I. Abstract

With a rise in global temperatures, increased numbers of heat related deaths are anticipated globally. In geographic areas that have not historically dealt with extreme heat events, many homes are not equipped with sufficient cooling mechanisms. In the Pacific Northwest, populations are vulnerable due to a common lack of air conditioning. Of 39 cities studied in the Pacific Northwest, 58.97% are experiencing an increase in the average yearly maximum and/or minimum temperatures. An increase in the average yearly maximum temperature in over half of the cities indicates that warm temperatures are rising; an increase in the minimum average yearly temperature indicates the cities are not cooling off at night. Furthermore, 23.07% of these cities are experiencing the urban heat island effect; these cities may additionally more vulnerable. We also found an increase in the average number of extreme heat days per year. With confirmation that there is a pattern of heating as well as an increase in extreme heat days, the Pacific Northwest may become increasingly susceptible to heat events. Without mitigating, such as making air-conditioning more readily available, we can expect an increase in heat related deaths in the Pacific Northwest.

II. Introduction and Background

There is a general consensus amongst scientists that the earth is experiencing a warming trend (Intergovernmental Panel on Climate Change, 2013). What is more readily debated and studied is the extent of the effects that this change will have. Historically, heat waves have caused more deaths than hurricanes, floods, and tornadoes combined (Wong et al., 2013). Current forecasts expect heat waves to increase in frequency, duration, intensity and are also associated with an increase in mortality (Clark et al., 2006). In the United States, it is estimated that 1500 people die each year due to heat related illness but it is important to note that the actual number may be higher because heat is often a contributing factor that exacerbates preexisting conditions (National Oceanic Atmospheric Administration, 2015; Wolfe et al., 2001). As shown in Figure 1, there is a strong relationship between mortality as heat begins to rise above 25°C (77°F). These foreboding prognoses make studying current trends even more valuable.
The area studied, the Pacific Northwest (hereafter referred to as PNW), is a particularly interesting case because it is normally associated with milder temperatures, substantial rain, and overcast weather. Recent events have drawn attention towards a potential heating trend; in 2009, the PNW experienced record high temperatures as well as the longest nighttime heat event ever in the area (Bumbaco et al., 2013). While the PNW may have more mild heat events than other areas of the United States, it has been shown that heat events do have a measurable impact on health (Bumbaco et al., 2013). With indication that the PNW may be experiencing increases in temperature, health concerns must be assessed in order to determine an appropriate plan of action.

The largest impacts are expected to be seen in cities that are accustomed to milder summers, are less equipped with air-conditioners and have a higher population density (Jackson et al., 2010). It has been seen that population density does have a significant correlation with surface temperatures, which may be important when discussing urban heat island, hereafter referred to as UHI (Chen and Zhou, 2004). This suggests that cities experiencing the UHI effect, with large populations, may be increasingly more vulnerable to heat events (Kinney et al., 2008).

Urban heat island is a regional climate occurrence that describes the phenomenon of development and human activities in cities influencing the air temperature in and around the city (Kim, 1992; Magee et al., 1999). Urbanization contributes to UHI effect because it strips the land of its vegetative cover and replaces them with impermeable surfaces such as concrete and asphalt. This decreased the area available for evapotranspiration while also increasing the abruption of solar radiation (Chen and Zhou, 2004). In addition, large buildings create radiative fluxes that lead to an increase in shortwave radiation absorption and decreases outgoing long wave radiation (Chen and Zhou, 2004). This is all in addition to added heat released from
houses, transportation, and industry. In the summer, the daily heating can allow the city to be 10°C (18°F) warmer than in nearby forests which is a concern for vulnerable communities (Kim, 1992).

In this paper we will look at heating and cooling trends in 40 cities in the PNW. Patterns of heating and cooling will be assessed and interpreted to identify what changes have been observed in the last 100 years. These trends will help us understand what is occurring currently as well as predict what we can expect in the future. We will then discuss various threats these trends may indicate as well as ways to mediate and combat them.

IV. Methods

To begin, 40 cities within Washington and Oregon were selected for our data sample. Students were assigned two cities to manage preliminary data analysis. Daily surface maximum and minimum uncorrected surface station temperatures from the National Climate Data Center (NCDC) were requested from stations located within or in close proximity to the city identified (Kalnay and Ming, 2003). Data was requested from January 1, 1900 to December 31, 2014; the longest and most complete data was desirable but many cities required the piecing together of data from more than one station. Complete data could not be collected for every city. Data was then prepped and imported into R-Studio by removing insufficient data points that would skew results. R-Studio was used to determine monthly and yearly minimum and maximum temperatures. The yearly averages were then used to determine a slope for the maximum and minimum temperatures. In addition, a maximum and minimum temperature average was found from data from 1960 to 1990. One standard deviation was then calculated and added to the mean value; this value was used to determine the extreme hot and cold threshold. R-Studio was then used to identify the yearly number of extreme heat and cold days from 1900 to 2014. Once
average temperatures, number of heat and cold days, and slopes were determined for all cities, analysis began.

