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A DETAILED EXAMINATION OF TÜRKİYE'S PROJECTED PRECIPITATION AND GROWTH SEASON TRENDS UNDER CLIMATE CHANGE CONDITION

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Abstract: This study presents a comprehensive analysis of Türkiye's changing precipitation patterns and growing season dynamics in the context of global warming, utilizing the Coupled Model Intercomparison Project Phase 5 (CMIP5) and various Representative Concentration Pathway (RCP) scenarios. In light of global warming, this study provides a thorough analysis of Türkiye's evolving precipitation patterns and growing season dynamics using multiple RCP scenarios and CMIP5. The research aims to fill a crucial gap in climate research by combining historical data and future projections to assess Türkiye's precipitation path under different greenhouse gas emission scenarios. The study employs linear regression for trend analysis and uses data from the Climate Change Knowledge Portal (CCKP), with a focus on precipitation data from 1986 to 2100. According to various RCP scenarios, this study's findings show a considerable variation in precipitation trends over the 21st century. The RCP 8.5 scenario predicts a significant decrease in precipitation, which would present difficulties for the management of water resources and agricultural productivity. In contrast, the least severe RCP 2.6 pathway shows a fairly stable pattern of precipitation. Complex seasonal hydrological responses to climate change are revealed by monthly precipitation analysis; RCP8.5 predicts an increase in the frequency of periods of drought and heavy precipitation events. The impact of these changes in precipitation on Türkiye's agricultural growing seasons was further investigated in this study. In high-emission scenarios, there was an initial tendency towards longer growing seasons, which were subsequently followed by shorter ones. This suggests that although global warming might initially result in an extended growing season, it might ultimately cause a reduction in it, particularly in situations where mitigation efforts are minimal. The need for adaptable strategies that can respond to long-term climate trends as well as seasonal variability was highlighted by this research. It draws attention to the fact that to mitigate the effects of climate variability, informed policy decisions and integrated resource management are essential. The results highlight the need for quick action to lower the risks associated with water and highlight the potential advantages of intensive mitigation efforts in stabilizing and extending growing seasons.

Keywords: Climate change projections, Hydrological variability, RCP scenarios analysis

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1. Introduction

Türkiye, which occupies a special geographical location, is experiencing notable climatic shifts attributed to global warming. Sen et al. (2012) and Turkes et al. (2020) have demonstrated through recent studies that there are increasing temperatures and altered precipitation patterns across the country. These changes have implications for various sectors, particularly agriculture and water resources. While these changes align with global trends, they manifest uniquely in Türkiye due to its diverse topography and climatic conditions.

The utilization of the Coupled Model Intercomparison Project Phase 5 (CMIP5) in this research is consistent with its significant contribution to the Fifth Assessment Report of "The Intergovernmental Panel on Climate Change" (IPCC). Türkiye's future climate scenarios can be understood and projected using the robust framework provided by CMIP5, renowned for its comprehensive climate modeling capabilities (Taylor et al., 2012; Dimri et al., 2023). This model was chosen because of its widespread adoption and thorough verification within the climate science community.

For estimating future climatic conditions under various levels of greenhouse gas emissions, the use of Representative Concentration Pathway (RCP) scenarios is essential in this study (Jiang and O'Neill, 2017; O'Neill et al., 2020; Gurney et al., 2022). Each RCP scenario, from high-emission to optimistic trajectories, provides insights into potential future climates and their implications for Türkiye. Successful planning and implementation of climate adaptation and mitigation plans require this approach.

Conducting a comprehensive analysis of Türkiye's precipitation and growing season length trends is crucial in light of the anticipated changes in both regional and global climates. The complicated relationship among climatic variables, including temperature, greenhouse gas emissions, and regional topography, demands a thorough examination of the likely evolution of precipitation patterns. Planning for agriculture, water management, and overall environmental sustainability in Türkiye depends on a deep understanding of these dynamics.

This study aims to adress a significant research gap in climate change by conducting a compherensive analysis of Türkiye's precipitation patterns and growing season length trends under different scenarios of climate change. The study provides important insights into the temporal and spatial changes in precipitation and growing season length trends, addressing both short- and long-term challenges posed by climate change. This is achieved by integrating historical data with future projections.

2. Materials and Methods

2.1. Data Acquisition and Selection for Climate Projection

2.1.1. Data source

The datas utilized in this study were obtained from The World Bank Group's Climate Change Knowledge Portal (CCKP) (Taylor et al., 2012; Dimri et al., 2023). This comprehensive database includes various climate-related data, encompassing historical records and future projections based on different Representative Concentration Pathway (RCP) scenarios (Dimri et al., 2023). Our analysis focused specifically on precipitation data spanning from 1986 to 2100.

2.1.2. Projection model

Indicator CMIP5 was used for the projections. The Fifth Assessment Report of the IPCC is greatly appreciated for the solid framework that CMIP5 provided for climate modeling.

2.1.3. Spatial resolution

The data was displayed at a spatial resolution of 1.0° x 1.0°, or roughly 100 km x 100 km. This resolution strikes a balance between computational feasibility and detail, rendering it suitable for capturing significant climatic trends over large geographic areas.

