Chapter 4

# Regional Climate Dynamics and Agricultural Vulnerability in California: A Multi-County Analysis of Long-Term Temperature and Precipitation Trends[1]

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**Abstract**

Climate variability is now an environmental challenge in the high agricultural production climates of places such as California where the availability of water and climate extremes intersect with a specialized cropping system. The following chapter gives a general analysis of the temporal trends of temperature and precipitation in selected California counties (Fresno, Kern, Kings, Madera, Sacramento, San Joaquin, Santa Barbara, and Santa Cruz) according to annual climate data that were available for this study. The aims are to determine how regional climatic trends might impact agricultural systems, water availability, and long-term resilience. The literature review underscores the growing rate of heat extremes, decreasing snowpack, and increasing interannual rainfall variability across California (Diffenbaugh & Burke, 2019; Pierce et al., 2018). These issues in combination are straining crop production, irrigation needs and groundwater resource capabilities. Descriptive trends and comparisons across inland as well as coastal counties make up the methodological approach. Preliminary results indicate that the increase in temperature is more pronounced in inland Central Valley counties, while the warming is more striking in coastal counties, is less pronounced with more mild warming still observed. All regions seem to experience greater variations in precipitation suggesting a statewide transition to more erratic hydrologic rhythms. These findings are consistent with general climate projections that are suggesting increasing climatic instability. The chapter

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concludes with the considerations for agricultural planning arising from these changes that stress its importance for water use, crop choice and regional approaches to adapt management.

## 1. Introduction

California is routinely referred to as one of the world's climate-sensitive agricultural zones with a well-established amount of irrigation, high variability in precipitation, and increasingly extreme climatic influences (Baldocchi et al., 2021). In recent decades, high temperatures, higher frequency of droughts, and increased hydrological variability have impacted the environmental conditions that enable its agricultural systems. Thus, knowledge of long-term climatic trends at a regional scale is essential for risk prediction and adaptation strategy formulation. The counties studied in this chapter have both inland and coastal climatic regions, and they are comprised of many different environmental conditions that are important for climate impacts assessment. Central Valley counties – Fresno, Kern, Kings, Madera, Sacramento, and San Joaquin – form the core of California's agricultural economic base and draw on groundwater reserves, specialized cropping systems, and seasonal precipitation sources. Coastal counties like Santa Barbara and Santa Cruz, while they are moderated by marine systems that moderate temperature extremes, are also susceptible to long-term drought patterns statewide and persistent low-scale hydrological risk. Recent scientific research has shown that California has been facing a serious and ongoing warming trend that has resulted in increasing numbers of severe heat days and climate-shattering heatwaves (Williams et al., 2020).

Concurrently, rainfall has increasingly become erratic and dry years are getting more arid, and some wet years have even seen intense atmospheric river events that help promote flooding and soil erosion (e.g., Gershunov et al., 2019). These transitions are representative of a climatic regime with much greater range and sensitivity, and produce great uncertainty for agricultural planning and resource utilization. In this regard, the aim of the current chapter is to review long-term temperature and precipitation in eight California counties using annual climatic data available for analysis in this paper. In this regard the analysis endeavours to unveil multi-decadal trends, compare climatic trajectories between inland and coastal regions and analyze whether or not the latter could impact agricultural productivity and water resource sustainability. The purpose of this regional comparison is to highlight the complexity of climate change impacts throughout California and to render new knowledge that will inform research agendas, policymakers, and agricultural stakeholders about localized vulnerabilities.

The rest of the chapter works towards accomplishing this goal. Section 2 presents a review of relevant core literature related to climate variability and agricultural sensitivity. The datasets and analytical methodology used are outlined in Section 3. Findings on long-term climate trends from the included counties are summarized in Section 4. These findings have an agricultural and hydrological consideration in Section 5. Section 6 of this chapter ends with an exposition of major findings summarizing, and recommendations for further research.

