Title
The Impact of Climate Change on Tourism in the Coachella Valley, California

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THE IMPACT OF CLIMATE CHANGE ON TOURISM IN THE COACHELLA VALLEY, CALIFORNIA

By

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Abstract

The Coachella Valley is famous for its hot climate, which draws tourists to enjoy its warm winters. Tourism is the biggest contributor to the Coachella Valley's economy, but climate change may pose a threat to tourism. Specifically, the magnitude and frequency of high temperatures is predicted to increase, which may shorten the tourist season. To understand how climate change will impact the region, we analyzed high resolution (~6 km) downscaled projected climate data from four global climate models under two future emission scenarios and three time periods—early 21st century, mid-century, and end of century. We investigated the annual distribution of daily maximum temperature for a historical period and in future projections to examine the shortened tourist season of temperatures below a threshold of 85 degrees Fahrenheit. We also examined the relationship between climate and attendance at local outdoor tourist attractions -- specifically, the local zoo and festivals. We observed strong seasonal relationships between daily maximum temperatures and the admission counts at a local zoo. We found that the region is likely to experience a shorter tourist season as the frequency of extreme temperatures increases.

INTRODUCTION

The Coachella Valley is a desert region about 120 miles southeast of Los Angeles, CA. The region has a hot and dry climate with many days exceeding 120℉ in the summer. The region's primary sources of revenue are tourism and agriculture, respectively (Coachella Valley Economic Partnership, 2016). During the warm winter months, the region draws in many visitors from Canada and colder states who enjoy the warm conditions. These visitors are commonly referred to as "snowbirds" and are crucial contributors to the local economy. During the snowbird season, which typically lasts from November to May and peaks in March, businesses and hotels turn a big profit. In the hot summer months when temperatures can be dangerously high, many businesses close because of the lack of customers. These trends are obvious when the seasonal employment, airport traffic and revenue from hotels are considered. Another important contributor to the tourism industry are the popular festivals that bring visitors to the area such as the Coachella Valley Music and Arts Festival, Stagecoach, the Palm Springs International Film Festival, and the major tennis tournament BNP Paribas Open. The Coachella Valley Music and Arts Festival alone brings in around 125,000 attendees for each day of the two three-day weekends. (Coachella Valley Economic Partnership, 2017) The area's golf courses and hiking trails are another main attraction for visitors.

Climate change will affect many factors of people's lives. Tourism and recreation are yet another example. Because of the increased frequency of extremely high temperatures, the tourism industry is vulnerable in the Coachella Valley. Many of the major tourist attractions in the Coachella Valley are all outdoors-based. Snowbirds may be less inclined to visit the region not only because of the high temperatures in the Coachella Valley, but also because their hometowns may not be cold enough to warrant their winter migration. The Coachella Valley

Music and Arts Festival and Stagecoach festivals occur during April, which could begin to be as hot as the summer months. Organizers of these festivals may have to consider shifting their dates or provide more cooling infrastructure in order to accommodate the visitors. Furthermore, regions with winter tourism will become more prevalent due to climate change because warmer winters are expected in many places (Scott et al., 2004). Thus, the Coachella Valley will be competing with more places for the same winter tourists. Without tourism, each household in the Coachella Valley would need to pay an additional $3,719 annually to maintain the current level of government services (Greater Palm Springs Convention and Tourism Bureau, 2017). Aside from the impacts on tourism, more frequent extreme temperatures can be dangerous toward public health, especially for those who are not acclimated to the desert climate. Extreme temperatures are known to have particularly morbid impacts on the elderly (Bunker et al., 2016) and people who are not acclimated to hot temperatures, such as snowbirds, the most. Both of these are crucial demographics in the Coachella Valley.

METHODS:

We used statistically downscaled global climate models, Localized Constructed Analogs (LOCA) for projections of extreme temperatures at the middle and end of this century. The data is publicly available on cal-adapt.org. (Pierce & Cayan, 2014). LOCA provides daily climate data at a resolution of 6 km for maximum and minimum surface air temperatures, total precipitation, specific and relative humidity, direct solar irradiance and wind speed. The primary variable that was used was daily maximum temperature. As compared to global climate models which are at 100 km resolution, downscaled data can be much more useful for assessing climate change at the local scale. Particularly in Southern California where topography is highly variable, 100 km resolution smooths out many critical topographic features that are important for climate. We assessed the accuracy of this model by comparing the modeled historical data to measurements by a NOAA weather station in Indio, CA from 1950 to 1979 (**Figure 2a**). The correlation between the modeled data and the NOAA records of maximum temperature had an R^2 of 0.60. Compared to the one-to-one line in the plot, daily maximum temperatures in CCSM4 were biased high in winter and low in summer relative to observations. The LOCA dataset produced downscaled outputs of 32 global climate models. This was a computationally expensive set of data. Therefore, a subset of ten GCM's was selected based on the models that show a good simulation of California's climate. From this subset, a smaller subset of four models was identified: CCSM4 (which is ranked as having the closest to the average value across all metrics), GFDL-CM3 (the "warm/dry" model), CNRM-CM5 (the "cool/wet" model), and HadGCM2-CC (the model that is ranked as the most unlike these other three, in order to give better coverage of the full spread of model results) (Cayan et al., 2018). When these four models were averaged (Figure 2b), the correlation with measured data was stronger (R^2 = 0.70) than when a single model was used; however, the bias between modeled temperature and observations remained the same as with CCSM4 alone.

