Predicted Impacts of Climate Change on Ground Level Ozone in Cities in the Western United States

Elizabeth Jayne Dresselhaus[1], Richard Wagner[2], Scott Landolt[3,4]

1:Fairview High School, 2: Metropolitan State University, 3:RAL/NCAR, 4:UCAR

Abstract

Ground-level ozone is a major pollutant throughout the world that causes many of the human health problems associated with air pollution. This project seeks to discover the impact of climate change on ground-level ozone in six cities in the Western United States. This was done by determining how many days per summer have ozone levels above the EPA standard (75 ppb) in the present climate and then estimating changes if the projected temperature values were to rise two or four degrees Fahrenheit. Models expect these temperature increases to occur near 2030 and 2050, respectively. The more stringent Canadian standard (65 ppb) was also used because studies show that ozone levels lower than the EPA standard are still detrimental to human health. The results showed an overall trend of increasing summer days with above-standard ozone: on average, the number of days above the American standard increased by 2.3 by 2030 and 5.0 by 2050 in these six cities. Average increases of 3.0 days by 2030 and 6.0 by 2050 were predicted using the Canadian standard. Significantly more days were expected to exceed the Canadian standard than the American standard. This study shows that all of the studied cities have summertime ozone levels that pose risk to human health and suggests that these problems will increase in the future with rising temperatures.

1. Introduction

Ground level ozone is a major pollutant throughout the world that causes many of the human health issues associated with air pollution. High concentrations of ground level ozone have been shown to increase mortality rates by .52% daily in urban communities in the U.S (Bell et al, 2004) and increase the severity of asthma symptoms in asthmatics (Devlin et al, 1997). The EPA categorizes ozone into six levels related to public health: Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, and Hazardous. The EPA sets the national standard at the boundary between Moderate and Unhealthy for Sensitive Groups, at 75 parts-per-billion (ppb). This standard holds significance because studies show that risk groups, such as asthmatics and people with pre-existing lung disease, are negatively affected when the ozone concentration exceeds 75 ppb (National Ambient Air Quality Standards, United States EPA, 2012). Some scientists advocate for lowering the standard because ozone levels lower than the current standard have also been shown to be detrimental to human health; a recent study shows that healthy young adults can witness lung inflammation at values as low as 60 ppb (Kim et al, 2011). Canada has the standard set a 65 ppb (Canadian Council of Ministers of the Environment, “Canada-Wide Standards for Particulate Matter (PM) and Ozone”) and it is possible that the American ozone standard may change to this concentration in the future.

Ground-level ozone is produced by volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of sunlight and heat; therefore, higher temperatures are expected to correlate with higher ozone values (Devlin et al, 1997). The midpoint of the range of 21 Intergovernmental Panel on Climate Change (IPCC) Atmosphere-Ocean General Circulation Models over six cities in the western United States show a temperature rise of about 1.9 degrees Fahrenheit by 2030 and 3.8 degrees Fahrenheit by 2050 (Solomon et al, 2007). The aim of this paper is to predict how these rising temperatures might change the probability that ozone levels will exceed the standard of 75 parts per billion set by the EPA, thus charting the effects that climate change could potentially have on air pollution and human health.

2. Background and Methods

a. Study region

This study investigates the effect of a potentially warmer climate on the ozone levels in six cities in the western United States which currently have air pollution issues. These cities are: Bakersfield, Dallas, Denver, Phoenix, Riverside (near Los Angeles), and Sacramento. The six cities chosen have different climates and also have seen little change in pollution levels over the past 10 years. The western United States was selected as the region for study because models expect the warming in this region to be greater during the summer (ozone season) than the winter, the opposite of what is anticipated in most regions (Solomon et al, 2007). The chosen cities also currently have high ozone and pollution levels and polluted cities are thought to be more vulnerable to increasing ozone concentrations in the future (Bell et al, 2007).

The summer months (June through August) were examined because these months have been shown to have the highest ozone levels in most cities (Reuten et al, 2012). The time-range was limited to ten years (from 2002 to 2011) because air pollution laws and regulations were instituted frequently in the latter half of the 20^{th} century (History of the Clean Air Act, US EPA, 2012).

b. Temperature and ozone data

The temperature data was acquired through the Preliminary Monthly Climate Data reports gathered by the National Weather Service and the data on ozone levels was collected by the EPA. Sites for ozone and temperature measurement were chosen within 15 km of each other. The EPA data set provides the daily 8-hour maximum ozone concentration based on hourly observations and the NWS records temperature data to the nearest degree Fahrenheit. Maximum daily temperatures were used because they align more closely with the maximum ozone level. Data was only excluded when one of the data sets (maximum temperature or ozone levels) was missing for a date. Depending on the city, between 89% and 97% of the data was present for both sets.

Unlike the EPA, which applies the 75 ppb ozone standard to an air quality region based on a three year average of the fourth-highest ozone concentration recorded annually at sites throughout the area (National Ambient Air Quality Standards, United States EPA, 2012), this study defines an exceedance as whenever the recorded 8 hour maximum is above 75 (or 65) ppb at only one station per city. Regulations such as the Clean Air Act have significantly improved air pollution in terms of other pollutants such as carbon dioxide but ozone has shown only a 28% improvement in the past 30 years (National Trends in Ozone Levels, United States EPA).

While it is recognized that several variables other than temperature also affect ozone, including the ratios of nitrogen oxide (NO_X) gases and emissions of volatile organic compounds (VOCs) and background ozone levels (Jacob and Winner, 2009) these variables tie into economic and social factors which are hard to predict in the future and therefore were not considered in this study.

c. Determining the link between temperature and ozone

The relationship between temperature and ground level ozone concentrations was investigated by quantifying the probability of an ozone exceedence (as defined by both the EPA and Canadian standards) for 5 degree temperature ranges in each city using the ten years of data gathered.

d. Determining the probability of exceedence in the future

Climate models predict an increase in temperatures in the future. The relationship between maximum temperature and ozone levels was applied to investigate the change in ozone concentrations using scenarios adding 2 and 4 degrees Fahrenheit to the current climate. To estimate when these temperature increases will occur, this study employs climate models in the form of a multi-model data set from the Intergovernmental Panel on Climate Change (IPCC). Since temperature projections from individual climate models vary, especially for specific regions, this study looks at ranges of predicted temperature rises from the data set of 21 Atmosphere-Ocean General Circulation Models (Solomon et al, 2007). All of the cities examined in this study fall within the same region of the country so the models predict similar manifestations of climate change in each city. By taking the midpoint of the models' range, it was found that the predicted temperature rise for the western United States is about 1.9 degrees Fahrenheit by 2030 and 3.8 degrees Fahrenheit for 2050 (ibid), as shown in Fig. 1, which were rounded to +2 degrees and +4 degrees to account for the +/- 1 degree uncertainty in the observed daily maximum temperature.