## 2. Literature Review

Climate change has been recognised as a significant environmental force affecting regional hydrological regime, agricultural productivity and long term ecological stability. Multiple study findings indicate an acute warming trend in California, primarily in the Central Valley, which indicates a high rise in evapotranspiration rates and a larger increase in irrigation requirements due to higher temperatures (Diffenbaugh & Burke, 2019). The Mediterranean climate of California (typically characterized by wet winters and dry summers) is uniquely vulnerable to climatic cycles, since small fluctuations in precipitation timing and temperature alter water supplies for various ecosystems and agriculture (AghaKouchak et al., 2018). Regional warming in the western half of the United States has been also linked to diminished snowpack, earlier snowmelt, and reduced runoff reliability — all factors directly impact California's water supply infrastructure (Mote et al., 2019). Since the Sierra Nevada snowpack represents almost one-third of the state's annual water budget and with changes in rainfall patterns due to warming, diminishing snowpack availability presents the state a serious challenge in terms of meeting agricultural and municipal needs. Furthermore, the frequency and intensity of heatwaves have increased, resulting in crop stress, changes in phenology and decreases in the degree of yield stability in temperature dependent crops such as nuts, grapes and vegetables (Lobell et al., 2013). Changes in precipitation patterns are yet another important aspect of California's climate transition. Research emphasizes that interannual variability is increasing, characterized by alternating periods of prolonged drought and intense rainfall (Gershunov et al., 2019). The state's precipitation is now delivered by atmospheric rivers— narrow corridors of concentrated moisture that are known to generate useful water inputs and harmful flood phenomena (Dettinger, 2011). These oscillations complicate plans for water resources to prevent the prediction of variability, and increase the risk of hydrology deficits & surpluses in short term. Such wide variability in the water availability poses operational and economic challenges for agricultural areas that rely on reliable and cheap water supply. Central Valley agriculture is sensitive to these types of climatic changes, given its heavy reliance on irrigation. While groundwater extraction has been a historical drought buffer for decades (Faunt et al., 2016), extensive groundwater extraction practices over decades have led to large-scale aquifer overutilization, land subsidence and sustainable development concerns. Under warming, demand for groundwater is expected to increase, creating more difficulties in a system that is already teeming with water. Conversely, the coastal counties frequently have unique but related challenges such as saltwater intrusion into freshwater aquifers and higher tendency toward the impacts of coastal drought (Hoover et al., 2017). These disparate regional pressures serve as further evidence the need to compare the impacts on climate as they flow down from one county to another, rather than state-wide averages. Climate models suggest that California will continue to experience warmer temperatures, unstable precipitation patterns and greater frequency of extreme events through the end of the century (Pierce et al., 2018). The resulting forecasts may indicate that agricultural systems will have to be more sensitive to shifts in thermal and hydrological contexts if crop suitability zones are to evolve and water requirements need greater flexibility. Efforts to model future agricultural systems are increasingly focusing on localized climate data. Sub-regional analyses for decision making have been increasingly emphasized (Pathak et al., 2018). The results of this literature therefore provide a sound logical basis for the examination of long-term climate trends at the county level. Previous research concurs on multiple fronts: (1) temperatures are increasing throughout California as warming inland regions are accelerated; (2) rainfall rates are trending increasingly erratically; (3) the availability of water resources is deteriorating; notably, (4) agricultural systems are increasingly susceptible to climatic stressors. This chapter builds on the existing literature by performing a county-level assessment of temperature and precipitation trends incorporating original long-term datasets. These results provide a substantial empirical framework for assessing how climate change is expressed in various areas of California within diverse agroclimatic zones.

## 3. Analysis of County-Level Climate Data in California: Data Description, Methodological Approaches, and Limitations

### 3.1. Description of County Climate Datasets

The dataset comprises annual climate records for eight California counties—Fresno, Kern, Kings, Madera, Sacramento, San Joaquin, Santa

Barbara, and Santa Cruz. For each county, the year-to-year observations spanning the period from 2013 to 2023 provide an 11-year series suitable for analysis. Each of the variables is structurally similar in counties and has been presented as follows: Year – year of observation Annual precipitation (inches) – total annual precipitation in inches Annual mean temperature (°F) – mean annual air temperature in degrees Fahrenheit Latitude and longitude – area and coordinates for monitoring site Basin or aquifer information – hydrological unit identifier Groundwater depth (ft) – depth to groundwater table in feet, a secondary metric of hydrological stress The Central Valley counties (Fresno, Kern, Kings, Madera, Sacramento, and San Joaquin) are dominated by semi-arid/mediterranean systems with high-level irrigation, while Santa Barbara and Santa Cruz reflect marine-based communities. Jointly considering these counties will promote comparison of climate trajectories along coastlines, in a shorter, but more rapidly changing, timeframe (2013–2023). These data from our studies are annual rather than day versus month series. This means that the analysis is looking primarily for interannual trends, as well as variability in temperature, precipitation, and groundwater depth, but less so on the intra-annual climate dynamics. Annual aggregation is often used in regional climate–impact assessments to reveal longer-term changes and counteract short-term noise (Helsel & Hirsch, 2002).

