UCLA California Center for Sustainable Communities

Climate Change, Extreme Heat, & the Future of LA's Electric Power System

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Introduction

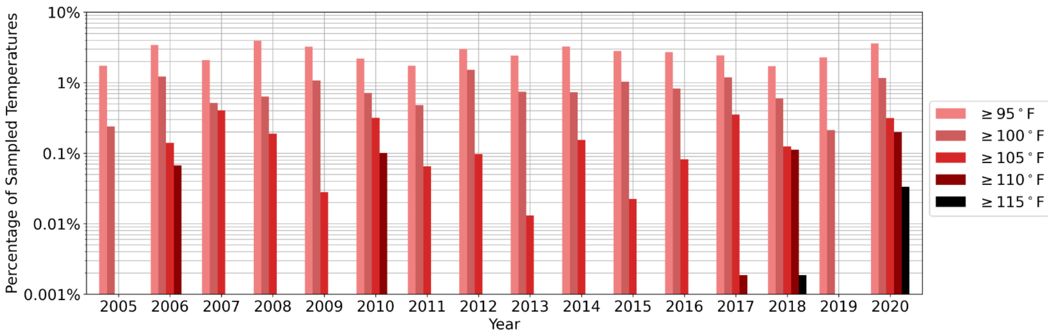
At the California Center for Sustainable Communities (CCSC) we are interested in better understanding the myriad of ways in which our changing climate will impact the stability and performance of critical infrastructure systems. The complex system which provides us with access to electric power stands out as being particularly important, as it powers the engines of commerce, telecommunications, water treatment and distribution, and increasingly, transportation vehicles and domestic appliances as well.

The increasing electrification of modern life is part of a deliberate effort to respond to the ongoing climate crisis. This is because options are readily available for the production of electricity from renewable and zero-carbon primary energy sources; thus, avoiding the harmful emissions of greenhouse gases from fossil fuel combustion. The changing composition of the demand for electricity which electrification portends, however, is running headlong into challenges associated with the experience of increased high heat due to climate change. Extreme heat events exacerbate not only the demand for electricity but also can significantly compromise our ability to both generate and transmit it during times of need.

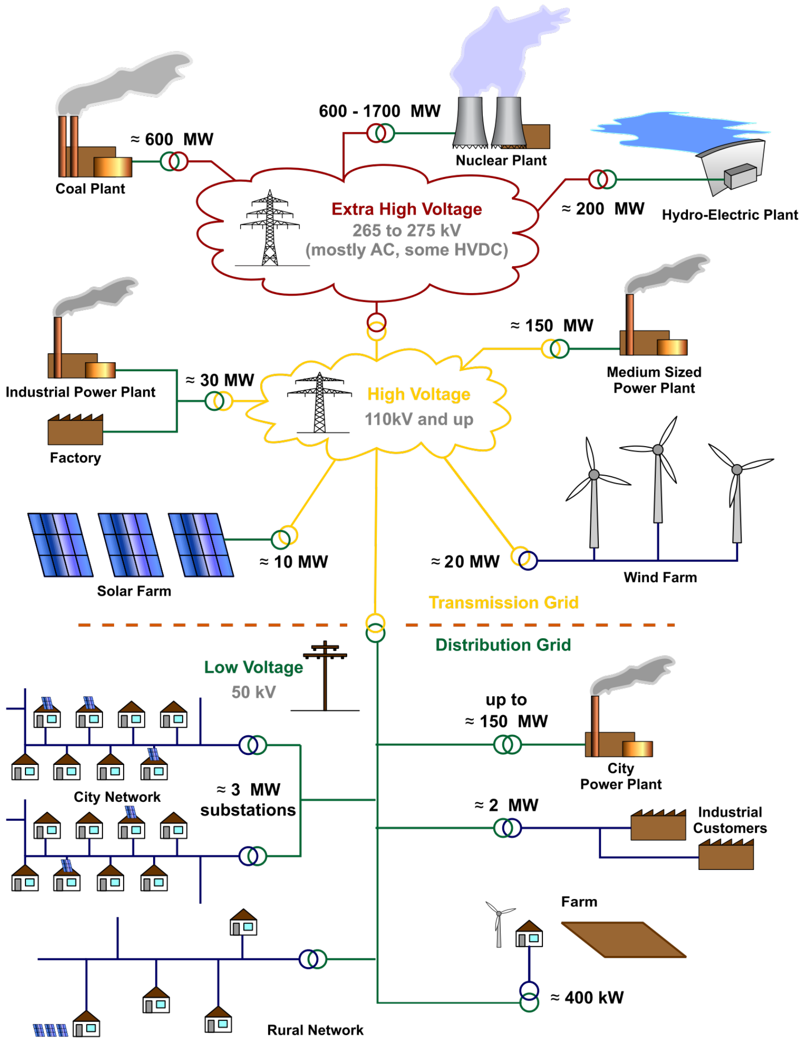
For LA residents climate change is no longer a distant or abstract concept because its effects are already being felt throughout the region. During just the past three years, for example, several new record high maximum daily temperatures have been recorded in numerous LA neighborhoods, with Van Nuys experiencing 118 °F in 2018 and more recently, in 2020, parts of Woodland Hills enduring temperatures of 120 °F. These developments are clearly illustrated in the figure below which shows the percentage of sampled maximum daily temperatures within the LA-Basin that were above different high heat thresholds for each year from 2005 to 2020.