2.1.4. Selection justification

The use of CMIP5 indicators has been widely accepted and validated within the climate science community, therefore, the credibility of these indicators justifies their inclusion in our study. The model's accurate projections are essential for comprehending potential future climate scenarios (Taylor et al., 2012; Dimri et al., 2023)

2.2. Scenarios Selection and Setup

2.2.1. Climate scenarios used

Detail the specific climate models included in the Multi-Model Ensemble (MME) used for projections. The MME approach provides a more reliable projection of climate variables by integrating the outputs from multiple climate models. This technique minimizes the uncertainties and biases associated with individual models, improving the accuracy of climate projections. The MME provides an extensive overview of potential climate futures by combining data from multiple models, which makes it an ideal tool for evaluating long-term climate trends and variability.

2.2.2. RCP scenarios

RCPs are scenarios that outline different greenhouse gas concentration trajectories (O'Neill et al., 2020). Each RCP represents a specific radiative forcing pathway:

RCP 2.6: Assumes significant mitigation efforts, leading to a peak in radiative forcing at approximately 3.0 W/m^2 before declining to 2.6 W/m^2 by 2100.

RCP 4.5 and 6.0: Intermediate scenarios, with radiative forcing stabilizing at around 4.5 W/m^2 and 6.0 W/m^2, respectively, without significantly decreasing emissions.

RCP 8.5: Represents a high greenhouse gas emissions trajectory, with radiative forcing reaching over 8.5 W/m^2 by 2100, reflecting minimal mitigation efforts.

Each RCP encompasses assumptions about greenhouse gas emissions, land use, and technological changes, influencing the extent of future climate change (Jiang and O'Neill, 2017; Gurney et al., 2022).

2.2.3. Projection periods

Near-Term (2020–2039): Emphasizing policy interventions and the direct consequences of climate change.

Mid-Century (2040–2059): Examining the transitional phase of climate impacts and current mitigation measures.

Late-Century (2060–2079): Evaluating the effects of present emission trends over the long run.

End-of-Century (2080–2099): Providing information on how the climate will change under various greenhouse gas scenarios at the end of the 21st century.

2.2.4. Regression analysis

To analyze the trends in precipitation data, a linear regression model was employed. The purpose of the regression analysis was to calculate the annual rate of change in precipitation for each RCP scenario. The process involved calculating the slope of the linear trend line indicating the annual change in precipitation.

The regression model was constructed as follows:

Data cleaning: Firstly, the dataset was carefully examined to detect any errors or missing data. Subsequently, the data were preprocessed to ensure compliance with the specifications for the regression analysis.

Model fitting: Linear regression was applied to each set of data corresponding to the historical and RCP scenario-specific series. The 'scipy.stats' Python library facilitated this process, with the linregress function simplifying the calculation of the slope and intercept.

Projection and analysis: By projecting future precipitation scenarios, this model offers insights into how Türkiye's precipitation may vary under different conditions.

Visualization tool: The seaborn and matplotlib libraries for Python, which are well-known for their adaptability and effectiveness in data visualization, were used to create the heatmaps.

3. Results

3.1. Precipitation Projections under Different RCP Senarios for Türkiye

Precipitation projections under different RCP scenarios indicate a significant variance in trends over the 21st century (Figure 1). The historical data indicates a decreasing precipitation trend, with a slope of -0.94 mm/year. This trend can be attributed to ongoing climate shifts, possibly influenced by human activity. Under the least severe pathway of the RCP 2.6 scenario, a slope of -0.08 mm/year suggest a relatively stable precipitation pattern. This implies the potential effectiveness of mitigation strategies aimed at reducing greenhouse gas concentrations. The slopes for the intermediate emissions and radiative forcing RCP 4.5 and RCP 6.0 scenarios are -0.51 mm/year and -0.59 mm/year, respectively. These intermediate trends, possibly influenced by delayed effects of emissions controls, exhibit a more noticeable decrease in precipitation, however at a slower rate compared to historical data. The RCP 8.5 scenario is predicted to bring about the most significant changes, with an accelerated decrease in precipitation indicated by a slope of -1.40 mm/year. This scenario implies that future precipitation patterns could be significantly changed, posing potential challenges to water resources management and agricultural productivity. It is characterized by high greenhouse gas emissions and a lack of effective mitigation efforts.

3.2. Monthly Precipitation Analysis under Different RCP Scenarios for Türkiye

Monthly precipitation anomalies by decade under various RCP scenarios are analyzed, and the results show a complex relationship between seasonal hydrological responses and climate change (Figure 2). The heatmaps show variations in precipitation in a striking way, with color gradients indicating the size of anomalies over time. Assuming a strict mitigation pathway, the range of variations in precipitation anomaly is relatively limited under the RCP 2.6 scenario. The first few decades exhibit minimal variations, but as the twenty-first century goes on, a slight trend toward several months of wetter weather becomes apparent. The decreased intensity of anomalies in this scenario highlights the possible advantages of aggressive climate mitigation measures. In contrast, the anomalies clarify an entirely different tale under the RCP 8.5 scenario, characterized by high greenhouse gas emissions and little mitigation efforts. Negative anomalies become more prevalent, especially during typically rainier months, which indicates a trend towards drier weather. The last few decades, especially those after 1970, have shown a noticeable increase in the frequency of dry spells. This indicates a potential disruption in the water cycle, which could have a significant impact on ecosystem services, agriculture, and water resources.