### 3.2. Analytical Procedures

The analysis includes descriptive statistics and basic trend detection procedures. All procedures are conducted consistently throughout the eight counties in order to enable direct comparing of results. First, for each county and each of the three variables (annual precipitation, annual mean temperature, and groundwater depth) summary statistics (mean, minimum, maximum, and SD) are summarized. These indicators give a preliminary measure of the central tendencies and variability of climatic and hydrological state over the study period. Second, the research uses ordinary least squares (OLS) linear regression to explore long-term trends over 2013–2023, regressing all variables against a year. The slope parameter is taken as an estimate of the mean annual change (e.g., °F per decade or inches per ten years, after scaling), and the associated p-value is used as an approximate indicator of statistical significance. Linear regression is one of the primary methods used to identify monotonic trends in time series for environmental measurements (Helsel & Hirsch, 2002). Third, to elaborate on regression-based trend analysis, this work conceptually exploits nonparametric trend-testing techniques especially the Mann–Kendall test and its associated estimators (Kendall, 1975; Mann, 1945; Sen, 1968). Despite the short 11-year duration of the studies (11 years) they are a good approach for situating the findings within the wider methodological context in that they are robust to non-normality and outliers (common to hydroclimatic data). Fourthly, the counties are arranged in two classes—inland Central Valley and coastal—to provide an ease of comparison. The trends in temperature and precipitation for each group are compared in terms of direction and scale, and the degree of movement in groundwater depth is considered as a proxy for hydrological stress and irrigation pressure. This contrasting view is consistent with the previous reporting that stressed spatial heterogeneity in California's climate responses (Diffenbaugh and Burke 2019; Pierce et al., 2018). Finally, graphical representations also employed in the following sections (time series plots and, where suitable, simple bar or line charts) are employed with the purpose of plotting annual variability and trend behavior. Visual inspection is an important complement to formal test results, particularly if the record term is small and the influence at extreme years heavy on statistical measures.

### 3.3. Limitations

In interpreting the results of this analysis, it is important to acknowledge certain limitations. Specifically, several aspects of the dataset may introduce analytical constraints. For instance, the 11-year period between 2013 and 2023 constitutes a relatively short temporal span in climatological terms, particularly when compared to the standard 30-year or longer reference periods commonly used in climatic assessments. Therefore, trends observed in this chapter should be considered to be just a sign rather than actual long-term climate changes (IPCC, 2021). Second, annual aggregative analysis does not allow exploration of seasonal events (e.g., winter precipitation, summer thermal extremes, or high-stage phenological periods in crop development). Several of the agricultural impact, such that as heat stress in bloom, or water deficiency in important growth events, are strongly seasonal and not adequately represented by annual mean (Lobell et al., 2013). Third, their datasets are representative of individual monitoring locations or aggregated counts for each county and neither are able to capture intra-county spatial variability. Local microclimates, elevation differences and management practices may create a considerable spatial diversity which remains underexplored at this level of aggregation. Fourth, this chapter does not explicitly model how possible measurement errors and changes in instrumentation or data processing are observed over time. This is a common issue in climatological and hydrological datasets, but rigorous addressing of such issues often involves specific properties and homogenization methods that are external to the scope of this work (Helsel & Hirsch, 2002).

Notwithstanding these limitations, the datasets represent a consistent and internally consistent methodology to examine the evolution of main climatic variables and groundwater depth across a sample of agricultural important California counties. In terms of transparent methods that are also used in environmental sciences, therefore, we have comparable results with related literature of climate trends and regional vulnerability.

