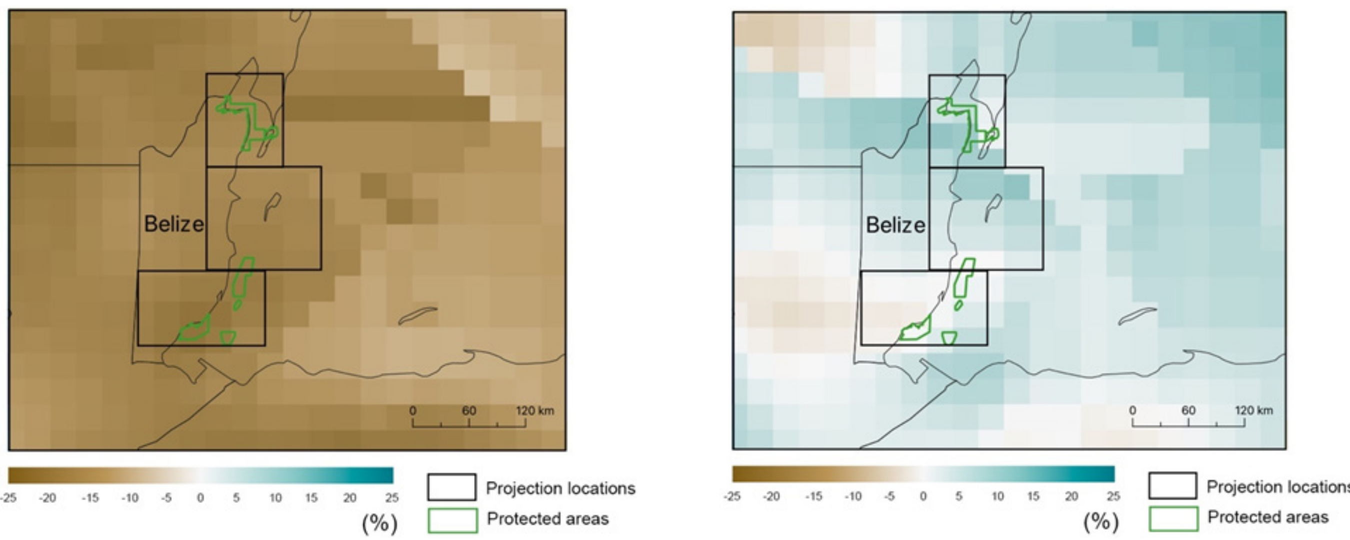
Low estimate (25th percentile) High estimate (75th percentile)

Data source: NASA NEX-GDDP

5.5 Precipitation

Under the low estimate, a decline in precipitation occurs across the region and Belize. There is a nearly uniform drying trend of between -10% and -20% by midcentury across all zones. Under the high estimate, Zones 1 and 2 are projected to experience small increases in precipitation (up to 10%) while Zone 3 sees mixed results but overall little change from the baseline. Inland areas in Belize see similar uniform decreases under the low estimate and minor increases in the high estimate by midcentury. The low estimate shows a more consistent drying trend as opposed to either small increases or negligible changes under the high estimate.

Figure 26. Annual mean precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile) | High estimate (75th percentile)

Data source: NASA NEX-GDDP

Precipitation in the project region

The ensemble mean across climate models projects a total precipitation amount of 1,231mm in Zone 1, 857mm in Zone 2 and 2,263 in Zone 3 over the historical baseline period. Zone 3 receives the most precipitation, followed by Zone 1 and 2. The majority of this precipitation is received during the wet season followed by lower levels in the dry season. By midcentury, annual precipitation change in Zone 1 ranges from -16% to 5% indicating high model agreement the region will experience some level of drying. Zone 2 sees a very similar range -14% to 2% with Zone 3 seeing a decline ranging from -14% to -1%. The range in rainfall change across seasons in the various zones are similar. These usually range from a higher magnitude decline in the low estimate to either a small decrease or a small increase in the high estimate, compared to the baseline.

Figure 27. Annual precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5

Figure 28. Annual precipitation change (%) under RCP 8.5 for 2050s compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

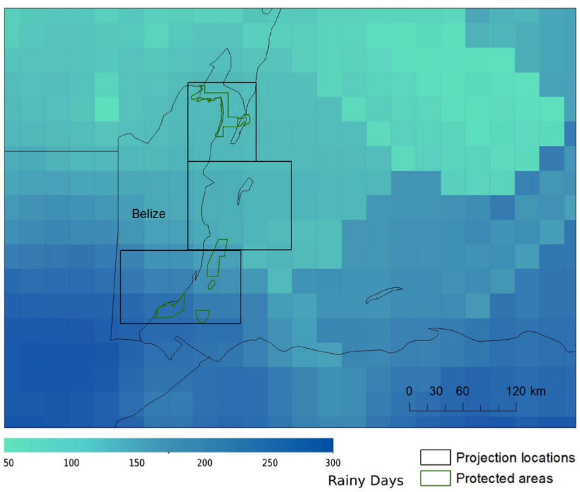
Seasons	Model Baseline (mm)	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Zone 1							
Annual	1,231	-7%	7%	-16%	5%	-14%	3%
Dry	359	-8%	6%	-11%	10%	-10%	-2%
Wet	872	-6%	6%	-15%	4%	-15%	7%
Zone 2							
Annual	857	-8%	5%	-14%	2%	-13%	1%
Dry	259	-11%	5%	-12%	7%	-13%	-3%
Wet	598	-7%	4%	-15%	2%	-15%	4%
Zone 3							
Annual	2,263	-8%	2%	-14%	-1%	-15%	-2%
Dry	647	-8%	3%	-11%	6%	-13%	-1%
Wet	1,616	-8%	2%	-16%	-1%	-17%	3%

Data source: NASA NEX-GDDP

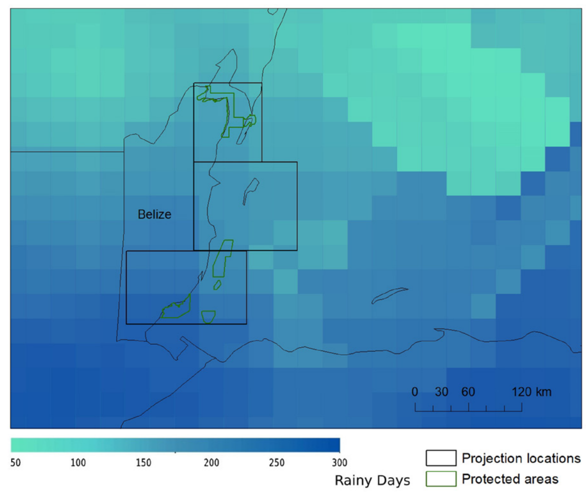
5.6 Rainy days

The region and the project areas are projected to experience many rainy days by midcentury under RCP8.5 (days per year over 1mm of rainfall). These range across the three Zones under the low estimate, with Zone 1 having the least number of rainy days (~50-125), followed by Zone 2 (~75-150) and Zone 3 (100-200). The pattern across the three Zones remains the same under the high estimate. Under the high estimate, the total number of rainy days is slightly higher than the low estimate, with Zone 1 seeing a range of ~100-175 rainy days per year, followed by Zone 2 (~150-250) and Zone 3 (~200-300).

Figure 29. Total number of rainy days per year (>1mm) in 2050s (2041-2070) under RCP 8.5



Low estimate (25th percentile)

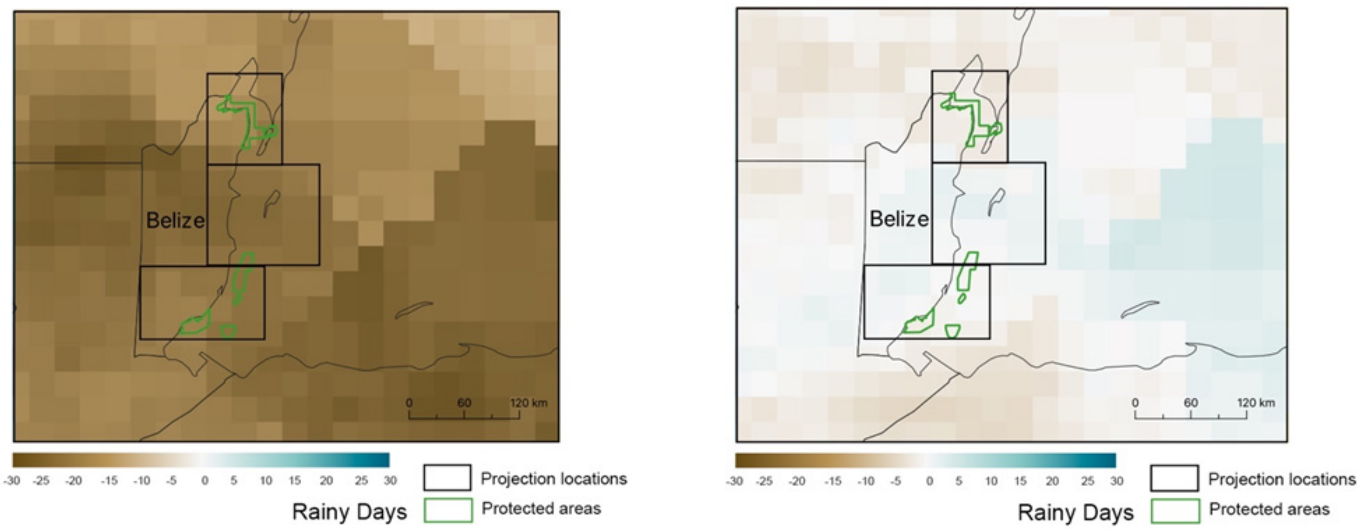


High estimate (75th percentile)

Data source: NASA NEX-GDDP

There is a decline in the number of rainy days compared to the baseline under the low estimate across the entire region and Belize. The largest decline is seen in Zone 2, but there are not major differences between the zones under the low estimate, with all three zones projected to experience decreases of between 15 and 30 rainy days per year by midcentury. Under the high estimate, Zone 1 is expected to see a slight decline in the number of rainy days (0 to 5 days), with the northern portion of Belize seeing a similar pattern. Zones 2 and 3 are projected to experience either no change or a very minor increase in the number of rainy days (0 to 3 days per year on average). It should be noted that models project a relatively high number of rainy days per year across most of the region in the baseline, so a decline under the low estimate or little change under the high estimate may not have a significant impact.

Figure 30. Change in number of rainy days per year (>1mm) in 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



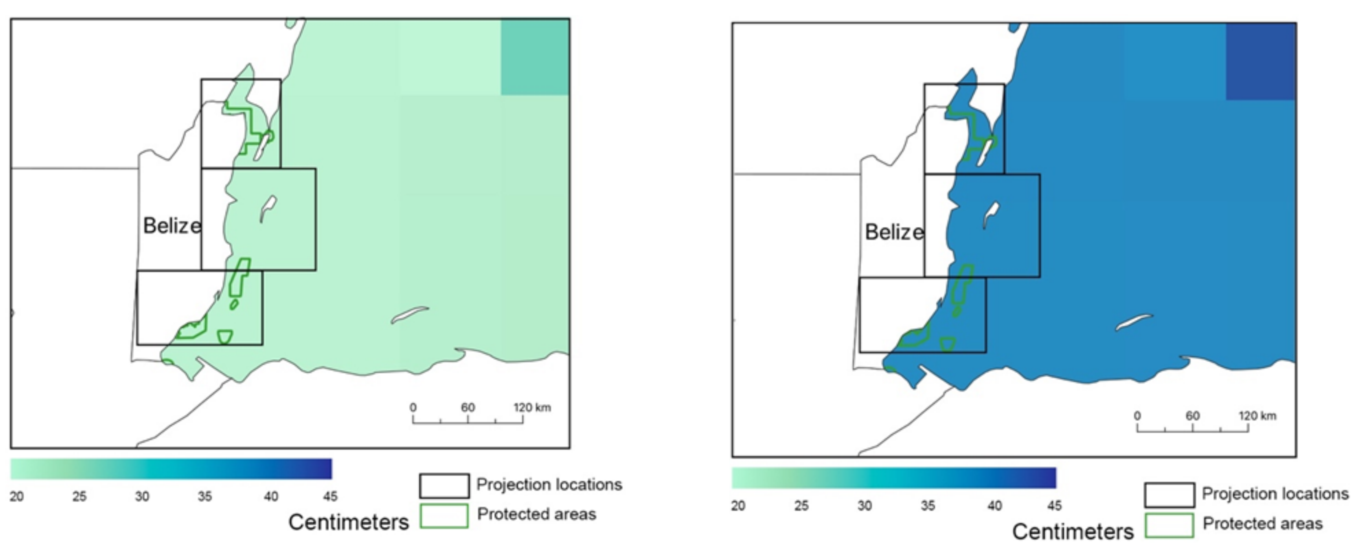
Low estimate (25th percentile) High estimate (75th percentile)

Data source: NASA NEX-GDDP

5.7 Sea level rise

Sea level is projected to increase along the coast of Belize with the increase being uniform across the entire coast. Sea level rise in the 2050s is ~20cm under the low estimate and just over 40cm for the high estimate.

Figure 31. Sea level rise in 2050s (2050-2059) compared to the baseline (2000-2004) under the combined RCP 4.5 and 8.5 scenario



Low estimate (25th percentile) High estimate (75th percentile)

Data source: Several datasets, including 24 CMIP5 climate models

6. CLIMATE RISK INFORMATION – GUATEMALA PROJECT REGION

6.1 Introduction to the Guatemala project region results

In addition to the regional observations and projections, this section focuses on the results for the Guatemala project area. Projections are provided for the entire peninsula and the specific project area. The target protected area site is Rio Sarstún Multiple Use Area.

Projections were developed for mean annual temperature, extreme heat days, precipitation change, rainy days and sea level rise. The methods used for projections are described in the methods section of the report.

6.2 Context

In Guatemala, the Smart Coast project focused its efforts in Río Sarstún Multiple Purpose Area, located in Livingston, within the Izabal department. Is one of the few declared protected areas in the Guatemalan Caribbean, and it is recognized as a wetland of international importance by the Ramsar Convention. It has an extension of 58,075 hectares and 22 communities are located within its boundaries. Sarstún protects an important percentage of the mangrove cover of the Guatemalan Caribbean and hosts fisheries of nutritious and economical importance.

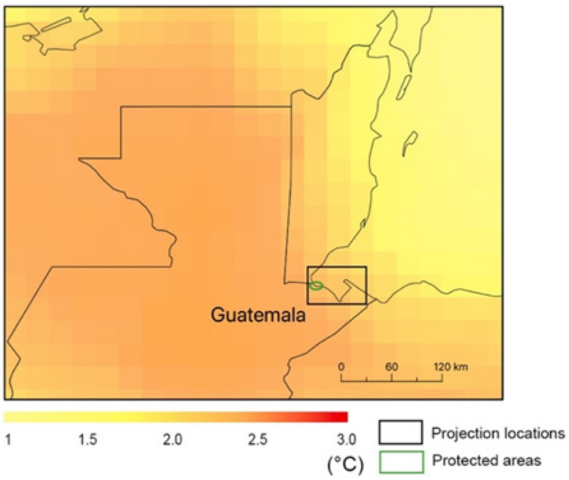
Río Sarstún' local communities have been witnessing climate change consequences for decades, but their impact has increased recently, e.g. drastic changes in the duration of the wet and dry seasons, with the rainy months reporting higher precipitation and the dry months being drier than before, which have had serious impacts on their crops for trade and self-consumption; a riskier or sometimes impeded mobility between communities due to high or low water level; need of relocating households given sea level rise, among others.

Even though the effects of climate change are being felt daily by the local communities and it has been recognized, on a national scale, that there is an urgent need to adapt to them, no specific actions are taking place to tackle them to date.

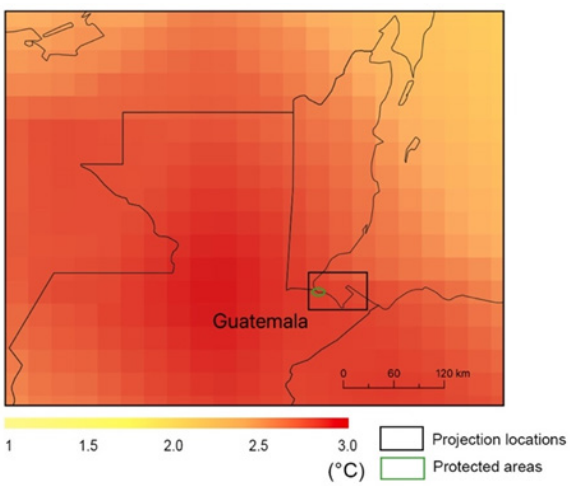
6.3 Mean annual temperature

Mean temperature is increasing across Guatemala by the 2050s. This increase is ~2°C in many areas under the low estimate (25th percentile), with the central regions of the country projected to warm slightly more. Under the high estimate (75th percentile), most areas see increases of at least 2.5°C, with many areas reaching 3°C warming.