In subsequent sections of this report, we shall take a deep dive into the spatial and temporal patterns of recent extreme heat events experienced throughout the LA area. We will discuss the implications of the changing local climate for the health of the region's electric power system. Finally, we will conclude by providing some perspective on the different ways that changing the architecture of the grid, to support more decentralized generation, may be the best long term strategy. **This is because with the evolving risks from climate change, developing clean energy generation capacity in-basin will likely provide the most resilience to communities.**

High Heat in LA: Annual percentage of daily maximum temperatures, sampled on a regular 2km grid within the LA area, observed to be above different high heat threshold limits (2005-2020).



The Electrical Grid's Architecture: Schematic diagram of key electrical grid components and architectural features.



The electric power grid is an enormously complex system. A significant portion of this complexity is owed to the fact that it has been built out over a period of more than 100 years of continuous operational use. The design of the grid largely assumes that electricity will only flow in only direction: from a few large generators out to many more smaller consumers. As the diagram above illustrates, this means that the grid actually has more of a tree-like structure. Within it individual customers are connected to generators by a labyrinthine network of power lines which constitute the "transmission" and "distribution" networks. The distinction between the two primarily has to do with the amount of electricity that a given line can carry and the distances over which it must travel. High heat can negatively impact the performance of both power plants and grid transmission & distribution infrastructure components alike. However, in terms of the grid, which is the focus of this analysis, the key source of vulnerability stems from the fact that heat reduces the ease with which electricity is able to move through conductive materials. Understanding why this increased "impedance" occurs and what it implications are for the future health of the grid is our next topic.

Impacts of Heat on the Electric Power Grid

At its most basic level, the power grid can be understood to be a vast network of conductive materials, like copper and aluminum, which have been intelligently pieced together to control the flow of electricity from the locations of generation to consumption. However, these materials are not perfect conductors. Thus, they present some resistance to this flow - resistance which manifests itself as the production of heat. Within most of the grid's components, this internal accumulation of heat is managed using a strategy called "passive cooling." This strategy assumes that you can design components in such a way that excess heat can be effectively transferred to the ambient air before it reaches critical levels. If this internal heat cannot be effectively dissipated, the ability of the component to accommodate the flow of electricity becomes reduced (in industry parlance the component becomes "derated"). Alternatively, in more extreme circumstances, the accumulation of heat can become so severe that it leads to a mechanical failure, resulting in a complete loss of function.

