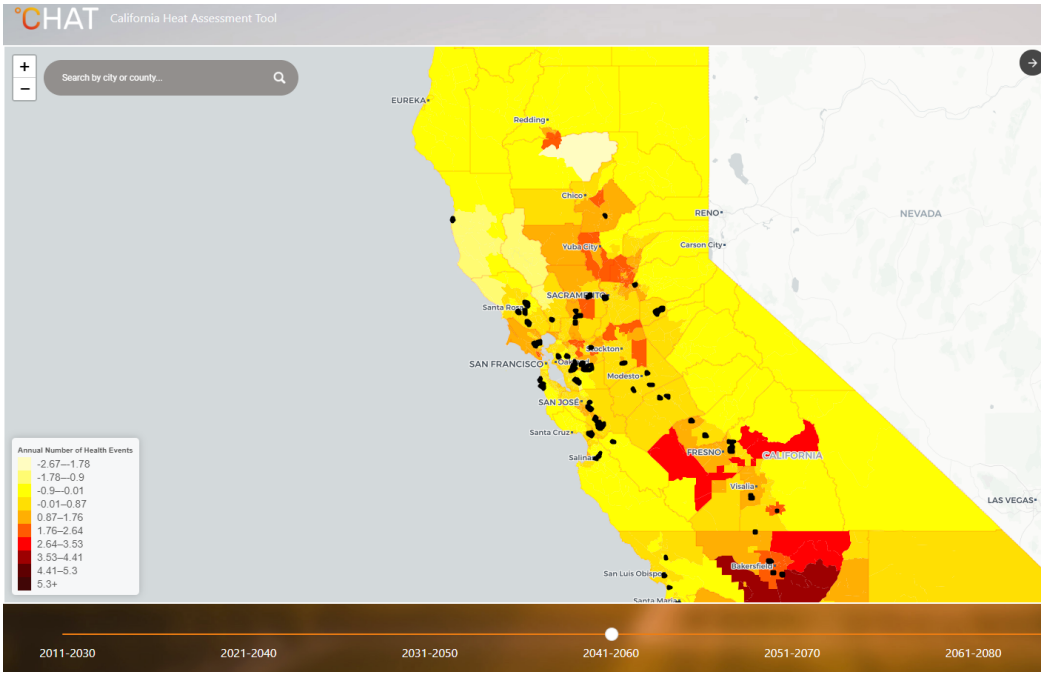
The California Heat Assessment Tool: Planning for the Health Impacts of Extreme Heat



Four Twenty Seven, August 2018

KEY TAKEAWAYS

- Current climate change projections show that a typical California summer in 2100 may be 4-5° F warmer than today. Heat waves are also lasting longer, occurring later into the summer season and in areas less accustomed to heat waves.
- Elderly or very young people, outdoor workers and individuals with preexisting health conditions or limited resources are most sensitive to the impacts of extreme heat and may be disproportionately affected. Some of these sensitive, or frontline, populations may experience adverse health impacts at temperatures 6-8° F lower than the general population.
- Current thresholds for heat alerts are based on temperatures that exceed certain statistical thresholds, rather than temperatures that cause public health impacts. These health-neutral thresholds may underestimate the health risks for the most sensitive populations.
- The online California Heat Assessment Tool (cal-heat.org) allows users to visualize projected changes in heat events that cause adverse health impacts, while also exploring data on social, health and environmental factors that contribute to heat vulnerability.

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INTRODUCTION

Extreme heat in California

California's climate is warming and in early July 2018 several places in Southern California set new all-time records with temperatures above 110°,[1] resulting in overburdened power grids and negative health impacts. The state currently experiences around 10 extreme heat days per year (in terms of climatological extremes, rather than heath impacts) and this could increase to 25-50 by 2050 and 100 by the end of the century.[2]

In addition to hotter temperatures, heat waves are becoming more humid, lasting longer than average and occurring in areas not accustomed to heat waves. Mitigating heat health impacts requires an understanding of the distribution of temperatures that will negatively affect the local populations.

Increasing extreme temperatures will bring more health risks to Californians. Each population has unique vulnerabilities driven by social, environmental and health factors. Elderly people and individuals with preexisting health conditions or limited resources are on the frontlines of these extremes, often experiencing disproportionate impacts. Populations who are used to mild coastal climates are also vulnerable as they are often not acclimated to higher temperatures.

Climate change will bring new risks for different regions in the state of California, and as such, will challenge the efficacy of traditional intervention strategies. Local agencies may struggle to effectively mitigate heat health impacts. The extent to which heat affects health and well-being will largely be determined by the ability to effectively commit local resources and capacity to implement applicable interventions and raise public awareness.