Figure 32. Annual mean temperature change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



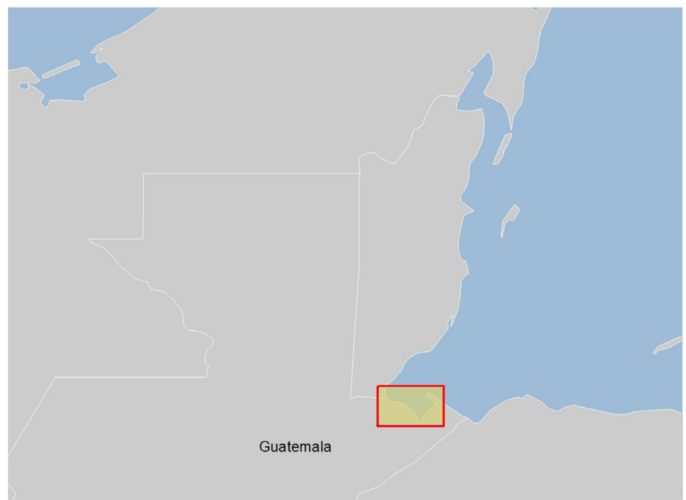
High estimate (75th percentile)

Data source: NASA NEX-GDDP

Mean Temperature in the project region

In the project region, mean temperature change ranges from ~1.8 to 3.0˚C by midcentury under RCP 8.5. The increase in temperature differs slightly across seasons. The difference between the low (25th percentile) and high (75th percentile) annual warming is ~1.2˚C. The warming in the wet season is slightly higher compared to mean temperature increases during the dry season.

Focal area in Guatemala



Coordinates

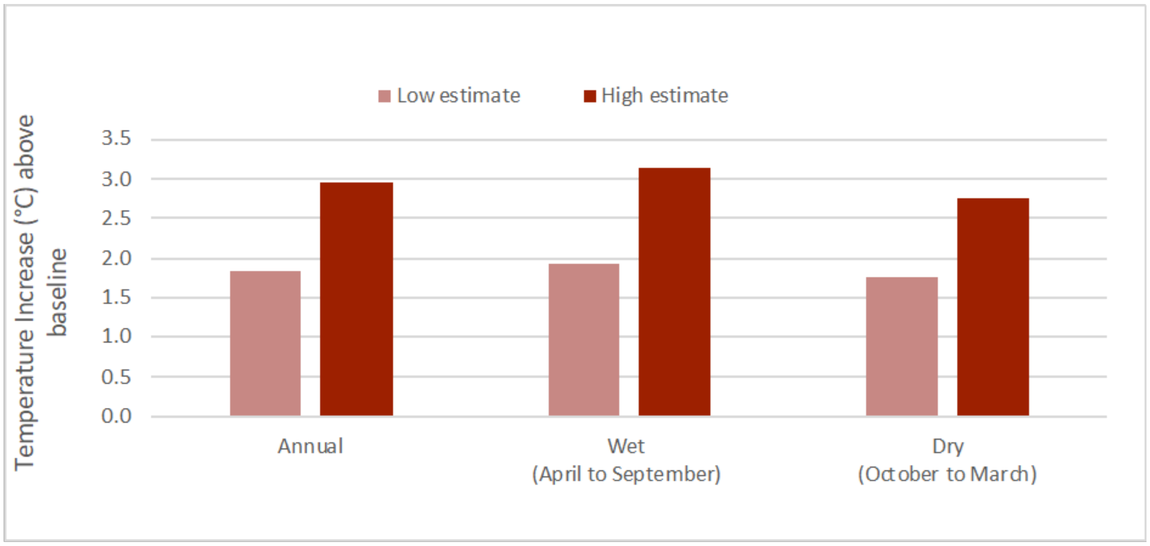
North = 15.9978

South = 15.6616

East = -88.3461

West = -88.9145

Figure 33. Annual mean temperature change (˚C) 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Annual mean temperature change (˚C) under RCP 8.5 for 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

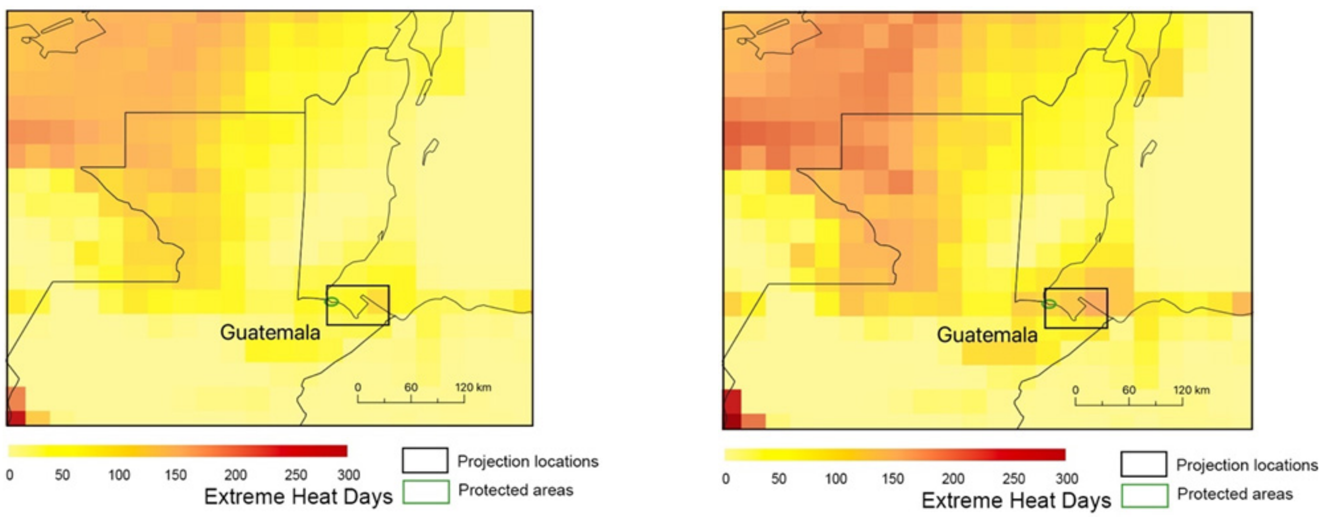
Seasons	Model Baseline	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Annual	26.1	0.8	1.2	1.8	3.0	2.9	4.8
Wet (April to September)	27.4	0.9	1.3	1.9	3.2	3.0	5.1
Dry (October to March)	24.7	0.8	1.1	1.8	2.8	2.8	4.5

Data source: NASA NEX-GDDP

6.4 Extreme heat days

The number of extreme heat days (>35°C) per year varies across Guatemala, with some of the inland regions seeing the highest number of extreme heat days by midcentury. The total number of days per year over 35°C ranges from ~50 to over 150 across northern and coastal Guatemala under the low estimate for RCP 8.5, with the highest total number of extreme heat days (150+) in the northwestern corner of the country. Under the high estimate, the spatial patterns of extreme heat days is similar to the low estimate, but with the total number of extreme heat days exceeding 150 days per year even in the coastal protected area and some inland northwestern areas are projected to experience more than 200 days per year above 35°C. The Caribbean coastal area in Guatemala experiences relatively high numbers of extreme heat days compared to the central part of the country under both estimates.

Figure 34. Total number of extreme heat days per year (>35°C) in the 2050s (2041-2070) under RCP 8.5



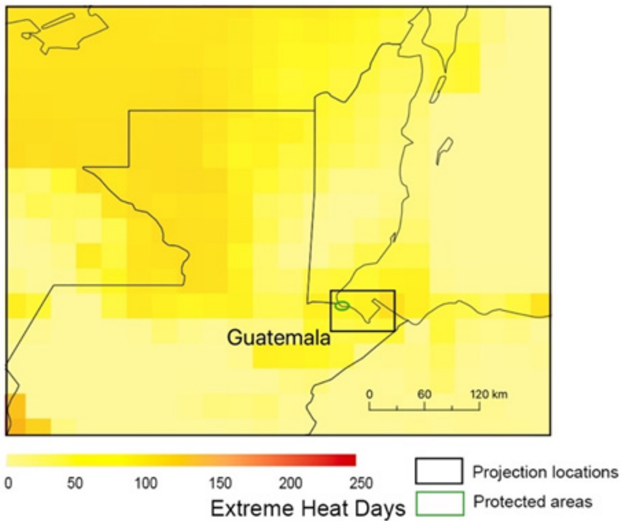
Low estimate (25th percentile) **High estimate (75th percentile)**

Data source: NASA NEX-GDDP

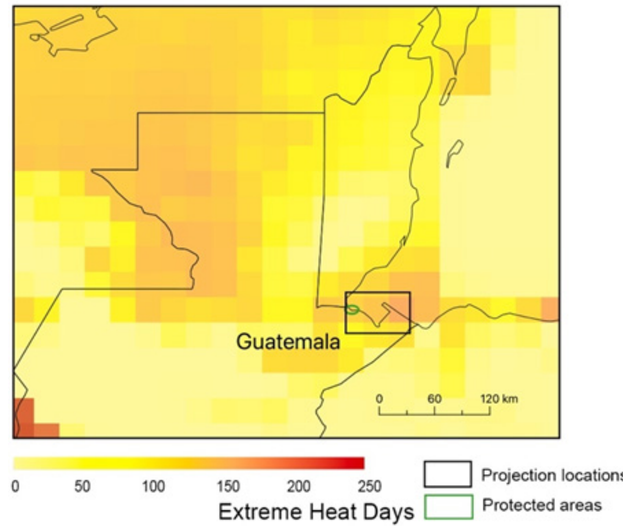
The change in number of extreme heat days (>35°C) per year varies across Guatemala. Under the low estimate, most areas see an increase of additional extreme heat days ranging from about 50 to 150 days per year compared to the baseline, with a slightly lower range of 50-100 within the coastal protected area.

The patterns are similar across the low and high estimates, with larger increases in extreme heat days under the high estimate. Many areas, including the Caribbean coastal region, see more than 150 additional extreme heat days per year under the high estimate when compared to the baseline.

Figure 35. Change in the number of extreme heat days per year (>35°C) in the 2050s (2041-2070) under RCP 8.5



Low estimate (25th percentile)



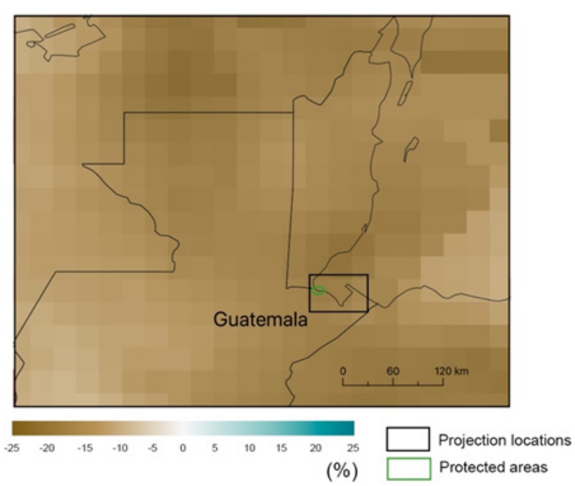
High estimate (75th percentile)

Data source: NASA NEX-GDDP

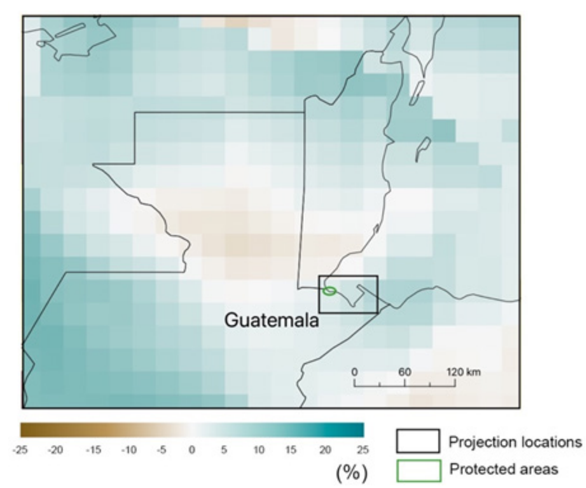
6.5 Precipitation

Under the low estimate, a decline in precipitation is projected across Guatemala. There is a nearly uniform drying trend of between -10% and -20% by midcentury across most of the country including the coastal area. Under the high estimate, the coastal protected area is projected to experience a small increase in rainfall of under 10%, despite projections of very slight declines in precipitation in the northern central area of the country. The low estimate shows a more consistent drying trend across the region, as opposed to small increases and some projected decreases in precipitation under high estimate.

Figure 36. Annual mean precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



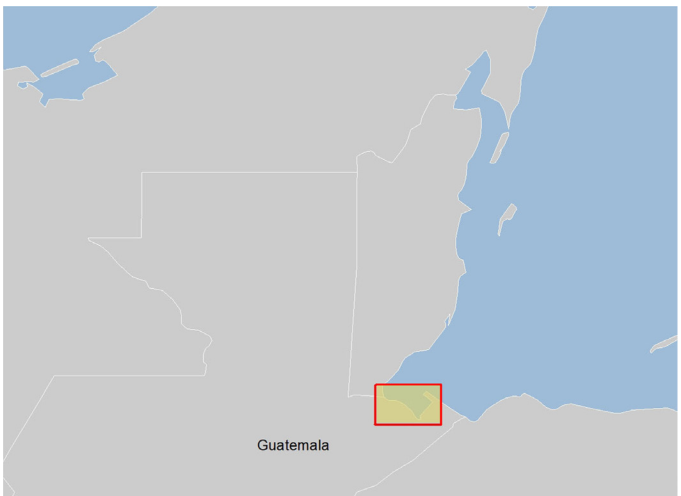
High estimate (75th percentile)

Data source: NASA NEX-GDDP

Precipitation in the project region

The ensemble mean across climate models projects a total precipitation amount of 2,756 mm per year in the baseline period. Most of this precipitation is received during wet season (1678.9mm), followed by lower levels in the dry season (1077.2mm). By midcentury, annual precipitation change ranges from -18% to 4%, indicating high model agreement that the region will experience some level of drying. The wet season is projected to experience a decline in precipitation, ranging from -2 to -27%, while the dry season may see a slight increase or decrease in precipitation (-10% to 9%). There is a significant likelihood of drying in the wet season.

Focal area in Guatemala



Coordinates

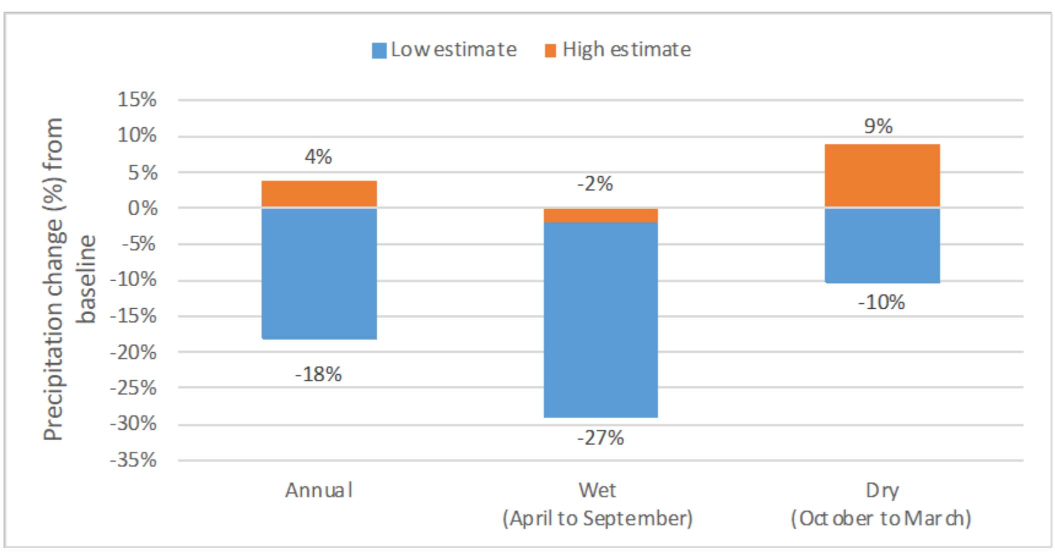
North = 15.9978

South = 15.6616

East = -88.3461

West = -88.9145

Figure 37. Annual precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Annual precipitation change (%) under RCP 8.5 for 2050s compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

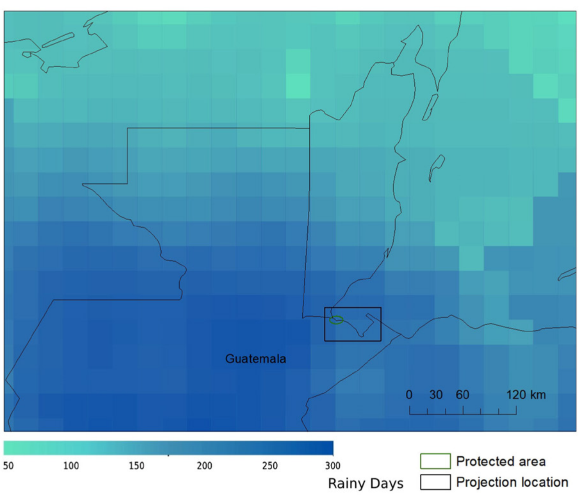
Seasons	Model Baseline (mm)	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Annual	2,756.1	-8%	2%	-18%	4%	-28%	-1%
Wet (April to September)	1,678.9*	-11%	0%	-27%	-2%	-34%	-3%
Dry (October to March)	1,077.2*	-2%	8%	-10%	9%	-23%	9%

Data source: NASA NEX-GDDP

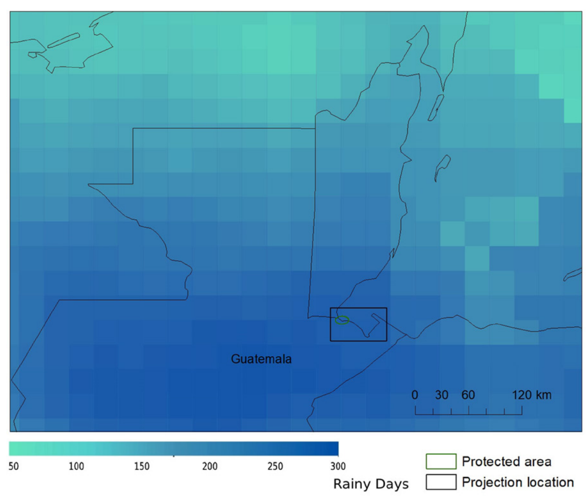
6.6 Rainy days

Guatemala is projected to experience a high number of rainy days per year (days with more than 1mm of rainfall) by midcentury across most of the country. The total number of rainy days under the low estimate for RCP 8.5 midcentury ranges from ~100-250+ days a year across the country, with the northern region near the Mexico border projected to experience fewer rainy days (~100-150). Under the high estimate, the spatial pattern in the total number of rainy days is similar to the low estimate, but with slightly higher values.