These findings highlight the critical role of temporal and seasonal scales in understanding the impacts of climate change on precipitation. The decadal analysis provides insight into the progressive nature of climate change, revealing how the manifestation of anomalies can shift from one decade to the next. This highlights the challenges in predicting and preparing for future hydrological conditions.

The results emphasize the urgency for adaptive strategies that adress both seasonal variability and long-term climatic trends. The clear trend of increasing precipitation anomalies, especially under high-emission scenarios, calls for an integrated approach to water management that considers the full spectrum of potential future climates.

The projected monthly precipitation by decade patterns (Figure 3), stratified across different RCPs, provide a compelling visual narrative of the potential hydrological shifts induced by climate change. The temporal range includes the near-term (2020–2039), mid-century (2040–2059), late-century (2060–2079), and end-of-century (2080–2099) periods. The temporal scope extends from historical baselines to the end of the twenty-first century.

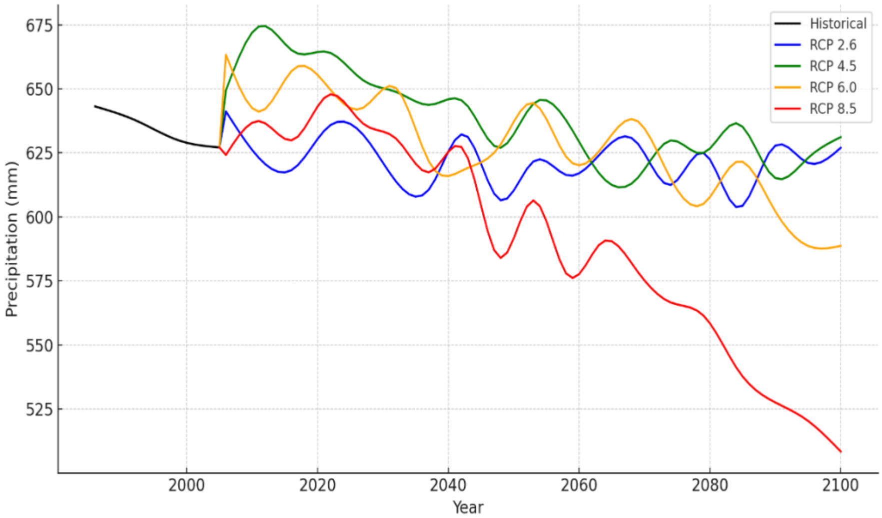

Figure 1. Precipitation projections under different RCP scenarios.

