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CLIMATE CHANGE VULNERABILITY ASSESSMENT AND FUTURE TEMPERATURE PROJECTIONS: A CASE STUDY OF QUINTANA ROO, MEXICO

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Abstract

This study addresses the climate change vulnerability of Quintana Roo, Mexico, a region renowned for its natural beauty and touristic appeal. Facing environmental challenges such as rising sea temperatures, reduced precipitation, and increased natural disasters, the region's susceptibility is exacerbated by its rapid population growth and high dependence on tourism. Utilizing the Representative Concentration Pathways (RCP) 4.5 and 8.5, this research employs the Max Plank Institute-Earth System Model on Low Resolution (MPI-ESM-LR) climate model to project temperature anomalies in the mid (2045-2069) and long term (2075-2099). The research objectives involve assessing vulnerability and projecting future temperature changes. Methodologically, the study isolates Quintana Roo using GIS, calculates temperature differences between reference and projected scenarios, and visualizes the results. The results indicate alarming temperature increases, reaching up to 4.1°C in the pessimistic scenario. The implications are profound, posing severe consequences for the region's equilibrium and livelihoods. In conclusion, this research underscores the critical need for immediate action to address climate change in Quintana Roo. As climate change is a global challenge, the findings contribute to the broader understanding of climate impacts on vulnerable regions.

Keywords: climate change, vulnerability assessment, Mexico, Representative Concentration Pathways (RCP), temperature projections

Introduction

Quintana Roo is a state of the Mexican country that is known for its natural beauty and its great truistic appeal, harboring some important destinations such as Cancun, Playa del Carmen and Tulum. Nonetheless, this coastal region faces significant environmental challenges, climate change being one of the most relevant. Rising sea temperatures, decreasing rainfall, ocean acidification, increasing numbers and intensity of natural disasters, and rising sea levels are some of the effects that could have significant impacts on the region (Botello et al., 2010)

Even though the capital of the state is Chetumal, with only 50 years of history the city of Cancun has been positioned as one of the most visited touristic destinations of the Mexican Republic. Data from the National Ministry of Tourism revealed the total income from lodging services in 2019 amounted to approximately $14.5 billion dollars USD and Quintana Roo stood out with the highest revenue volume representing 22.2% of the total income (DATATUR, 2023). Additionally, the National Institute of Statistics and Geography (INEGI, 2020) reports that as of 2020, Quintana Roo has a total population of

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1,857,985 inhabitants. Moreover, the state boasts the highest population growth rate in the country at 3.5%, presenting significant challenges in meeting the growing demand for resources in the area.

Vulnerability Assessment

This region has a swarm subhumid climate with rains in summer and the type of soil in the area is characterized by having an abundant layer of humus resting on limestone rock, which is a very porous soil type that allows filtrations to the underground aquifer. Some of the ecosystems that prevail in this region are wetlands, subevergreen and subdeciduous medium forests, mangroves, peten, and coral reefs (CONABIO, 2017). These coastal ecosystems are highly vulnerable to climatic events such as storms and hurricanes since they serve as the first natural barrier that protects the coast.

The General Law of Climate Change defines *vulnerability* as:

> "The degree to which systems can be adversely affected by climate change, depending on whether they are capable or incapable of coping with the negative impacts of climate change, including climate variability and extreme events." (Ley General de Cambio Climatico, 2012)

Vulnerability is not only determined by unfavorable climatic conditions but also by the community's ability to prevent, cope with, and recover from the impacts that climatic conditions may have. It is of utmost importance to analyze such vulnerability to understand the challenges facing the region and assess its adaptive capacity. The study area is geographically vulnerable, as it is exposed to extreme weather events like hurricanes and sea-level rise, endangering mangroves and coral reefs. It is projected that the continuous rise in sea level will lead to beach erosion, saline intrusion into the karstic aquifer, and the loss of natural coastal habitats, which are changes that pose a risk to infrastructure, the touristic economy, and local biodiversity (Botello et al., 2010)

Past events such as hurricane Wilma in 2005 have proven that the region is vulnerable to climatic disasters that cause floodings and damage to infrastructure, which put at risk the safety of the communities and tourists. Likewise, rising temperatures can lead to increased incidence of vector-borne diseases such as dengue, affecting the health of the local population and visitors.