Figure 38. Total number of rainy days per year (>1mm) in 2050s (2041-2070) under RCP 8.5



Low estimate (25th percentile)

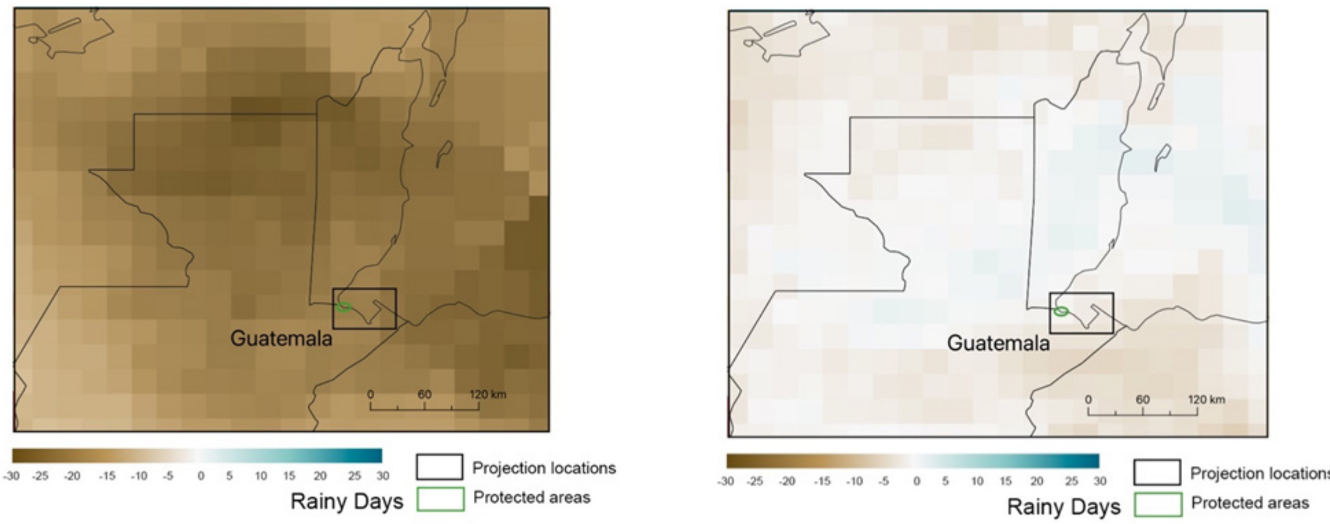


High estimate (75th percentile)

Data source: NASA NEX-GDDP

There is a decline in the number of rainy days compared to the baseline under the low estimate. The northern region near the Mexico border is projected to experience a sharper decline in the number of rainy days (decreasing by as many as 30 days per year). Most areas in Guatemala, including the coastal protected area, see a decline of ~5-20 days per year. Under the high estimate, many areas experience little to no increase in the number of rainy days, with changes projected to be fewer than 5 days per year in either direction. The strong agreement on either declines or little change in the number of rainy days across the region indicates that total rainfall in the future may be spread over fewer days. It should be noted that models project a relatively high number of rainy days per year across most of the region in the baseline, so a decline under the low estimate or little change under the high estimate may not have a significant impact.

Figure 39. Change in number of rainy days per year (>1mm) in 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



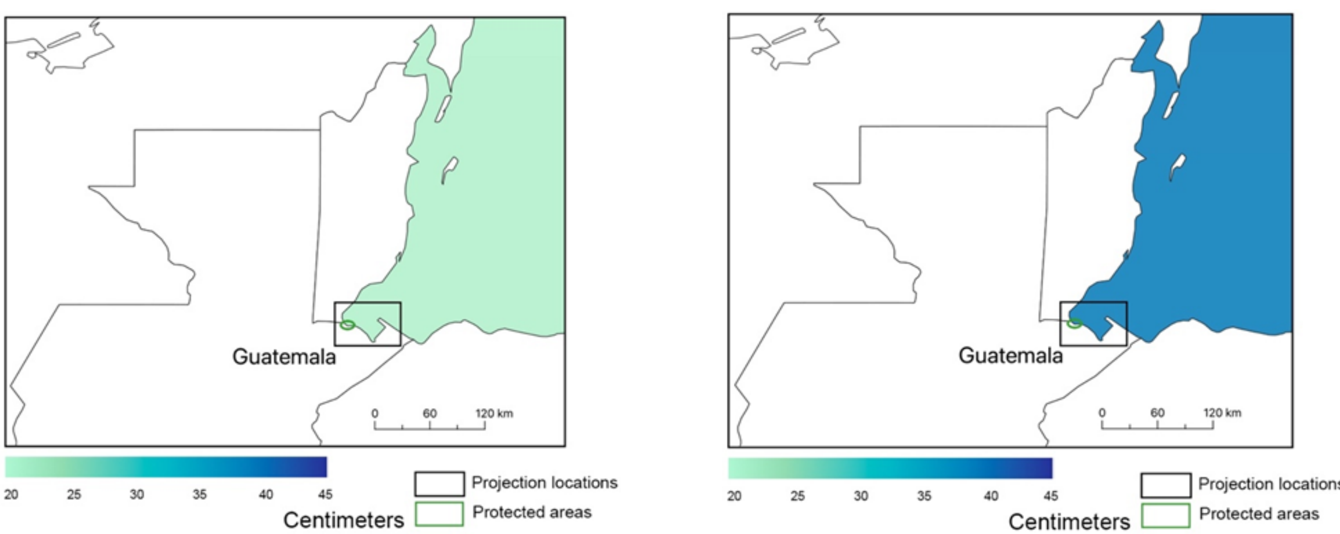
Low estimate (25th percentile) | High estimate (75th percentile)

Data source: NASA NEX-GDDP

6.7 Sea level rise

Sea level is projected to increase in the Caribbean side of Guatemala. Sea level rise in the 2050s is about 20cm under the low estimate and just over 40cm for the high estimate.

Figure 40. Sea level rise in 2050s (2050-2059) compared to the baseline (2000-2004) under the combined RCP 4.5 and 8.5 scenario



Low estimate (25th percentile) | High estimate (75th percentile)

Data source: Several datasets, including 24 CMIP5 climate models

7. CLIMATE RISK INFORMATION – HONDURAS PROJECT REGION

7.1 Introduction to the Honduras project region results

In addition to the regional observations and projections, this section focuses on the results for the Honduras project area. Projections are provided for the region and the specific project area. The target protected area sites are Honduras: focus is on four protected areas: Cuyamel-Omoa National Park, Jeannette Kawas (Punta Sal) National Park, Punta Izopo National Park, and Bahía de Tela Marine Wildlife Refuge and an 11,700 ha large connecting zone between two of the protected areas. Additionally, the Cayos Cochinos area is also included in the target area.

Projections were developed for mean annual temperature, extreme heat days, precipitation change, rainy days and sea level rise. The methods used for projections are described in the methods section of the report.

7.2 Context

As a country highly threatened by climate events such as hurricanes and sea level rise, Honduras' population seeks for solutions to cope with climate changes. The Smart Coast project has supported communities from 5 protected areas: Cuyamel Wildlife Refuge, Omoa National Park, Janette Kawas National Park, Bahia de Tela Marine Wildlife Refuge and Punta Izopo National Park, and an interconnexion zone between Cuyamel and Janette Kawas to understand climate threats and build resilience through ecosystem-based adaptations.

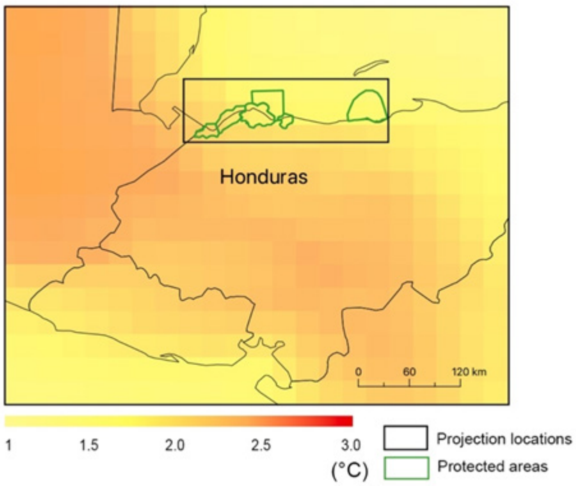
Climate hazards identified by communities include droughts, heavy rainfalls in short periods, landslides due to water-saturated soils, coastal erosion, and water scarcity. In the 2020 rainy season, project areas were hit by two hurricanes and 15 cold fronts increasing communities' vulnerability and displacing entire communities due to floods and landslides. These events pressured communities to find solutions to adapt.

Communities and authorities have understood the importance of using protected areas in their ecosystem-based adaptation strategy and are incorporating strategies such as watershed management or mangrove protection and restoration in the protected areas management plans and in the country adaptation contribution for the Honduras Nationally Determined Contribution (NDC). This also helps communities to protect their tourism and fisheries livelihood, preparing them for new climate threats in the near future.

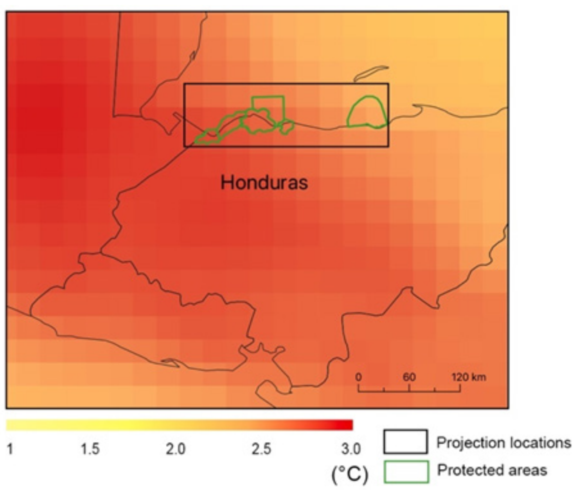
7.3 Mean annual temperature

Mean temperature is increasing across Honduras and the region by the 2050s. This increase ranges from 1.5-2.0°C in Honduras under the low estimate (25^{th} percentile). Under the high estimate (75^{th} percentile), most areas in Honduras see increases of at least 2.5°C, with some inland areas reaching 3°C warming.

Figure 41. Annual mean temperature change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Low estimate (25th percentile)



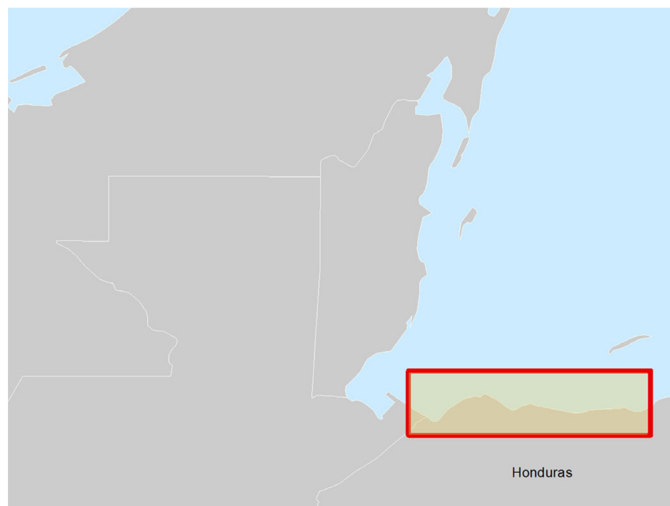
High estimate (75th percentile)

Data source: NASA NEX-GDDP

Mean Temperature in the project region

In the project region, annual mean temperature changes range from ~1.7 to 2.7˚C by midcentury under RCP 8.5. The increase in temperature is very similar across seasons. The difference between the low (25th percentile) and high (75th percentile) annual warming is ~1.0˚C.

Focal area in Honduras



Coordinates

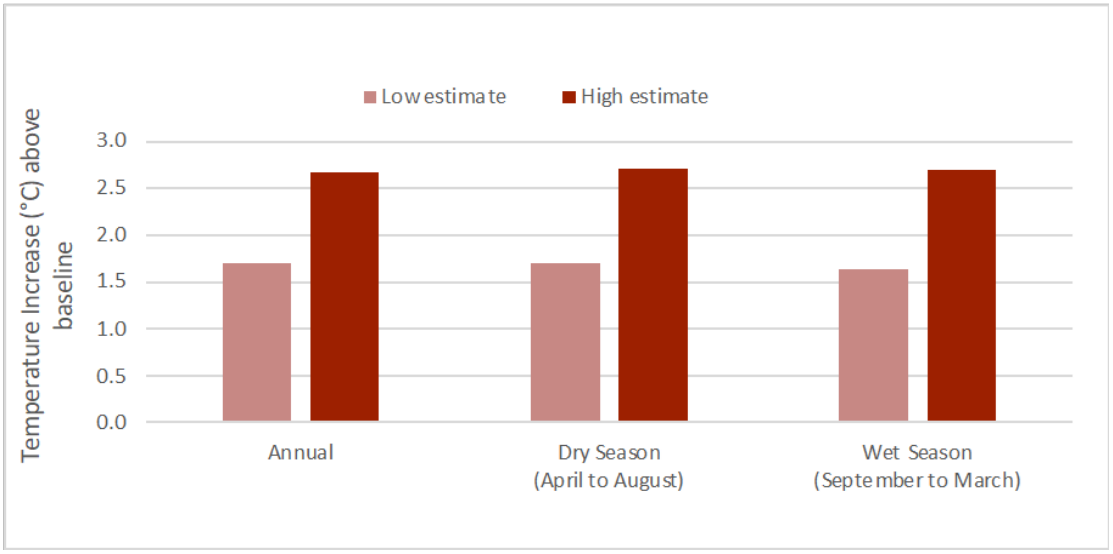
North = 16.1123

South = 15.58

East = -86.27943

West = -88.33

Figure 42. Annual mean temperature change (˚C) 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Annual mean temperature change (˚C) under RCP 8.5 for 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100) compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

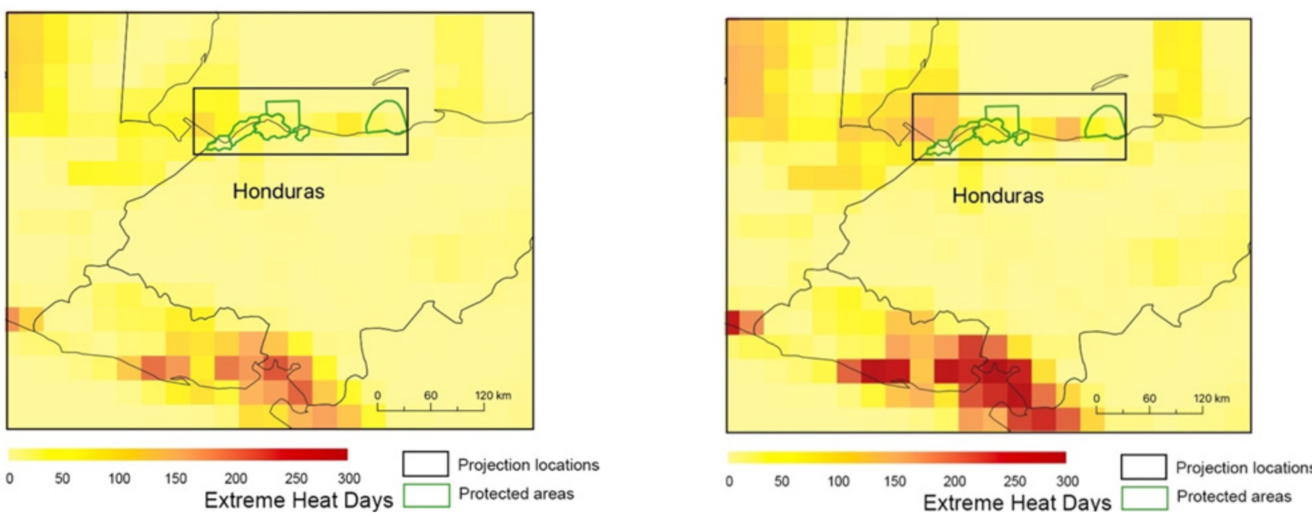
Seasons	Model Baseline	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Annual	25.6	0.7	1.1	1.7	2.7	2.7	4.3
Dry (April to August)	26.7	0.8	1.2	1.7	2.7	2.7	4.4
Wet (September to March)	24.8	0.7	1.1	1.6	2.7	2.7	4.4

Data source: NASA NEX-GDDP

7.4 Extreme heat days

The number of extreme heat days (>35°C) per year varies across the region and in Honduras. The coastal region of interest in the north is projected to experience a slightly higher total of extreme heat days by midcentury than the rest of the country under RCP8.5. The coastal project area is projected to reach ~50 extreme heat days per year under the low estimate with some areas along the western side of the coast experiencing nearly 100 days per year on average. Most inland areas in Honduras see up to 50 days of extreme heat per year under the low estimate. Under the high estimate, the spatial distribution of extreme heat days remains similar, with northern and southern areas of the country experiencing more days over 35°C compared to the low estimate by midcentury. The total number of days over 35°C in the project area under the high estimate are expected to reach ~100-175 days per year in some areas along the northern coastal region of Honduras. Most inland areas see a range of about 10-100 days under the high estimate.