In this context, California funded its Fourth Climate Change Assessment, a state-mandated research program to assess climate change impacts in California. As part of this assessment, Four Twenty Seven developed the California Heat Assessment Tool to fill identified gaps in information for local jurisdictions to advance the understanding of how heat waves are changing at a local level.

Four Twenty Seven conducted a User Needs Assessment (UNA) to better understand local policies and processes in responding to extreme heat events and the current tools and resources stakeholders use to inform their planning and response activities. This culminated in a UNA report based on responses from public health, planning and emergency preparedness stakeholders. It identifies a need for more robust pre-planning for heat adaptation such as changing urban design and social programs. A new online decision-support tool presenting local information on both heat and populations can help facilitate the implementation of such programs. Responding to this need, Four Twenty Seven collected and analyzed data to define locally-applicable thresholds of extreme heat, project how local extreme heat events may change over the century and create a tool that allows local practitioners to plan for locally-specific heat impacts.

Understanding health impacts of extreme heat

Extreme heat has adverse effects on human health[3] and evidence suggests that climate change will increase the global number of heat-related deaths.[4]

[1]Samenow, Jason. "Record heat put thousands of Californians in the dark Friday. Scientists predicted this from climate change." Washington Post. 9 July 2018. https://www.washingtonpost.com/news/capital-weather-gang/wp/2018/07/09/record-heat-put-thousands-of-californians-in-the-dark-friday-scientists-predicted-this-from-climate-change/?noredirect=on&utm_term=.4178c96a2f1b

[2]Pierce, D.W. (ed). (2012). California Climate Extremes Workshop Report. Scripps Institution of Oceanography.

[3]Astrom, C., H. Orru, J. Rocklov, G. Strandberg, K.L. Ebi, and B. Forsberg. 2003. Heat-related respiratory hospital admissions in Europe in a changing climate: a health impact assessment. BMJ Open 2013; 3: e001842

[4]Hales, S., S. Kovats, S. Lloyd, and D. Campbell-Lendrum. 2014. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva: World Health Organization.

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Among natural disasters in California, heat was responsible for the most deaths in the last 30 years. The 2006 heat wave killed more than 600 people and resulted in over 1,200 hospitalizations, 16,000 emergency department visits, and nearly $5.4 billion in costs,[5] while other recent events such as the 2017 Wine County fires and the 1989 Loma Prieta and 1994 Northridge earthquakes killed less than 80 people each.[6,7]

Current climate change projections for California show that a typical summer is predicted to be 4-5° F warmer by 2100.[8] Increasing average temperature[9] increases the frequency and severity of extreme heat events.[10] The 2006 heat wave was also abnormally humid, with very high nighttime temperatures that hindered physiological recovery at night, a trend that is expected to worsen in the future.[11]

An important part of the human body's self-regulation of temperature is to cool itself through sweating, but humidity hinders this process. Humidity and pockets of stagnant warm air are uncharacteristic in most areas of the state. However, more humid, nighttime-dominated heat waves have begun to occur more frequently and are predicted to intensify over the coming century.[12] Coastal, foothill and mountainous communities not accustomed to the combination of heat and humidity are particularly susceptible.

Figure 1. Outdoor workers are particularly exposed to adverse health impacts from extreme heat.

Lower nighttime temperatures can offer essential respite from extremely hot days. However, relative warming is often stronger at night than during the day,[13] limiting the opportunity for physiological recovery and contributing to increased mortality.[14] Increasing nighttime temperatures can also increase energy demand as residents are more likely to run their air conditioners at night. This in turn can lead to power outages,[15] leaving residents without cooling mechanisms and particularly threatening people dependent on electrified life supporting machines such as ventilators or electric powered oxygen machines.[16]

[5]Knowlton, K., M. Rotkin-Ellman, L. Geballe, W. Max, and G. Solomon. (2011). Six Climate Change–Related Events in The United States Accounted for About $14 Billion In Lost Lives And Health Costs Health Affairs 30(11): 2167-2176.
[6]Dubuzinksis, Alex. "Death toll from California blazes rises to 43, after teen dies." 30 October 2017. Reuters: https://www.reuters.com/article/us-california-fire/death-toll-from-california-blazes-rises-to-43-after-teen-dies-idUSKBN1D004Z
[7]Cal OES Contingency Plan for Excessive Heat Emergencies, 2014: http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/ExcessiveHeatContingencyPlan2014.pdf
[8]Heat Adaptation Workgroup, a subcommittee of the Public Health Workgroup. 2013. California Climate Action Team, Preparing California For Extreme Heat: Guidance and Recommendations. California Climate Action Team. http://www.climatechange.ca.gov/climate_action_team/reports/Preparing_California_for_Extreme_Heat.pdf.
[9]Stocker, T. F., D. Qin, G. K. Plattner, et al. (2013). IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
[10]Pierce, D.W. 2012
[11]Gershunov, A., D.R. Cayan, and S.F. Iacobellis. 2009. The Great 2006 Heat Wave over California and Nevada: Signal of an Increasing Trend. Journal of Climate 22(23): 6181–6203.
[12]Pierce, D.W. 2012
[13]Easterling, D.R., B. Horton, P.D. Jones, et al. 1997. Maximum and Minimum Temperature Trends for the Globe. Science 277(5324): 364–367.
[14]Hémon, D., and E. Jougla. 2003. Surmortalité Liée À La Canicule D'août 2003: Rapport D'étape.
[15]Alawar, A., E.J. Bosze, and S.R. Nutt. 2005. A Composite Core Conductor for Low Sag at High Temperatures. IEEE Transactions on Power Delivery 20(3): 2193–2199.
[16]Klinger, C., O. Landeg, and V. Murray. 2014. Power Outages, Extreme Events and Health: A Systematic Review of the Literature from 2011-2012. PLOS Currents Disasters.

