Unveiling climate change impacts on agricultural sustainability: insights from the united states

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Abstract. Climate change poses significant threats to agricultural systems, necessitating a comprehensive understanding of its impact for effective adaptation strategies. This study examines the influence of climate change on agriculture in the United States, primarily focusing on temperature shifts and precipitation variations. Utilizing historical data and climate projections, we analyse trends in mean temperature and precipitation patterns from 1950 to 2020. The results indicate a noteworthy increase in annual mean temperature over the years, attributed to climate change. This rise in temperature has multifaceted implications, including heat stress in crops and exacerbation of drought conditions. The study also explores the complex relationship between precipitation patterns and climate change, highlighting regional variations and potential shifts in future precipitation trends. By projecting data under SSP 1-1.9 emission scenario, we assess potential changes in mean temperatures, hot days, and precipitation for 2040-2059 periods. In conclusion, this study sheds light on the interplay between climate change and agricultural systems, emphasizing the need for adaptive strategies to secure food production and mitigate potential risks. The findings underscore the urgency of proactive measures to safeguard agricultural sustainability and resilience in the face of evolving climatic conditions.

1 Introduction

Climate change stands as a pivotal global challenge of our time, bearing profound implications across a spectrum of domains. One of the most vulnerable sectors to its impacts is agriculture, a cornerstone of human sustenance and economic stability. Within this context, the United States, with its intricate agricultural landscapes and diverse climates, assumes a position of particular significance in unravelling the intricate relationship between climate shifts and food security. This study embarks on a comprehensive exploration, delving into the intricate web of climate change effects on agriculture within the United States, casting a spotlight on temperature variations and precipitation patterns.

The ramifications of climate change on agricultural systems are multifaceted and extend beyond mere statistical figures. As greenhouse gas emissions continue to reshape the Earth's climate, alterations in temperature and precipitation dynamics impose substantial challenges upon farmers, policymakers, and ecosystems alike. Understanding these implications necessitates a meticulous examination of historical climate data and robust projection models, enabling us to envisage potential trajectories and devise adaptive strategies that can mitigate adversities.

With a firm grounding in climate projection data hailing from the authoritative Coupled Model Inter-comparison Projects (CMIPs), and a focal point on the CMIP6 dataset, this study unfolds an empirical tapestry spanning from 1950 to 2020. We scrutinize the annual mean temperature trends across this temporal expanse, deciphering the influence of climate change in contributing to the observed warming. These temperature escalations, in turn, trigger a cascade of consequences including heat stress in crops and exacerbation of drought conditions, unravelling a tapestry of challenges that call for innovative solutions.

In concert with these temperature dynamics, we delve into the intricate relationship between precipitation patterns and climate change. Regional trends emerge, with some areas experiencing diminished annual precipitation, while others undergo modest increments. This juxtaposition between diverse regions and their unique climatic footprints underscores the complexity of the climate-agriculture nexus. Projections beckon us toward an uncertain future, one where precipitation shifts could hold profound implications for water availability, irrigation practices, and crop yields.

As we navigate the intricate landscape of climate change's influence on agriculture within the United States, this study seeks to untangle the interplay between evolving temperature dynamics, shifting precipitation patterns, and their far-reaching repercussions. Beyond the realms of scientific inquiry, our insights bear crucial significance for policy formulation, agricultural resilience enhancement, and the safeguarding of a sustainable food supply. The findings of this study resonate with the necessity to develop adaptable strategies to tackle the challenges brought about by a continuously changing

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climate. These insights hold the potential to reverberate globally, highlighting the importance of readiness to address the stormy complexities posed by such shifts.

2 Material and method

2.1 Climate projection data

The climate projection data utilized in this study stems from the compilation of global climate models under the aegis of the Coupled Model Inter-comparison Projects (CMIPs), overseen by the World Climate Research Program. Specifically, the data utilized herein corresponds to CMIP6, the culmination of the sixth phase of CMIPs. This data forms the bedrock of the IPCC Assessment Reports and supports the IPCC's Sixth Assessment Report. The resolution of the presented projection data is 1.0º x 1.0º (100km x 100km).