Figure 43. Total number of extreme heat days per year (>35°C) in the 2050s (2041-2070) under RCP 8.5

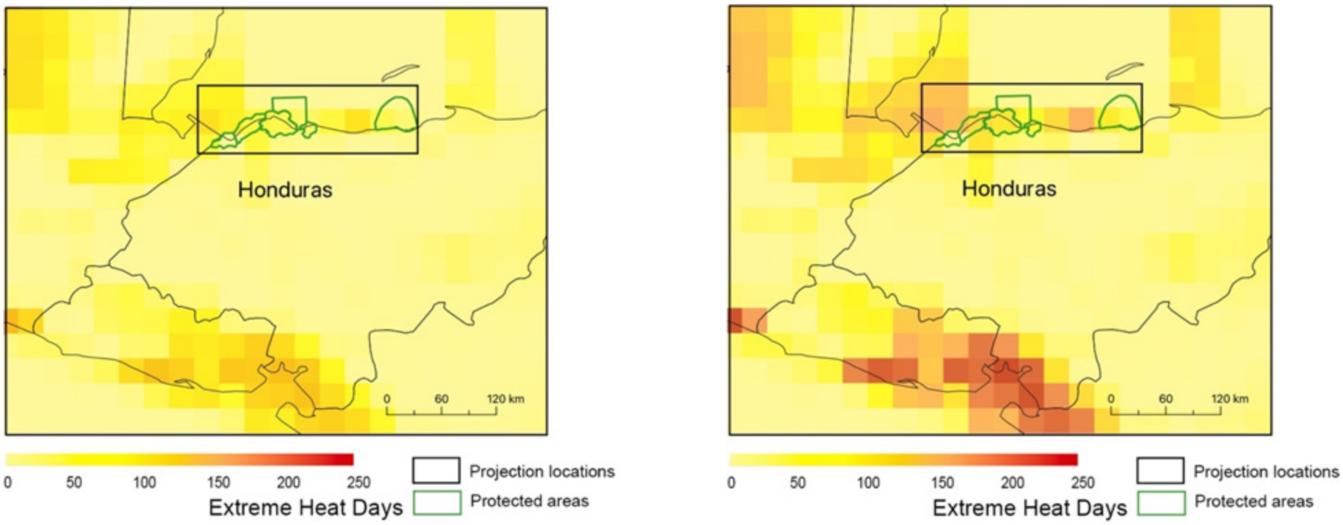


Low estimate (25th percentile) **High estimate (75th percentile)**

Data source: NASA NEX-GDDP

The change in number of extreme heat days (>35°C) per year varies across the region and in Honduras. The coastal project area in the north is projected to experience a larger increase (~50-100 additional days per year) of extreme heat days under the low estimate compared to central Honduras, while the southern border of the country is projected to see an increase of 100+ extreme heat days. The spatial patterns of changes in extreme heat days are again similar across the low and high estimates. Within the coastal protected area, the region could experience more than 150 additional extreme heat days per year under the high estimate, compared to the baseline.

Figure 44. Change in the number of extreme heat days per year (>35°C) in the 2050s (2041-2070) under RCP 8.5



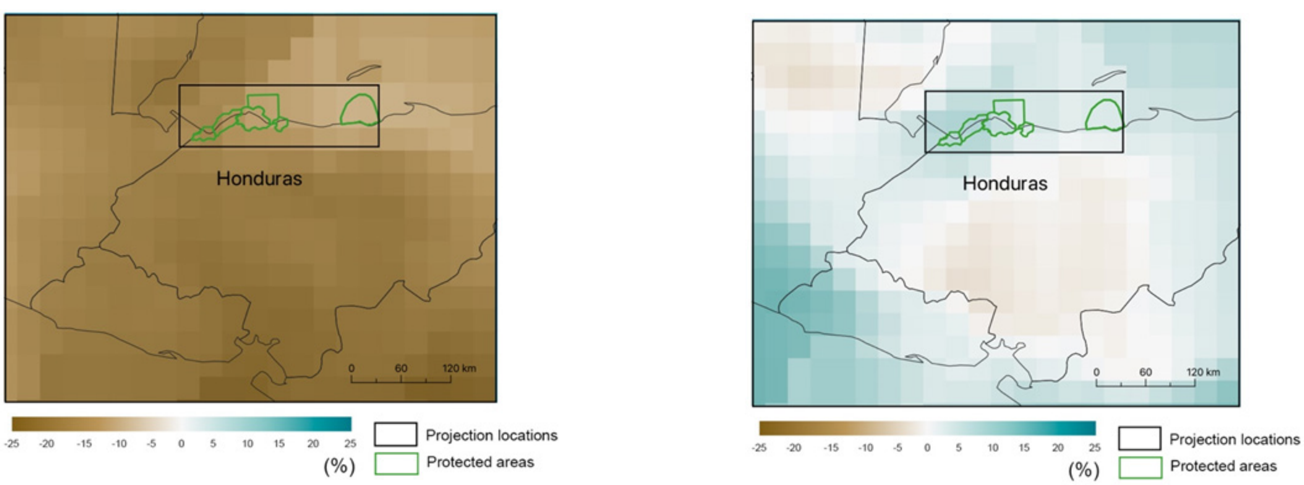
Low estimate (25th percentile) High estimate (75th percentile)

Data source: NASA NEX-GDDP

7.5 Precipitation

Under the low estimate, a decline in precipitation is projected across the region and in Honduras. The decreases are relatively smaller along the coastal areas of Honduras, compared to inland areas in the rest of the country. The decrease in precipitation ranges from about -5 to -25% under the low estimate, with precipitation in the project area projected to decrease by about -5% to -15%. Under the high estimate, the coastal protected area is projected to experience a slight increase in precipitation of less than 10%, although central Honduras sees a small decline in precipitation even under the high estimate. The low estimate shows a more consistent drying trend as opposed to small increases or little change in precipitation under high estimate.

Figure 45. Annual mean precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



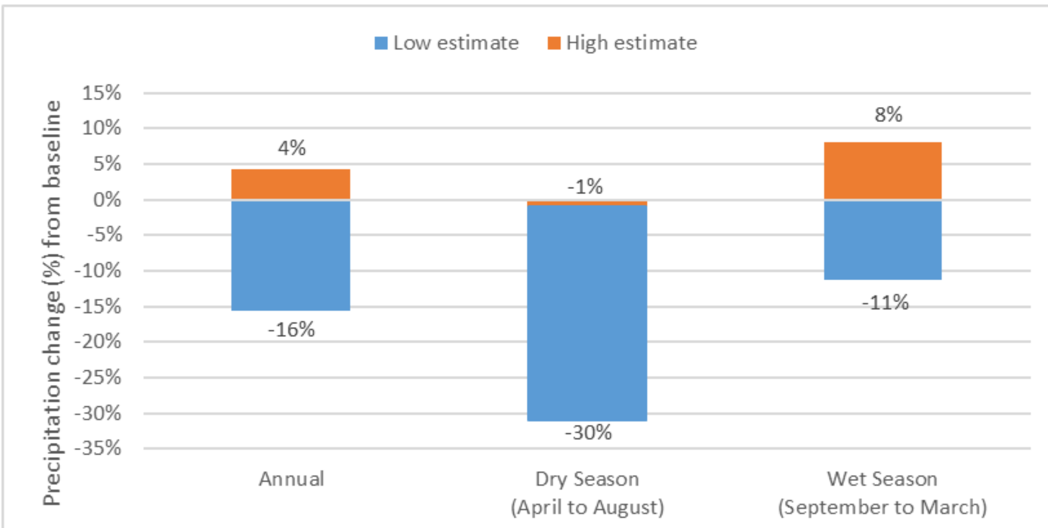
Low estimate (25th percentile) High estimate (75th percentile)

Data source: NASA NEX-GDDP

Precipitation in the project region

The ensemble mean across climate models projects a total precipitation amount of 1,690mm per year in the baseline period. The majority of this precipitation is received during the wet season (1,085mm), followed by lower levels in the dry season (605mm). By midcentury, annual precipitation changes range from -14% to 2%, indicating high model agreement the region will experience some level of drying. The dry season sees a decline in precipitation, ranging from -1 to -30%, while the wet season may see a slight increase or decrease in precipitation (-11% to 7%). There is a significant likelihood of drying in the dry season.

Figure 46. Annual precipitation change 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



Annual precipitation change (%) under RCP 8.5 for 2050s compared to the 1980-2005 baseline: low (25th percentile) and high estimates (75th percentile)

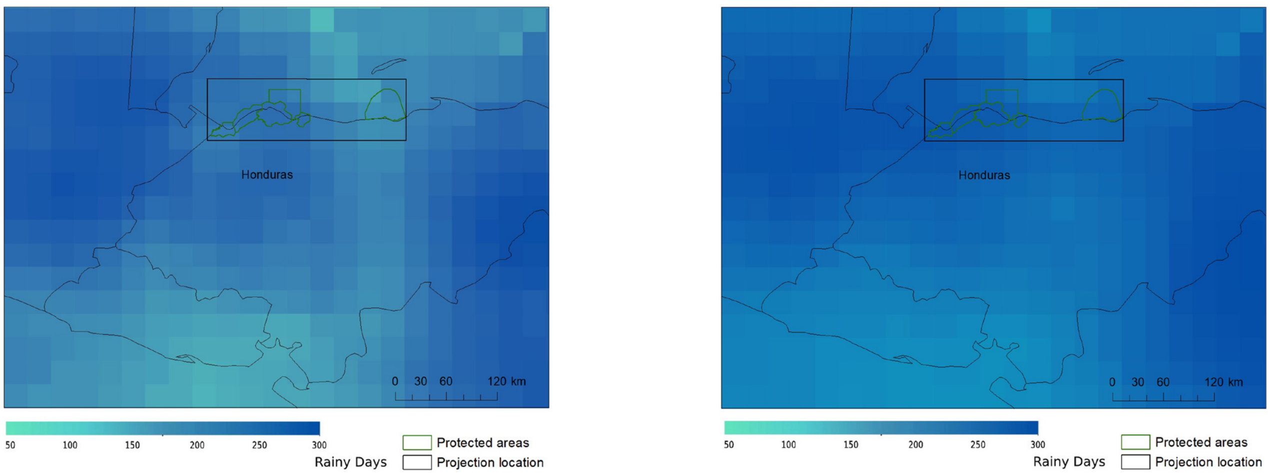
Seasons	Model Baseline	2020s		2050s		2080s	
		Low	High	Low	High	Low	High
Annual	1,690.6	-6%	3%	-14%	2%	-26%	-1%
Dry (April to August)	605.3	-12%	3%	-30%	-1%	-40%	-6%
Wet (September to March)	1,085.3	-3%	5%	-11%	7%	-25%	2%

Data source: NASA NEX-GDDP

7.6 Rainy days

The region and the project area are projected to experience a high number of rainy days per year (days with more than 1mm of rainfall). The total number of rainy days under the low estimate for RCP 8.5 ranges from 100-250 days per year by midcentury, with the project area in Honduras seeing slightly lower levels, ranging from ~150-200 days per year. Under the high estimate, the total number of rainy days is slightly higher than the low estimate, at around 200-300 days per year across the region. The project area sees a range of ~200-250 rainy days per year under the high estimate. The pattern of rainy days remains similar under both estimates.

Figure 47. Total number of rainy days per year (>1mm) in 2050s (2041-2070) under RCP 8.5



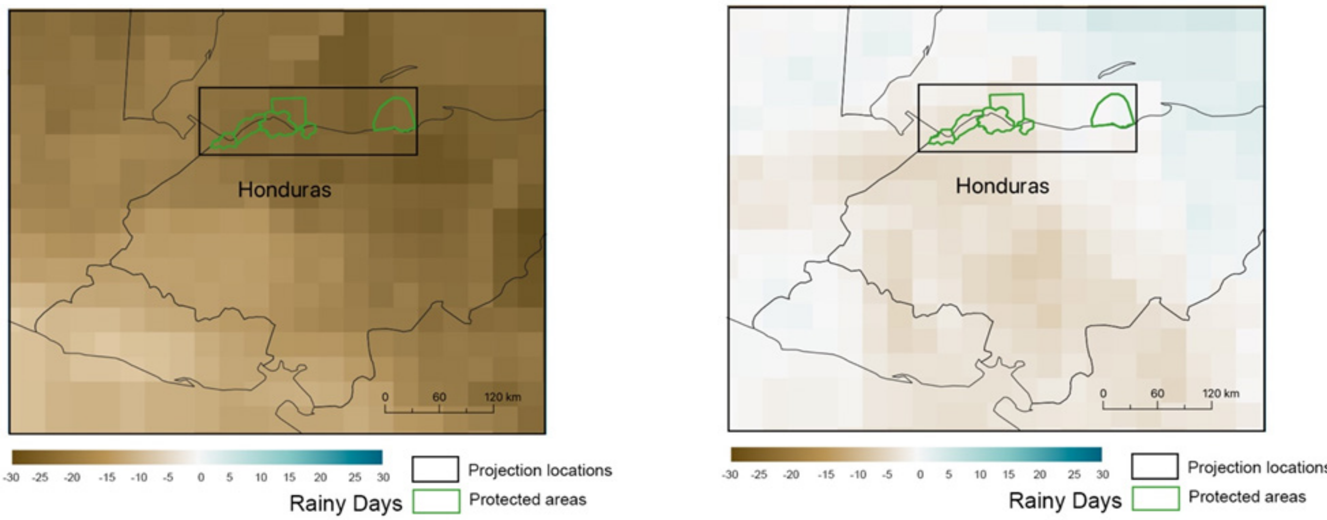
Low estimate (25th percentile)

High estimate (75th percentile)

Data source: NASA NEX-GDDP

There is a decline in the number of rainy days compared to the baseline under the low estimate across the entire region, with this decline appearing more pronounced along the northern coast of Honduras. In Honduras the number of rainy days is projected to decrease by between 15 and 30 days per year compared to the baseline, with larger magnitude decreases in the coastal protected area than in the southern and western parts of the country. Under the high estimate, the central and western regions in Honduras see a decline in rainy days ranging from 0 to 5 fewer days per year, while the eastern edge of the country is projected to see an increase of less than 5 days per year. Many parts of the country are projected to experience very minor, if any, change in the number of rainy days per year on average. The project area along the northern coast is projected to experience a slight decrease of 0 to 5 fewer days per year in most areas. It should be noted that models project a relatively high number of rainy days per year across most of Honduras in the baseline, so a decline under the low estimate or little change under the high estimate may not have a significant impact.