To make our predictions, we used the average of the outputs from the four recommended models when possible. Otherwise, we simply used CCSM4 since it was found to be the model with the closest value to the average of the other models.

Representative concentration pathways (RCP) have been used to categorize different climate forcing scenarios (Meinshausen et al., 2011). Each RCP represents a different amount of radiative forcing (W/m^2) in the atmosphere that is caused by different scenarios of current and future greenhouse gas emissions. We used three of the representative climate scenarios that the

LOCA dataset provides: historical, RCP 4.5, and RCP 8.5. RCP 4.5 represents the mitigation scenario in which radiative forcing is stabilized shortly after the end of the century. RCP 8.5 represents the business-as-usual scenario, in which greenhouse gas emissions continue to increase into the next century. The historical period was defined as a model representation of the averaged climate during 1951-1980. This period is representative of the climate during the time when the tourism industry kicked off in the Coachella Valley. The midcentury period is the averaged climate for the years 2035-2064. The end of the century was defined as the averaged climate during the years 2070-2099.

Although more research is needed to determine the relationship between climate and human behavior, the daily maximum temperature serves as a good indicator of comfort level. Other studies have used climate to assess the impact on tourism. A tourism climate index (TCI) has been used to quantify tourist comfort using climate data (Mieczkowski, 1985). This index is based on meteorological variables that in combination represent the overall comfort of a tourist. The index gives a number up to 100 to represent how optimal the climate is for visitors. In this index, the most heavily weighted variable is temperature. As a desert, the Coachella Valley lacks precipitation and humidity for most of the year, yielding plenty of hours of sunshine. Furthermore, global climate models have not found a robust trend in precipitation under climate change so further research would be needed before assessing the impact of projected precipitation. Climate models project only subtle changes in wind speeds (5-10%) (Kulkarni & Huang, 2014). Therefore, the main variable that impacts comfort in the region is temperature. We focused this study on analyzing historical and future projections of daily maximum temperature as an indicator of tourist comfort. Since of all these variables daily maximum temperature is given the most weight when determining human comfort, it is a reasonable assumption that daily maximum temperature is the determining factor on whether or not tourists will want to visit the Coachella Valley. Mild weather has been defined in the range of 64-86°F (van der Wiel et al., 2017). Within this range, weather does not disrupt society the way climate extremes do. A threshold temperature of 85°F was used in this study as a determining factor as to whether or not tourists were likely to visit the Coachella Valley.

RESULTS

More frequent extremely high temperatures are expected in the desert. The histograms in **Figure 3** show the shift in the distribution of daily maximum temperatures in Indio, CA, using the same RCPs and time periods defined previously. The figure shows how in all scenarios, the temperature distribution shifts to the right, with higher daily maximum temperatures throughout the year, and more extremely hot days (above the historical 95^{th} percentile) than in the historical period. In the middle of the century, the RCP 8.5 and RCP 4.5 scenarios are similar, since the RCP 4.5 scenario assumes that emissions continue increasing into the middle of the century and declining thereafter. By the end of the century, there are significantly more extremely hot days in the RCP 8.5 scenario as compared to the RCP 4.5 scenario.

Since extremely hot days are likely to be the weather variable that drives tourists away, we looked at how many more extremely hot days the Coachella Valley would see under these different scenarios. As shown in **Figure 4**, extremely hot days will become more common in Indio, CA. An extremely hot day was defined as a day where the daily maximum temperature was over the 95^{th} percentile (106°F) during the historical period, or above the purple line in the histograms in Figure 3. By the middle of the century, an average of 21% of the days of the year are above this percentile in the RCP 4.5 scenario. In the RCP 8.5 scenario, an average of 23% of the days are above this temperature. By the end of the century, 23% of the year has extreme temperatures in RCP 4.5 and 30% of the year has extreme temperatures in RCP 8.5.