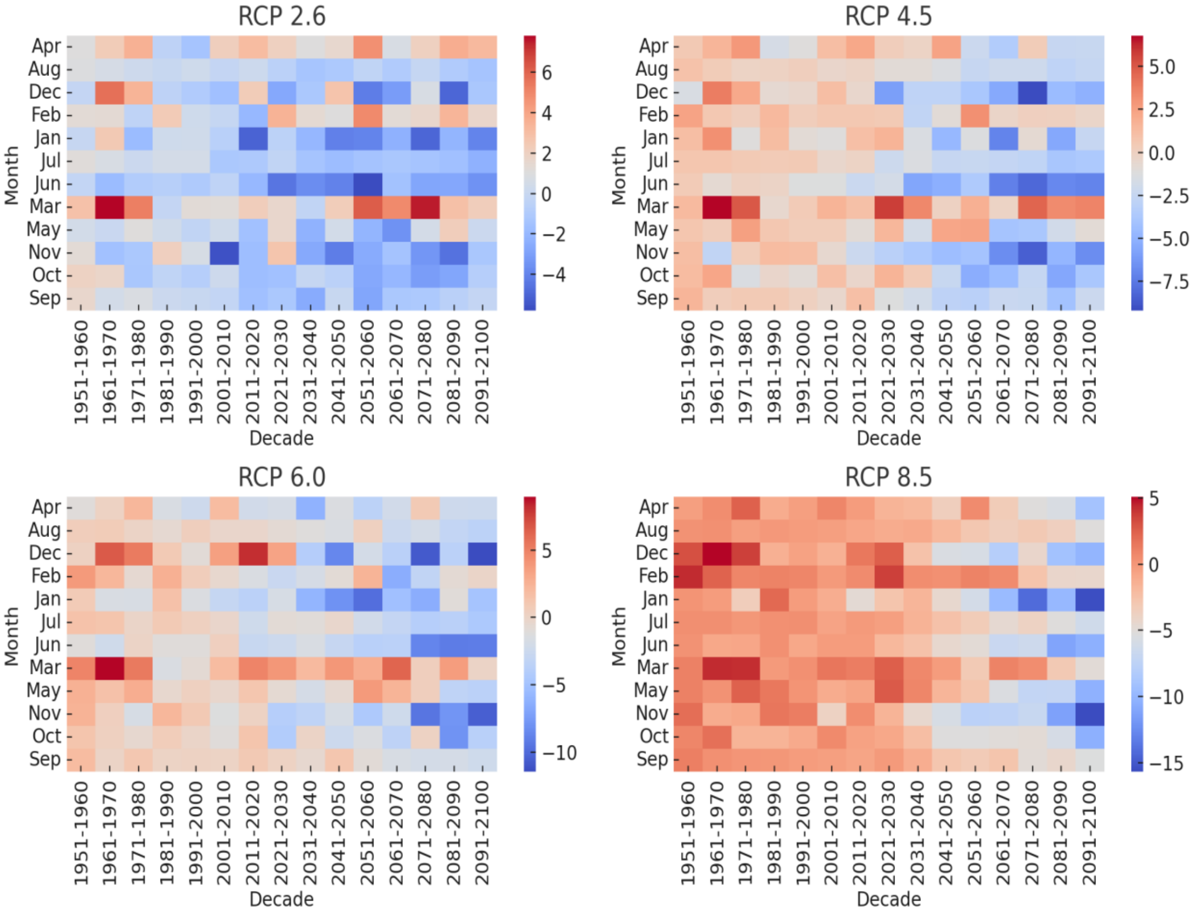

Figure 2. Monthly precipitation anomalies by decade under different RCP scenarios.

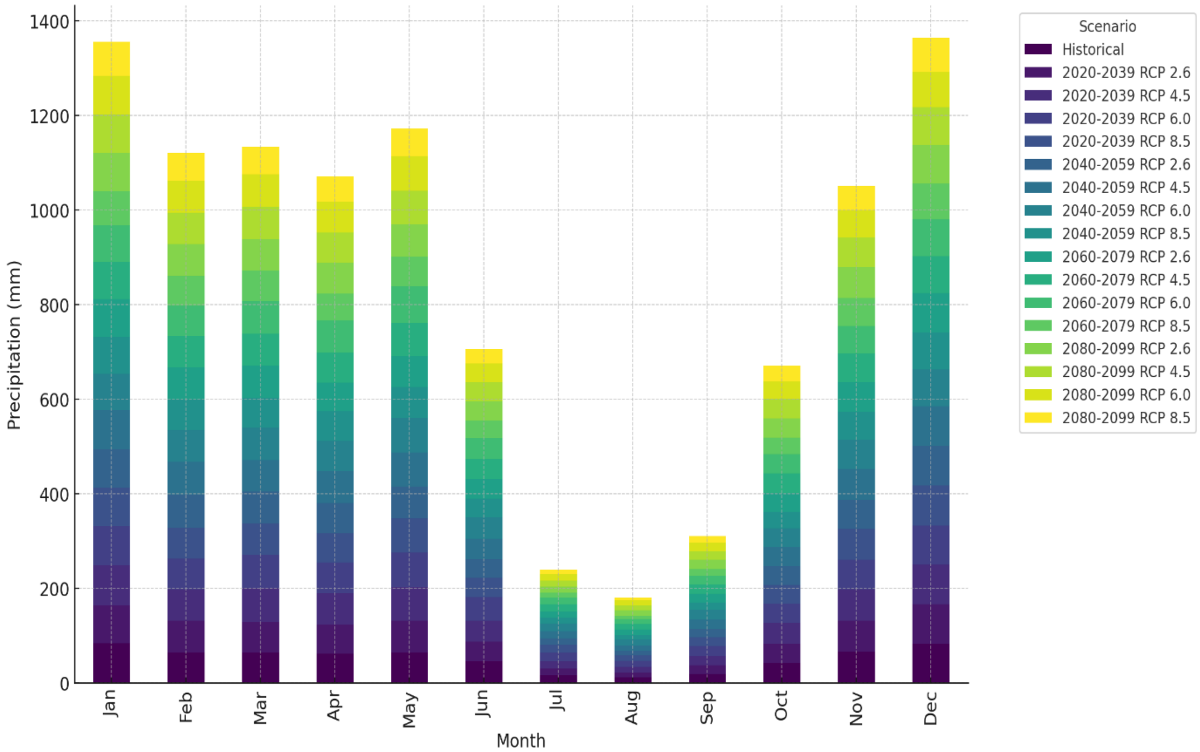

Figure 3. Monthly precipitation by decade across RCP scenarios.

The baseline comprises historical precipitation data, where the natural climatic rhythm is defined by the seasonal peaks and troughs of precipitation. It is predicted that under different scenarios of greenhouse gas concentrations, this rhythmic pattern will change significantly. All RCPs' near-term projections (2020–

2039) demonstrate a continuation of the historical pattern, with a few minor variations that point to the beginning of change.