Lastly, the region is vulnerable because of its economic reliance on tourism. Since the local economy is tightly intertwined with the touristic industry, big disruptions or downturns in tourist activity can impact the region's financial stability significantly which was proven during the 2020 global pandemic.

Representative Concentration Pathways

In 2014, the Intergovernmental Panel on Climate Change (IPCC) presented its Fifth Assessment Report in which they introduced the four Representative Concentration Pathways (RCPs). For research and climate modeling purposes, these trajectories represent four distinct scenarios of radiative forcing, signifying the additional energy that could reach the Earth due to heightened greenhouse gas concentrations. These scenarios offer an estimable description of how the future can develop. Ranging from mitigation-driven scenarios like RCP2.6 to high-emission scenarios like RCP8.5, they encapsulate a broad spectrum of possibilities influenced by socioeconomic development and climate policies (IPCC et al., 2014). The numerical designation of each RCP corresponds to its total radiative forcing projection for the year 2100, reflecting a range from 2.6 W/m^2 to 8.5 W/m^2. Modelled values of changes in global mean surface temperature for each radiative forcing trajectory are outlined in Table 1.

Table 1: Projection of the Change in Global Mean Surface Temperature for the Mid and Late 20th Century in the RCP Scenarios (IPCC et al., 2014).

Scenario	Global Mean Surface Temperature Change (°C)	
	2046 - 2065	2081 - 2100
RCP 2.6	0.4 – 1.6	0.3 – 1.7
RCP 4.5	0.9 – 2.0	1.1 – 2.6
RCP 6.0	0.8 – 1.8	1.4 – 3.1
RCP 8.5	1.4 – 2.6	2.6 – 4.8

The optimistic emission scenario is the most rigorous (RCP 2.6), which represents the outcomes of urgent and effective climate policy implementation where the temperature increase relative to pre-industrial levels remains below 2°C, and greenhouse gas sequestration exceeds global emissions. The RCP 4.5 and 6.0 scenarios represent stabilization trajectories where greenhouse gas emissions peak and then decline at a moderate pace. Lastly, the pessimistic scenario is RCP 8.5, which projects significant increases in global temperature ranging from 1.4 to 2.6°C in the medium term to 4.8°C by 2100. These trajectories consider the effects of policies aimed at limiting climate change in the 20th century and will serve as a guideline for the temperature projections in this work.

Materials and Methods

For this work the RCP 4.5 and 8.5 RCP scenarios were selected to project the possible temperature changes in the medium (2045-2069) and long term (2075-2099) in the region of Quintana Roo, Mexico. The climate change model selected to conduct this analysis is the MPI-ESM-LR (Max Planck Institute-Earth System Model on Low Resolution) from the Max Planck Institute for Meteorology in Hamburg, Germany. The model was obtained from the Vulnerability Atlas of the National Institute of Ecology and Climate Change in Mexico (INECC, 2020). This model was chosen due to its widely recognized accuracy and reliability in simulating climate scenarios, making it the optimal choice for the analysis.

After that, the Geographic Information System (GIS) called QGIS was used to isolate the state of Quintana Roo, and a map layer was generated for each scenario, starting with the base temperature information between 1950 and 2000. Subsequently, the temperature difference between the reference layer and each studied scenario was calculated to obtain the temperature anomaly for the region. Additionally, the expected average temperature information was transferred to a database to generate relevant graphs. Following this methodology, the potential temperature anomalies in the state of Quintana Roo under four different climate change scenarios were visualized. This information will serve as the basis for an analysis of the potential impacts of climate change in the study area in future work.

Results and Discussion

Four maps were obtained showing temperature anomalies for the medium and long term compared to the average temperature recorded between 1950 and 2000 in the pessimistic (RCP 8.5) and stabilization (RCP 4.5) scenarios. These maps reveal that anomalies ranging from 1.4 to 4.1 °C are projected for the Quintana Roo region, with the highest temperatures expected in the southwest of the state.