While intentions were to acquire and process all data in the same manner, it is important to note that errors occurred during processing. Many locations have incomplete data or extraneous values that must be identified and removed. For many cities, this was not adequately completed. Individually, I removed data values that appeared inaccurate. Due to the nature of the flawed data, no significance values were calculated, as they would have false implications. Calculations and graphs should be used as indicators of a potential trend but data must be re-processed in the future to insure accuracy.

V. Results

A compilation of the slope trends within the PNW was geographically mapped (Figure 2). This map helps to illustrate that there is no clear pattern of heating and cooling in relation to geographical location. A majority of 61.5% of the cities are experiencing either UHI or warming. This map was also used to determine an arbitrary division between coastal and inland cities.

The population of 39 cities were also compiled and graphed in Figure 3 to help indicate any patterns between the trends in slope of average yearly temperature in relation to population; no definitive pattern was observed. UHI is indicated by a decrease in the mean maximum temperature as well as an increase in the mean minimum temperature; the two begin to converge. Figure 4 shows the trends in Pendleton Oregon that are indicative of the UHI effect. This trend was observed amongst 23.07% of the cities studied.

A sum of the number of cities experiencing an increase in the slope of average yearly heating or cooling was taken (Table 1). Of the 39 cities included, 58.97% are experiencing an increase in the slope of average yearly maximum and minimum temperature. Coastal and inland
cities were also observed separately; the differentiation can be observed on Figure 2. Of coastal cities, 63.63% are experiencing an increase in the slope of average yearly maximum and minimum temperature. Of inland cities, 52.94% are experiencing an increase in both average yearly maximum and minimum temperature.

Averages of the number of extreme heat and cold days were taken and graphed (Figure 5 and 6). Average extreme heat days increased from 1900 to 2014 with a slope of 0.0378 (Figure 5). Average extreme cold days from 1900 to 2014 increased with a slope of 0.0277. More concrete calculations are needed to definitively determine the significance of these slopes.

**VI. Discussion and Conclusion**

Heating and cooling trends of Pacific Northwest cities by geographic location are shown in Figure 2. A trend of heating decreasing and cooling increasing is indicative of UHI effect (orange dot); a trend of heating increasing and cooling decreasing is indicative of warming (green dot). With 61.5% experiencing either UHI or warming, it is clear, that the majority of cities observed in the PNW are experiencing a pattern that may threaten vulnerable communities.

Cities experiencing UHI effect (23.07%) are of particular interest due to the relationship with population density; we observed no strong correlation between large populations and UHI. UHI may have a relationship with population density, but it has a stronger correlation with percentage of urban surfaces and NDVI (Chen and Zhou, 2004). Future areas of study could focus on the density at which these populations are configured as well as the percentage of these cities that is covered with urban surfaces. With more information, concrete reasons why cities like Pendleton, OR are experiencing UHI may be explained (Figure 3). Regardless, the cities experiencing UHI are significant due to the increased vulnerability from the higher temperatures. With a strong relationship between temperature and mortality (Figure 1), cities experiencing UHI
should begin developing mitigation processes.

There are already some tested mitigation strategies to deal with the UHI effect. The first is the use of cool roofs; these roofs are white or high-albedo roofs that, in theory, will increase the reflective ability of buildings within cities. These have been shown to be mildly successful but have a high degradation rate within the first year as the roof becomes less clean (Li et al., 2014). Green roofs refer to the use of soil and plants on roofs to increase evapotranspiration (Li et al., 2014). This method redirects energy into latent heat as well as increases irrigation, which provides a cooling effect. During a study conducted during the 2008 June 7th-10th Baltimore heat wave, researchers determines that to reduce UHI by 1°C, 30% of roofs in Baltimore would need to be green or cool (Li et al., 2014). Considering that UHI can increase a city’s temperature by up to 10°C yet 30% participation only reduces the effect by 1°C, it is undetermined whether these strategies are worth the investment.

Other mitigation strategies include an increase in availability to air-conditioning. Due to the historical patterns of mild summers, many in the PNW are not equipped with AC systems (Jackson et al., 2010). AC systems are one of the first lines of defense to combat the effects of heat related events. However, there is also an economic burden associated with increased use of AC that residents with a low or fixed-income, like the elderly, may not be able to afford (Bumbaco et al., 2013). Elderly, urban poor, and chronically ill are the most at risk with regards to heat related deaths (O’Neill et al., 2009). A study conducted in 2010 focused on mortality predictions due to climate change heat events found that the largest number of excess deaths is expected within the 65 years and older community (Jackson et al., 2010). This community is often more vulnerable due to financial constraints; many live on a fixed income and do not posses proper cooling mechanisms (like AC). Predicting future heat related deaths are an
imprecise science because adaptations are very difficult to account for (Kinney et al., 2008); a study in 2013 found that there were 10 more heat days in 2005 than in 1956, but it also found that heat related deaths have gone down slightly due to mitigation (Wong et al., 2013). With the knowledge that AC systems can reduce the number of deaths, increasing availability for vulnerable communities will be crucial for mitigating heat related deaths.