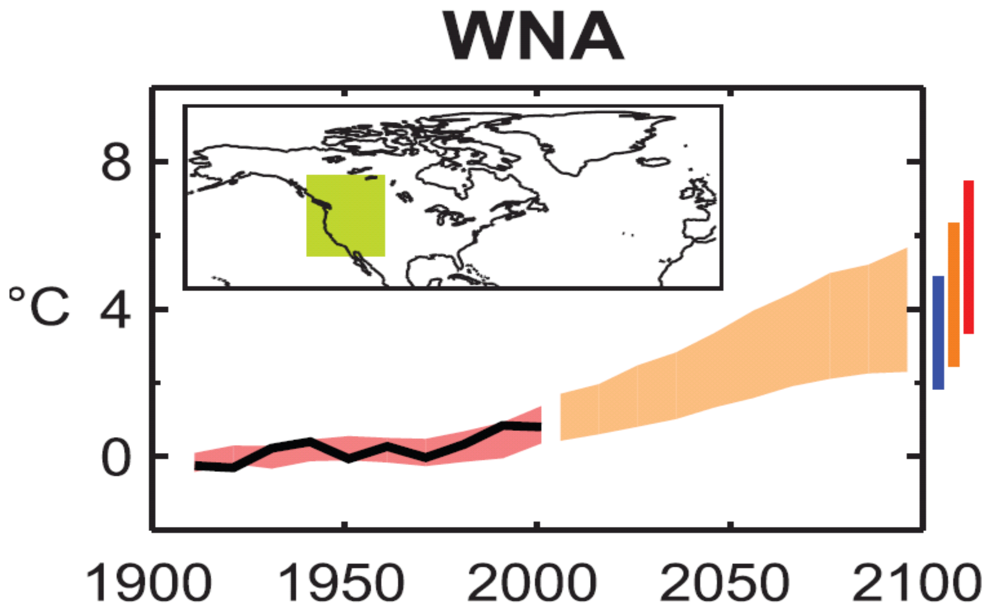

Figure 1: Warming Chart for Western North America from the IPCC Fourth Report Assessment (2007, Figure 11.11 in the report). This projection is an average of 21 Atmosphere-Ocean General Circulation Models; the orange region on the graph shows the range of predicted warming values in the future.

3. Results and Discussion

a. Temperature and ozone correlation

As shown in Table 1, and Figure 2a, ozone concentration and maximum temperature showed a statistically significant correlation, but the correlation was not strong enough to predict a day's ozone concentration given its temperature.

Table 1: Pearson Correlation values (r) and coefficients of determination (r^2) for the cities. *** indicates .1 percent chance or less that the null hypothesis (that there is no correlation between ozone concentration and temperature) is true. The null hypothesis can be rejected for all six cities. Coefficient of Determination values show that, while the correlations are significant, temperature is not a good predictor of ozone concentration

City	Pearson Correlation(r)	Coefficient of Determination (r^2)
Sacramento	0.769***	.592
Bakersfield	0.756***	.571
Denver	0.742***	.550
Riverside	0.699***	.488
Dallas	0.409***	.167
Phoenix	0.235***	.055

Since using a linear trend line for the data showed significant correlation but little accuracy in predicting a day's ozone level given its temperature, the data was processed using a histogram showing the probability of an ozone exceedence for a given temperature range, as shown in Fig 2b. There was a visible result showing increasing probability of ozone exceedences as the city's temperature increased.

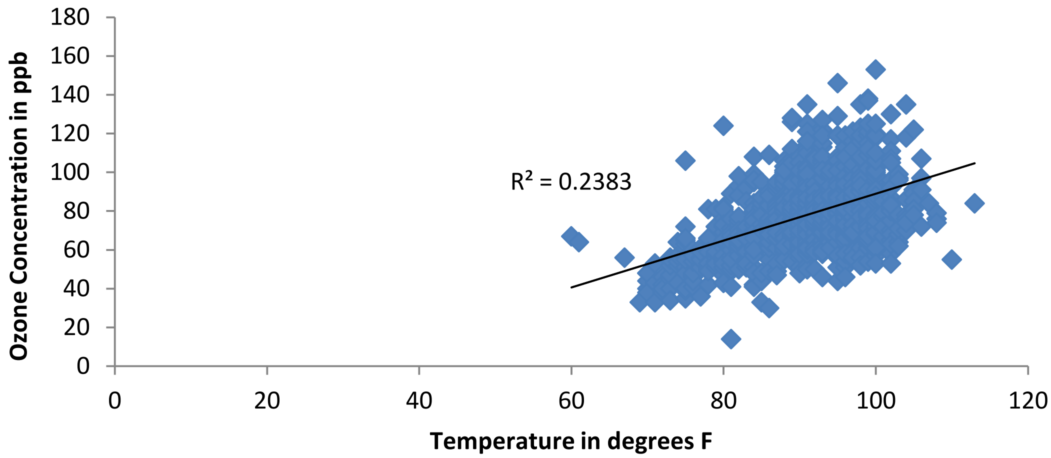

Figure 2a: Ground level ozone concentration (8 hour maximum) versus the maximum daily temperature for Riverside, CA. Data used from the months June-August, 2002-2012 (the time range was extended for Riverside because June 2008 ozone data was not recorded).

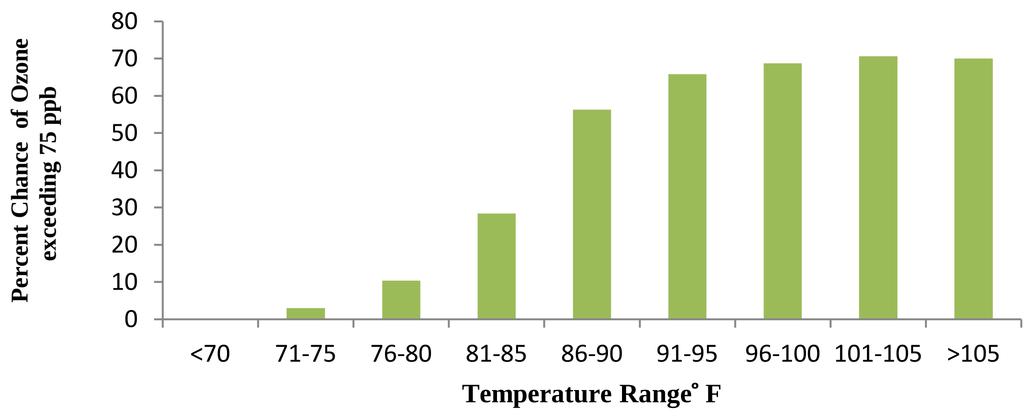

Figure 2b: Histogram showing the probabilities of ozone exceeding 75 ppb in each temperature range for Riverside, CA.