Figure 48. Change in number of rainy days per year (>1mm) in 2050s (2041-2070) compared to the 1980-2005 baseline under RCP 8.5



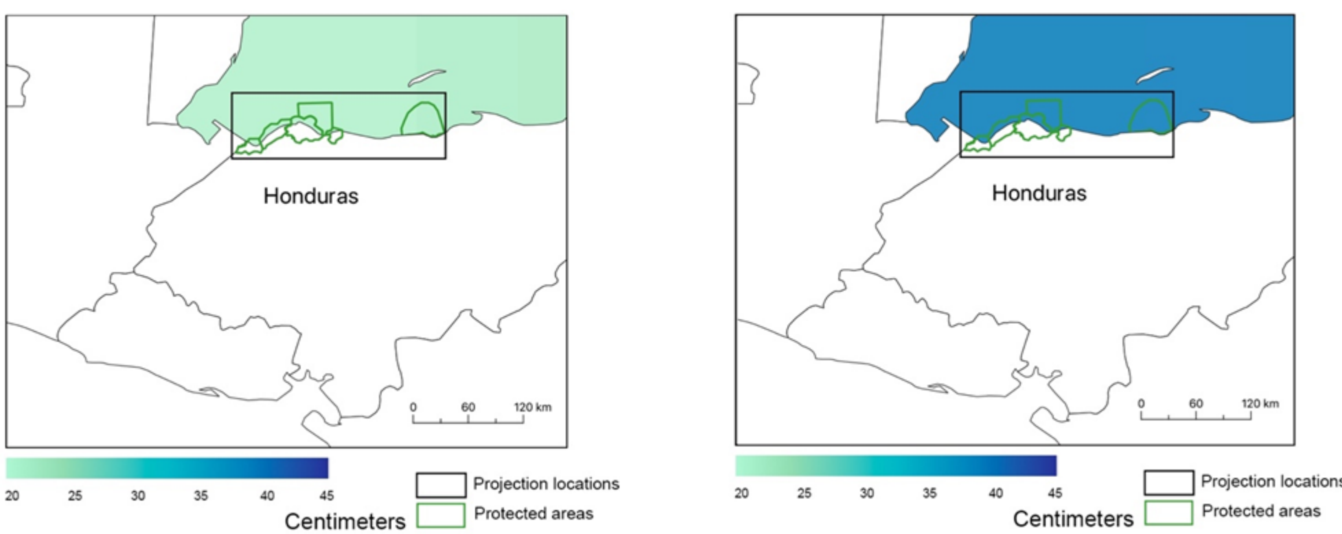
Low estimate (25th percentile) **High estimate (75th percentile)**

Data source: NASA NEX-GDDP

7.7 Sea level rise

Sea level is projected to increase in the Caribbean side of Honduras. Sea level rise in the 2050s is about 20cm under the low estimate and just over 40cm for the high estimate.

Figure 49. Sea level rise in 2050s (2050-2059) compared to the baseline (2000-2004) under the combined RCP 4.5 and 8.5 scenario



Low estimate (25th percentile) **High estimate (75th percentile)**

Data source: Several datasets, including 24 CMIP5 climate models

8. APPLICATIONS OF CLIMATE RISK INTO SECTORS

All sectors and systems in the Mesoamerican Reef region will be impacted by climate change. Implications of a changing climate and its impacts for several sectors are presented below. Climate projections, like those presented in this report, can equip decision-makers with information about emerging risks, which can be taken into account in planning activities. This section briefly examines how planners can begin to consider and apply climate risk information to build resilience to the impacts of climate change in several sectors. There is a more in-depth focus on biodiversity and ecosystem services, given the focus of the Smart Coasts project. Brief overviews on agriculture and fisheries, health and urban areas and infrastructure sectors are presented below. Linkages between sectors should also be considered when planning. Impacts will often affect several sectors in different ways, while responses and adaptation measures taken in one sector may have implications for other sectors as well. Responses to climate impacts – such as adaptation policies – will have implications and knock-on effects, which need to be identified and planned for.

8.1 Biodiversity and ecosystem services

The Mesoamerican Reef Region is rich in both terrestrial and marine biodiversity, with a range of vital ecosystems that benefit people through the services they provide. Climate change will impact ecosystems and species in multiple ways, with each ecosystem or species responding differently to climate variables, leading to complex interactions in a linked system. Biodiversity and ecosystem services are vulnerable to slow onset climate changes like increased warming and precipitation variability as well as shocks and stresses from extreme events. When planning for conservation in a changing climate, traditional climate variables (e.g., total precipitation, temperature, extreme heat, sea surface temperature) need to be considered, along with other estimated climatic changes that may be essential for species (e.g., shifts in seasons).

Impacts of a changing climate

Observed changes include shifts in plant and animal ranges, seasonal changes (phenological changes) and altered levels of abundance (Settele et al. 2014). Many species are unable to move fast enough to keep up with the pace of climate change. A large portion of species also face increased extinction risk under projected climate change and the risk is exacerbated by pressures such as habitat modification, overexploitation, pollution, and invasive species. Ecosystem disturbances are caused by extreme events such as droughts, fires, and pest outbreaks. If disturbance regimes exceed the range of current natural climate variability, changes could alter the structure, composition, and functioning of ecosystems.

Range-restricted species, slow-moving species, low-dispersal species and species already facing high threats are likely to be the most vulnerable to climate change (Settele et al. 2014). In terms of investing in adaptation measures, it will be necessary in many cases to consider trade-offs between conserving vulnerable species and species that are most likely to survive in a changing climate. Indirect effects of climate change need to be considered and planned for, including cascading impacts on other sectors and human responses to climate change (e.g., land use change, infrastructure development, etc.) and their resulting effects on biodiversity. Accounting for extreme events and possible surprises is also critical when planning any adaptation interventions for wildlife and biodiversity (e.g., restoration using species appropriate for a changing climate, wildlife corridors, etc.).

Different species will respond uniquely to a changing climate and the thresholds for each species or groups of species will likely differ (Settele et al. 2014). Identification and monitoring of thresholds for species and ecosystems – tipping points at which they will no longer provide benefits to people – are key to ecosystem-based adaptation planning. For some species like corals, bleaching thresholds are well known. In some instances, this information may not exist and, therefore, identifying "known unknowns" is essential. For example, the variables and thresholds for mangroves species are less well known. Expert consultations and species-specific research will be vital to understanding thresholds and adaptation mechanisms.

Coastal and marine ecosystems

Coastal and marine ecosystems are especially vulnerable to climate change. Sea level rise impacts coastal ecosystems through habitat contraction, geographical shift of associated species and loss of biodiversity and ecosystem functionality (IPCC, 2019). Ocean warming, sea level rise and tidal changes pose major risks for some species leading to their migration, reduced survival, and local extinction. Cascading impacts on ecosystem structure and functioning has been caused by altered interactions between species. Many marine species have undergone shifts in geographical range and seasonal activities in response to ocean warming, resulting in shifts in species composition, abundance and biomass production of ecosystems (IPCC, 2019a). The overall status of the Mesoamerican reef ecosystem is critically endangered. It is affected by multiple threats including hurricanes, lionfish invasion, overfishing, pollution, ocean acidification, rising sea surface temperatures, and disease outbreaks among urchins and corals. As all threats are predicted to increase into the future, there is urgent need to understand the interactions among them and evaluate potential management needs (Nicholson, 2017).

Responding to a changing climate

Existing protected area management plans and species action plans need to be reviewed in the light of a changing climate. They should be updated or changed to prevent maladaptation and to 'climate-smart' existing activities by reviewing them considering the observed and projected changes documented in this report. Improved monitoring of species and ecosystem response to changing variables, along with ongoing reevaluation of the effectiveness of climate-adapted conservation measures is essential as the climate continues to change.

Indirect effects of climate change need to be considered and planned for, as adaptation responses to climate change from other sectors can have unintended negative outcomes for ecosystems.

Management actions can reduce the risk of impacts on species and ecosystems due to climate change, as well as increase the inherent adaptive capacity. Ecosystem-based adaptation can reduce coastal risk and provide multiple other benefits such as carbon storage, improved water quality, biodiversity conservation and livelihood support (IPCC, 2019b). A comprehensive analysis of multiple ecosystem services was carried out by Stanford University. Climate change projections developed by Columbia University, presented in this report, were integrated into these analyses and can help decision makers identify and prioritize key services and locations that benefit people in the region.

Impacts in the Mesoamerican reef region[4]

Countries and subregions in the Mesoamerican reef region have similarities and differences in their local biodiversity, ecosystems and impacts.

In the Yucatan peninsula of Mexico, mangroves have faced degradation due to extreme weather events. In addition to infrastructure development and land use change, climate hazards are an increasing threat to coastal wetlands. Land use change and infrastructure development are driving the loss of coastal wetlands, which will significantly impact the ability of habitats to provide protection from coastal hazards to local communities. Changes in storms and hurricane conditions are expected to affect the coastal environment impacting the quality of underground water, soil conditions and ecosystem services along the area.

In Guatemala, coastal ecosystems play a major role in protecting communities against the effects of climate change, especially mangroves. While local communities are aware of the linkages between a healthy mangrove and an increase in coastal protection, this has not been sufficient to protect them due to contextual factors. Sediment flow driven by deforestation and other inland activities from the upper part of the watersheds pose a major threat to the coastal ecosystems due to its impacts on water quality in the Guatemalan Caribbean and coordinated action is urgent to control this issue. Nature-based tourism in the Guatemalan Caribbean is projected to be highly impacted by climate change. Given the high reliance on tourism income in the region to support livelihoods, there is an urgent need to consider the projected impacts for tourism, with planning being vital to minimize its effects.

In Honduras, project target protected areas and key ecosystems such as mangroves and coral reefs are very important to reduce coastal vulnerability from sea level rise and climate extreme events in the country's northern coast, reducing risk for at least 30,000 people in the region. Coastal tourism in the region could be impacted and reduced due to climate change effects, although promotion of other attractions and activities such as inland-based tourism could help communities to adapt. Coral health and fisheries are and will be negatively impacted by climate change, especially in scenarios of increased rainfall. Watershed protection and restoration, complemented by coral protection can help communities to build resilience and maintain both fisheries and tourism livelihoods.

In Belize, ecosystems play an important role in reducing risk along the coast. Habitat loss within marine protected areas

4 Contributions to this section have been provided by conservation practitioners in the region, based on studies and local knowledge.

increases the relative coastal exposure, thus conserving and restoring ecosystems will help reduce risks associated with sea level rise and coastal hazards. Although climate change impact on sediment export is less in Belize, compared to Guatemala and Honduras, protecting forest cover and adopting best management practices in watersheds should be a priority to preserve soils and downstream benefits, and reduce sediment runoff to the marine environment. Effective mangrove protection and restoration, and coral reef conservation, can have the potential to bring greatest benefits for coastal protection, tourism visitation and fisheries/lobster catch, while seagrass protection can have the potential to bring great benefits for coastal protection and lobster catch.

The marine ecosystems in Mesoamerica have several challenges. Global warming that is already locked in the atmosphere will undoubtedly put pressure on reefs, increasing the likelihood of deadly coral bleaching and other diseases that could seriously jeopardize the health and existence of coral reefs by the end of the century. In this region, local action is needed to strengthen the effectiveness of marine protected area management. Actions should be designed to remove or minimize local stressors that might negatively affect the health of coral reefs, allowing the ecosystem to leverage on its natural resilience and enabling natural adaptation processes to occur. Some of these actions include:

- Implementing an integrated water monitoring system for marine protected areas to track water quality, including turbidity (sedimentation), and pH as well as the presence of potentially harmful diseases.
- Enhanced in-situ sea surface temperature assessment to track changes over time and use adequate equipment (temperature and luminosity sensors) while complementing assessment with NOAA's Coral Reef Watch degree heating weeks data.
- Building partnerships with academic institutions and research centers to continuously generate and compile scientific and technical information, data and knowledge to inform coastal management.
- Implementing a more inclusive approach to management, strengthening community/stakeholder engagements and building capacities of local communities.

Ecosystem services analyses by Stanford University

Ecosystem service modeling was carried out by Stanford University's Natural Capital Project to support the identification of critical ecosystem services and the impacts of a changing climate on these services. Some key findings include:

- ***Coastal risk reduction***: The model results suggest that the northern coast of the Yucatan Peninsula is at greatest risk from coastal hazards across the region, due to the potential for storm surge. Other factors influencing exposure to hazards include coastal relief and wave exposure. Sea level rise alone will expose more shoreline to coastal hazards, but loss of coastal ecosystems combined with sea level rise will put communities throughout the Mesoamerican reef region at even greater risk of flooding and erosion.
- ***Tourism and recreation***: Tourism to the MAR region is projected to shrink by 29% - 65% in 2050 under the RCP 8.5 climate scenario due to increasing temperature, increasing days of extreme heat, and changes in precipitation and coral cover. All four countries are likely to experience a loss of tourism due to climate change, though the impacts vary spatially with some potential increases in tourism in cool, inland areas of Honduras and Belize
- ***Sediment export/retention***: Land cover types plays an important role in reducing sediment export to the shoreline. Climate change impact on sediment export is spatially heterogeneous, affecting Guatemalan and Honduran watersheds more significantly, which are already contributing the largest amount of sediment to the ocean. Climate impacts on precipitation and sediment export vary spatially, thus some coral reef regions are more vulnerable to those projected changes in climate (BZ: Port Honduras, Sapodilla Cayes, Turneffe Atoll and South Water Caye; HN: Cayos Cohinos, Interconnexion, J. Kawas).
- ***Fisheries***
  - ***Target reef fish***: The potential changes in sediment export as a result of climate change have relatively minimal influence on coral health and targeted reef fish biomass. Direct impacts of climate on coral health (e.g., through sea surface temperatures, bleaching, and ocean acidification) are likely to have greater impacts.
  - ***Caribbean spiny lobster***: Lobster are sensitive to changes in sea-surface temperature. For example, assuming that juvenile survivorship decreases at temperatures above 30°Cleads to a 50% drop in catch under more extreme climate projections (e.g., the 75th percentile). However, the severity of rising sea surface temperature on population dynamics depends upon the threshold at which survivorship is impacted. If early life stages of lobster can withstand higher temperatures, then the catch will be less affected (e.g., only 20% decrease in catch).

Increasing land and ocean temperatures, sea-level rise and changing precipitation patterns with climate change will in general negatively affect the delivery of coastal risk reduction, fisheries, sediment retention and tourism benefits for communities in and around the protected areas. However, the degree to which climate threatens services varies spatially and among climate variables and ecosystem services. Some climate impacts (e.g., sea level rise and temperature) have greater effects on some services (e.g., coastal risk reduction, tourism and lobster production) than others (e.g., sediment retention and target biomass). The results of the study suggest the combination of ecosystem degradation and climate change would have far greater impact on ecosystem services (e.g., sediment retention, coastal risk reduction, lobster fisheries, tourism) than climate alone. These results highlight the importance of conserving and restoring ecosystems to help buffer the impacts of climate change.

8.2 Health

A changing climate has both direct and indirect effects on human health. Human health is sensitive to changing rainfall patterns, warming temperatures, and changes in extreme heat and other extreme events (Smith et al., 2016). Climate change is already impacting health in various ways including injury and mortality from increasingly frequent extreme weather events such as heatwaves, storms, floods, disruption of food systems, malnutrition, increases in water and vector borne diseases. Additionally, climate change impacts psychosocial health and mental health issues (WHO, 2021).

One direct variable that has the potential to cause significant risk of injury and death is due to more intense heat waves. In many places, heat is already a significant weather-related killer. Heat waves and an increase in the frequency of very hot days, coupled with high humidity, can cause death and severe health complications. The elderly and young are most at risk, while outdoor workers can also be severely affected by heat (Sherwood and Huber, 2010). The implications of such a large increase in extreme heat will need to be considered in public sector plans. Interventions to prevent heat exposure (e.g., increasing cooling, ventilation or insulation of buildings, creating cooling stations) and other adaptation measures will be necessary to combat heat-related deaths (Horton et al., 2017).

Increased risks of food- and water-borne diseases and vector-borne diseases are also expected with a changing climate (Smith et al., 2016). Warming has enabled some vectors and pathogens to spread to new regions; for example, the spread of disease vectors such as mosquitos is associated with warming temperatures and changing rainfall patterns. Extreme events, such as floods, can spread waterborne diseases, while droughts can also cause the spread of pathogens as water flows diminish and stagnation reduces water quality (Smith et al., 2016).

Climate change will affect human health in ways that interact with food security. The likelihood of extreme events such as heatwaves, droughts, and floods will increase in frequency and magnitude, resulting in a decrease in food security. People's nutritional status interacts with other stressors and affects their susceptibility to illness (IPCC, 2019b).

The IPCC states that the most effective measures to reduce human vulnerability to climate change in the near term are programs that improve basic public health measures such as the provision of clean water and sanitation, securing essential health care, and increasing capacity for disaster preparedness and response (Smith et al., 2016). Identifying risks, impacts, and vulnerable populations and planning for health impacts play a key role in reducing vulnerability. This requires collaboration of stakeholders from many sectors working together, such as medical professionals, researchers, hydrometeorological scientists, and urban planners.

8.3 Agriculture and fisheries

Climate change impacts on the agricultural sector present a substantial challenge to food security, nutrition, and livelihoods. Whilst crops can benefit from higher carbon dioxide concentrations, both crops and livestock are sensitive to shifting climate variables such as changes in rainfall patterns, higher day and night-time temperatures, heat waves, and other extreme events. The resulting impacts on agriculture are already evident in several regions of the world. All aspects of food security – food availability, access, utilization, and stability – are affected by climate change (Porter et al., 2014).

Climatic thresholds related to various crops – e.g., the damaging levels of specific variables like night-time temperatures, solar radiation, and rainfall – are known in many cases, although the impacts of additional variables and specific impacts on local farming systems requires further research (Rosenzweig and Hillel, 2015). Livestock systems are impacted by climate change mainly through increasing temperatures and precipitation variation. Climate change is also causing distributions of pests and diseases to change, affecting production negatively in many regions. Smallholder farming systems are highly vulnerable because they are highly dependent on agriculture and livestock for their livelihood. The IPCC states interrelationships exist between changing rainfall patterns, food, livelihood security and migration. Where extreme poverty is prevalent, people may be forced to migrate, exacerbating potential for ensuing conflicts (IPCC, 2019b).