Knowing that temperatures are likely to increase, it was important to determine how tourism might be impacted by daily maximum temperatures in this region. In order to assess the correlation between temperature and tourism in the region, we analyzed daily visitation data for The Living Desert Zoo and Botanical Gardens, which is a popular outdoor attraction in Palm Desert, CA. As can be seen in **Figure 5**, for the years 2013-2018, daily visitation oscillated with the measured daily maximum temperature. Also, as the correlation plot shows, the number of visitors to the zoo starts to decline at about 85°F, which is consistent with the defined range of comfortable temperatures in van der Wiel et al., 2017. These results show that the daily maximum temperature does have a relationship with the number of visitors. This threshold was also applied to the snowbird season.

The snowbird season is known to have a strong relationship with temperature. Using this modeled data, we analyzed how the snowbird season would shorten under the three different scenarios and compared three different time periods (**Figure 6**). We assumed that the snowbird season lasted while the maximum temperature was at or below 85°F, given that daily maximum temperatures generally remained below this threshold during the historical snowbird season of November through April. Above this temperature, people (especially visitors who are not acclimated to hot temperatures) would not be comfortable and may not pursue touristic activities in this region. With the 85ºF threshold, by the middle of the century the snowbird season would only last from about mid-November to mid-March in both RCP 4.5 and RCP 8.5, with the season starting about a week later in the RCP 8.5 scenario. By the end of the century, the snowbird season would not have shortened significantly in the RCP 4.5 scenario but would only last roughly from December to mid-March, which is only 3.5 months compared to the historical 5.5 months. In other words, the snowbird season could shorten from 27-32% by the end of the century, depending on the emissions trajectory that is taken.

We examined the projected daily maximum temperatures during the traditional festival dates of the Coachella Valley Music and Arts Festival, the Palm Springs Film Festival and BNP Paribas Open (**Figure 7**). Fifteen-year intervals were chosen because the Coachella Festival did not start until the year 1999, so the original historical period of 1950-1980 would not accurately represent the baseline of temperatures when the festival was first held.

The maximum of the daily maximum temperatures during the events was a reasonable metric for determining the impact of the events since the extreme events are highly impactful. Historically, the maximum daily maximum temperature during these festivals was 96°F for BNP Paribas Open, 106°F for the Coachella Valley Music and Arts Festival, and 84°F for the Palm Springs International Film Festival. By the end of the century, the maximum daily maximum temperature was projected to be 105-109°F for BNP Paribas Open, 108-113°F for Coachella Festival, and 92-98°F for the Palm Springs Film Festival (depending on the representative concentration pathway). The most change in temperatures was seen for the Palm Springs International Film Festival, which occurs in January.

DISCUSSION AND CONCLUSIONS

We used downscaled global climate models to compare the historical and projected distribution of extreme temperatures in the Coachella Valley and assess the impact of this on tourism. We analyzed two emissions scenarios and three time periods. The RCP 4.5 emissions scenario would be easier to adapt to than RCP 8.5 scenario, which saw more dramatic changes under all metrics. There is no dispute that global temperatures are expected to increase due to climate change. We had assumed a temperature threshold of 85°F as an indicator of tourist activity since mild temperatures were defined as 64-86°F (van der Wiel et al., 2017). The correlation between daily maximum temperature and the number of visitors at the Living Desert showed that this was a valid assumption, as the number of visitors declined after crossing this temperature threshold. This further shows that this temperature threshold was an appropriate assumption for determining the snowbird season.

Our findings have shown that not only will there be more extremely hot days, but there will be significantly fewer cool days by the end of the century, with virtually no days in which the daily maximum temperature was below 70°F by the middle of the century. The increased frequency of high temperatures implies that the snowbird season could shorten by up to 32% by the end of the century, all things equal. That is, assuming people only respond to temperature and they will not adapt to warming. Although future economic research would be needed, this could potentially mean that the local economy would lose up to the same percentage of revenue from tourism. Since tourism is the primary source of revenue for the Coachella Valley, this would be a major impact to the local economy. Because of global warming, it is expected that there will be an increasing number of cities with climates suitable as winter sun destinations (Scott et al., 2004), so the Coachella Valley may experience more competition for the snowbird market from cities that will gain new opportunities to attract these same visitors. The redistribution of climate resources for tourism could impact many factors of people's lives, such as employment, business revenue, and the amount of taxes that residents pay.