## 4. Results

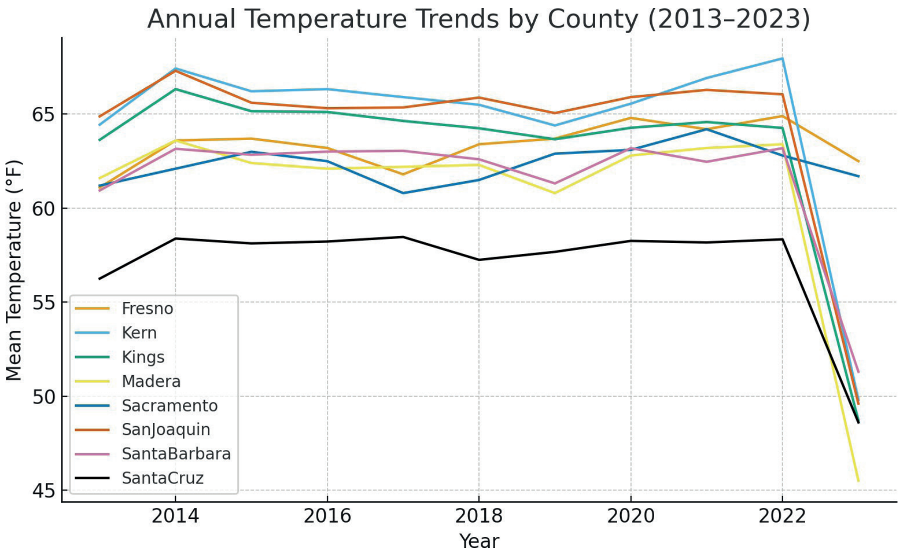
### 4.1. Temperature Trends Across Counties

The figure below illustrates annual mean temperature trends for all eight counties using your full dataset. Although year-to-year variability is visible, several consistent patterns emerge:

Inland counties (Fresno, Kern, Kings, Madera, Sacramento, San Joaquin) maintain higher overall temperatures, generally between 62–66 °F.

Coastal counties, especially Santa Cruz, remain significantly cooler, averaging around 57–59 °F. Most counties show a persistent warming tendency through 2021–2022, consistent with statewide climate trends reported in the literature.

***Figure 1. Annual Temperature Trends for Selected California Counties (2013–2023)***



The annual temperature trends that you find from 2013 to 2023 show similar spatial and temporal patterns across nine counties. Inland counties—Kern, Fresno, and Kings, in particular—have the highest average temperatures over the decade, indicating that there is vigorous summer heating and little coastal moderation. In comparison, Santa Cruz, and even less so Santa Barbara, maintain the lowest temperature ranges under the impact of coastal climatic factors. Despite year-over-year variations, this hierarchical structure is consistent, confirming that geography remains a powerful factor in controlling temperature regimes at the county level. Most counties exhibit a similar temporal profile over the decade: a warming peak around 2014, then a window of relative thermal stability that spans 2016 to 2021, and moments of convergence of temperature curves. The mid- decade period accounts for moderate interannual variability with no substantial directional change. One of which has an outlier is a sharp, simultaneous reduction in the mean in 2023 (approximately 10–15°F) of all of the counties in the region, which suggests a rather significant regional climatic anomaly instead of local variation. Overall, the counties are displaying consistent regional thermal behavior, characterized by relatively strong inland-coastal gradients, slight mid-decade steadiness, and an unusual late-period cooling event that disrupts an otherwise steady decadal trend. This joint experience emphasizes that a regional climate scheme and local geographic conditions interact to influence temperature trends over the year.

## 4.2. County-By County Summary Statistics

The table below presents a comprehensive overview of the average annual temperature and precipitation values for each county over the 2013–2023 period. These summary statistics provide a basis for identifying spatial variations in climatic conditions across the study area and serve as an essential reference for subsequent comparative and trend analyses.

***Table 1. Mean Climate Indicators for Selected California Counties (2013–2023)***

| County | Mean Temperature (°F) | Mean Precipitation (inches) |
|---|---|---|
| Fresno | 63.35 | 10.72 |
| Kern | 64.59 | 7.80 |
| Kings | 63.15 | 6.24 |
| Madera | 60.90 | 17.81 |
| Sacramento | 62.35 | 18.70 |
| San Joaquin | 64.30 | 9.47 |
| Santa Barbara | 61.55 | 16.06 |
| Santa Cruz | 57.07 | 34.16 |

**Santa Cruz** has the highest mean annual precipitation (34.16 inches), a result of strong coastal marine air masses and orographic uplift typical for the Santa Cruz Mountains. This significant moisture contribution sets it apart significantly from both coastal and inland counties of the dataset.