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Through the urban heat island effect, cities often experience higher temperatures than nearby rural or suburban areas, particularly at night, due to their impervious surfaces such as cement and dark roofs. This amplifies the severity and duration of heat waves in cities and increases the differential between rural and urban temperatures. Air pollution exacerbates the health impacts of extreme heat, placing further stress on the body's systems. Likewise, high temperatures also increase the concentrations of particulate matter. Ozone formation requires heat and sunlight, so hotter summers may increase average ozone concentrations.

CHALLENGES FOR PUBLIC HEALTH PLANNERS

Heat planning

California's Office of Emergency Services (Cal OES) Excessive Heat Contingency Plan[17] provides guidance for state and local government agencies based on three phases: seasonal readiness, heat alert and heat emergency. The guidance around extreme heat that is provided by the state is very high-level. Local cities and counties are required to incorporate extreme heat into several types of emergency response and adaptation plans and there is ambiguity about who is responsible for both long-term planning and mitigation as well as responding to specific heat health emergencies. This leads to confusion about how heat planning should be funded and implemented.

Resources are often lacking for local public health departments. If local resources are not adequate, the local jurisdiction must request assistance from the next jurisdictional level, starting with the county, then the region and the state. However, local jurisdictions are responsible for paying for the resources provided by higher levels of government, which often prevents small, under-resourced areas from requesting help. Likewise, the state has minimum thresholds for intervention in terms of the number of people in need of medical treatment, so even if they request help many of the smaller, under-resourced counties may not qualify to receive assistance.[18]

Preventing health impacts from heat is no easy task. Several common responses to heat events tend to have limited effectiveness. Most local heat interventions consist of alerting residents of risks through several communication channels and encouraging residents to gather in cooling centers. However, this assumes that exposed residents trust government officials enough to take routine-disrupting, protective measures based on public alerts alone. Likewise, residents must often rely on their own transportation or that of family or friends to reach the cooling centers, and this is not an option for many frontline individuals. Solutions to these issues can include more widespread education about the severity of health impacts from extreme heat events and an understanding of the specific needs and sensitivities of each neighborhood. It is also valuable to empower individuals, particularly those at greatest risk, to understand their exposure and access the available resources.

Frontline communities

The Impacts of increasing extreme heat in California will not be felt evenly across populations, as susceptibility to adverse health impacts is driven by many interacting factors including age, income, health, community networks and acclimatization. During the 2006 heat wave heat illnesses began to appear between 80.6-96.8°F for Coastal regions and 91.4-107.6°F[19] for populations in the Central Valley, driving different health outcomes across the state. Individu-

[17]Cal OES Contingency Plan for Excessive Heat Emergencies, 2014
[18]Seville, A, Steinberg, N et al. 20176. California Heat & Health Projection. Four Twenty Seven: http://427mt.com/wp-content/uploads/2017/01/427_CA_HeatHealth_DecisionTool_UserNeedsAssessment-1.pdf
[19]Gershunov, A., and K. Guirguis. 2012. California Heat Waves in the Present and Future. Geophysical Research Letters 39(18): n/a-n/a.

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als with pre-existing health conditions,[20] outdoor workers, outdoor athletes,[21] infants and young children,[22] pregnant women[23] and homeless individuals are all highly susceptible to extreme heat.

Figure 2. Elderly individuals are particularly susceptible to adverse health impacts from extreme heat.