To obtain a quantitative value for showing climate change's impact on ozone, probabilities were used to predict how many days each summer would have ozone levels above the standard for each city for the current climate and the projected future climate.

The temperature increases from the IPCC models, as described in section 2d, were added to each data point in every city to determine the new expected temperature distribution which was then used to predict the number of ozone exceedence days per summer in future climates using the probabilities exemplified by Figure 2b.

b. Current Temperature and Ozone Distributions

The following section shows two graphs for each city preceded by a summary of findings for that city. The first figure shows the distribution of the city's maximum temperatures in the summertime and the second shows the probability of an ozone exceedence in that temperature range. Probabilities are shown for both the EPA Standard (75 ppb) and the Canadian Standard (65 ppb). For Bakersfield, the graphs for the two standards are shown separately but are combined in subsequent cities.

Bakersfield, CA

By the EPA Standard (75 ppb), the Bakersfield data show about a 40% chance of an ozone exceedence in its most common temperature range of 96-100 degrees F and the probability of ozone exceedence increases with each subsequent temperature range (Figs. 3a and 3b). By the Canadian Standard (65 ppb, Fig. 3c), an ozone exceedence occurs 70% of the time in Bakersfield's most common temperature range of 96-100 degrees F and the probability of ozone exceedence increases with each subsequent temperature range, approaching 100% for temperatures over 105 degrees Fahrenheit

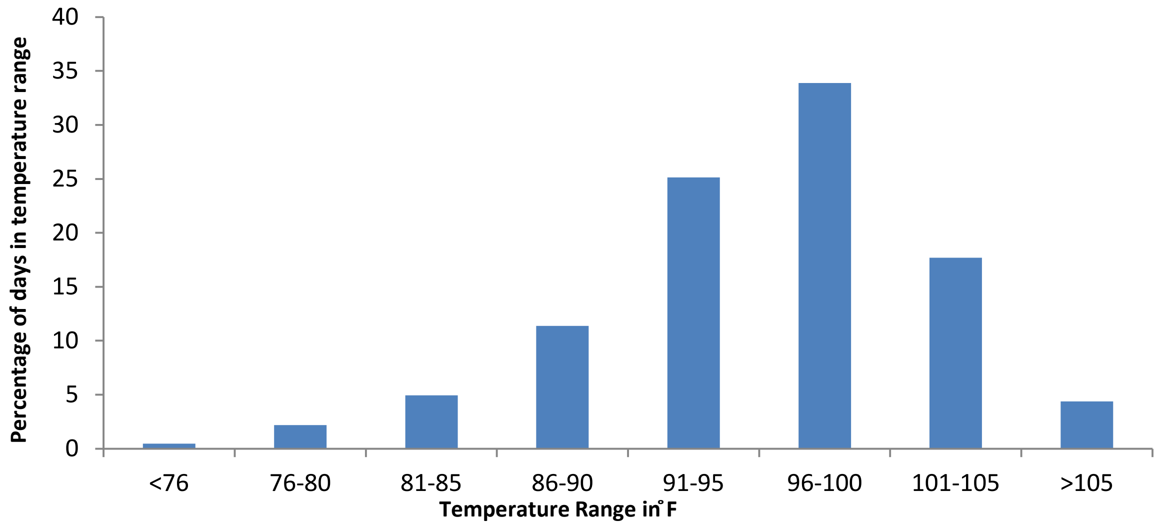

Figure 3a: Distribution of maximum temperatures for Bakersfield, CA for summer months (June-August) from 2002-2011

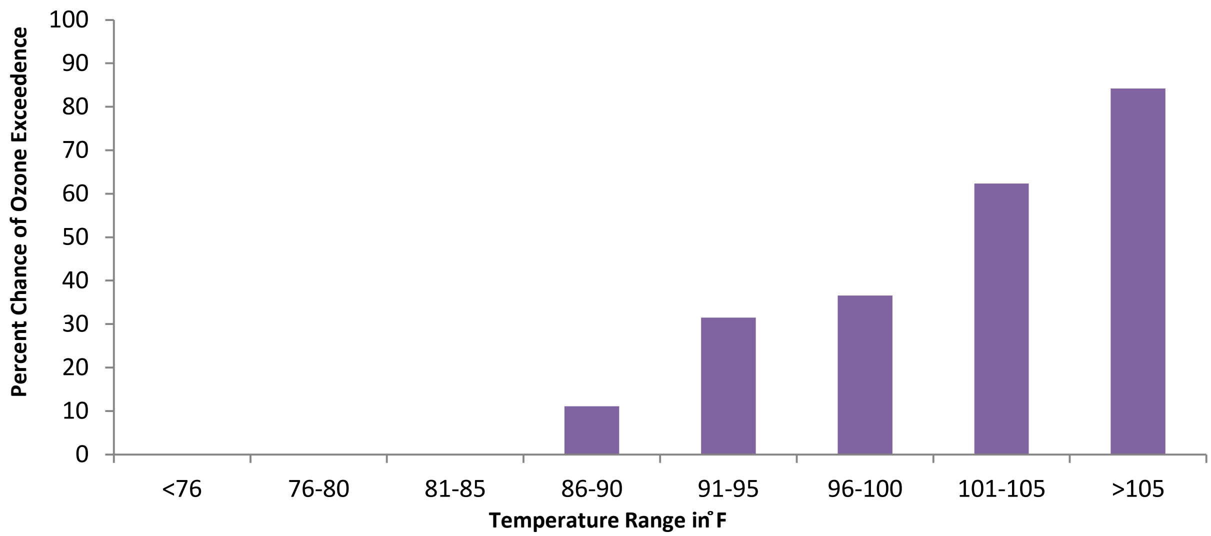

Figure 3b: Probability of ozone exceedence in given temperature ranges for Bakersfield, CA using data from June-August of 2002-2011. Exceedence defined based on the EPA standard of 75 ppb