Subsistence agriculture is expected to be the most vulnerable to climate change, due to its intermittent production and reliance on maize and beans. Up to 30% of rangers in Guatemala and Honduras, and 13% in Mexico, depend on rainfed agriculture, suggesting high degrees of sensitivity to climate variability and food insecurity. Long term climate change and variability significantly affect the productivity of maize and bean production, affecting the livelihoods of smallholder farmers as well as the food security of the region. Overall, a decrease in suitability and yield is expected in Mexico and Central America. This suggests the need for resources to build adaptive capacity and agricultural innovation. Sustainable ancient farming systems such as raised-field agriculture in Mexico and tropical forest garden in Central America can be considered as options (IPCC, 2019b).

Projections of future climate changes enable informed planning and utilization of existing options and technologies that build resilience in the agriculture sector. They help to determine necessary adaptation strategies, research, collaboration and expertise required both in the near and longer term. Adaptation options include shifts in sowing and harvesting windows, adjustments in plant density, changes in water application that improve water efficiency, best management practices that improve soils and reduce erosion, and planting of cultivars and species with greater tolerance to extreme weather. These practices will likely be necessary to adapt to climate change even as progress is made toward closing yield gaps through agricultural development. Adaptations to soil carbon loss can maintain and improve soil fertility through prevention of runoff and erosion, and management of nutrients through vegetation residues and manure. Many analyses have demonstrated the effectiveness of soil management and changing sowing date, crop type or variety. Additionally, access to a wide range of adaptation technologies for precipitation change is important (IPCC, 2019b).

Fisheries, a vital livelihood in the region, are also impacted by climate change. In many regions, declines in the abundance of fish and shellfish stocks due to direct and indirect effects of climate change and biogeochemical changes have already contributed to reduced fisheries catches. Warming-induced changes in the spatial distribution and abundance of some fish and shellfish stocks have had positive and negative impacts on catches, economic benefits, livelihoods, and local culture. Future shifts and decreases in abundance are projected to affect income, livelihoods, and food security of marine resource-dependent communities. Rebuilding overexploited or depleted fisheries and responsiveness of existing fisheries management strategies can reduce negative impacts on fisheries (IPCC, 2019a).

8.4 Urban areas and infrastructure

Urban areas are characterized by dense populations, buildings and infrastructure, making them sources of resilience and, at the same time, vulnerable to climate change. Over half the world's population lives in cities today, and by the 2050s over two-thirds of the world's population will be housed in urban areas (Revi et al., 2014). Cities must be prepared for the realities of climate change combined with the increase in population density that will make these challenges more difficult (Rosenzweig et al., 2018).

The intersecting components of infrastructure – energy, transportation and water – can have a domino effect during an extreme event, with an impact on one sector in turn affecting other sectors. Managing these intersecting components in urban areas is critical to improving

climate change resilience. Energy suppliers can use temperature projections to alter the design of power systems so that they can operate under extreme temperatures, as well as planning for more frequent peak-load scenarios. In coastal cities, the combination of more frequent extreme sea level events and extreme rainfall and river flow events will make flooding more probable. Buildings, roads and railways projected to be located in flood plains and low-lying coastal areas may need to be relocated, and evacuation routes identified. During an extreme event like a flood, improving the resilience of telecommunications infrastructure such as cell phone towers will allow the other infrastructure systems, as well as decision-makers, to maintain vital communication during a disaster.

Drought and other climate impacts will increase the scale and depth of urban poverty overall. In relation to health, heat waves in cities can cause increased morbidity and mortality rates as a direct result of heat stress (Rosenzweig et al., 2018). Differential vulnerability of urban residents to climate change is driven by factors such as differing levels of physical exposure determined by location of residential and occupational areas, failure to provide access to critical infrastructure and services, social characteristics, as well as institutional governance weaknesses including absence of community engagement. Climate change amplifies vulnerability and hampers adaptive capacity, especially for the poor, elderly, children and women, and ethnic minorities, as these groups often lack proper access to resources and adequate urban services as well as functioning infrastructure (Rosenzweig et al., 2018). In order to increase equity and climate justice, there must be participatory processes that incorporate impacted communities and involvement of civil society as well as monitoring and evaluating to ensure resilience goals are met. Long term goals have to include equity and environmental justice as they build adaptive capacity through human wellbeing, social capital, and sustainable social and economic urban development.

To address these risks, the first step is for decision makers to take stock of current vulnerabilities. This includes developing indicators of current at-risk neighborhoods across a city which could include household income, age, stability of infrastructure, water quality and availability, sanitation, access to transportation and social networks. Planners can also survey current and future infrastructure vulnerabilities to highlight priority areas for adaptation. It will also be critical to evaluate the interdependencies among these various infrastructure systems to prevent failures from one system to affect another. Once these vulnerabilities are known, the second step is for leaders and managers to look at how these various indicators will be vulnerable in the face of the climate projections presented in this report. By looking at a city's vulnerabilities today and comparing them to how they might fare under future climate conditions, decision makers can take the third step to plan and implement adaptation measures to improve resilience in urban areas and associated infrastructure.


© Antonio Busiello / WWF Mesoamerica

9. FUTURE WORK

Several areas for future work have been identified to build on this analysis of climate risk information for the Mesoamerican Reef region.

Activities proposed for future work include:

- Coastal inundation mapping and analysis of coastal flooding and storm surge impacts using static or dynamic modeling
- Climate projections focused on improving the knowledge of hazards and extreme events such as droughts and extreme precipitation
- Monitoring of key climate thresholds to support decision makers in making better resilience decisions (e.g., key climate thresholds related to main species and ecosystems, monitoring protocol for key climate thresholds)
- Monitoring pilot climate adaptation projects using remote sensing analyses (e.g., ecosystem changes related to recent extreme events, changes to pilot project sites from ongoing extreme events)
- Climate projections using CMIP6 climate models and regional climate models
- Crop modeling and climate impacts on agriculture in the region
- Stakeholder engagement to integrate climate risk information into sectoral planning

© Antonio Busiello / WWF Mesoamerica

10. CONCLUSION

The Mesoamerican Reef Region is projected to experience increased temperature, changing precipitation patterns, extreme heat, sea level rise, sea surface temperature increase and ocean acidification.

Climate projections can equip decision-makers with information about emerging risks which can be considered in planning activities. While they rely on the best available information, including the most recent global climate models and datasets, precise projections of climate change are impossible given inherent uncertainties. One important way to reduce that uncertainty is through the approach followed in these pages by showing the full range of possible futures that could arise from climate change—rather than 'most likely' numbers that can be misleading.

Due to the range of outcomes in the climate projections, evolving vulnerabilities and future actions people will take to address climate-related problems, it is important to take a flexible adaptation pathway approach. This approach means that planning must account for the range of possible climate futures, it does not limit future adaptation options and it allows for re-evaluation and changes in approach if new information arises. This will require building resilience to accommodate the potential impacts of climate changes on ecosystems, livelihoods, infrastructure and economic growth.

The effects of climate change in the region are already being felt currently and will increase in the coming decades, challenging a vulnerable population highly centered on climate-dependent livelihoods and ecosystem services. This vulnerability can be expected to increase in the future, as climate models project rising sea levels that would have devastating effects on the coastline, increased temperatures that will challenge agriculture productivity and affect human health through more frequent extreme hot days, and changing precipitation patterns that will affect agricultural livelihoods nationwide. It is thus critical that all sectors—biodiversity and ecosystem services, health, agriculture, urban areas and infrastructure and others —begin planning for these risks to ensure continued economic growth is climate resilient.

© Antonio Busiello / WWF Mesoamerica

REFERENCES

Hausfather, Z., & Peters, G. P. (2020). Emissions–the 'business as usual' story is misleading. Nature 577, 618-620. doi: https://doi.org/10.1038/d41586-020-00177-3

Horton, R., Bader, D., Kushnir, Y., Little, C., Blake, R. and Rosenzweig, C. (2015). New York City Panel on Climate Change 2015 Report. Chapter 1: Climate Observations and Projections. Ann. N.Y. Acad. Sci., 1336: 18–35.

Horton, R., De Mel, M., Peters, D., Lesk, C., Bartlett, R., Helsingen, H., Bader, D., Capizzi, P., Martin, S. and Rosenzweig, C. 2017. Assessing Climate Risk in Myanmar: Technical Report. New York, NY, USA: Center for Climate Systems Research at Columbia University, WWF-US and WWF-Myanmar.

IPCC. 2019a. Special report on the ocean and cryosphere in a changing climate. Intergovernmental Panel on Climate Change. [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

IPCC. 2019b. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Nicholson, E. 2017. IUCN. Mesoamerican Reef, a Critically Endangered ecosystem. Available from: https://iucnrle.org/blog/meso-american-reef-critically-endangered-ecosystem/

Porter, J.R., L. Xie, A.J. Challinor, K. Cochrane, S.M. Howden, M.M. Iqbal, D.B. Lobell, and M.I. Travasso. 2014. Food security and food production systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 485-533.

Revi, A., D.E. Satterthwaite, F. Aragón-Durand, J. Corfee-Morlot, R.B.R. Kiunsi, M. Pelling, D.C. Roberts, and W. Solecki. 2014. Urban areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 535-612.

Rosenzweig, C., Solecki, W., Romero-Lankao, P., Mehrotra, S., Dhakal, S., & Ali Ibrahim, S. (Eds.). 2018. Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge: Cambridge University Press, New York.

Settele, J., Scholes, R., Betts, R. A., Bunn, S., Leadley, P., Nepstad, D., ... & Winter, M. 2015. Terrestrial and inland water systems. In Climate change 2014 impacts, adaptation and vulnerability: Part A: Global and sectoral aspects (pp. 271-360). Cambridge University Press.

Sherwood, S. C., & Huber, M. 2010. An adaptability limit to climate change due to heat stress. Proceedings of the National Academy of Sciences, 107(21), 9552-9555.

Smith, K.R., A. Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn. 2014. Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754

WHO. 2021. COP26 special report on climate change and health: the health argument for climate action. Geneva: World Health Organization; 2021. License: CC BY-NC-SA 3.0 IGO. Available from: https://www.who.int/publications-detail-redirect/cop26-special-report

ANNEX 1: METHOD IN DETAIL

Climate projections were developed using the NASA Earth Exchange Global Daily Downscaled (NEX-GDDP) dataset with 21 CMIP5 climate models for most variables. The methods and models used for some variables differ and are detailed in Table 1 and the following sections. Projections for the Mesoamerican Reef region shown below were developed for Representative Concentration Pathway (RCP) 8.5 and two estimates are given low (25^{th} percentile) and high (75^{th} percentile) to provide a range of future possibilities.

Table A1. Summary of projected essential climate variables influencing climate-induced hazards within this report

Variables influencing hazards	Seasons	Time slices	Future emissions scenarios	Datasets and Resolution	Regions
Temperature • Change	Annual Seasonal projections developed for project regions* Seasons vary by region **See regional section for projections*	Climate model Baseline (1980-2005) 2020s (2011-2040)** 2050s (2041-2070) (presented in report) 2080s (2071-2100)** ***Projections available by request*	RCP 8.5 (presented in report) RCP 4.5*** ****Projections available by request*	NASA NEX GDDP 21 climate model outputs derived from CMIP5 0.25 degrees (~25km)	Overall region Project locations in - Mexico - Belize - Guatemala - Honduras See Figure 1
Extreme heat • Days over 35°C					
Precipitation • Change • Rainy days (days over 1mm)					
Sea level rise • Change	Annual	Climate model baseline (2000-2004) 2020s (2020-2029) 2050s (2050-2059) 2080s (2080-2089)	RCP 4.5 and 8.5 combined	24 CMIP5 models and other datasets (see methodology)	Entire coastline spanning project area
Sea surface temperature • Change	Annual Summer (August to October)	Climate model Baseline (1980-2005) 2020s (2011-2040) 2050s (2041-2070) 2080s (2071-2100)	RCP 8.5 (presented in report) RCP 4.5*** ****Projections available by request*	5 CMIP5 models	Mesoamerican ocean region See Figure 2
pH	Annual			2 CMIP5 models	

Interpreting low and high estimates

In this report, projections are presented as ranges. For temperature, extreme heat and precipitation projections, these estimates are based on a ranking (from most to least) of the outcomes of the 21 global climate models under each greenhouse gas emissions scenarios (results for RCP 8.5 shown in report). We define the low estimate as the 25th percentile of the 21 global climate models under the RCP 8.5 emissions scenario. We define the high estimate as the 75th percentile of the 21 global climate models under the RCP 8.5 emissions scenario.

The 25th percentile, or low estimate, is defined as the value that 25 percent of the model outcomes (5 out of the 21 values) are the same or lower than, and 75 percent of the model outcomes (16 out of the 21 values) are the same or higher than. This 25th percentile value is the model outcome for which 75 percent of the model results reflect a larger increase (or, if the value is negative, a smaller decrease), and thus is considered the low estimate.

The 75th percentile, or high estimate, is defined as the value that 75 percent of the model outcomes (16 out of the 21 values) are the same or lower than, and 25 percent of the model outcomes (5 out of the 21 values) are the same or higher than. This 75th percentile value is the model outcome for which 25 percent of the model results reflect a larger increase (or, if the value is negative, a smaller decrease), and thus is considered the high estimate.

Using a range rather than a single number is especially important for variables such as precipitation, where model projections can range from a decrease to an increase.

Note: Like all future projections, climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system, and limited understanding of some physical processes. For this analysis, the levels of uncertainty are characterized using state-of-the-art climate models and multiple scenarios of future greenhouse gas concentrations. The projections are not true probabilities, instead representing environmental responses to plausible outcomes given socioeconomic and geopolitical decisions, and the projections can be used in scenario planning for risk management for future climate.

Methodology for temperature and precipitation projections

Temperature and precipitation projections were developed using the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset released in 2015 (NASA, 2015). It is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs).

The two RCPs in the dataset are RCP 4.5 and RCP 8.5. The CMIP5 GCM simulations were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections from the 21 models and scenarios for which daily scenarios were produced and distributed under CMIP5. Each of the climate projections includes daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2100. The spatial resolution of the dataset is 0.25 degrees (approximately 25 km x 25 km).

For this analysis, three time slices were developed to represent 30-year averages – 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-20100). Results in this report feature the 2050s timeslice under RCP 8.5. Datasets with other results are available upon request.

The low and high estimates were computed to capture a range of possible future outcomes. The low estimate value reflects the 25th percentile among 21 model projections under each RCP. The high estimate reflects the 75th percentile for each RCP. This report presents low and high estimates for RCP 8.5. Presenting the projections as a range most accurately represents possible future climate conditions for decision-makers and planners applying risk-based approaches to climate change adaptation and resilience.

The Mesoamerican Reef Region overview section contains annual results for the entire region, while the project locations include area-averaged projections for annual and seasonal projections.

Temperature change

Temperature change factors reflect changes of daily mean temperature in °Cin reference to the climate model base period (1980-2005).

Extreme heat days

Extreme heat days reflect the total number of days over 35 °Cfor each future timeslice.

Precipitation change

Precipitation change factors reflect percent changes of total rainfall in reference to the climate model base period (1980-2005).

Rainy days

Rainy days reflect the total number of days with at least 1 mm of rainfall for each future timeslice. This is presented both as the total and change from the model base period (1980-2005).

Methodology for sea level rise projections

A four-component strategy was used to develop sea level rise projections.

First, the ocean term is comprised of two elements: global thermal expansion and local ocean height. The ocean term is taken from the 24 Coupled Model Intercomparison Project 5 (CMIP5, 2016) models (http://cmip-pcmdi.llnl.gov/cmip5/data_portal.html; Taylor et al., 2012); while the first is global, the second is for an individual ocean grid box, after re-gridding to a 1° x 1° grid.

Second, ice melt was estimated for the Greenland Ice Sheet, the two Antarctic Ice Sheets, and glaciers and ice caps. All but the last are based on Bamber and Aspinall, 2013; ice melt for glaciers and ice caps are based on Marzion et al., 2012; Radic et al., 2013. For the ice loss terms, the fingerprint terms that represent the effects of corresponding planetary response of ice loss on sea level rise are not included (these are the gravitational, isostatic, and rotational effects resulting from ice mass loss).

Third, we included land water storage based on IPCC AR5 WG1 (Church et al., 2013).

Fourth, we included vertical land movement/glacioisostatic adjustments (GIA) from Peltier's GIA model (Peltier, 2004).

For each of these three components of sea level change, set percentiles of the distribution were estimated (10^{th}, 25^{th}, 75th, and 90^{th} percentiles). The sum of all components at each percentile is assumed to give the aggregate model-outcome range of sea level rise projections.

Decadal projections were generated by averaging over ten-year intervals and subtracting average values for 2000-2004. Decadal projections were developed for the 2020s (2020-2029), 2050s (2050-2059) and 2080s (2080-2089).

Note: The sea level rise method was developed by the Climate Impacts Group during the CMIP5 era, which is a combined approach using both RCP 4.5 and 8.5. In addition to results from 24 CMIP5 climate models, the database and projections include several other sea level change components (see methods section for details). Since then, CCSR presents results of RCPs separately to communicate trajectories of change associated with different levels of climate mitigation.

Methodology for sea surface temperature projections

Sea surface temperature projections were developed using 5 CMIP5 climate models (CanESM2, CSIRO-Mk3-6-0, FGOALS-s2, GISS-E2-R, MIROC-ESM). It is comprised of downscaled climate scenarios for the globe that are derived from the CMIP5 GCM across two RCPs, RCP 4.5 and RCP 8.5. The spatial resolution of the dataset varies based on models and ranges from 1 degree to 2.5 degrees (approximately 100 km to 250 km).