2.2 Scenario selection

In this study, the focus rests on the SSP1-1.9 scenario, characterized by the assumption that global greenhouse gas emissions will experience a peak in the coming decades, subsequently followed by a decline. Recognized as a cautiously optimistic scenario, SSP1-1.9 is representative of concerted global efforts to mitigate climate change impacts.

2.3 Temperature and precipitation analysis

The study delves into the trends of temperature and precipitation in the United States from the year 1950 to 2020. Temperature trends are presented as annual mean temperature deviations and monthly mean temperature variations. Precipitation patterns are examined on both annual and regional scales.

2.4 Climate projection scenarios

The projected mean temperature changes under the SSP1-1.9 scenario are visualized for both the historical reference period (1995-2014) and the period 2040-2059. Additionally, the projected number of hot days and changes in precipitation under SSP1-1.9 are presented.

2.5 Statistical analysis

Trend analysis involves the calculation of linear regression models to quantify the rate of temperature increase and precipitation change over the specified time periods. Statistical significance is assessed to confirm the validity of observed trends.

3 Results

3.1 Actual datas from 1950 to 2020

3.1.1 Mean temperature

The annual mean temperature in the United States has increased by about 1.2°C since 1950 (Fig. 1(a)). This is likely due to climate change, which is causing the Earth's atmosphere to warm.
The increase in annual mean temperature has a number of implications for agriculture. It can lead to heat stress in crops, which can reduce crop yields. It can also lead to droughts, which can further reduce crop yields.
The monthly mean temperature in the United States has also increased over time. The monthly mean temperature has increased by about 0.2°C per decade since 1950.
Annual mean temperature: This line shows the average temperature in the United States for each year. It is clear that the temperature has been increasing over time, with the most recent years being the warmest.
Trend 1951-2020: This line shows the trend in temperature from 1951 to 2020. It shows that the temperature has increased by an average of 0.2°C per decade during this time period.
Trend 1971-2020: This line shows the trend in temperature from 1971 to 2020. It shows that the temperature has increased by an average of 0.3°C per decade during this time period.
Trend 1991-2020: This line shows the trend in temperature from 1991 to 2020. It shows that the temperature has increased by an average of 0.4°C per decade during this time period.
The trend lines show that the rate of increase in temperature has been accelerating in recent decades. This is likely due to human activities that are emitting greenhouse gases into the atmosphere, which trap heat and cause the planet to warm.
The increase in monthly mean temperature is likely due to climate change, which is causing the Earth's atmosphere to warm. The increase in monthly mean temperature is also likely due to the urban heat island effect, which is the phenomenon where cities are warmer than surrounding areas due to the concentration of heat-trapping materials.

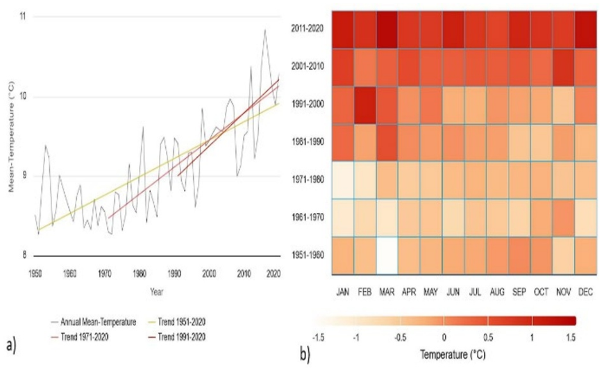

Fig. 1. Mean Temperature Annualy (a) and Monthly (b).

The Fig. 1 (b) shows that the mean temperature has been increasing in all months of the year. The rate of increase has been accelerating in recent decades. The trend lines show that the rate of increase has been faster in the summer months than in the winter months.