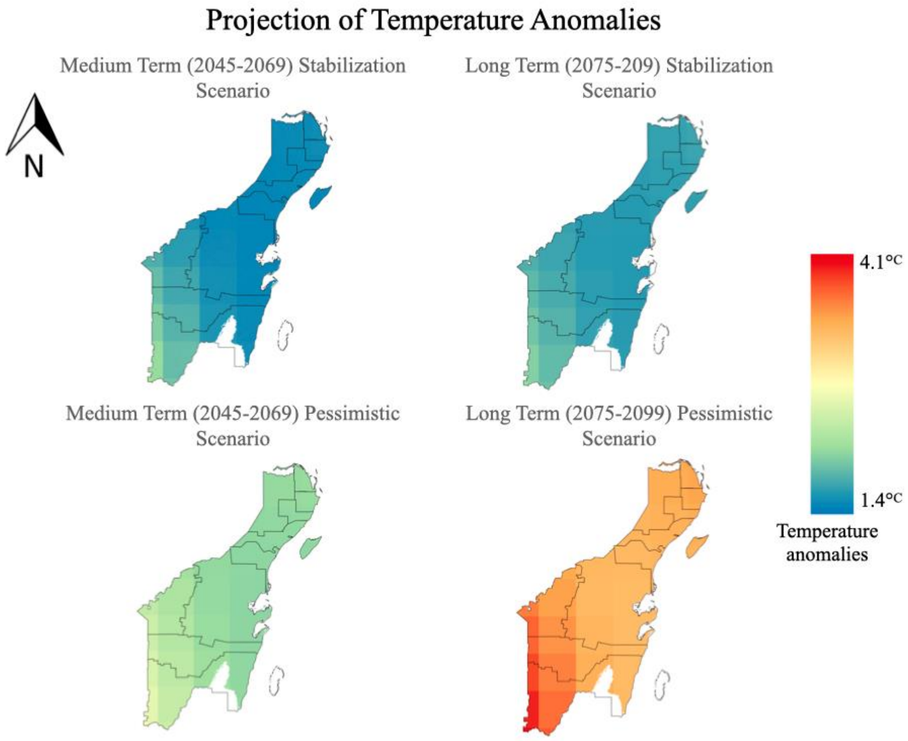

Figure 1: Projection of annual average temperature anomalies in RCP4.5 stabilization and RCP8.5 pessimistic scenarios for medium and long term generated using the climatic model MPI-ESM-LR in the Quintana Roo, Mexico area.

In the stabilization scenario (RCP 4.5), annual average temperature anomalies vary between 1.4 °C and 1.9°C in the medium term and 1.7 °C and 2.1 °C in the long term. However, the pessimistic scenario (RCP 8.5) shows annual average temperature anomalies between 1.9 °C and 2.7 °C in the medium term and between 3 °C and 4.1 °C in the long term.