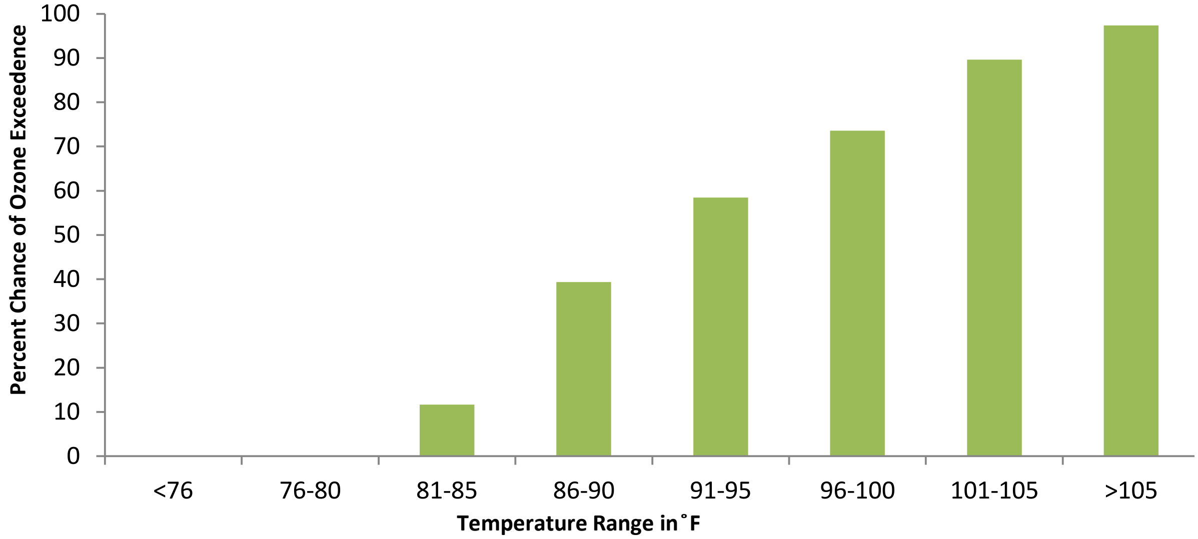

Figure 3c: Probability of ozone exceedence in given temperature ranges for Bakersfield, CA using data from June-August of 2002-2011. Exceedence defined based on the Canadian Standard of 65 ppb.

Dallas, TX

Dallas exhibits about a 20% chance of an ozone exceedence in its most common temperature range of 96-100 degrees F by the Canadian Standard and about a 10% chance by the EPA standard (Fig 4). The exceedence probability increases with temperature except for the range 96-105 degrees Fahrenheit when the probability decreases with temperature. This trend is seen using both standards and there is no explanation yet for this abnormal phenomenon.

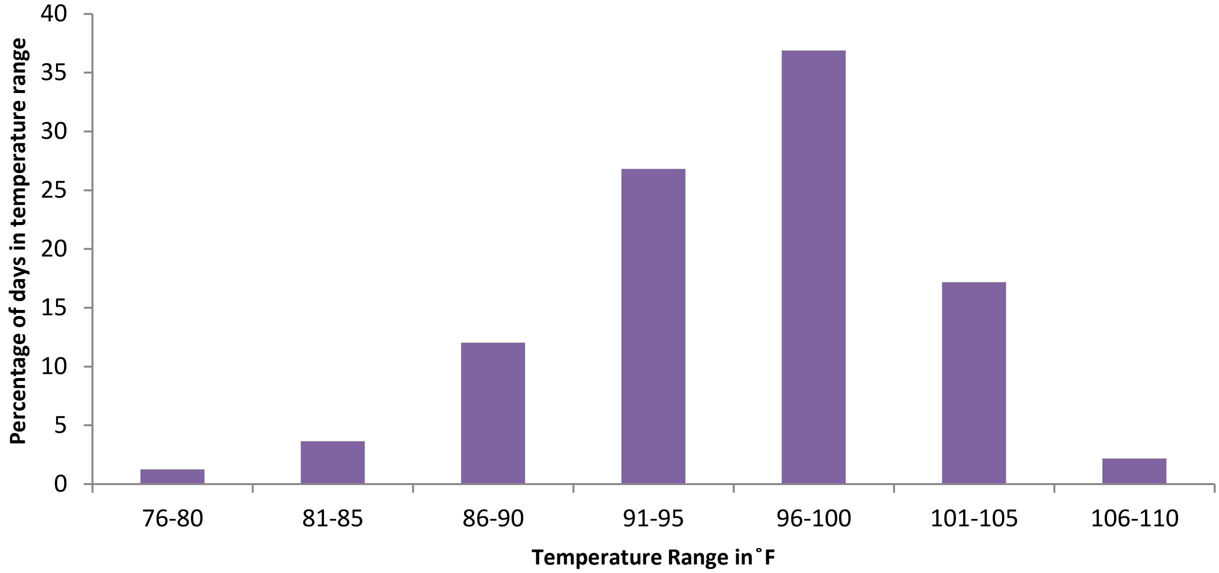

Figure 4a: Distribution of maximum temperatures for Dallas, TX for summer months (June-August) from 2002-2011

