Abstract

Empirical studies exploring the response of human mobility to varying temperature across the United States are often completed under the assumption of relatively stable social and policy environment. Given the behavioral changes associated with shelter-in-place restrictions and guidelines, has there been an impact on the movement 11patterns in response to extreme heat across the San Francisco Bay Area? To explore this question, we created a highly resolved mobility metric utilizing Safegraph’s Neighborhood Patterns data, and combined the results with gridMET temperature data and demographic data from the US census. We then used a binned fixed effects regression model to characterize the mobility response to temperatures across the region. We find that when compared to the two years prior, 2020 saw an overall reduction in movement. In addition, while extremely hot temperatures historically resulted in an increase in mobility between census block groups, in 2020 there were dramatic declines in movement when compared to lower temperatures in the same year. Given these observations, further research may explore the role public indoor spaces previously had in heat mitigation and adaptation strategies that allow for continued activities in extreme temperatures.

Intro/Background

As of October 2021, COVID-19 has been a devastating cause of death for nearly 700,000 individuals in the United States, and has been the third leading cause of death for nearly two years (NCHS 2020, Zhou & Stix 2020). As the virus has spread across the country, government responses to the COVID-19 pandemic have seen high spatial variability as individual municipalities have instilled their own guidelines and ordinances in the absence of a blanket federal order (Dave et al. 2020, Diffenbaugh et al. 2020). The pandemic has also again revealed the inequalities in healthcare access among various socio-economic classes (Hooper et al. 2020, Tai et al. 2020). From the early days of the virus discovery in the US, the California Bay Area has consistently seen some of the most restrictive pandemic management policies in the US (REF). These Shelter in Place policies heavily restricted business operations and travel for the subsequent year.

While the specific conditions of 2020 created by a mixture of public policy and behavioral changes in response to the COVID-19 pandemic, we can utilize this ‘natural experiment’ to explore the influence of these pressures on mobility patterns during periods of extreme heat. As climate change increases the number of extreme heat events, we can anticipate that the mobility patterns seen on the hottest days will become more frequent (REF). To what extent might similar regulations or environmental pressures change movement in the face of other non-climate drivers?

Studies have been published on large scale mobility patterns throughout the course of the pandemic. Some have shown that COVID-19 protocols did in fact change mobility patterns across the country, and many regions saw an increase in the frequency of visitations to public, outdoor spaces (REF). In this paper, we create a mobility index in order to characterize the small scale, daily movement patterns throughout the San Francisco Bay area in 2020. We then explore the relationship of this index with temperature throughout the summer, and compare those results to the previous two years. Finally, we focus on periods of extreme heat in order to [explore where individuals were traveling under these altered conditions].

Methods

We utilized the gridMET meteorological dataset to collect 4-km gridded daily maximum temperature data. Using the county boundaries from the US Census, we calculated the mean recorded temperature of all grid cells within each county across the bay area (gridMET ref). For this analysis, we selected dates from May – September for the years 2018-2020. We used US Census estimates of median income to assign income groups to each census block group, and split the data into five buckets of equal size.

We analyze mobility patterns using the SafeGraph Neighborhood Patterns dataset. For every US census block group, we selected the number of identified home devices, and the number of stops in a given day. We define the number of visitors as the number of stops minus home devices. The values were then normalized to the number of home devices for each block group to calculate our final mobility index value (MI). This value was calculated daily for each census block group. Year to year comparisons are done by taking the average of the summer mobility in each year.

We explore the relationship between temperature and mobility on any given day in the Bay area utilizing a binned fixed effects regression model. We group temperatures from 16 - 38°C, and assign a bin at intervals of four. Two models were run using the daily temperature data and the calculated MI value for that day in each census block group. The first contained values from May-September 2018 and 2019. The second only contained days from 2020. The results of each model were bootstrapped to calculate the 95% confidence interval.

[1] Y​it​ = βX​it​ +​ n​i​ + δ​t​ +​ 𝜃​1​it​ + ε​it *Where Yi*​ *t*​ *is the change in mobility (MI); Xi*​*t i*​*s the average maximum high temperature in county i during month t; ni*​ ​*is the county fixed effects;* δ*t*​ ​*is the year & month fixed effect;* 𝜃​*1it*​ *are state-specific linear time trends;* ε*i*​ *t i*​ *s an error term that accounts for correlation between counties and within a state in a given year.*

*Second pipe is clustering*

*Look at ERL paper*

To further understand the trends in visited locations on the hottest days of the summer, we categorized census block groups based on their population density—calculated by diving the US Census population value for the block group by the land area. Every block group above the 75th percentile for the region was labeled as “dense”, and the bottom 25th percentile was labeled as sparse. Then, in order to investigate where individuals were visiting, we subset the data to include only the days in the hottest bin (>= 34°C ) find the average mobility index of those days, and select for the most mobile block groups (MI >= 3).

Results

We find that our calculated MI shows a decrease in movement in the summer of 2020 when compared to the previous two years from an average MI of 1.13 visitors per resident to 0.67. The largest decrease occurred prior to the start of the summer season, in mid-March to early April. This coincided with at the beginning of Shelter in Place policies in the bay area that began on March 16th, 2020. Mobility hovered around 0 for the first month of policy restrictions, with the lowest recorded date occurring on March 31st, 2020 with an MI of -0.47 [REF OF SIP start date?]. 4037 of 4950 census block groups in the studied regions saw a decrease in mobility from the summer of 2019 to 2020. 2072 of those experienced a >= 50% decrease in mobility. Across income groups, initial restrictions led to coalescence across all income. As the year progressed and some activities were reinstated across the bay, census block groups with the highest median income continued to have lower visitation than most groups, where prior to the pandemic they tended to have some of the higher MI values [FIG + PANEL]. The annual temperature patterns remained consistent from 2019 to 2020, and the days with the lowest temperatures coincided with overall lower MI [FIG + PANEL].

For our binned regression, we explore the relationship between temperature and MI in 2020, and in the previous two years. Consistent with our overall mobility analysis, the typical MI value for any day in 2020 is lower than the previous year. In addition, we see that the response pattern shifted in 2020. In the previous two years, hotter temperatures resulted in an increase in mobility, with a particularly sharp increase at temperatures above 34°C. In 2020, the relative maxima rests at days where the temperature was between 26-30°C, and sharply declines at temperatures above 34°C. These results indicate that MI is more sensitive to hot temperatures under Shelter in Place policies and the social conditions of 2020.

Although there was a clear trend of reduced movement at high temperatures, individuals continued to travel across the Bay Area throughout the summer of 2020. The total number of census block group with a high mobility index decreased from 434 to 231 from 2019 to 2020 (a 49% decrease). However, the proportion of those block groups that had been identified as either dense or sparse was higher during 2020, while block groups with a median population density made up less of the highly visited locations. The distribution of the highly mobile dense

Discussion

Fig 1

* The first month mobility pattern is consistent with studies that investigated the changes in mobility during 2020 compared to previous years as a result of movement-restricting COVID-19 policies [REF].

Further Research

* Timing of shifts in policy throughout the summer and the subsequent mobility shifts
* 2021 and long term effects