Elderly individuals are also particularly susceptible to heat-related illness due to several factors including pre-existing health conditions, physiological stress and in some cases, social isolation or limited mobility. In California, individuals over the age of 65 were found to be particularly affected during the 2006 heat wave, comprising 52 percent of all heat-related hospitalizations, although they only represent 11 percent of the state's population. This group is rapidly growing in California.[25]

Income is another important indicator of susceptibility to extreme heat, as most preventative measures require resources, including air conditioning, water, transportation to cooling centers and access to clear information. Nearly 90 percent of all victims of the 2006 heat wave lived in socio-economically deprived areas.[26] Latino and Hispanic groups along the North and Central Coast were particularly affected[27] possibly due to a high number of crop workers, a highly exposed group whose adverse health incidents have been largely underreported.[28]

Thresholds

There is no universal definition of a heat wave and definitions vary based on scale and context. The National Weather Services (NWS) is the primary organization responsible for tracking heat waves and issuing warnings. The NWS uses climate-focused thresholds and defines a heat wave as two consecutive days where the daytime high and nighttime low temperatures exceeds a certain threshold, which is usually between 80 and 105° F.

Many California NWS offices issue alerts when the daytime heat index exceeds 105-110°F for two consecutive days. However, thresholds vary based on the judgment of local meteorologists, rather than public health experts. The NWS only issued six heat alerts for California from 2000 to 2009 even though there were 19 instances during that period in which

[20]Barrow, M. W., and K. A. Clark. 1998. Heat-Related Illnesses. *American Family Physician* 58(3): 749–756, 759.
[21]Vanos, J.K., J.S. Warland, T.J. Gillespie, and N.A. Kenny. 2010. Review of the physiology of human thermal comfort while exercising in urban landscapes and implications for bioclimatic design. International journal of biometeorology 54(4):319-334.
[22]Schwartz, J. (2005). Who Is Sensitive to Extremes of Temperature? A Case-Only Analysis. Epidemiology 16(1): 67-72.
[23]Basu, R., V. Sarovar, and B.J. Malig. 2016. Association Between High Ambient Temperature and Risk of Stillbirth in California. American Journal of Epidemiology, kwv295.
[24]Bassil, K.L., and D.C. Cole. 2010. Effectiveness of Public Health Interventions in Reducing Morbidity and Mortality during Heat Episodes: A Structured Review. International Journal of Environmental Research and Public Health 7(3): 991–1001.
[25]California Department of Finance. 2014. E-1 Population Estimates for Cities, Counties, and the State — January 1, 2015 and 2016. http://www.dof.ca.gov/Forecasting/Demographics/Estimates/E-1/. Accessed on 10/12/16.
[26]Defined as more than 50 percent of the population in their zip code living below the Federal Poverty Threshold. Trent, R.B. (2007). Review of July 2006 Heat Wave Related Fatalities in California. California Department of Health Services Epidemiology and Prevention for Injury Control Branch Page 1. http://www.cdph.ca.gov/HealthInfo/injviosaf/Documents/HeatPlanAssessment-EPIC.pdf.
[27]Knowlton, K., M. Rotkin-Ellman, G. King, et al. (2009). The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits. Environmental Health Perspectives 117(1): 61
[28](CDC) Centers for Disease Control and Prevention. (2016). Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments. The National Institute for Occupational Safety and Health (NIOSH). https://www.cdc.gov/niosh/docs/2016-106/

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heat events led to negative health outcomes.[29] Current heat thresholds are not always relevant for frontline populations with limited resources or existing health conditions or for communities living in cooler climates that are not physiologically or technologically acclimated to extreme heat. In such areas temperature anomalies often fall below NWS thresholds, yet still generate significant heat health impacts.

Health-based threshold definitions, on the other hand, use the relationship between temperature and morbidity and mortality to determine the temperature at which negative health outcomes occur[30, 31] Defining heat thresholds based on human health is likely to be the most effective for planning and preparing for heat health emergencies, as there is much evidence both in California and across the U.S. that heat impacts on health manifest at much lower temperatures than those commonly used in local warning systems.[32, 33] As heat reduction efforts remain a local challenge, tailored intervention strategies rely on local heat wave thresholds based on population characteristics.

REDEFINING EXTREME HEAT

Characteristics of heat health events

To address heat-related risks, city and county planners must understand the thresholds at which heat presents a danger to the populations in their jurisdictions. These thresholds must be people-focused and based on local public health sensitivities, to avoid misinformed long-term planning.

The California Heat Assessment Tool uses statistically-derived, health-informed thresholds specific to each census tract across the state, based on historical medical and weather data. That means heat health events are defined by a set of meteorological conditions over several days that have been associated with significant negative public health impacts in a specific location. To identify the relevant signatures of extreme heat events that defined these heat thresholds we examined the temperature, humidity and duration of historic heat health events as well as the corresponding rate of visits to local emergency rooms.

To enable this analysis, the California Office of Statewide Health and Planning provided data on emergency room visits for the months of May through September from 2005-2013. This data included the date of visit and the patient's zip code, age and race. We summed emergency room visits for individuals under four and above 65 as well as all non-white individuals, to define a frontline cohort. To meet data suppression requirements we up-sampled zip code tabulation areas into Heat Wave Zones. We then aggregated climate data up from a four km resolution to match the spatial scale of the medical data.