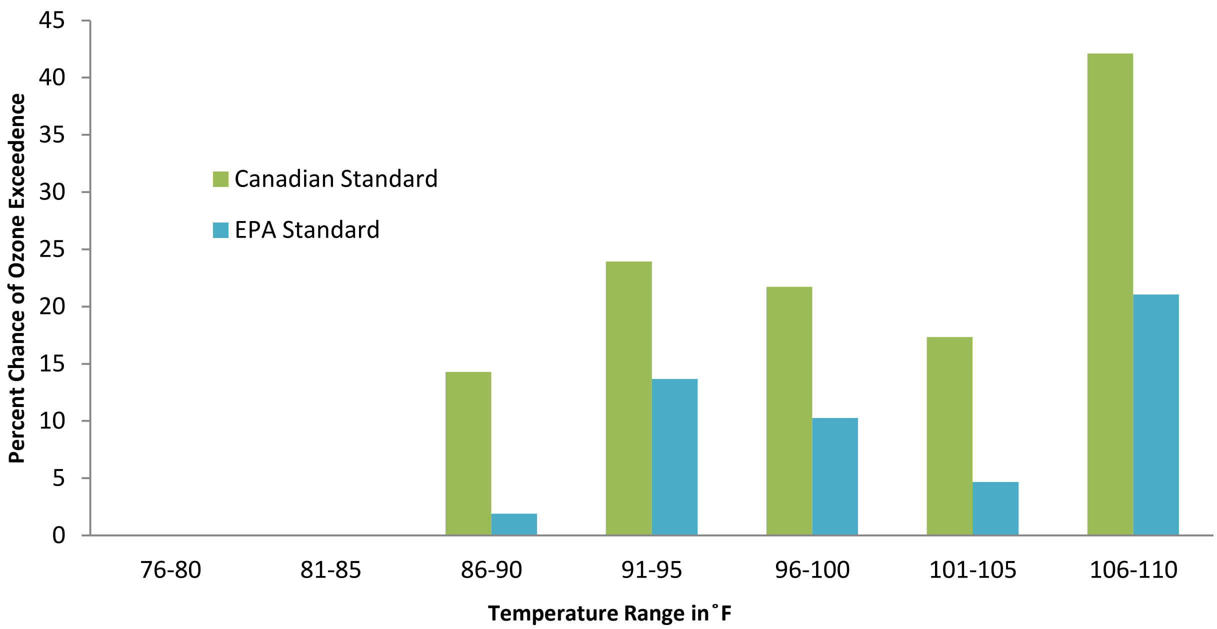

Figure 4b: Probability of ozone exceedence in given temperature ranges for Dallas, TX using data from June-August of 2002-2011. Exceedences defined based on the Canadian Standard of 65 ppb and EPA standard of 75 ppb

Denver, CO

Denver shows about a 60% chance of an ozone exceedence in its most common temperature range of 91-95 degrees F by the Canadian Standard and about a 20% chance by the EPA standard (Fig. 5). The overall trend is an increase in exceedence probability with temperature with some slight fluctuations in regards to both standards.

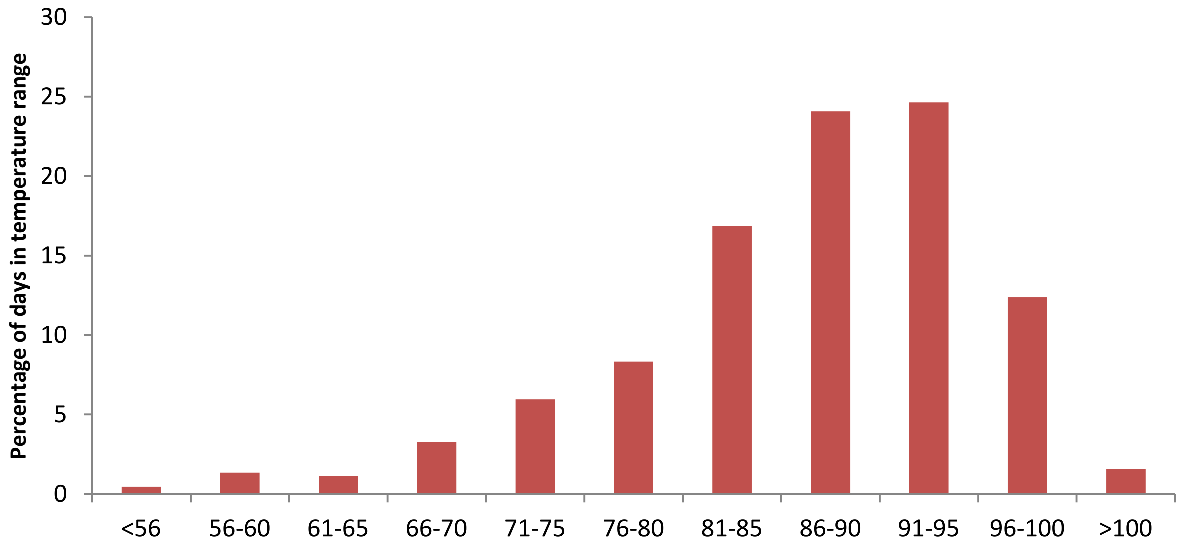

Figure 5a: Distribution of maximum temperatures for Denver, CO for summer months (June-August) from 2002-2011

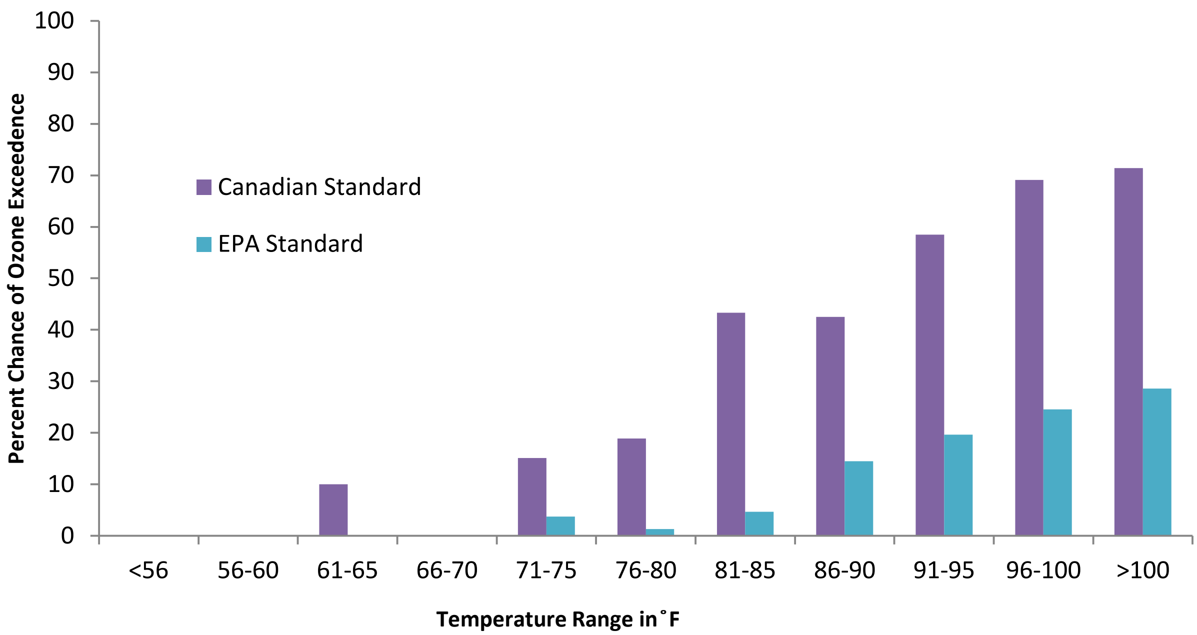

Figure 5b: Probability of ozone exceedence in given temperature ranges for Denver, CO using data from June-August of 2002-2011. Exceedences defined based on the Canadian Standard of 65 ppb and EPA standard of 75 ppb.

Phoenix, AZ

Phoenix exhibits about a 25% chance of an ozone exceedence in its most common temperature range of 101-105 degrees F by the Canadian Standard and about a 5% chance by the EPA standard (Fig. 6). There is no consistent trend shown by either standard. This case needs further research to determine the cause of Phoenix's irregular data and confirm the lack of a trend. The most likely explanations are meteorological phenomenon or an ozone saturation point with high enough temperatures.