The deviations from historical norms become more noticeable as the century goes on. All RCPs, including the most optimistic RCP 2.6, start to show changes in the mid-century projections (2040–2059), with certain months displaying significant deviations from the historical precipitation levels. The projections for the late century (2060–2079) show a clear divergence, especially with the RCP 8.5 scenario, which shows the greatest reductions in precipitation. This trend becomes more pronounced by the end of the century (2080–2099), when the RCP 8.5 scenario predicts a significant decrease in precipitation during the traditionally rainy months, while RCP 2.6 maintains more in line with historical patterns, however with some modifications. The scenarios presented in RCP 4.5 and 6.0 illustrate intermediate flows and a complex trajectory. The moderate precipitation decline in these scenarios suggests that mid-range mitigation measures might not be enough to prevent substantial changes in the monthly precipitation distribution. It is noteworthy to observe the variation in the anticipated alterations among the RCPs, underscoring the intricate interplay between emissions scenarios and precipitation dynamics interact. Despite the general decline in precipitation, the distribution and degree of change are closely related to the emissions pathways that are being followed.

This analysis highlights the importance of considering both temporal and spatial scales in precipitation projections. The significance of taking into account both temporal and spatial scales in precipitation projections is highlighted by this analysis. Monthly precision enables a better understanding of potential seasonal resource challenges. The information highlights the urgency of developing focused adaptation plans that can handle the extremes and unpredictability of future climates.

3.3. The Analysis of 20mm+ Precipitation Events under Different RCP Scenarios for Türkiye

When significant amounts of precipitation (more than 20 mm) are analyzed historically and projected for the future, a pattern that is consistent with the hydrological cycle increasing under elevated greenhouse gas concentrations is revealed (Figure 4). The historical data provides a baseline by demonstrating variability in the frequency of these events but not an obvious long-term trend. The frequency of heavy precipitation events first declines under the RCP 2.6 scenario, which reflects a pathway of significant mitigation, and then gradually increases towards the end of the century. This implies that vigorous emissions reductions may lead to the hydrological cycle's eventual stabilization and recovery. On the other hand, heavy precipitation events are projected to occur more frequently under RCP 8.5, which assumes high greenhouse gas emissions in the lack of major mitigation efforts. This pattern suggests that the hydrological cycle is becoming more intense, which will probably lead to more frequent flooding and related socioeconomic effects. The frequency of heavy precipitation events varies in scenarios RCP 4.5 and RCP 6.0, which correspond to intermediate emission levels, but there is an overall increasing trend. In contrast to RCP 6.0, which exhibits more fluctuation, the RCP 4.5 scenario predicts a more stable increase. This suggests that variations in emissions paths could lead to variability in precipitation patterns.

This analysis highlights the increased likelihood of extreme precipitation events in all future scenarios, with the highest emissions scenario showing the greatest increase in risk. The observed trends emphasize the urgent need for adaptation plans to mitigate the risk of flooding and other water-related disasters. The data also suggests taking proactive steps to mitigate these changes by limiting greenhouse gas emissions to slow down the rate at which they progress.

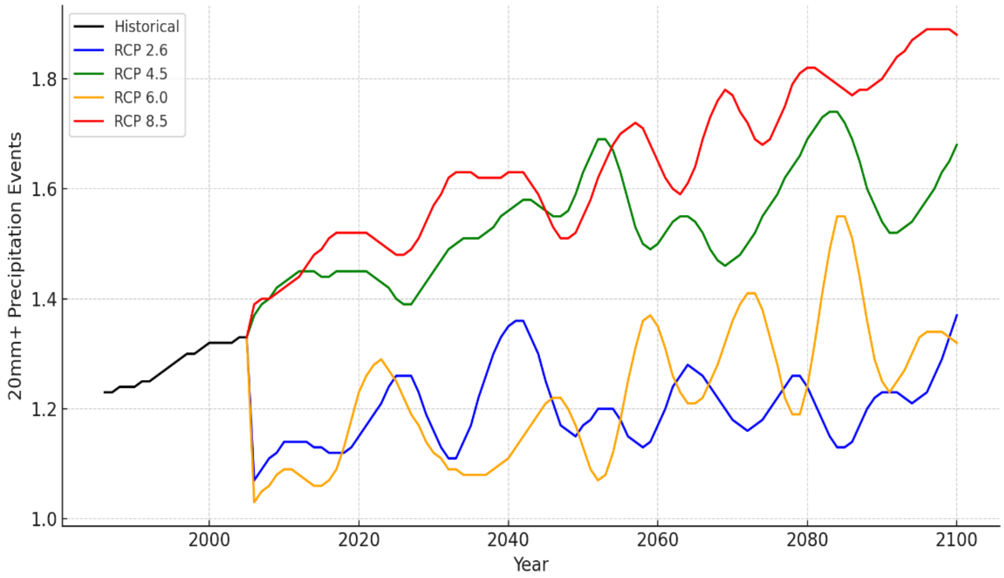

Figure 4. Change in annual 20mm+ precipitation events from 1986 to 2100 based on historical data and RCP scenarios.

The heat maps of monthly anomalies in heavy precipitation events (exceeding 20 mm) that are displayed provide light on the subtle changes that are predicted to occur under different RCP scenarios in the 20th and 21st centuries (Figure 5). Understanding the distinct effects of climate change on monthly precipitation extremes depends on this temporal-spatial analysis.