We established a baseline of emergency room visits by calculating the average number of emergency room visits on days between the 25th and 75th temperature percentiles. Then we compared the number of emergency room visits during the different heat health event variants to the number of visits that occurred during standard temperatures. We tested different standard definitions of extreme heat events, including various temperature thresholds and durations, called 'signatures' for each heat health event.

[29]Guirguis, K., A. Gershunov, A. Tardy, and R. Basu. 2014. The Impact of Recent Heat Waves on Human Health in California. Journal of Applied Meteorology and Climatology 53(1): 3–19.
[30](CDC) Centers for Disease Control and Prevention, Climate and Health Program. (2014). Projecting Climate-Related Disease Burden: A Guide for Health Departments. Jeremy J. Hess, Shubhayu Saha1, Paul J. Schramm, Kathryn C. Conlon, Christopher K. Uejio, George Luber.
[31]Petitti, D. B., D.M. Hondula, S. Yang, S.L. Harlan, and G. Chowell. (2016). Multiple Trigger Points for Quantifying Heat-Health Impacts: New Evidence from a Hot Climate. Environmental Health Perspectives 124(2), 176-183.
[32]Guirguis et al., 2014
[33]Smith, T.T., B.F. Zaitchik, and J.M. Gohlke. (2013). Heat waves in the United States: definitions, patterns and trends. Climatic change, 118(3-4), 811-825

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We then calculated the average number of emergency room visits for each heat health event signature (temperature, duration and humidity) and compared these numbers with the heat health event baseline to identify the heat health events with the largest effect size, i.e. the combination of temperature, duration and humidity that drove the greatest increase in emergency room visits due to heat-related conditions. This was done for the general and frontline cohorts, accounting for the month and duration of heat health events. This analysis allowed us to develop more accurate, locally-specific heat wave definitions based on historical data, which became our baseline for future projections.

Projecting future heat health events

To project the change in heat health events for each heat wave zone we applied downscaled projections developed by the Scripps Institute.[34, 35] These projections include daily minimum and maximum temperature and relative humidity for both RCP 4.5 (moderate mitigation scenario) and RCP 8.5 (business as usual). We analyzed 24 climate models to identify the projected occurrences of heat health events defined for the frontline and general population cohorts, considering identifiers based on season, duration, temperature and humidity levels. For the signatures of heat health event determined for each cohort and the July 2006 heat wave we grouped the climate models into bins based on how many heat health events they projected.

Table 1. Social, health and environmental indicators associated with heat vulnerability. Factors marked with an asterisk (*) were not included in the principal component analysis.

Indicator	Definition
SOCIAL FACTORS	
African American*	Percent of residents that identify as African American
Asian*	Percent of residents that identify as Asian
Children*	Percent of population aged 5 years or younger
Education	Percent over the age of 25 without a high school diploma or GED
Elderly	Percent of population aged 65 years or older
Hispanic*	Percent of residents that identify as Hispanic
Linguistic Isolation	A "limited English speaking household" is one in which no member 14 years old and over (1) speaks only English or (2) speaks a non-English language and speaks English "very well." In other words, all members 14 years old and over have at least some difficulty with English
NHOPI*	Percent of residents that identify as Native Hawaiian or Other Pacific Islanders
Non-White*	Percent of Non-White residents
Outdoor Workers	Percent of people employed and aged > 16 years working outdoors
Poverty	Percent of population whose income in the past year was below poverty level
Transit Access*	Percent of population residing within at least 1/2 mile of a major transit stop
Vehicle Access	Percent of occupied households with no vehicle ownership
HEALTH FACTORS	
Ambulatory Disability	Percent of population having serious difficulty walking or climbing stairs
Asthma	Asthma emergency department visits per 10,000 people
Cardiovascular	Heart attacks per 1,000 people
Cognitive Disability	Percent of population having physical, mental, or emotional problems, difficulty remembering, concentrating, or making decisions
Low Birth Weight	Percent of low weight births (<5.5 lbs.)
ENVIRONMENTAL FACTORS	
Change in Development	Percent change (estimated) of land area from unpaved to paved due to development in 2050
Impervious Surfaces	Percent of area covered by impervious surfaces such as concrete or buildings (population weighted)
Ozone Exceedance	Three-year ozone concentration exceedance above state standard
Particulate Matter Concentration	Annual mean ambient concentration of PM2.5
Tree Canopy	Percent of area not covered by tree canopy (population weighted)
The Urban Heat Island*	Temperature difference from nearby rural areas

[34]Pierce, D.W., Cayan, D.R. and Thrasher, B.L., 2014. Statistical downscaling using localized constructed analogs (LOCA). Journal of Hydrometeorology, 15(6), pp.2558-2585.
[35]Pierce, D.W., Cayan, D.R., Maurer, E.P., Abatzoglou, J.T. and Hegewisch, K.C., 2015. Improved bias correction techniques for hydrological simulations of climate change. *Journal of Hydrometeorology*, *16*(6), pp.2421-2442.