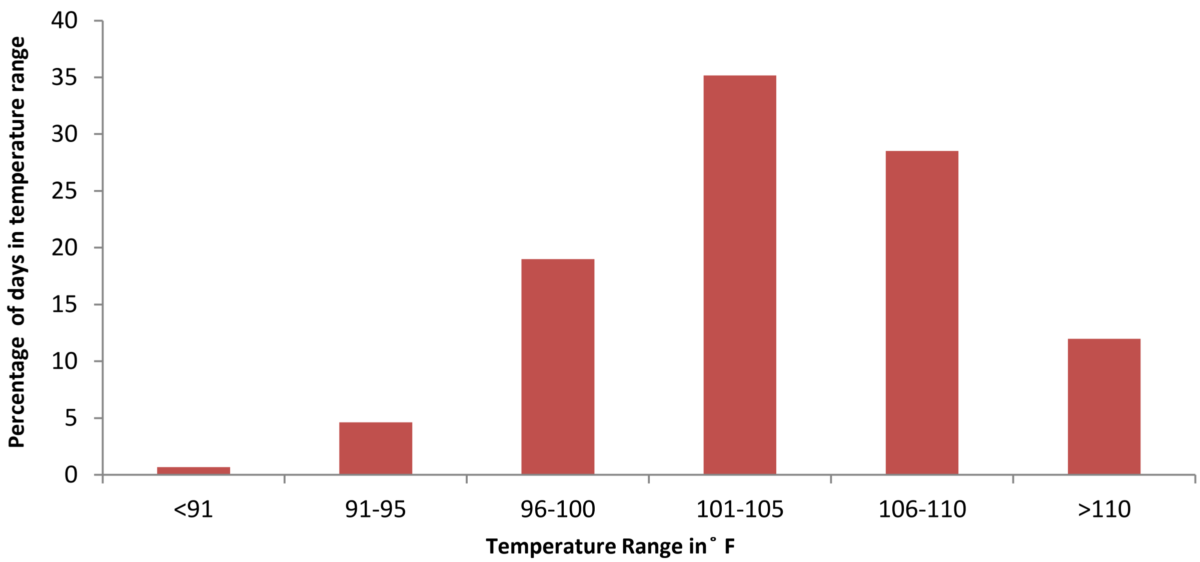

Figure 6a: Distribution of maximum temperatures for Phoenix, AZ for summer months (June-August) from 2002-2011

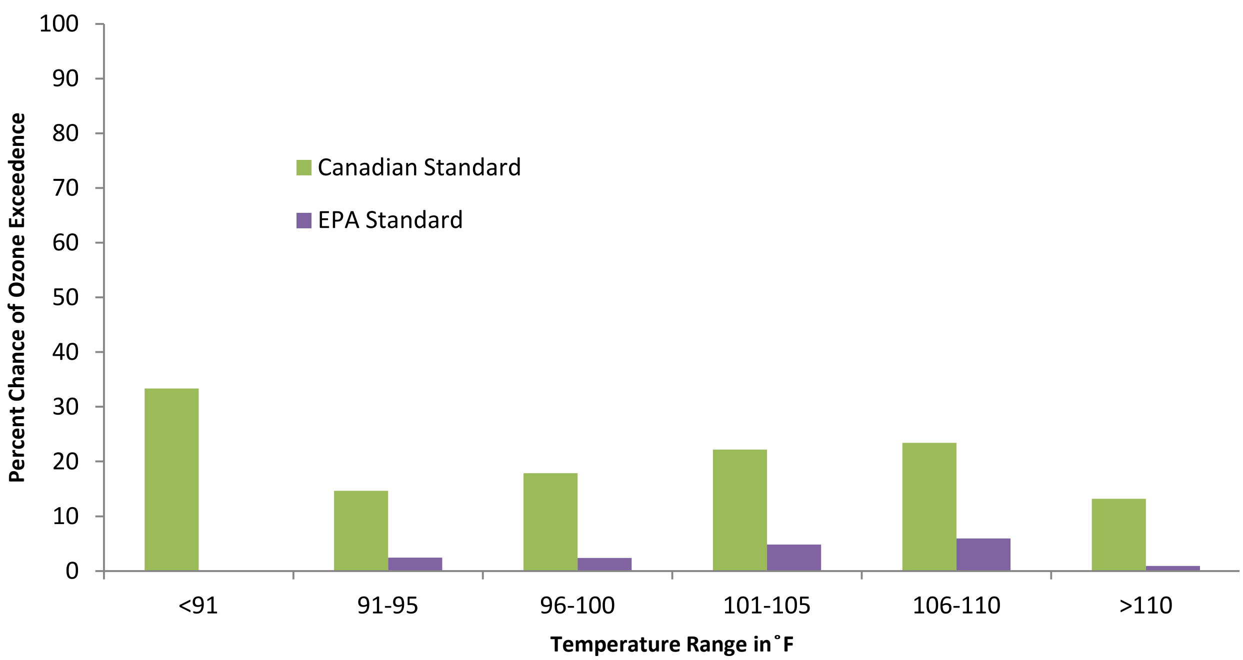

Figure 6b: Probability of ozone exceedence in given temperature ranges for Phoenix, AZ using data from June-August of 2002-2011. Exceedence defined based on the Canadian Standard of 65 ppb and EPA standard of 75 ppb

Riverside, CA

Riverside shows about an 85% chance of an ozone exceedence in its most common temperature range of 91-95 degrees F by the Canadian Standard and about a 65% chance by the EPA standard (Fig. 7). The overall trend is an increase in exceedence probability with temperature with a slight fluctuation for lower temperature ranges for the Canadian Standard. The exceedence probability plateaus at high temperatures, approaching 70% by the EPA Standard and 90% by the Canadian standard.