Under the scenarios used in this study, the impact of climate change on the festivals in the Coachella Valley were not apparent. Modeled projections show that the maximum daily maximum temperatures during BNP Paribas Open would only increase by 9-13°F by the end of the century. Maximum daily maximum temperatures would only increase by 2-7°F by the end of the century for Coachella Festival and 8-14°F for the Palm Springs International Film Festival. However, although the temperatures may increase, the venues may provide more cooling infrastructure to accommodate their guests. California has been shown to experience less warming in the springtime relative to other seasons (Sun et al., 2015) so it may be that the festivals occur during an optimal time to limit climate change effects. Furthermore, considering the standard deviation of the data, the increase in the maximum daily maximum temperature does not appear to be statistically significant for each of the festivals. There were differences of a few degrees for each festival.

Since tourism corresponds well with seasonal oscillations in temperature, the increased frequency of extremely hot temperatures in the Coachella Valley are likely to affect tourism, which in turn affects many aspects of the lives of residents such as taxes, employment, and quality of government services. Although economic reports have recently found that tourism in the area is thriving, this may not be sustainable under a warmer climate, as warmer temperatures may make people less likely to consider the Coachella Valley later in this century. More interdisciplinary research is needed in order to make definitive statements about the impact of extreme temperatures in the economy. However, it is clear that tourism does correspond well with temperature and the season with pleasant temperatures is bound to get shorter. Beyond tourism, the increased frequency of extreme temperatures may also impact the local economy by other means such as energy consumption, infrastructure, and agricultural productivity.

LIST OF FIGURES

FIGURE 1: The Coachella Valley

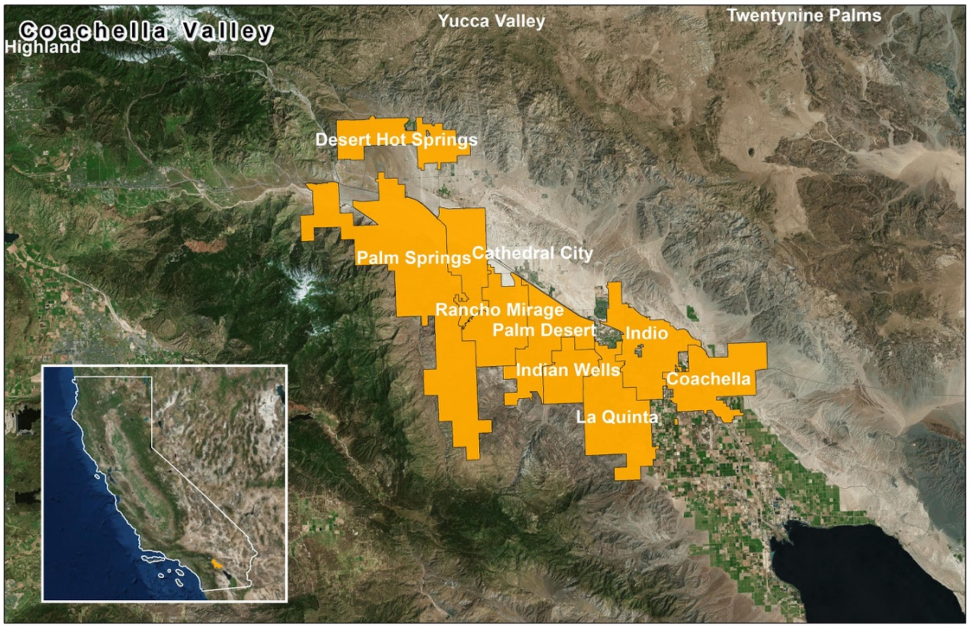


Figure 1. The Coachella Valley is a desert region in the inland region of Southern California. It consists of nine major cities (shown as orange polygons).

FIGURE 2: Correlation Plot (Model vs NOAA Record)