For this analysis, three time slices were developed to represent 30-year averages – 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2010). Results in this report feature the 2050s timeslice under RCP 8.5. Datasets with other results are available upon request.

The low and high estimates were computed to capture a range of possible future outcomes. Given that 5 climate models were used for this analysis, the low estimate value reflects the lowest value of the 5 model outcomes and the high estimate reflects the highest value for each RCP. This report presents low and high estimates for RCP 8.5.

Projections are area averaged over the Mesoamerican ocean region (see Figure 2), as these ocean models have lower spatial resolution than the downscaled NEX dataset and including additional grid cells can help capture better regional information.

Sea surface temperature change factors reflect changes of daily mean sea surface temperature in °C in reference to the climate model base period (1980-2005).

Methodology for pH projections

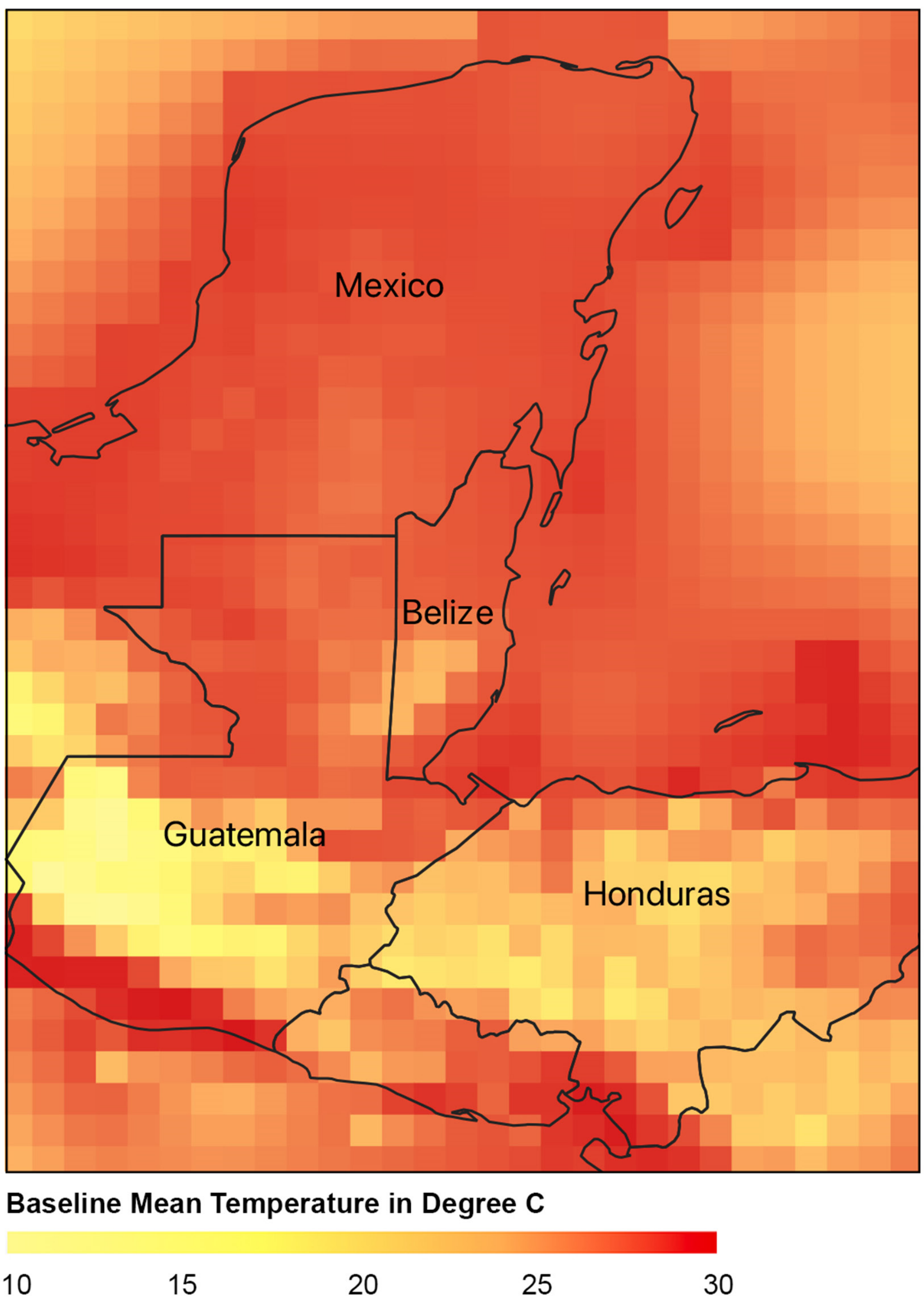
pH projections were developed using 2 CMIP5 climate models (CanESM2 and HadGEM2-CC). It is comprised of downscaled climate scenarios for the globe that are derived from the CMIP5 GCM across two RCPs, RCP 4.5 and RCP 8.5. The spatial resolution of the dataset varies based on models and ranges from 1 degree to 2 degrees (approximately 100 km to 200km).

Similar to the analysis of sea surface temperatures, three time slices were developed to represent 30-year averages – 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2010). Project partners and stakeholders prioritized the 2050s timeslice under RCP 8.5, included in this report, as these are considered to be most useful for planning purposes. Datasets with other results are available upon request. Given that 2 climate models were used for this analysis, a range of outcomes is not presented for pH projections. Projections are area averaged over the Mesoamerican ocean region (see Figure 2).

The absolute value of pH is sea surface temperature change factors reflect changes of daily mean sea surface temperature in °C in reference to the climate model base period (1980-2005).

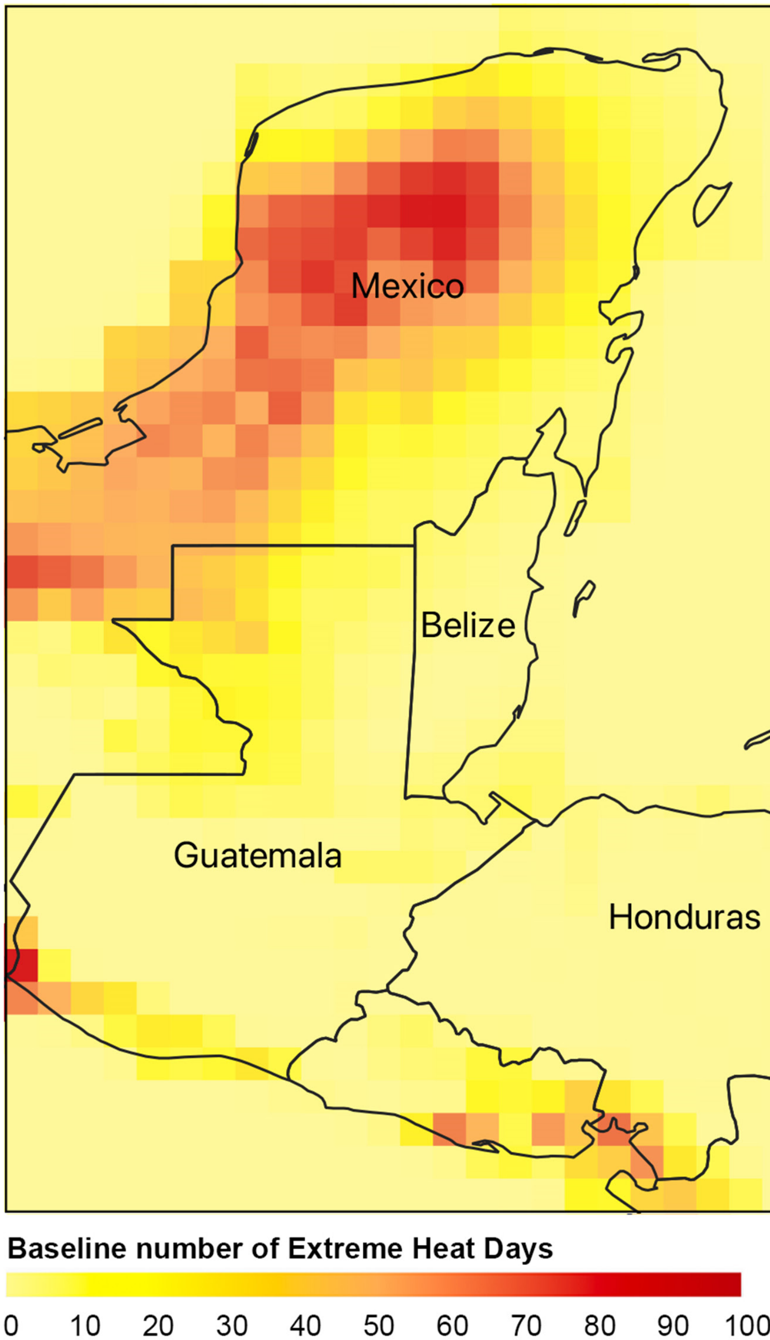
ANNEX 2: REGIONAL BASELINE MAPS

Baseline annual mean temperature (1980-2005)



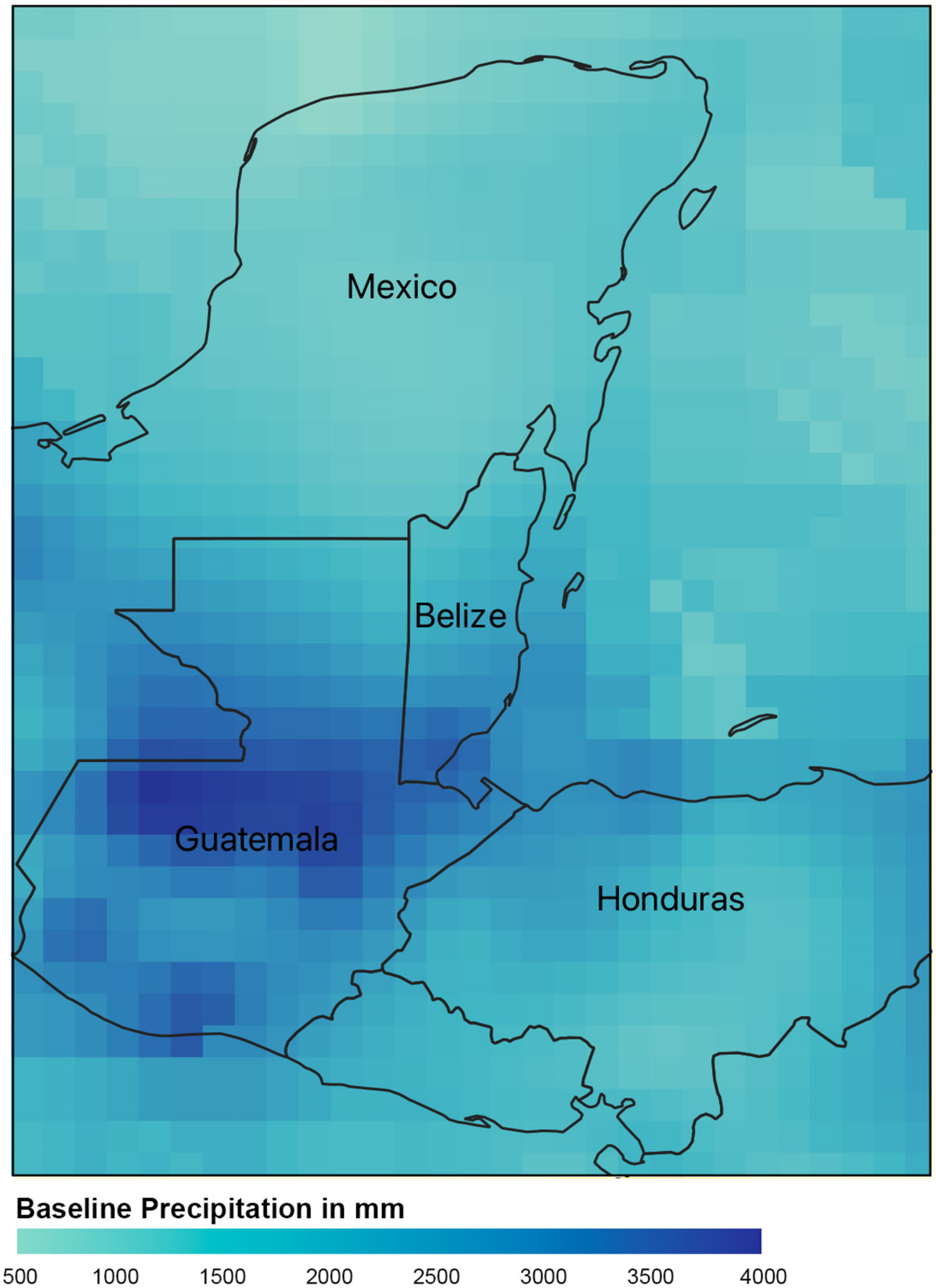
Data source: NASA NEX-GDDP

Baseline extreme heat days (1980-2005)



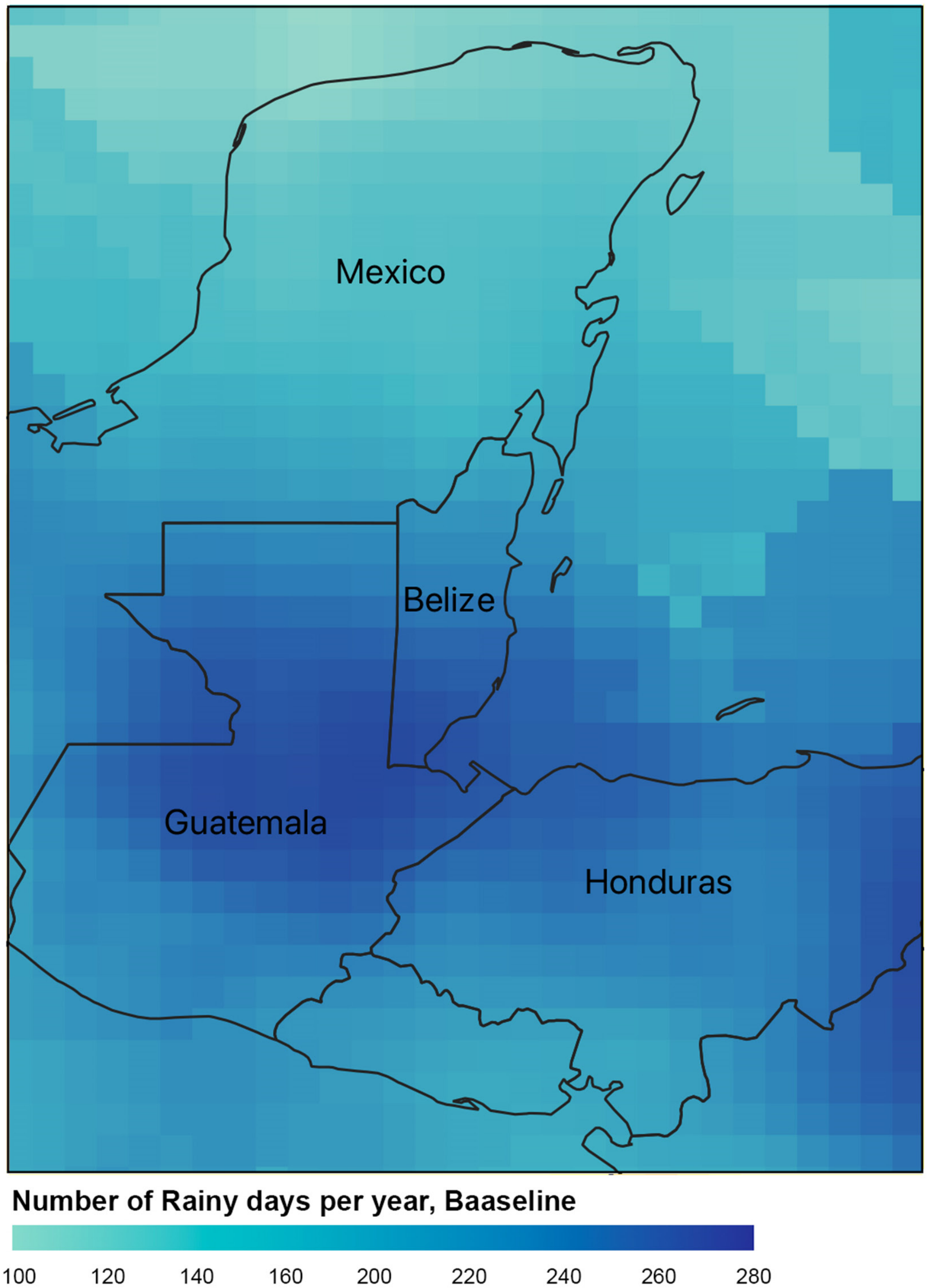
Data source: NASA NEX-GDDP

Baseline annual mean precipitation (1980-2005)



Data source: NASA NEX-GDDP

Baseline rainy days (1980-2005)