The anomalies exhibit fluctuations within a narrow band in the RCP 2.6 scenario, which assumes strict efforts to mitigate climate change. This indicates a relatively stable pattern of heavy precipitation events. Despite slight increases or decreases in certain decades, overall stability indicates that precipitation extremes could be decreased with effective mitigation.

The moderate emission reduction pathway known as RCP 4.5 exhibits a mixed pattern of anomalies, with some periods most notably the mid-21st century pointing to possible increases in heavy precipitation events. This hypothetical scenario highlights the complexity of intermediate climate responses, in which some areas might see increased variability in extreme weather occurrences. The heat map for RCP 6.0 shows that as the century goes on, the climate will become drier with more notable negative anomalies. This raises the possibility of fewer heavy precipitation events, which could have a significant impact on disaster mitigation and the management of water resources.

The most notable negative anomalies are found in RCP 8.5, the pathway with the least mitigation and the highest greenhouse gas emissions, especially in the second half of the twenty-first century. A drier climate with fewer heavy precipitation events may cause more droughts, affecting ecosystem services, agriculture, and water security. The differences between various emission scenarios and their possible effects on heavy precipitation events are highlighted by the heat map analysis. It emphasizes the importance of understanding seasonal and localized variations in precipitation to develop effective risk management and adaptation plans.

The presented data highlights the necessity for emissions reductions to mitigate the negative effects of climatic changes on precipitation extremes. Therefore, it recommends a forward-looking approach to climate policy, emphasizing the urgency of addressing emissions to safeguard against the potential consequences of altered precipitation patterns.

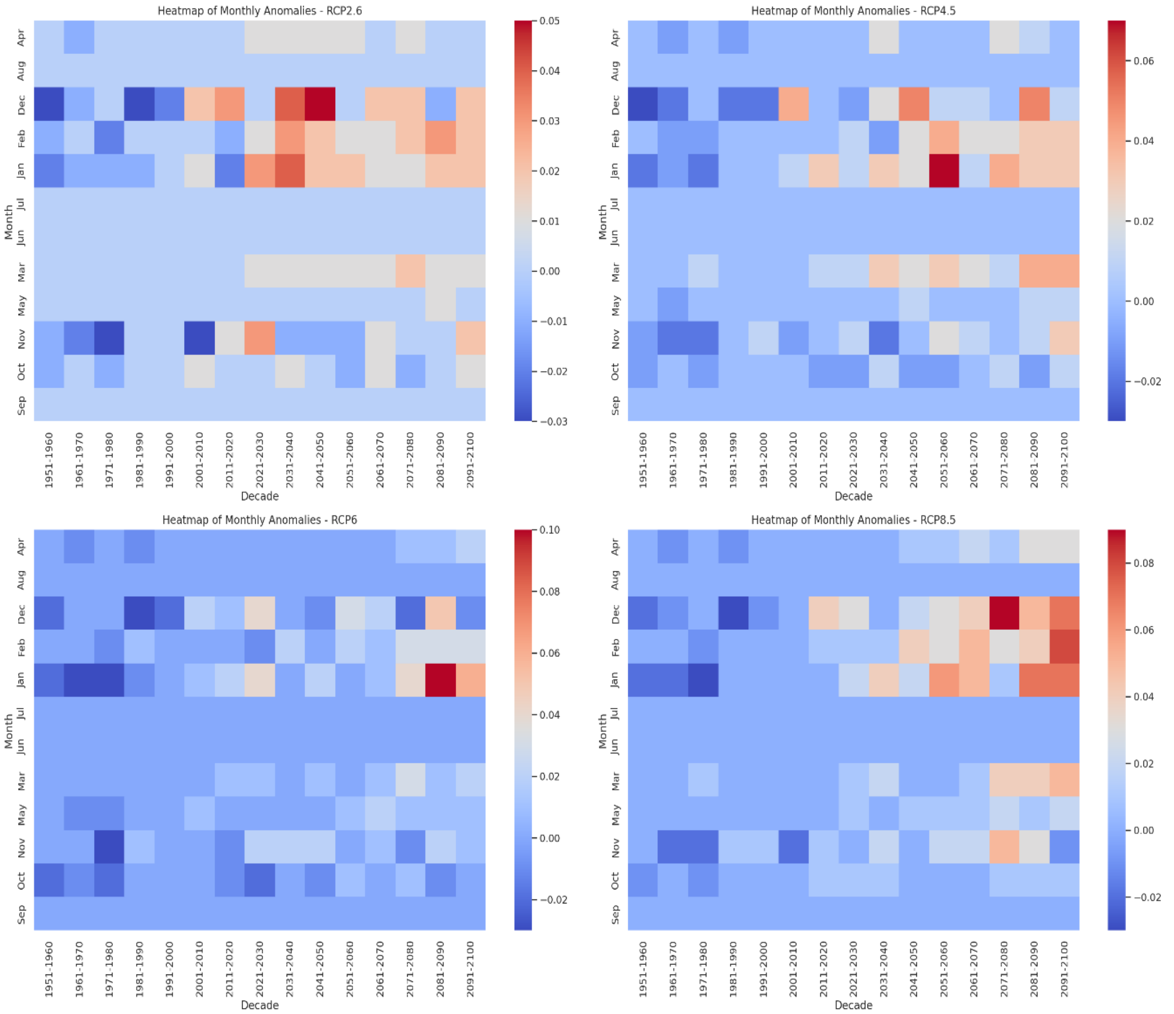

Figure 5. Monthly 20mm+ precipitation events anomalies under different RCP scenarios.