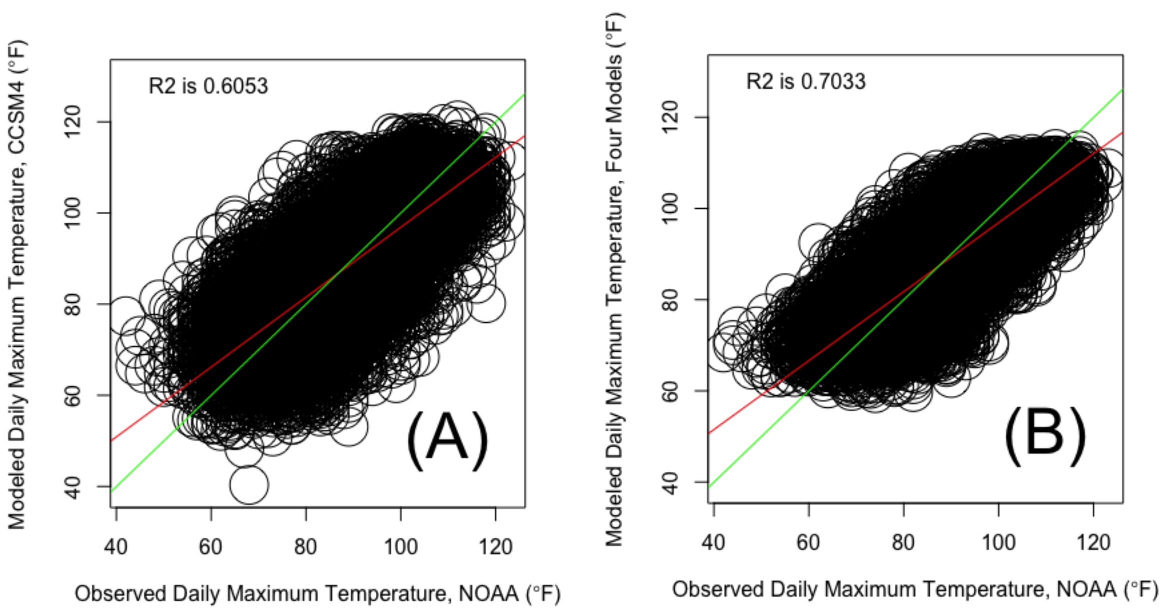


Figure 2. Analysis of the accuracy of the LOCA modeled daily maximum temperature in Indio, CA (ºF) for the years 1950-1979. (A.) We compared the downscaled CCSM4 model output to measurements by a NOAA station in Indio, CA to assess the validity of the model. The red line shows the linear fit of the correlation. The green line shows the 1-to-1 line for assessment of bias. The R^2 value is shown in the upper left. (B.) Shows the correlation between the same NOAA measurements and the average of four climate models: CCSM4, CNRM-CM5, GFDL-CM3, and HadGCM2-CC.

FIGURE 3: Frequency Distribution for Daily Maximum Temperature in Indio, CA

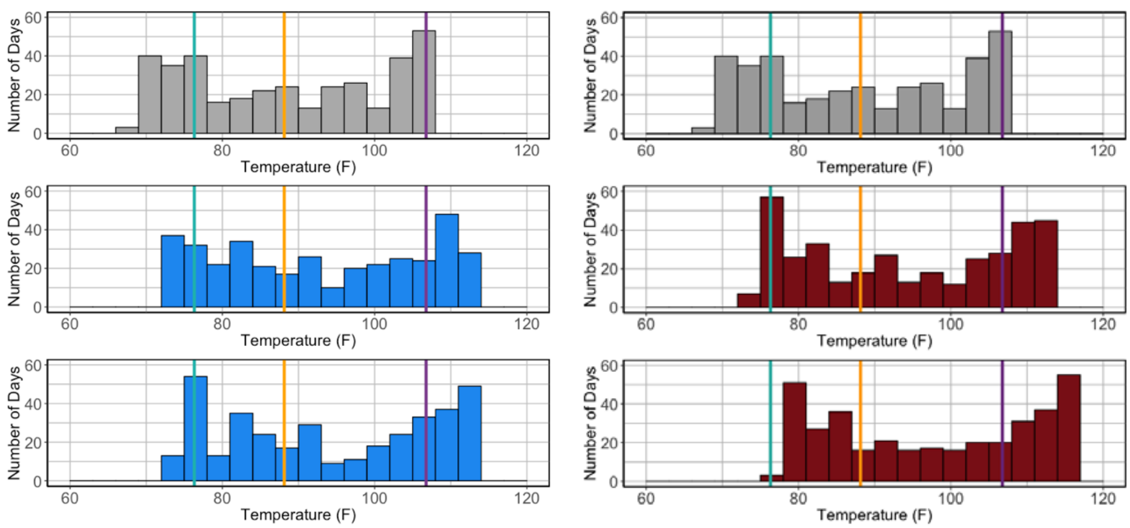


Figure 3: The distribution of daily maximum temperatures in Indio, CA using the average of four models. The historical projections are shown in grey, representing the average of the years 1951-1980. The middle row shows the middle of the century (2035-2064). The bottom row shows the end of the century. Blue bars represent the RCP 4.5 scenario while red bars represent the RCP 8.5 scenario. For reference, the green vertical lines represent the 25th percentile during the historical period. The orange line shows the 50th percentile during the historical period. The purple line shows the 95th percentile during the historical period.