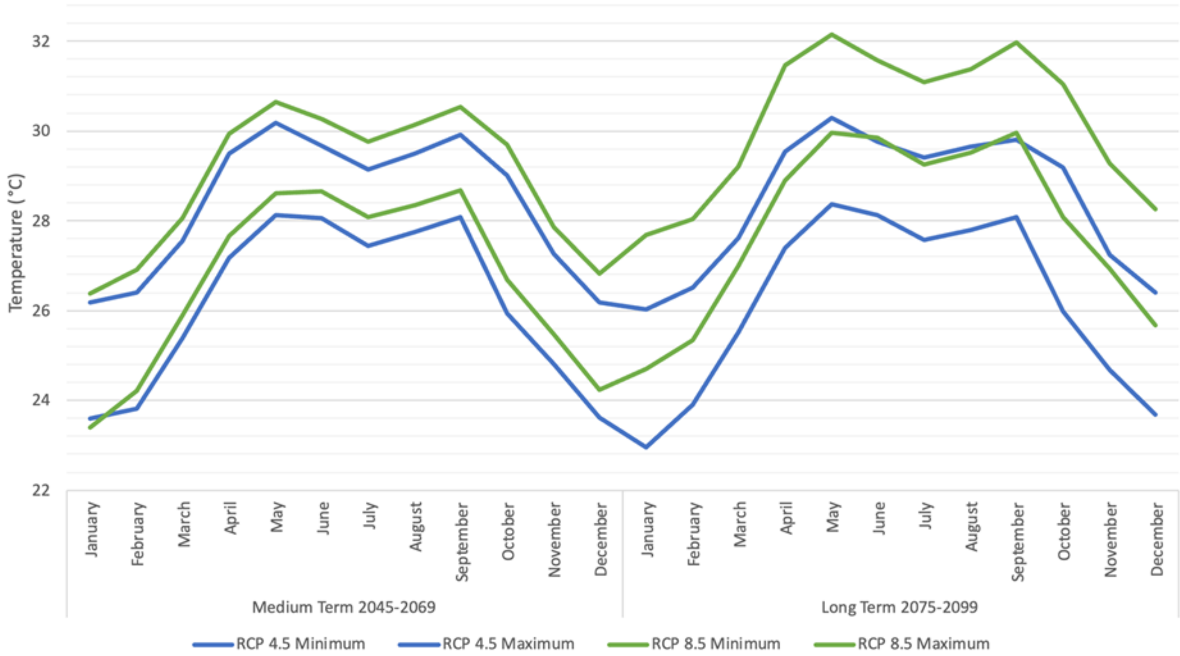

Figure 2: Graph of Monthly Average Temperature Projection according to the MPI-ESM-LR model in the Quintana Roo, Mexico area.

Figure 2 shows the modeled average temperature for each month in the respective scenarios and timeframes using the climate model MPI-ESM-LR. It is observed that for both scenarios, the highest temperatures are reached between the months of April to October, reaching up to 32 °C of average temperature in the months of May in the long term in the pessimistic scenario (RCP 8.5). In the stabilization scenario (RCP 4.5), the highest average temperature is expected in May in the long term at 30.29 °C.

The projected temperature changes indicate a concerning scenario for the Quintana Roo area, as a notable increase in the annual average temperature of up to 4.1°C is expected in the long term in the pessimistic scenario. This would have serious consequences for the balance of ecosystems and biodiversity in the region, as well as for economic activities and the livelihoods of inhabitants.

In the Paris Agreement, the involved nations established the goal of limiting the increase in global average temperature to 2°C in this century through the reduction of greenhouse gas emissions, to which Mexico committed. In the state of Quintana Roo, the stabilization scenario RCP 4.5 is the trajectory that should be followed to meet this goal, which implies implementing climate mitigation measures to reduce greenhouse gas emissions in the long term. Some mitigation strategies that could be pursued include energy efficiency and transitioning to low-carbon energy sources, as well as implementing state-level policies and regulations that encourage emission reduction, promote sustainable practices in various sectors, and manage land use sustainably.

Furthermore, the discussion underscores the need for interdisciplinary approaches integrating economic, social, and environmental considerations in climate action plans. While authorities have taken steps to promote sustainability and resilience, challenges persist in financing, stakeholder coordination, and permitting processes. Addressing these obstacles requires concerted efforts and strengthened collaboration among all stakeholders involved.

Conclusion

The state of Quintana Roo faces significant environmental challenges due to climate change. The effects of rising temperatures, decreasing rainfall, ocean acidification, and sea-level rise pose a significant risk to the region. Additionally, rapid urbanization and population growth present additional challenges for the supply of all types of resources to the area.

Climate change is the greatest challenge facing humanity today, as its causes and repercussions have impacts on all living beings inhabiting the planet, as well as on future generations. It is a highly complex issue composed of many interconnected problems, where it is impossible to devise a strategy that addresses only one problem without repercussions on others. Therefore, sustainable and interdisciplinary strategies that integrate economic, social, and environmental axes must be proposed to achieve results with the greatest long-term positive impact.

Authorities have promoted policies and regulations that foster sustainability and resilience to climate change. In addition, protected natural areas have been created, and conservation and restoration programs for key ecosystems have been implemented. However, there are still challenges and limitations in the implementation of these measures. Financing, coordination among stakeholders, and permitting for development require greater attention and strengthening. It is crucial to continue monitoring and evaluating the impacts of climate change in the state of Quintana Roo.

The protection of natural ecosystems, the promotion of sustainable tourism, and raising awareness among the local community and tourists are fundamental elements to ensure the long-term preservation of this diverse region.

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Declaration of Interest Statement

The authors declare that they have no conflict of interests.

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