3.4. Growing Season Length under Different RCP Scenarios for Türkiye

The growing season length's temporal evolution, as shown by data from observations and projections under various RCP scenarios (Figure 6), offers a deep understanding of climate change impacts on agriculture. A baseline is set by the historical reference period (1986–2005) against which notable expansions and contractions of the growing season are evaluated.

Under the RCP 2.6 scenario, characterized by low greenhouse gas emissions and significant mitigation efforts, the length of the growing season exhibits moderate fluctuations with an overall trend of slight increase. This implies that strict climate regulations may help to stabilize and potentially improve the growing season for agriculture, protecting against the more extreme climate change effects. It is possible to observe a more identified variability in the growing season length when we proceed to RCP 4.5, an intermediate scenario. There is an initial increase, which is followed by a period of stability and then a decline towards the end of the century. This illustrates the mitigation strategies related to this pathway's limited and partial efficiency. A tendency toward a shorter growing season in the later half of the century is indicated by the RCP 6.0 scenario, which shows a similar pattern to RCP 4.5. This highlights the necessity for more effective mitigation strategies to maintain agricultural productivity.

In RCP 8.5, which assumes high emissions without significant mitigation efforts, the growing season starts longer, peaks in the mid-century, and then experiences a drastic decrease. According to this scenario, agricultural viability may decline as the century goes on, which could have a significant impact on both food security and the stability of the agricultural industry's economy.

The variations in growing season length under various emissions scenarios highlight the critical dependence of agricultural systems on climate conditions. These findings imply that, despite the warming climate may temporarily lengthen the growing season in some places, the risks of increased variability and possible decline in the absence of substantial emissions reductions are likely to outweigh these benefits.

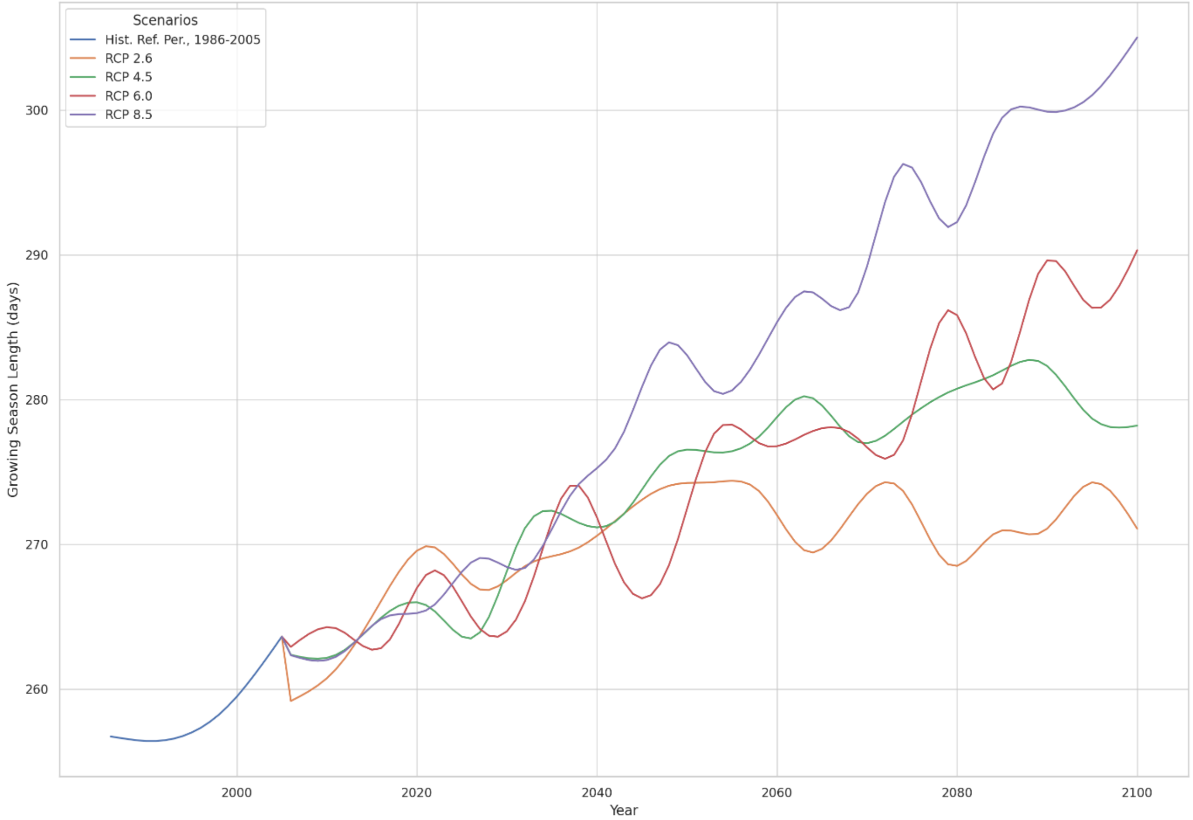

Figure 6. Growing season length under different RCP scenarios.