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There are bins for the 5th (least amount of heat health events projected), 33rd, 50th, 67th and 95th percentile to help visualize uncertainty and provide a range of best-case and worst-case outcomes.

Assessing frontline populations

There are many social, health and environmental factors that contribute to making certain populations disproportionally susceptible to extreme heat events. To determine the vulnerability of census tracts, we ran a statistical analysis called Principle Component Analysis, which enabled us to identify which variables explained the most variation seen between populations. Table 1 shows social, health and environmental indicators that influence an individual's vulnerability to extreme heat. From this we devised a single composite score, the Health-health Action Index, that provides a snapshot of which census tracts may be most susceptible to change in heat health events.

CHAT: THE CALIFORNIA HEAT ASSESSMENT TOOL

Features and functionalities

The California Heat Assessment Tool compiles the projected occurrences of health-based heat events with the data on vulnerable populations, into an interactive state map that can be zoomed to the census tract level. Users can choose different parameters of heat thresholds, including average minimum temperature, average maximum temperature, average minimum relative humidity and average event duration, or annual number of heat health events to determine the map's color scale.

A timeline allows users to visualize how heat health parameters are projected to change in the future, in 20-year time spans ending with 2099. It is important for health practitioners and planners to understand how each parameter of extreme heat is expected to change in their areas and also to understand the distribution of different social, health and environmental vulnerabilities. Clicking a vulnerability indicator prompts an outline to appear around the census tracts in the top tenth percentile for the indicator. Scrolling over a census tract prompts a tool tip showing the tract's rank relative to its county and to

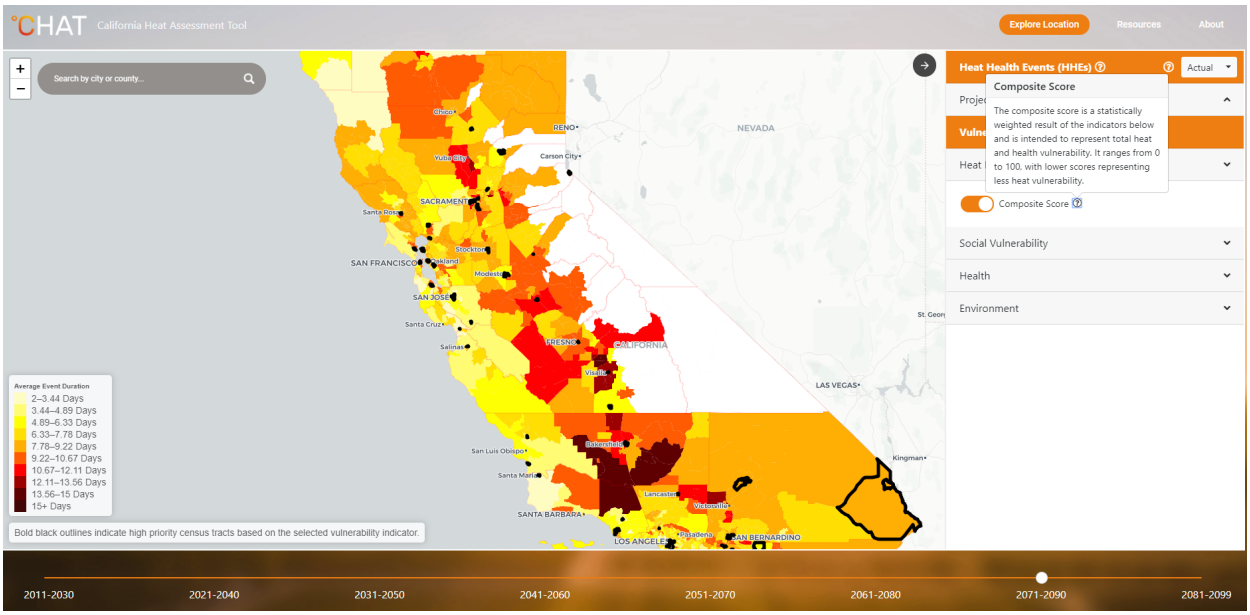

Figure 3. The CHAT interface displaying projected duration of heat health events by census tract in the timeframe 2071-2090. Census tracts that are in the highest tenth percentile for the Heat Health Action Index composite score have bold black outlines.

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the whole state for the chosen vulnerability indicator. This provides a quick snap shot of which tracts may be priority areas.