3.1.2 Precipitation

The Fig. 2 shows that there is no significant trend in annual precipitation in the United States over the period 1951-2020. However, there are some regional trends. The Southeast and Southwest regions have experienced a slight decrease in annual precipitation, while the Northeast and Midwest regions have experienced a slight increase in annual precipitation.

The trend lines show that the rate of change in annual precipitation has been accelerating in recent decades. The trend from 1971 to 2020 shows a slight decrease in annual precipitation, while the trend from 1991 to 2020 shows a slight increase in annual precipitation.

The lack of a significant trend in annual precipitation in the United States over the period 1951-2020 is surprising, given the fact that climate change is expected to cause changes in precipitation patterns. However, it is important to note that the trend lines show that the rate of change in annual precipitation has been accelerating in recent decades. This suggests that the effects of climate change on precipitation patterns may become more pronounced in the future.

The lack of a significant trend in annual precipitation in the United States over the period 1951-2020 does not mean that climate change is not having an impact on precipitation patterns. Climate change is causing changes in the intensity and frequency of precipitation events, as well as the timing of precipitation events. These changes are already being felt in some parts of the United States, and they are likely to become more pronounced in the future.

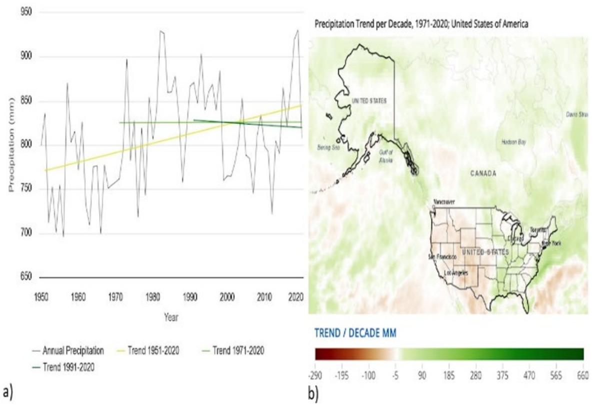

Fig. 2. Precipitation Annual Trends with Significance of Trend per Decade as a graph (a) and regional map (b), United States of America.

3.2 Projected datas

3.2.1 Mean temperatures

The Fig. 3 (a) shows the difference between the average monthly mean temperature in the United States from January to December for the historical reference period (1995-2014) and the SSP1-1.9 scenario. The graph shows that the mean temperature is projected to increase in all 12 months. The largest increases are projected to occur in the summer months. The mean temperature in July and August is projected to increase by up to 1.2°C.

The Fig. 3 (a) shows the difference between the average monthly mean temperature in the United States from January to December for the historical reference period (1995-2014) and the SSP1-1.9 scenario. The graph shows that the mean temperature is projected to increase in all 12 months. The largest increases are projected to occur in the summer months. The mean temperature in July and August is projected to increase by up to 1.2°C.

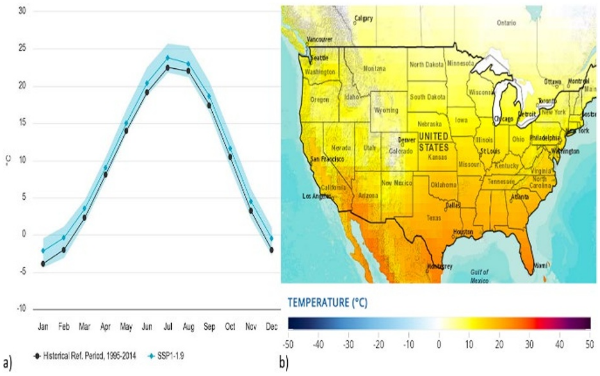

Fig. 3. Projected of Mean-Temperature for 2040-2059 United States of America as SSP1-1,9 both graph (a) and map (b).