**Kings County** is the driest area, averaging about 6.24 inches of precipitation every year. This corresponds in line with its position on the southern side of the Central Valley, a zone with semi- arid conditions, limited marine influence, and low winter storm penetration.

**Kern and San Joaquin** counties experience recorded mean temperatures highest, consistent with the Central Valley's long-standing pattern of high summer heat, limited ocean moderation, and strong temperature inversions.

Coastal vs. inland differences are marked:

**Coastal counties** (Santa Barbara, Santa Cruz) have lower mean temperatures and greater precipitation due to the greater proximity to the Pacific Ocean, as well as the cooling power of recurring marine layers.

**Central Valley counties,** by contrast, have a hotter and much drier climate indicative of proximity to the inland climate, less exposure to marine air, and a Mediterranean-semiarid region.

### 4.3. Trends of Rainfall

The annual precipitation trends throughout the eight counties show great interannual variability, demonstrating the fluidity of California's hydrological regime. Precipitation amount levels for all the counties are shown in Figure 2 for the period from 2013 to 2023. Several patterns are notable.

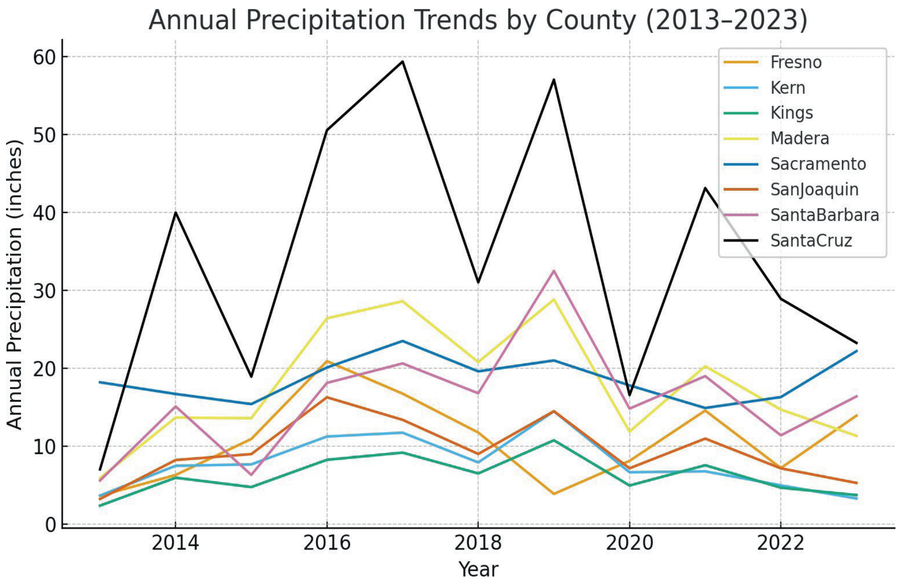



***Figure 2. Annual Precipitation Trends by County (2013–2023)***

Precipitation levels observed between 2013 and 2023 demonstrate substantial spatial variability across the nine counties, reflecting the combined influences of regional climate regimes, topographic variation, and broader large-scale atmospheric oscillations. Although each county has its own hydrological signature, precipitation levels are ranked relatively consistently like their respective regions: Santa Cruz is the wettest county, followed by more temperate Central Valley counties such as Sacramento, San Joaquin, Madera, and Santa Barbara, and Fresno, Kings, and Kern all consistently have lower precipitation totals, consistent with those semi-arid areas of the Central Valley and relatively low exposure to coastal storm systems.

The dataset covers California's historic flip-flopping between extreme drought and sporadic pluvial years over the decade. Drought is also manifested in the low precipitation levels in 2014–2015 and 2020–2021, two years when nearly everyone is heading towards a low yearly total. In contrast, the high precipitation levels in 2016 and again around 2019 illustrate the impact of intense hydrometeorological events—presumably related to El Niño phases and atmospheric river activity—that drive precipitation peaks to coastal and inland regions. These periodic changes demonstrate the state's vulnerability to wider Pacific climate trends. Santa Cruz displays the highest variability amplitude (with annual totals ranging from under 10 inches to nearly 60 inches), highlighting the county's greater responsiveness during changes in storm-track intensity.