Overall, a majority of cities is experiencing a positive trend when looking at average yearly heating and cooling temperatures (Table 1). Inland and coastal cities were separated in order to observe and differences; 63.63% of coastal cities are experiencing an increase in both averages while 52.94% of inland cities are experiencing a similar trend. Of all the cities included, 58.97% are experiencing and increase in the average yearly maximum and minimum temperatures. More research into the significance of this increase is necessary but these patterns do reinforce that overall heating is occurring. In addition, an increase in the average minimum temperature specifies that the average minimum temperature is rising. This means that the temperature is not dropping as low at night.

There is a misconception that heat events are only related to peak heat during the day. A 2013 study showed that the PNW is experiencing an increasing trend of nighttime heat events (Bumbaco et al., 2013). A similar study modeled heat events across the globe, found that increases in intensity and frequency in response to a double in CO$_2$ was due largely to a reduction in nocturnal cooling rather than due to daytime heat (Clark et al., 2006). This is illustrated by an increase in the average minimum temperatures. Our data shows that while there is an upward trend in average maximum temperature (daytime temperature) there is also an upward trend for minimum temperature (nighttime temperature). With higher temperatures at night, cities and homes in the PNW do not have the opportunity to cool off as much and maintain a higher
temperature; this will further increase the dependence on AC systems.

Due to the added threat to health, heat events are of particular importance to identifying vulnerability; extreme heat days are a good indication of frequency of heat events. From 1900 to 2014, the slope of extreme heat days in the PNW increase at a slope of 0.0378 (Figure 5); a clear indication of an increase in heat that is also reflected in the increase in average yearly maximum temperatures. This further reinforces the heating trend and need for mitigation in the PNW. An increase in extreme cold days from 1900 to 2014 contradicts earlier data that indicates that average yearly minimum temperatures are increasing (Figure 6). This may indicate that spikes in temperature occur and signify extreme cold days, but the overall trend shown by yearly average data still indicates warming. More research into the significance of the pattern observed may help further explain the trend as well as help model for the future.

In conclusion, indications of a warming trend and UHI were discovered. Positive trends in extreme heat days may suggest that the PNW will experience more in the future. Mitigation strategies are largely reliant on air-conditioning systems, which have been proven effective. Accurately modeling the future of the PNW’s climate will help provide support for developing a strong mitigation strategy. Cities experiencing UHI are important areas of focus due to the added heat. Additionally, vulnerable communities should be recognized and infrastructure to support them should be developed. Overall, the PNW is likely to experience more heat events in the future. These occurrences will likely increase heat related death, but we have the knowledge to begin alleviating those issues now. As always, more research is absolutely necessary to reiterate these findings and further develop their implications.
VII. Figures and Tables

Figure 1: The Relationship of Temperature and Mortality (Wong et al 2011).
Figure 2: Map showing the heating and cooling trends as indicated by average yearly slope of maximum and minimum temperature according to location. Grey line reflects arbitrary division between inland and coastal cities. Omitted Redmond.
Figure 3: Bar Graph showing the population in Pacific Northwest Cities. Bars are organized and colored based on average yearly slopes of maximum and minimum temperatures. Omitted Redmond.

<table>
<thead>
<tr>
<th>City</th>
<th>Tmax Slope Increasing</th>
<th>Tmin Slope Increasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Cities</td>
<td>14 of 22 (63.63%)</td>
<td>14 of 22 (63.63%)</td>
</tr>
<tr>
<td>Inland Cities</td>
<td>9 of 17 (52.94%)</td>
<td>9 of 17 (52.94%)</td>
</tr>
<tr>
<td>All Cities</td>
<td>23 of 39 (58.97%)</td>
<td>23 of 39 (58.97%)</td>
</tr>
</tbody>
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Table 1: This table shows the percentage of cities experiencing an increase in their Tmax or Tmin slope. The division of coastal cities and inland cities can be observed on Figure 2. Omitted Redmond.
Figure 4: An example of a city, Pendleton, that is experiencing the Urban Heat Island effect.
Figure 5: Average Extreme Heat Days for Pacific Northwest cities from 1900-2014. Omitted Hillsboro, Redmond, Sunnyside, and Wenatchee.
Figure 6: Average extreme cold days in Pacific Northwest Cities from 1900 to 2014. Omitted Klamath, Olga, Redmond, Sunnyside, and Wenatchee.
Works Cited


National Oceanic and Atmospheric Administration, cited 2015: What is a heat index? Know when you just can’t sweat it out. [Available online at http://www.noaa.gov/features/02_monitoring/heatindex.html.]