This visualization provides an entry point to explore the data for each census tract. Clicking on a census tract sends users to a window with the background data on historical and projected heat health events. Users can adjust these visuals based on general or frontline thresholds, seasons and the percentile of climate models. Data can be viewed as the actual heat health event numbers or the relative change. There is also an option to view data on the 2006 heat wave.

KEY FINDINGS

Regional trends

Looking at several characteristics of heat health events provides a more complete understanding of their potential public health impacts. While heat health events are expected to become hotter throughout the state, understanding changes in their duration and frequency provides further insights for planning.

All regions, except for possibly the North Coast under low-end projections, should expect more frequent heat health events by the end of the century. Changes in the number of events are most pronounced during the mid-summer months of June, July and August. In the North Sierra region, four to six additional mid-summer heat health events could occur every summer by mid-century.

When comparing projections to locally observed temperatures during July 2006, we found that an event equivalent to the 2006 heat wave has a 50 percent chance of occurring two to three times per year in parts of Monterey County and San Luis Obispo County. Both counties were particularly affected by the 2006 heat wave.[36] In El Dorado and Placer Counties in the Northern Sierra, 2006 heat wave conditions, with daytime temperatures over 110° F, could occur once every year and remain for up to a week by the end of the century under a business as usual scenario.

Increasing duration of heat health events is perhaps the most consistent trend in our projections across California. In parts of the Central Valley, the duration of the average heat health event could increase by up to two weeks and the area could experience an additional four to six events per summer by mid-century. The wider Central Valley will experience the greatest relative increases in the frequency and duration of heat health events in all scenarios and probabilities, particularly in the mid-summer months.

Maximum and minimum temperatures will increase statewide during heat health events, but the highest relative changes in nighttime temperature are most apparent along the coasts. Air conditioning is typically less prevalent here than in warmer regions and these populations are not as acclimated to hot temperatures. In the late season, higher changes in temperature are apparent across all regions, and large swaths of the North Coast in Sonoma and Mendocino Counties could experience heat health events that are, on average, 10° F hotter during the mid-summer by mid-century, under a business as usual scenario. Under the same scenario, areas in Los Angeles and San Diego could experience heat health events up to 12° F hotter than the historical record (1984-2013).

Frontline populations

Our analysis of emergency room visits for frontline populations shows that heat health events occurred almost twice as frequently for the frontline cohort as identified by the National Weather Service, whose determination of events is based solely on temperature and duration, rather than on health impact. Heat health events identified for the frontline cohort were

[36] Knowlton et al., 2009

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also associated with 18 percent more heat-related emergency room visits than those observed solely during officially declared events.

Comparing emergency room visits of the general population to those of the frontline population during heat waves shows that the appropriate temperature signature for frontline subgroups may be up to 6-8° F lower than the general cohort in some areas. This population may begin experiencing adverse health impacts at significantly lower temperatures than the general population. This demonstrates the importance of having separate thresholds for frontline and general populations in each census tract.[37]

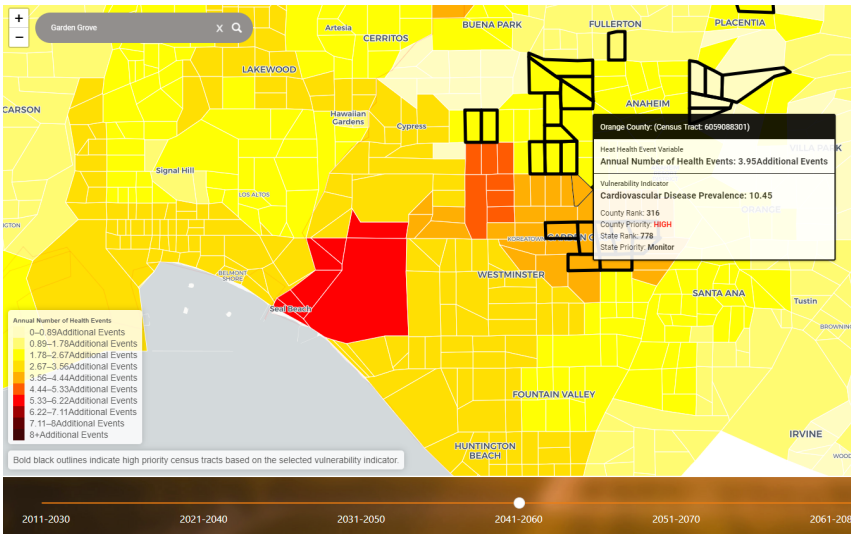

Figure 4. Census tracts around Garden Grove in Orange County colored based on the projected change in heat health events defined based on the local population. Tracts with the highest prevalence of coronary disease relative to others in their county are outlined in black.