FIGURE 4: Extremely hot days in Indio, CA

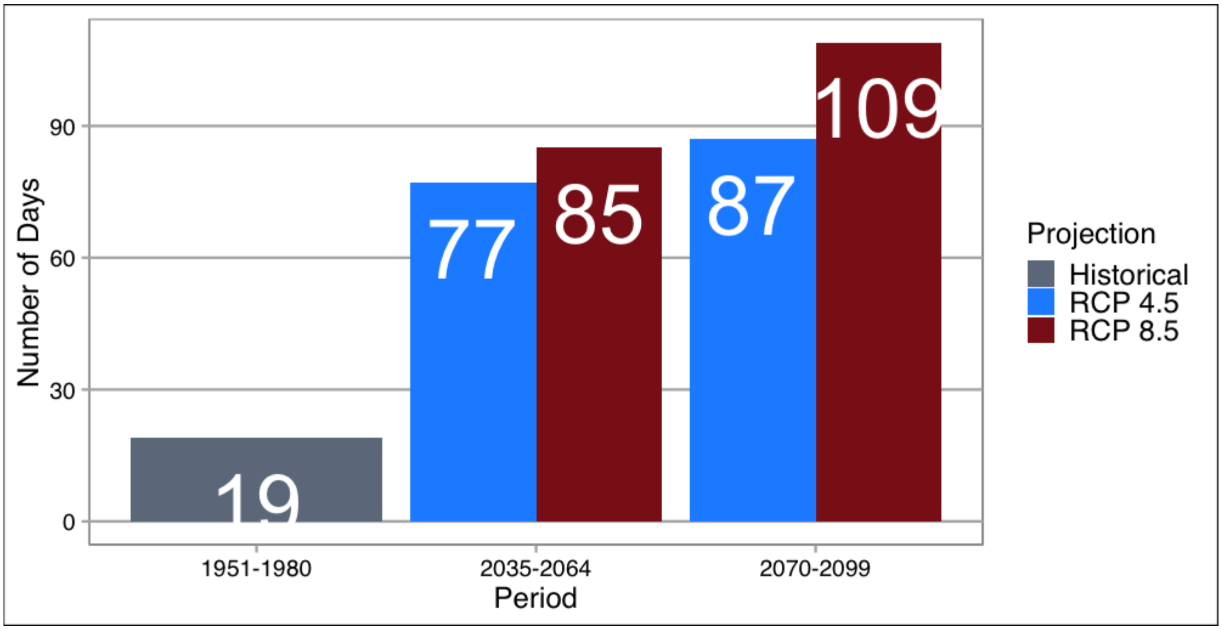
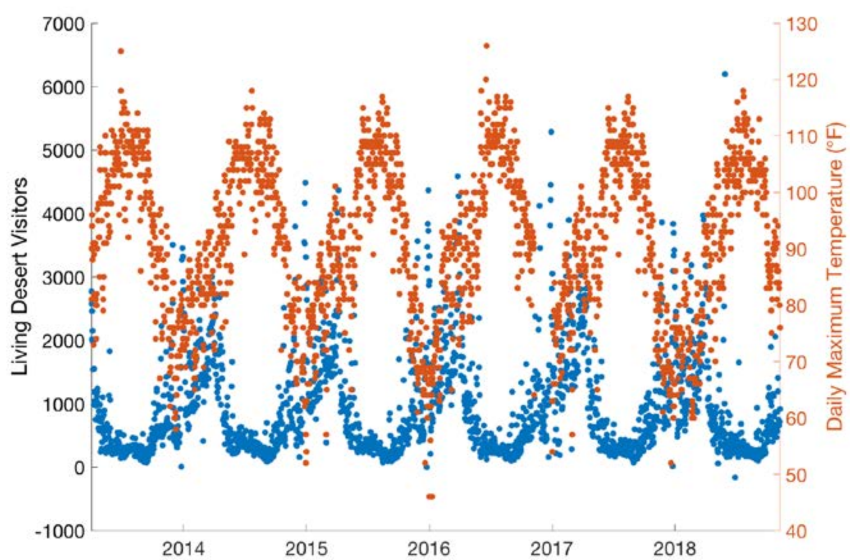


Figure 4. Extremely hot days in Indio, CA. An extremely hot day was defined as one where the daily maximum temperature was at or above the 95th percentile in the historical period (1951-1980). Each bar represents the number of extremely hot days averaged over the thirty-year time periods. The gray bar represents the historical projections. The blue bars represent RCP 4.5. The red bars represent RCP 8.5.