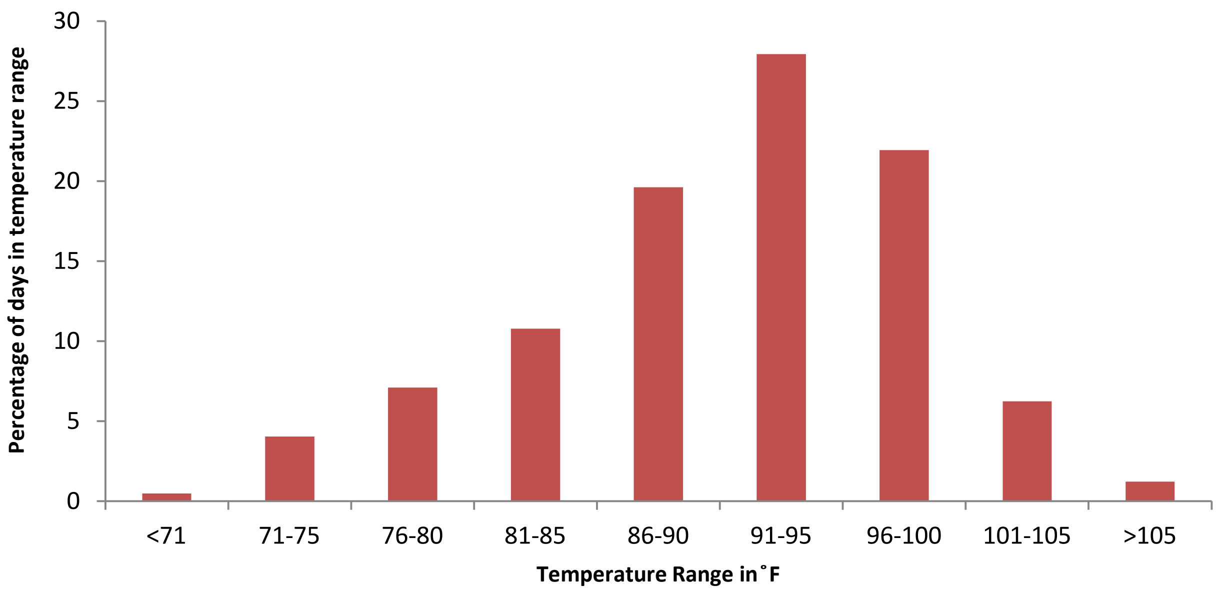

Figure 7a: Distribution of maximum temperatures for Riverside, CA for summer months (June-August) from 2002-2011

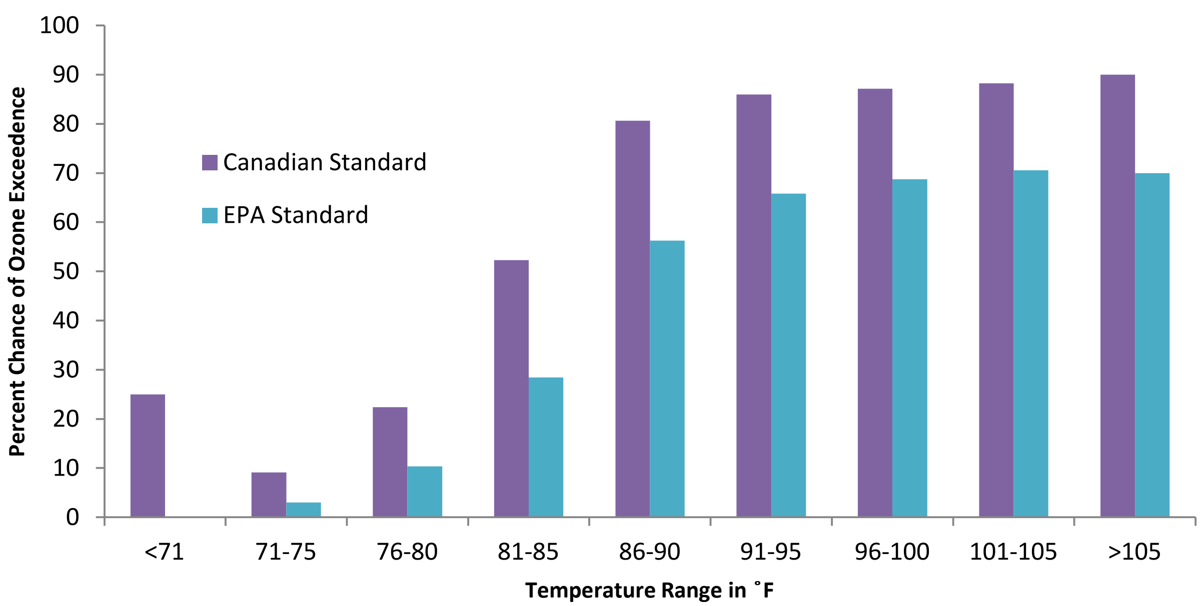

Figure 7b: Probability of ozone exceedence in given temperature ranges for Riverside, CA using data from June-August of 2002-2011 and June of 2012. Exceedence defined based on the Canadian Standard of 65 ppb and EPA standard of 75 ppb. Since data from June 2008 was not collected, data from June 2012 was used.

Sacramento, CA

Sacramento demonstrates about a 25% chance of an ozone exceedence in its most common temperature range of 91-95 degrees F by the Canadian Standard and about a 10% chance by the EPA standard (Fig. 8). The overall trend is an increase in exceedence probability with temperature with some slight fluctuations by the Canadian standard data. This data also shows that Sacramento would be very sensitive to future temperature increases as the exceedence probabilities increase dramatically in the higher ranges.

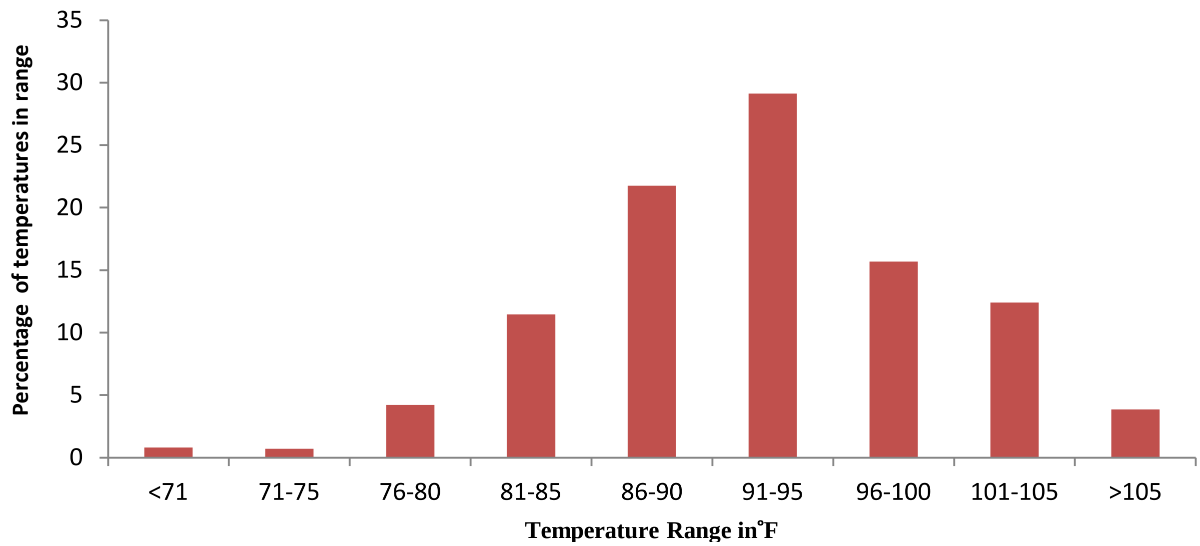

Figure 8a: Distribution of maximum temperatures for Sacramento, CA for summer months (June-August) from 2002-2011.