To help identify areas most vulnerable to heat-related health impacts, we overlaid projections for future temperature with current socio-economic data. The comparison of relative changes in heat to existing levels of social vulnerability can help shed light on the anticipated heat-related risks under a hypothetical scenario, holding variables such as population growth and demographic changes constant. This data is included at the census tract level, providing a granular view of which neighborhoods may be most sensitive to heat because of their demographic and socio-economic characteristics.

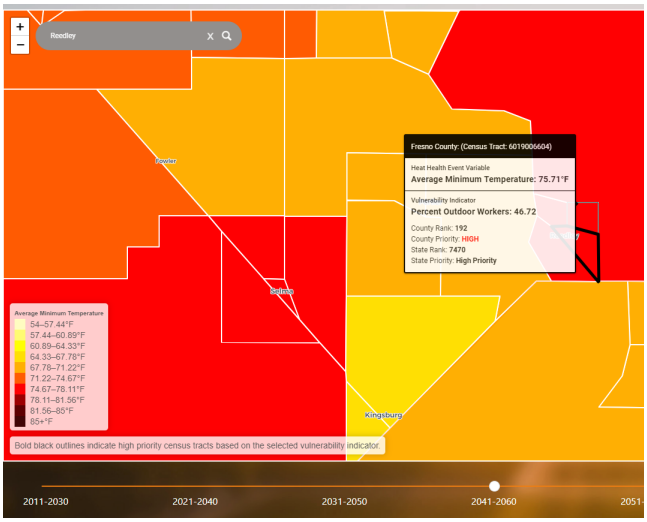

Figure 5. Census tracts in Reedley in the Central Valley, colored based on their projected average minimum temperatures in 2041-2060 and with the tract with the highest percentage of outdoor workers relative to the rest of the county outlined in black.

This evaluation strategy may help planners and policymakers co-locate areas of high relative change and heat vulnerability. For example, urban areas in East Oakland, Redwood City and East Palo Alto in the San Francisco Bay Area show high percentages of low-income residents without vehicles or high school diplomas. These census tracts also show high levels of projected relative change in frequency of heat health event events and thus stand out with frontline communities that will likely experience high increases in extreme heat.

Likewise, census tracts around Garden Grove (Fig. 4), in Southern California, have high levels of asthma prevalence, low birth weights and cardiovascular disease, as well as high projected increases in

[37]Heat thresholds should be updated every few years as demographics, the climate and the varying degrees of adaptation change over time.

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heat health events. Areas in the Central Valley, such as Reedley (Fig. 5) and Delano with high prevalence of outdoors workers and linguistic isolation are projected to experience high relative increases in minimum temperatures and duration of heat health events which is a dangerous combination that impedes physiological recovery at night.

Understanding both the projected changes in locally-relevant heat health event and local environmental, social and health data, planners can implement more targeted interventions based on the public health needs of their specific jurisdictions.

Preparing for a hotter future

By understanding the distribution of vulnerable populations and the temperatures at which they experience adverse health effects, alongside projected temperatures across the state, planners and health practitioners can implement preparations tailored to the specific needs of their residents.

While adequate thresholds alone do not prevent heat-related illnesses and death, locally relevant heat health thresholds and contextual information can help support officials in sustainability, housing, transportation, urban planning and public health. These thresholds can be leveraged alongside expertise on the drivers of heat to implement appropriate planning efforts. For example, land use influences urban temperature and human health. Hence greening efforts, when combined with an understanding of the most exposed areas, provide an opportunity to mitigate the impacts of increasing temperatures.

Technologies for alternative roofing systems are also a heat reduction strategy. Roofs that can lower surface temperatures, thereby decreasing subsequent sensible heat flux to the atmosphere. The installation of green roofs has resulted in meaningful reductions in air surface temperature in urbanized regions of China and the U.S.[38]

A strong social network with a high degree of community engagement and trust is an important characteristic of a resilient community,[39] as connected neighbors are more likely to look out for each other during an emergency. Social capital is community-specific and challenging to quantify. However, local programs such as Meals on Wheels, home weatherization and aging and adult services, can help initiate mechanisms for communicating risk and offering support to those most vulnerable.

The adaptation efforts and long-term planning strategies that will be most effective depend on the needs of the local community. Understanding the heat health events and social, environmental and health characteristics of each neighborhood can help prioritize the most effective and efficient planning efforts.

LEGAL NOTICE

The California Heat Assessment Tool was produced in partnership with Argos Analytics, the Public Health Institute and Habitat Seven, with technical support from the California Department of Public Health.

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[38]Zhang, J., Zhang, K., Liu, J. and Ban-Weiss, G., 2016. Revisiting the climate impacts of cool roofs around the globe using an Earth system model. *Environmental Research Letters*, *11*(8), p.084014.
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ABOUT FOUR TWENTY SEVEN

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