FIGURE 5: Temperature Relationship with Living Desert Visitors



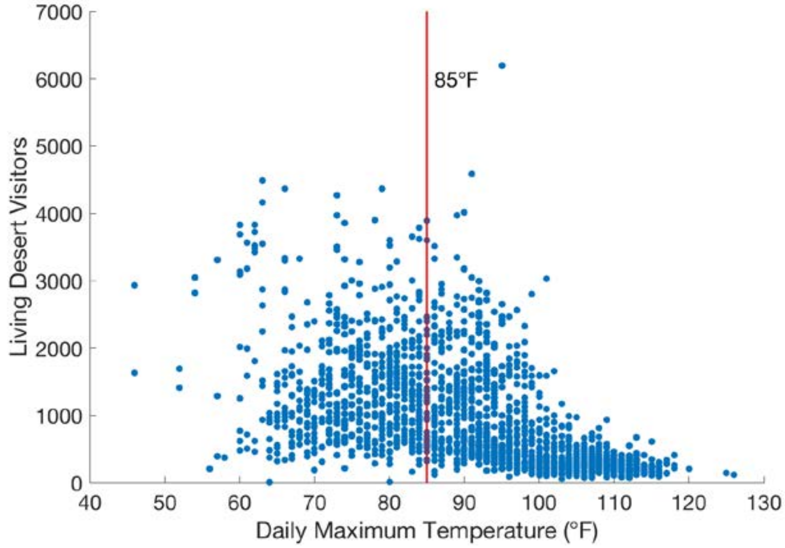
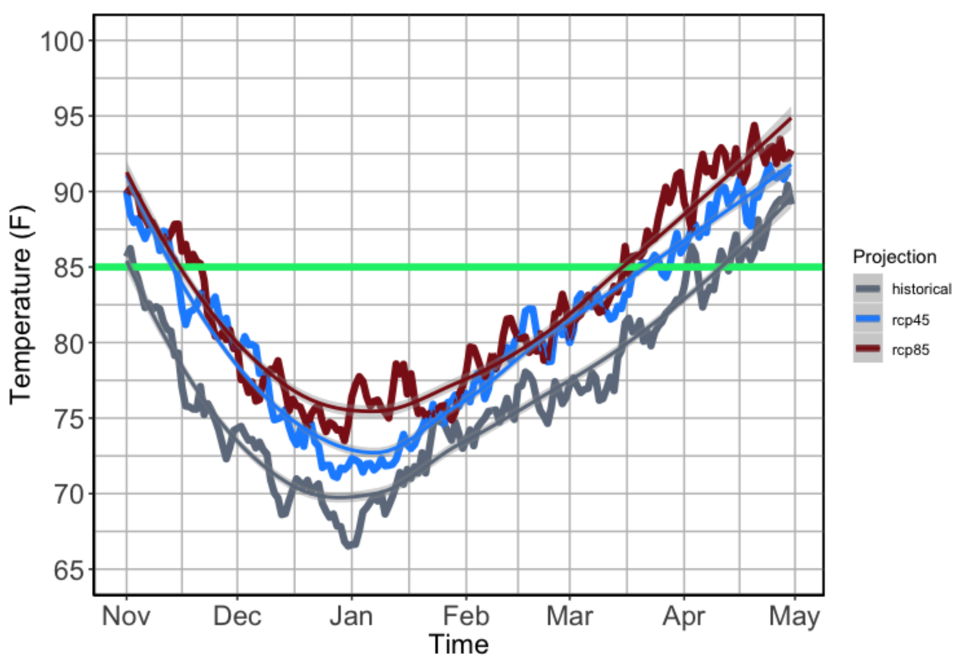


Figure 5. (Top) The top graph shows the seasonal cycle of visitors at the Living Desert between 2013-2018. The daily maximum temperature is shown in blue while the number of visitors to the zoo on that day are shown in green. (Bottom) The bottom graph shows the correlation between temperature and zoo visitors. The vertical line marks the 85°F temperature.