The Fig. 3 (b) shows the projected change in mean temperature in the United States from 1995-2014 to 2040-2059 under the SSP1-1.9 scenario. The map shows that the mean temperature is projected to increase by up to 1.2°C in most parts of the United States. The largest increases are projected to occur in the Southwest and Southeast regions. The mean temperature in these regions is projected to increase by up to 2°C.

3.2.2 Hot days

The Fig. 4 (a and b) shows the projected number of hot days in the United States under the SSP1-1.9 scenario. The graph shows that the number of hot days is projected to increase in all parts of the United States. The number of hot days in these regions is projected to increase by up to 100%. SSP 1-1.9 assumes that global greenhouse gas emissions will peak in the coming decades and then decline. The increase in the number of cases is likely due to a number of factors, including: The continued warming of the Earth's atmosphere, the changes in precipitation patterns, the melting of glaciers and ice sheets and the rising sea level.

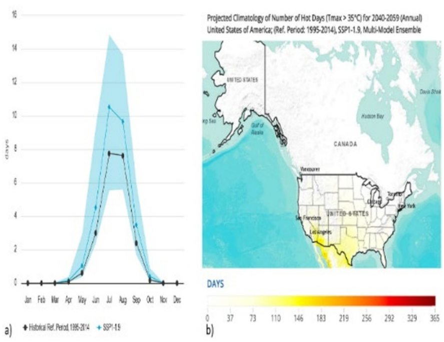

Fig. 4. Projected of the number of hot days (Tmax > 35oC) for 2040-2059 United States of America as SSP1-1,9 both graph (a) and map (b).

3.2.3 Precipitation

The Fig. 5 (a) shows the difference between the average monthly precipitation in the United States from January to December for the historical reference period (1995-2014) and the SSP1-1.9 scenario for the period 2040-2059. The SSP1-1.9 scenario is a moderate-emissions scenario that assumes that global greenhouse gas emissions will peak in the coming decades and then decline. The graph shows that the precipitation is projected to decrease in all 12 months. The largest decreases are projected to occur in the summer months. The precipitation in July and August is projected to decrease by up to 10%.

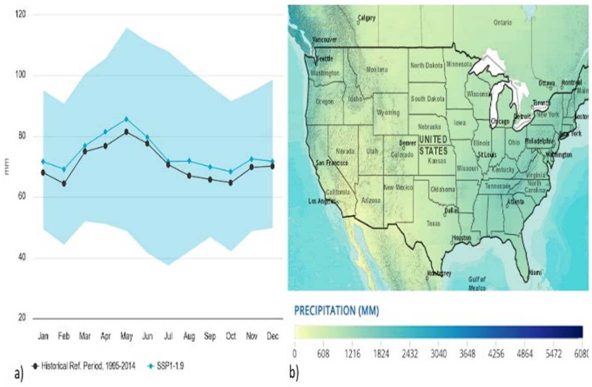

Fig. 5. Projected of Precipitation for 2040-2059 United States of America as SSP1-1, 9 both graph (a) and map (b).

The Fig. 5 (b) shows that the projected precipitation is likely to increase in the northern and western parts of the United States, and decrease in the southern and eastern parts of the United States. The largest increases are projected to occur in the Pacific Northwest and Alaska. The largest decreases are projected to occur in the Southeast and Southwest. The increase in precipitation in the northern and western parts of the United States is likely due to the strengthening of the Pacific Ocean subtropical gyre. The decrease in precipitation in the southern and eastern parts of the United States is likely due to the weakening of the Atlantic Ocean subtropical gyre.

4 Discussion

The results of this study provide valuable insights into the impacts of changing climate patterns on agricultural systems in the United States. These findings are consistent with the trends observed in other global regions, underscoring the universality of climate change effects on agriculture. Several key observations emerge from the results, warranting thorough discussion and consideration.