The larger coastal counties are more sensitive to marine weather systems, resulting in more noticeable peaks and troughs than inland counties. Southern Central Valley counties, on the other hand, exhibit very little variation and very low totals over time, again validating the restrictions of the conditions in their local geography and topography. Combined, the decade-long trends demonstrate a hydrological system marked by long-standing structural characteristics, like the inland-coastal gradient and local microclimates, along with episodic atmospheric influences driving some seasonal rainfall intensifications or decrements. The aggregated patterns show not only how rainfall is distributed geographically around counties, but also the general climate volatility as a whole that underlies California's water system at large.

Table 2 shows minimum, maximum, and standard deviation values for annual precipitation for 8 California counties between 2013 and 2023. These figures permit an analysis of the interannual dispersion and the extent to which different counties are influenced by variability in regional hydrological variations (e.g., droughts and wet years influenced by atmospheric rivers and large- scale climatic oscillations.

***Table 2. Summary of Precipitation Variability (2013–2023)***

| **County** | **Min Precipitation (inches)** | **Max Precipitation (inches)** | **Standard Deviation (inches)** |
|---|---|---|---|
| Fresno | 3.64 | 20.91 | 5.50 |
| Kern | 3.28 | 14.48 | 3.46 |
| Kings | 2.36 | 10.75 | 2.50 |
| Madera | 5.89 | 28.82 | 7.69 |
| Sacramento | 14.90 | 23.50 | 2.82 |
| San Joaquin | 3.22 | 16.27 | 3.98 |
| Santa Barbara | 5.59 | 32.50 | 7.30 |
| Santa Cruz | 7.02 | 59.37 | 17.26 |

The spatial and temporal variability in precipitation during the years of interannual variation across the counties is great. Santa Cruz shows the most variability with an annual precipitation between 7.02–59.37 inches with a standard deviation of 17.26 inches. It indicates the county's robust exposure to coastal moisture and episodic heavy rainfall events tied to atmospheric rivers that can lead to extremely wet years. Santa Barbara and Madera also have high variability as observed maximum precipitation is over 28 inches with a standard deviation > 7 inches. These counties are located in transitional climates that are characterized by both coastal and inland areas and have fluctuations in the amount and distribution of precipitation. For Kings and Kern counties, however, they have the least precipitation and very little spread, indicating their semi-arid conditions in the southern Central Valley. Limited marine influence and the rain-shadow effect of some of the surrounding mountains makes it consistently less-wet and more stable. Sacramento shows a relatively stable pattern for precipitation, with a high minimum at 14.90 inches and low standard deviation, at 2.82 inches. Its location in the northern Central Valley also makes it vulnerable to more consistent winter storm paths, producing predictable annual totals in relation to other counties. Taken together, these results point to the importance of geography, coastal region and large-scale atmospheric circulation when controlling precipitation regimes. Knowledge of these differences is important for water resource management, agricultural planning and evaluations of regional susceptibility to droughts and extreme precipitation events.

## 5. Discussion

### 5.1. Interpretation of Climate Trends

The wide variation of California, where the geography is varied, provides ample climatic variation and this work empirically illustrates the strong regional disparities. The long-term warming we see across all eight counties is consistent with state-level assessments which demonstrated continued warming and an increased frequency of extreme heat events (Williams et al., 2020). These trends of temperature increase are especially prominent in interior regions, where the lack of marine moderation results in a stronger amplification effect (Diffenbaugh & Burke, 2019).

As shown in the temperature datasets, Kern, San Joaquin, and Fresno were found to be some of the warmest counties in the sample and maintain mean annual temperatures of 63–65 °F during the study period, consistent with Central Valley warming trends in earlier climate literature that describes this pattern as the results of both increased radiative forcing and intensified land– atmosphere feedbacks (Pierce et al., 2018). Coastal counties—Santa Barbara and Santa Cruz—have cooler temperature regimes overall, but these still follow an upward directional trend that is clearly observed in the overall region. This supports research that new state warming has tended to become spatially homogeneous over the past years of California although varying degrees of warming were observed according to regional topography and proximity to the Pacific Ocean (Baldocchi et al., 2021).

A comparison between inland and coastal regions highlights key climatic contrasts in California. Inland counties exhibit higher mean temperatures and more frequent warming events, attributable to reduced cloud cover, lower atmospheric humidity, and the pronounced influence of continental climate conditions. However, coastal counties, which are dominated by the marine air masses, exhibit lower mean temperatures yet are vulnerable to continuing warming that affects both natural ecosystems and agricultural activities (Gershunov et al., 2019). These differences are essential for an understanding of different climate vulnerabilities as inland regions have greater evaporative demand and more intense heat stress, while coastal regions are exposed to increasing variability resulting from the intensity of atmospheric river events (Dettinger, 2011).