FIGURE 6: The Snowbird Season



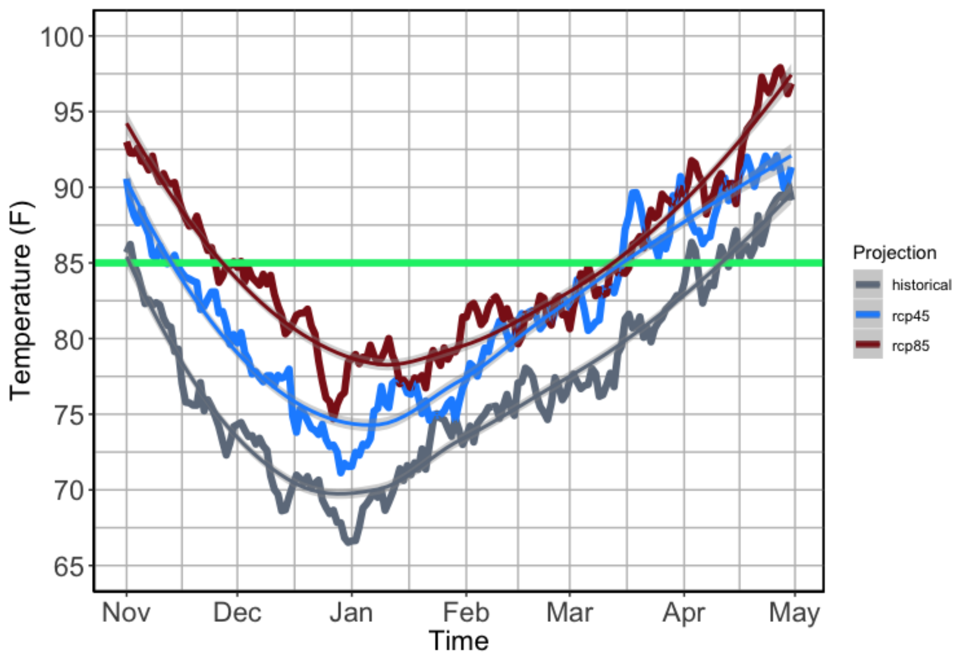
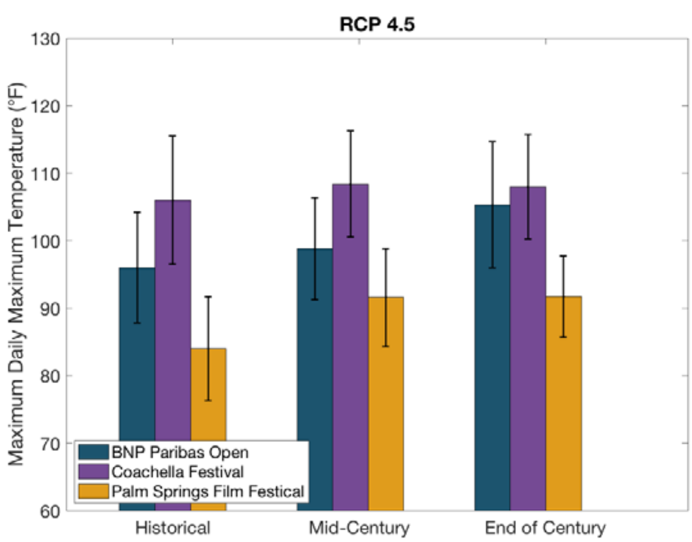


Figure 6. Projections of the snowbird season in Indio, CA based on daily maximum temperature projections using an average of four downscaled models. For each projection, the daily maximum temperature from four models is averaged. The smooth line is the LOWESS (Locally Weighted Scatterplot Smoothing) of this averaged data. The gray lines represent model representation of the historical period between 1951-1980. The blue lines represent RCP 4.5. The red lines represent RCP 8.5. The horizontal green line is the temperature of 85°F which we defined as the threshold at which it would be too hot for tourists. This analysis was done for two time periods: (Top) The mid-century period (2035-2064) and (Bottom) the end of the century (2070-2099).

FIGURE 7: Maximum daily maximum temperature during festivals



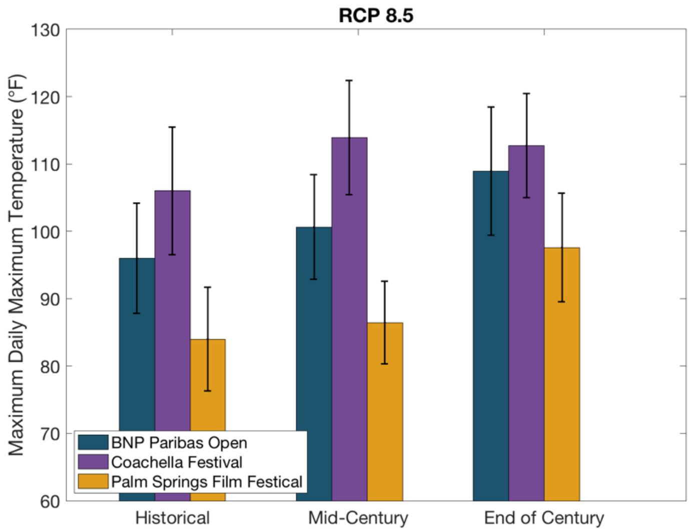


Figure 7: The maximum daily maximum temperature during the traditional dates of three festivals in the Coachella Valley. The downscaled CCSM4 model outputs were used. BNP Paribas Open (teal) occurs during the second and third week of March. The Coachella Valley Music and Arts Festival (purple) occurs during the second and third week of April. The Palm Springs International Film Festival (yellow) usually occurs during the first two weeks of January. The RCP 4.5 scenario is shown on the top and the RCP 8.5 scenario is shown on the bottom. Each projection shows three time periods: historical (2000-2014), the middle of the century (2050-2064) and the end of the century (2085-2099). The error bars show the standard

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