4. Discussion

The current study reveals that, under various RCP scenarios, Türkiye's growing season length varies noticeably. In the early decades, there was a tendency toward longer growing seasons, which were then followed by shorter ones, particularly in high-emission scenarios. A global perspective on the effects of climate change is given by Ruosteenoja et al. (2011), who highlight changes in temperature and precipitation. Their results are consistent with the current study's observation of a longer growing season initially and a shorter one later on in Türkiye, indicating that global warming may initially extend the growing season but may also eventually cause it to decrease in Türkiye. Their findings about the lengthening growing season as a result of rising temperatures directly relate to the work being done now, especially when considering the implications for Turkish agriculture. Vizy et al. (2015) highlight how local climate systems can react differently to global climate drivers by focusing on regional climate variability. This study provides evidence in favor of the hypothesis that regional traits, like those present in Türkiye, can have a major impact on the local display of global climate trends. In their study, Arslantaş and Yeşilırmak (2020) investigate the climatic growing season in Türkiye's western Anatolia. Their results regarding the extended growing season as a result of rising temperatures are directly correspond to the present investigation, especially when considering the implications for Turkish agriculture.

The current study, also, provides a thorough examination of Türkiye's precipitation trends under various RCP scenarios. An important reduction in precipitation should be noted, especially in high-emission scenarios (RCP 8.5), which could be a direct consequence of global warming. As noted in studies like Demircan et al. (2014), increased temperatures can disrupt atmospheric circulation patterns, affecting precipitation distribution. Land use changes in Türkiye, including urbanization and deforestation, as discussed by Ciftci and Sahin (2023), might be contributing to local climatic alterations, influencing rainfall patterns. This is consistent with the findings of Bağçaci et al. (2021), who highlighted the impact of anthropogenic changes on local climates. Thus, this indicates possible difficulties in managing Türkiye's water resources and agricultural output.

The Mediterranean climate, which dominates much of Türkiye, is characterized by its own unique set of climatic interactions. According to studies by Aziz and Yücel (2021), regional climatic phenomena like the Mediterranean Oscillation are important factors in determining patterns of precipitation. Regional climate variations were also studied by Demircan et al. (2014) and Demircan et al. (2017), with a particular emphasis on the Mediterranean basin. Their results demonstrate the more extensive regional effects of climate change and confirm the trends found in the current study. These studies' consistency emphasizes how urgent it is to address Türkiye's hydrological changes caused by the climate.

The observation of a reasonably stable precipitation pattern under the RCP 2.6 scenario in the current study is consistent with the findings of Okkan (2014) and Ciftci and Sahin (2023). The combined results of these studies highlight the potential effectiveness of strict climate mitigation measures in stabilizing precipitation patterns, which is especially pertinent for Türkiye's policy-making process.

Bağçaci et al. (2021) and Aziz and Yücel (2021) support the importance of the seasonal and decadal variability in precipitation patterns found in the current study for Türkiye's agricultural sector. In light of changing seasonal rainfall patterns, these studies emphasize the importance of adaptive agricultural practices as a means of guaranteeing Türkiye's food security.

Seker and Gumus (2022) offer valuable perspectives on beneficial approaches to water resource management. When the results of this study are taken into account, it is evident that Türkiye needs to manage its water resources in a proactive and integrated manner to mitigate the effects of changing patterns of precipitation.

According to the current study and Yeşilköy and Şaylan (2022), changes in the hydrological cycle brought on by warming temperatures may increase in extreme weather events. This covers variations in precipitation intensity and frequency in addition to changes in precipitation quantity. Because of these shifting precipitation patterns, Türkiye's agriculture industry, which is crucial to the country's economy, may encounter serious challenges. Studies like Okkan (2014) and Seker and Gumus (2022) highlight the necessity of adaptive agricultural practices and water management strategies.

5. Conclusion

There is a complicated relationship between growing season dynamics, the frequency of extreme weather events, and precipitation trends. Some individuals may view a longer growing season as a positive outcome of global warming, but these benefits can be overshadowed by the inherent threat of more frequent and severe weather events.

This current comprehensive analysis delineates a future where precipitation patterns, extreme weather events, and agricultural growing seasons are increasingly influenced by climate change. The anticipated changes in hydrological dynamics under all RCPs highlight the need for effective mitigation and flexible approaches. The data highlights the potential benefits of rigorous mitigation efforts in stabilizing and potentially extending the growing seasons also calls for immediate action to reduce water-related risks, particularly under higher emission scenarios. This emphasizes how important it is to make well-informed policy decisions and practice integrated resource management to protect against the various effects of climate variability in Türkiye.

Author Contributions

The percentage of the author(s) contributions is presented below. The author reviewed and approved the final version of the manuscript.

	E.Ç.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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