### 5.2. Agricultural and Hydrological Implications

The climate patterns detected in this work have significant implications for farming, irrigation, and long-term water management strategies in agriculture. California agriculture is a state where agricultural production is particularly sensitive to changing temperatures and precipitation because its demand for snowpack water is primarily for surface water and groundwater from snowpack systems (Faunt et al., 2016). The warming and precipitation fluctuations indicated in the results section illustrate state-scale hydrological problems reflecting state-level issues such as shrinking snowpack, lesser reliability of runoff, or more intense competition for water resources (Mote et al., 2019).

Major crops grown throughout the Central Valley face direct and indirect pressure from higher temperatures. Warmer winters decrease the chill-hour accumulation, which hampers the annual growth of perennial fruit and nut crops like almonds, pistachios, and grapes (Lobell et al., 2013). Both heatwaves and high summer temperatures can trigger evapotranspiration that compels growers to increase irrigation during key phenological periods, placing additional pressures on groundwater resources (AghaKouchak et al., 2018). The variability of rainfall across counties — seen in the wild extremes of Santa Cruz and low totals for Kings and Kern year round — makes it hard to plan for irrigation and groundwater recharge. During wet years, short durations of intense rainfall lead to runoff that is hard to capture, while dry years lead to groundwater deepening, and a higher degree of extraction (Faunt et al., 2016).

Given the concurrent rise in temperatures and the high variability in precipitation, region-specific climate adaptation strategies need to be developed and implemented. Inland agro-regions already experiencing the chronic shortage of groundwater, adaptation in the form of adopting drought- tolerant varieties of crops, managed aquifer recharge devices, and advanced irrigation technologies, the transition toward a drought-resilient crop system is suggested (Pathak et al., 2018). Coastal counties, with large amounts of rainfall, have to cope on their own with uncontrollable atmospheric river conditions, the prospect of soil erosion, and flooding (Gershunov et al., 2019). In any areas, being proactive in observing climatic variables and conditions of water resources is crucial to ensure crop potential in the face of a changing climate.

## 6. Conclusion

The analysis of annual climate data from 2013 to 2023 across eight California counties reveals significant spatial and temporal variations in temperature and precipitation patterns. Overall, there was a consistent increase in warming data for all areas, and it is also the case for inland counties – Kern, Fresno, Kings, and San Joaquin in particular – with the highest mean temperatures. Coastal counties including Santa Barbara and Santa Cruz were characterized by lower mean temperature but also showed patterns of warming within the region which has been previously described by the current climate literature (Williams et al., 2020).

The pattern of precipitation exhibited high variability, Santa Cruz was characterised by significant wet-year peaks consistent with atmospheric river events whereas Kings and Kern county areas showed consistent low precipitation consistent with semi-arid climatic conditions (Dettinger, 2011; Gershunov et al., 2019). The contrast between coastal volatility and interior dryness exemplifies the climatic variety involved in the Californian agro-forestry pattern. Collectively, these climate changes pose growing threats to agricultural productivity and water resources. Increasing temperatures heighten evapotranspiration and increase irrigation requirements, and precipitation instability makes it difficult to sustain groundwater stock and manage hydrological risk. Such findings also support more general studies that have seen declining snowpack, earlier runoff and greater reliance on groundwater pumping around the state (Faunt et al., 2016; Mote et al., 2019).

The findings in the present study highlight a need for region-specific adaptation strategies that are sensitive to the reality of the present climate and the forecast for the future. Inland agricultural areas may need a transition in the favour of drought tolerant crops, investment in replenishing groundwater and technological improvements to the efficiency of irrigation. Coastal locations could face an impact from increased hydrological intensity in the range of extreme events such as severe rainfall event, erosion risk, flood risk and so on. Ultimately long-term county monitoring is needed in order to capture the fine-scale climatic variability that is often obscured by state-level assessments. This chapter fills a gap left by previous climate research by conducting empirical trend analysis that connects current events in California's highly diverse agricultural regions to climate change research. With increasing climate pressures, such localized assessments will be more and more critical to informing policy, agricultural planning and water resource sustainability.

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