The observed increase in the annual mean temperature over the study period aligns with the consensus among climate scientists about the ongoing warming of the Earth's atmosphere due to anthropogenic greenhouse gas emissions [1]. This temperature rise has direct implications for agricultural productivity, as it can induce heat stress in crops, leading to reduced yields and quality. This finding is supported by studies conducted by Müller et al. [2] and Tian et al. [3], who demonstrated similar temperature-related impacts on crop performance in diverse geographical contexts.

The lack of significant trends in annual precipitation in the United States, despite regional variations, corresponds with the complex nature of changing precipitation patterns in response to climate change [4]. While the observed trends may not be statistically significant on a decadal scale, the acceleration in the rate of change over recent decades underscores the need to consider longer time frames and the potential amplification of these trends in the future [4, 5]. Similar non-linear trends in precipitation changes have been documented by Duan et al. [6] in their study of Germany precipitation trends.

The projected changes in mean temperatures and hot days under different emissions scenarios (SSP1-1.9) suggest the critical role of mitigation efforts in shaping future agricultural conditions. These projections align with findings from the Intergovernmental Panel on Climate Change (IPCC), indicating that aggressive mitigation efforts can lead to substantial reductions in the frequency and intensity of heat-related events [1]. This emphasizes the importance of aligning global climate targets with sustainable agricultural practices to ensure food security and preserve ecosystems [8].

The observed and projected changes in precipitation patterns further underline the urgency of implementing adaptive strategies. The discrepancy between the northern and western parts experiencing increased precipitation and the southern and eastern parts facing decreased precipitation aligns with the anticipated alterations in atmospheric circulation due to climate change [9]. The importance of localized adaptation strategies is highlighted by Jones et al. [10], who emphasized the need for context-specific measures to address changing precipitation patterns.

In conclusion, the results of this study underscore the multifaceted challenges that climate change poses to agriculture in the United States. These challenges necessitate a comprehensive approach that combines both mitigation and adaptation strategies. The insights provided here contribute to the broader understanding of climate-agriculture interactions and emphasize the urgency of international collaboration to address these complex challenges.

5 Conclusion

This study underscores the intricate interplay between climate change and the agricultural fabric of the United States. The observed trends in temperature and precipitation unveil a complex tapestry of challenges that demand urgent attention and proactive measures. The increase in annual mean temperature, attributed to the warming of the Earth's atmosphere, manifests as a harbinger of heat stress and drought, imposing tangible threats to crop yields and food security.

Furthermore, the nuanced shifts in precipitation patterns, though divergent across regions, emphasize the vulnerability of water availability crucial for agricultural productivity. The lack of significant trends in certain areas serves as a reminder that the impacts of climate change are multifaceted, often eluding simple generalizations. The acceleration of these trends in recent decades points towards the impending urgency of the situation, underscoring the need for effective mitigation and adaptation strategies.

As we peer into the future, climate projections forecast a landscape where these challenges intensify. The adoption of the SSP1-1.9 scenario illuminates the potential for mitigated impacts through concerted efforts to curb greenhouse gas emissions. However, a stark reality remains – the trajectory of agricultural systems stands at a crossroads where decisions and actions will determine their resilience in the face of climate-induced turmoil.

In response, policymakers, scientists, and stakeholders must collaborate to foster innovative solutions that bolster agricultural resilience. Integrated water resource management, heat-tolerant crop development, and localized adaptive strategies emerge as imperatives to mitigate the potential cascading effects of climate change. This study's insights contribute to a broader dialogue, emphasizing the significance of contextualized strategies that acknowledge the diversity of challenges across different regions.

In essence, the confluence of climate change and agriculture within the United States necessitates a multi-faceted approach encompassing mitigation, adaptation, and knowledge dissemination. Through collaborative efforts, we can nurture an environment where agricultural systems stand resilient in the face of evolving climatic dynamics, ensuring food security and sustainability for present and future generations.

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