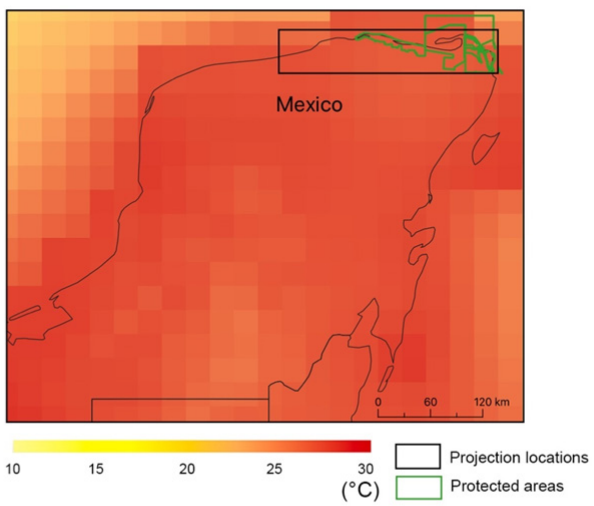


Data source: NASA NEX-GDDP

ANNEX 3: COUNTRY BASELINE MAPS

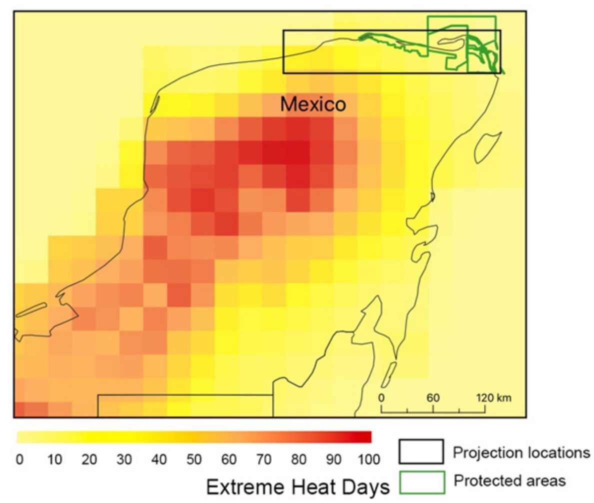
A3.1 Mexico baseline maps

Baseline annual mean temperature (1980-2005)



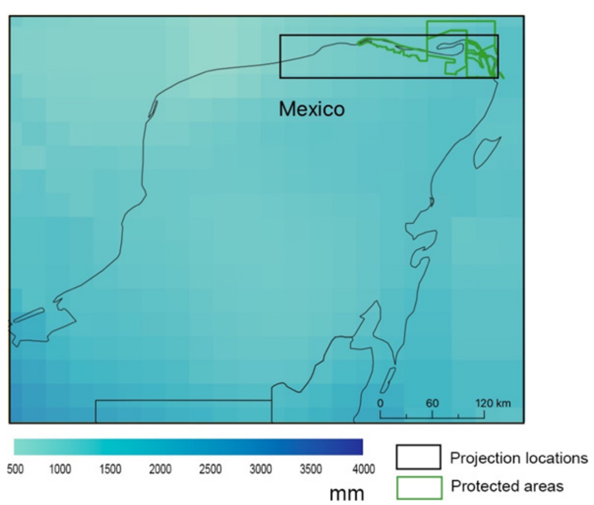
Data source: NASA NEX-GDDP

Baseline extreme heat days (1980-2005)



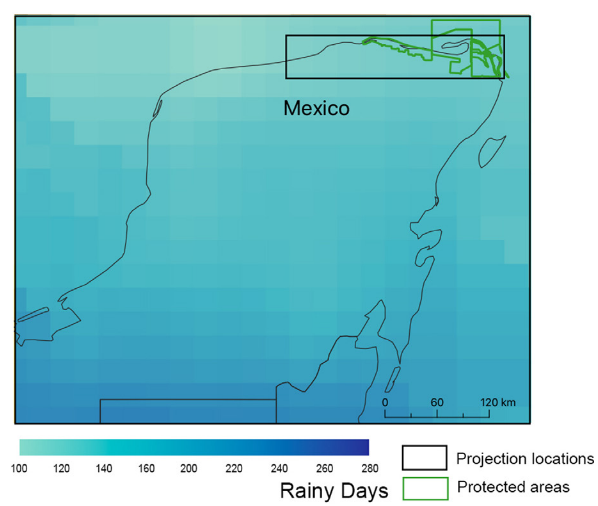
Data source: NASA NEX-GDDP

Baseline annual mean precipitation (1980-2005)



Data source: NASA NEX-GDDP

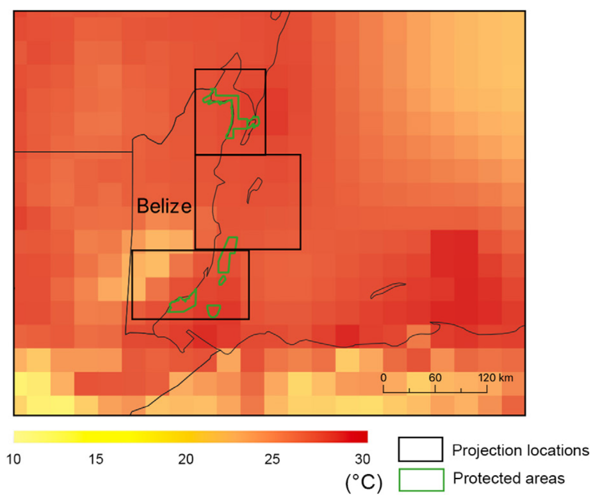
Baseline rainy days (1980-2005)



Data source: NASA NEX-GDDP

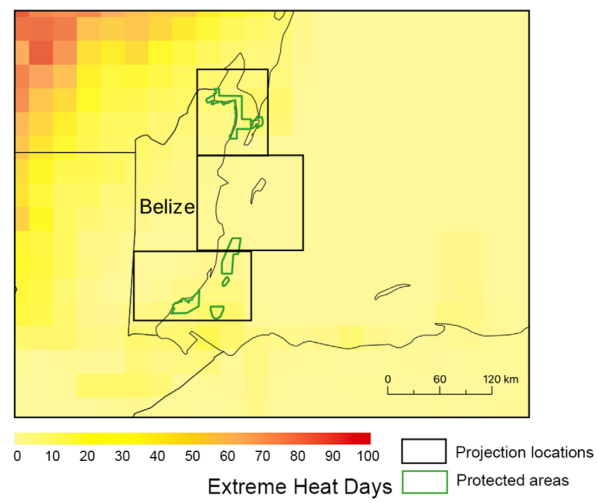
A3.2 Belize baseline maps

Baseline annual mean temperature (1980-2005)



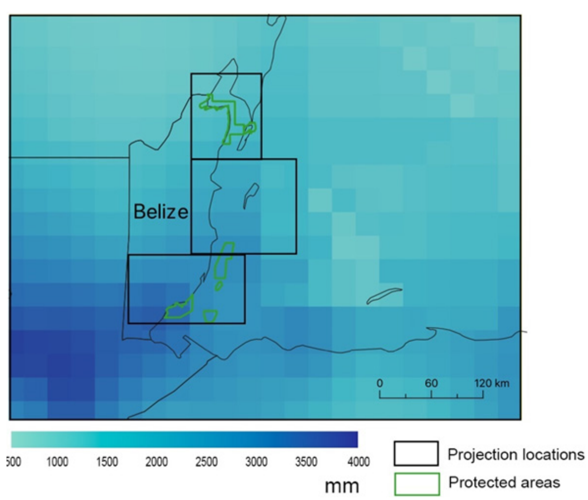
Data source: NASA NEX-GDDP

Baseline extreme heat days (1980-2005)



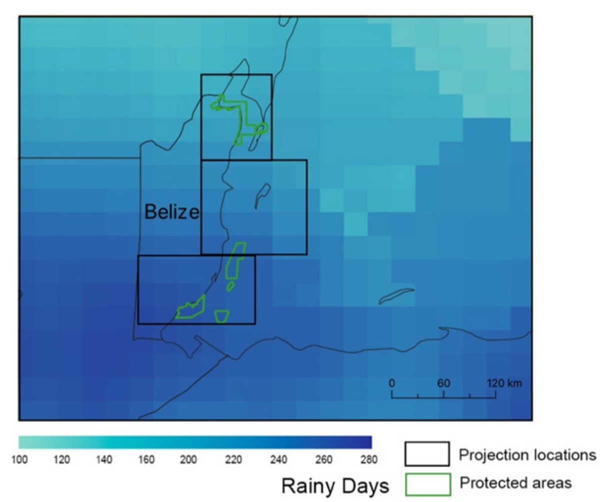
Data source: NASA NEX-GDDP

Baseline annual mean precipitation (1980-2005)



Data source: NASA NEX-GDDP

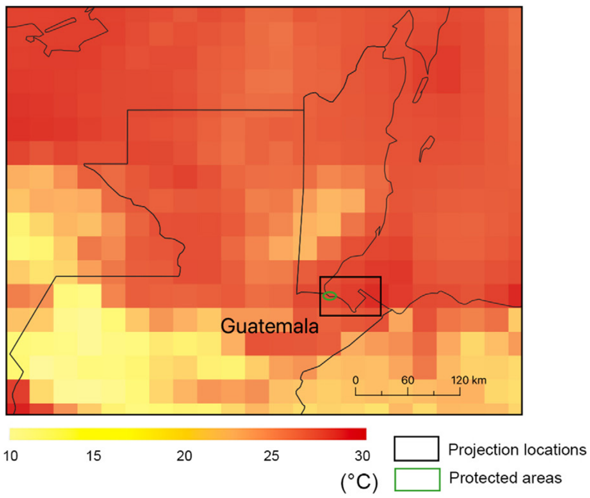
Baseline rainy days (1980-2005)



Data source: NASA NEX-GDDP

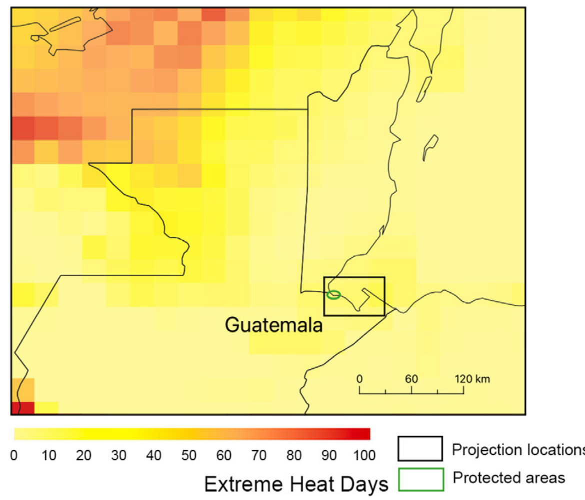
A3.3 Guatemala baseline maps

Baseline annual mean temperature (1980-2005)



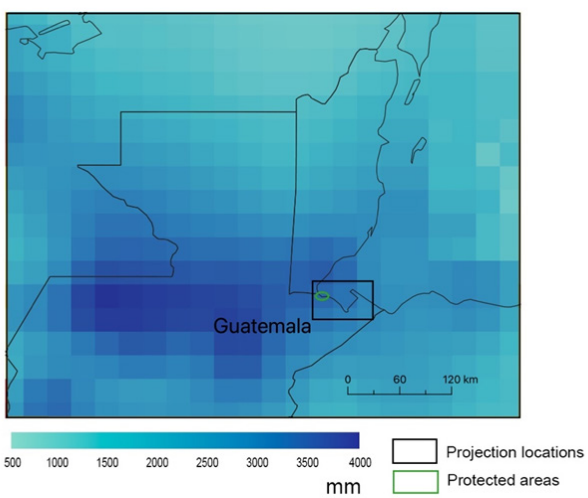
Data source: NASA NEX-GDDP

Baseline extreme heat days (1980-2005)



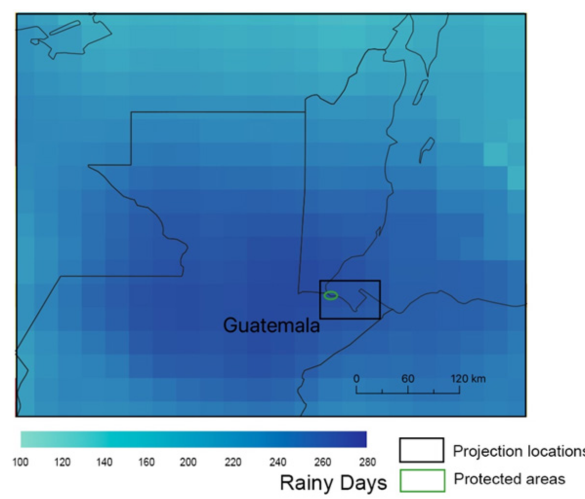
Data source: NASA NEX-GDDP

Baseline annual mean precipitation (1980-2005)



Data source: NASA NEX-GDDP

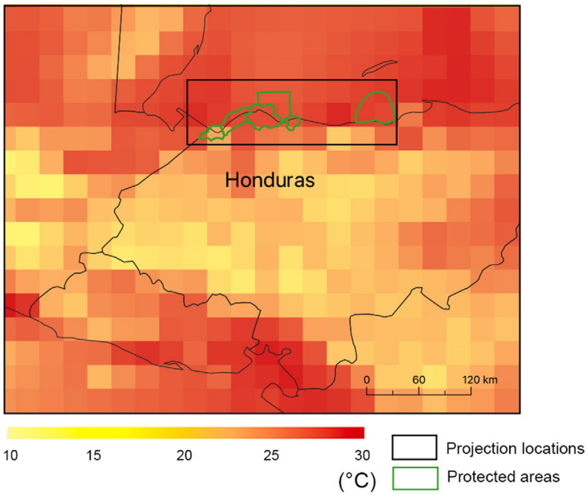
Baseline rainy days (1980-2005)



Data source: NASA NEX-GDDP

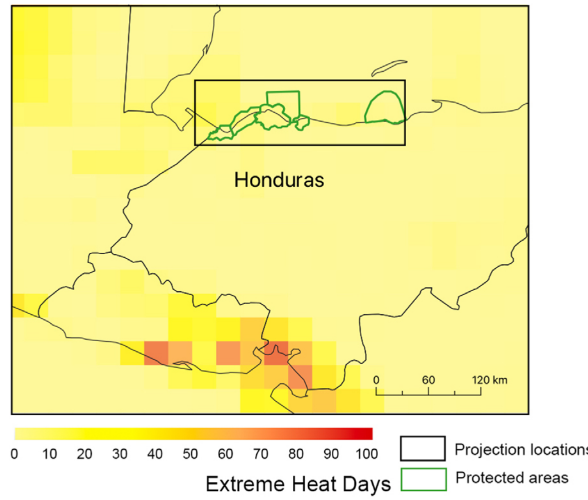
A3.4 Honduras baseline maps

Baseline annual mean temperature (1980-2005)



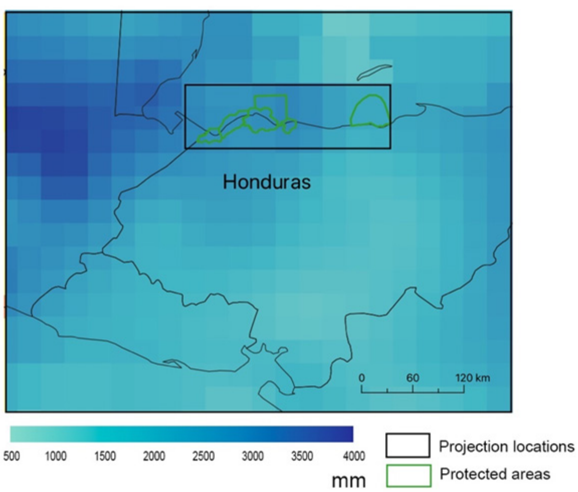
Data source: NASA NEX-GDDP

Baseline extreme heat days (1980-2005)



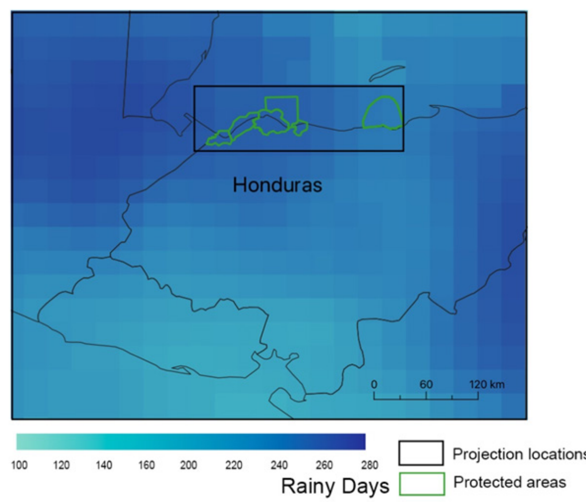
Data source: NASA NEX-GDDP

Baseline annual mean precipitation (1980-2005)



Data source: NASA NEX-GDDP

Baseline rainy days (1980-2005)



Data source: NASA NEX-GDDP

WWF

Working to sustain the natural world for the benefit of people and wildlife.

together possible™

panda.org

© 2023
Paper 100% recycled
WWF® and ©1986 Panda Symbol are owned by WWF. All rights reserved.

WWF Mesoamerica, 15 Avenida 13-45, Zona 10, Colonia Oakland, Ciudad de Guatemala, Guatemala. Tel. +502 2366-5856

For contact details and further information, please visit our website at **wwfca.org**

Cover photography: © Antonio Busiello / WWF Mesoamerica