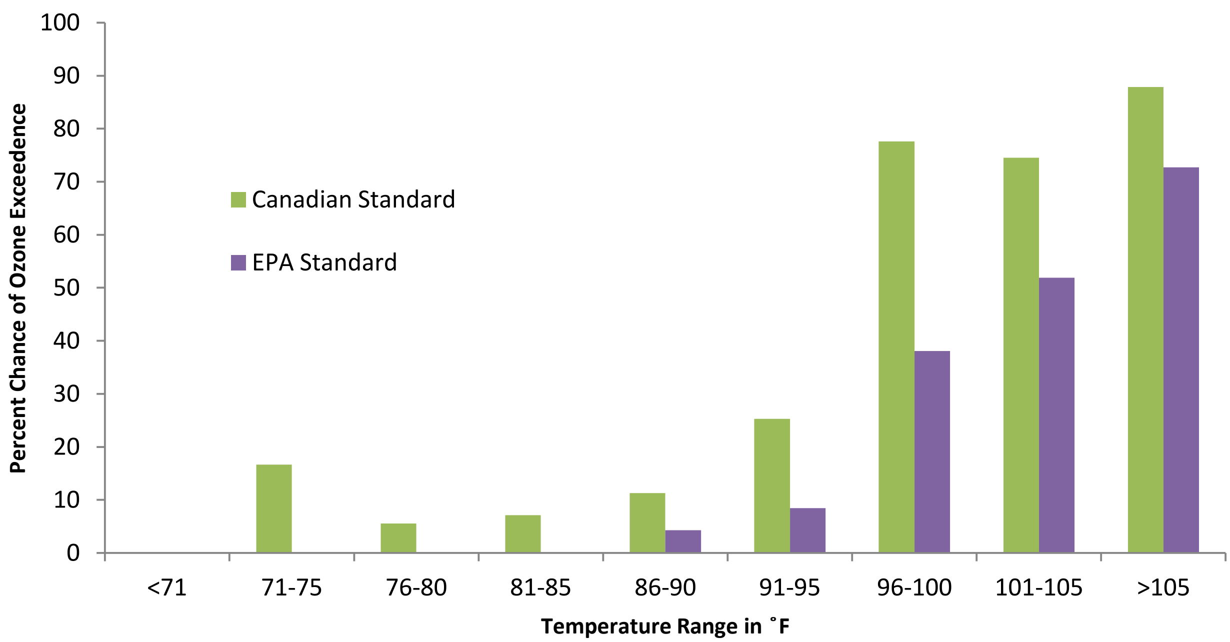

Figure 8b: Probability of ozone exceedence in given temperature ranges for Sacramento, CA using data from June-August of 2002-2011. Exceedences defined based on the Canadian Standard of 65 ppb and EPA standard of 75 ppb.

c. Predicted Ozone Exceedences in the Future

Table 2: Number of days per summer expected to have ozone levels above the Canadian standard (65 ppb).

City	Current Climate	Predicted Climate 2030	Predicted Climate 2050
Riverside	67.4	70.8	73.1
Bakersfield	59.6	64.3	69.6
Denver	40.7	44.4	47.9
Sacramento	32.9	37.5	44.5
Phoenix	18.7	19.0	17.2
Dallas	18.4	19.5	21.2

Using probabilities shown in Fig. 2b, the number of days per summer expected to have ozone levels above the Canadian standard (65 ppb) are shown in Table 2. These results were interpolated by using climate predictions of +2 degrees F for 2030 and +4 for 2050 to determine the expected number of exceedences. All cities except for Phoenix show significant increases in ozone exceedence days in future climates.

Table 2: Number of days per summer expected to have ozone levels above the EPA standard (75 ppb).

City	Current Climate	Predicted Climate 2030	Predicted Climate 2050
Riverside	49.4	52.7	55.1
Bakersfield	33.4	38.0	44.2
Sacramento	17.1	20.6	26.2
Denver	11.9	13.7	15.5
Dallas	8.2	8.5	9.2
Phoenix	3.7	4.0	3.2

Similarly, Table 3 shows the number of days predicted to exceed the EPA standard of 75 ppb, calculated in the same way Cities other than Phoenix also show significant increases in ozone exceedence days by the EPA standard, showing that these cities will have problems meeting the standard in the future.

d. Model Verification Using Data from Summer 2012 in Denver

The mean maximum temperature in Denver during the summer of 2012 was 92 degrees, five degrees higher than the mean of the previous five years, 87 degrees. When the probabilities were used for this temperature increase, the yield was 16.4 days predicted to have ozone levels exceeding 75 ppb. EPA measurements showed that there were 18 days over the summer that recorded an ozone exceedence by the American standard, showing the model developed in this paper to be reliable, even with the known limitations of our methods which include: lack of control for social and economic factors influencing NO_X ratios and VOC emissions that affect ground-level ozone, and the climate change that occurred during the time period of this experiment.

4. Conclusion

The results of this study show that ozone levels tend to rise with increasing temperatures and that we can expect to see more summer days in the future with dangerous ozone levels in most cities. Rising temperatures expected from climate change tend to increase ozone pollution: on average, the number of days above the American standard increased by 2.3 by 2030 and 5.0 by 2050. Average increases of 3.0 days by 2030 and 6.0 by 2050 are predicted using the Canadian standard

The study also suggests that the effects of climate change on air quality will vary somewhat between climates and that some geographic areas are more vulnerable to ozone increase with temperature in the future: Bakersfield shows a significant increase in the number of exceedence days as its climate warms and Dallas shows little change while Phoenix actually shows a decrease in exceedence days. A good way to extend this investigation would be to look at multiple ozone and temperature collection sites throughout each city because that would provide more data and more accurate probabilities without lengthening the time period of the study.

All of the cities in this study are likely to have problems meeting the American standard whether or not if it is lowered to 65 ppb and are likely to experience an increase in ozone related health problems as temperatures increase in the future.

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