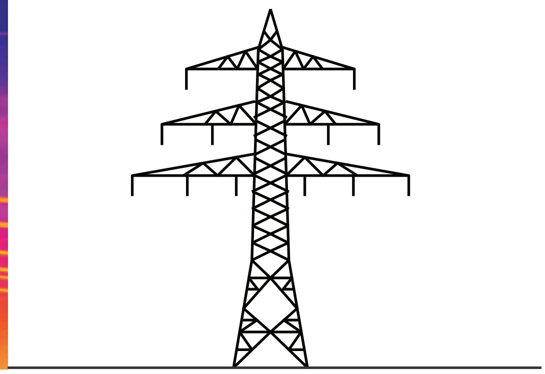
This internal buildup of heat can actually be visualized by using infrared cameras to image different grid infrastructure components while in-use. A series of these thermal images are shown in the figure on the following page. They illustrate the relative differences in the temperature of the ambient air for power lines, transformers, and other common grid components that are being subjected to sustained loads. As these images clearly illustrate, thermal management is an important engineering design consideration at all levels of the electric power system.

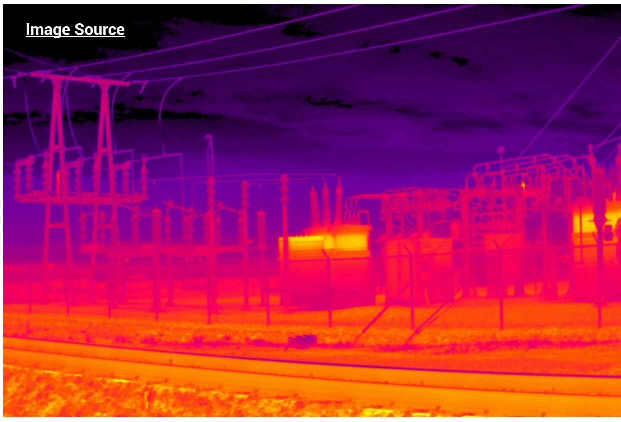
Passive cooling strategies have historically been favored in the design of grid infrastructure components because they can be both robust and energy efficient. These properties stem from the fact that there is no need to operate mechanical cooling equipment such as fans or circulation pumps which both consume energy and are prone to malfunction due to the presence of numerous moving parts. However, passive cooling strategies are vulnerable to changes in ambient temperatures which go beyond the threshold ranges that were assumed when the components were initially engineered. This can become a significant problem in situations where components are aging, have long design lifespans, are being subjected to increased loads, and/or are located in areas where the climate is rapidly changing with respect to the frequency and duration of extreme heat events.

Unfortunately, throughout the LA area and elsewhere across the Western United States, many of these triggers are aligning in undesirable ways that are likely to create significant future challenges for the reliability of the power system. Consider, for example, how the peak demands for electricity most commonly occur when the weather is hot - for use in air conditioning. It is also during these same periods, when ambient air temperatures are high, that grid components become less-and-less efficient transmitting power. This situation creates a vicious feedback loop whereby the more energy is demanded the less effectively it can be delivered, resulting in a huge amount of strain being placed upon the entire system. The amount of strain and the potential risks that it poses in terms of system outages, or other types of disasters such as wildfires, has a lot to do with the average distance between the sources of power production and the centers of demand. As we shall later discuss, placing generation resources further away from customers increases the vulnerability of the system to outages stemming from transmission component failures.

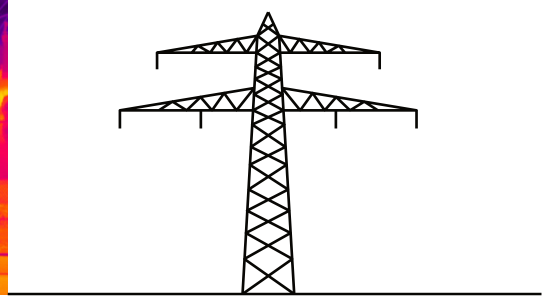
Passive Cooling Strategies: Thermal images illustrating the build up of internal heat within different grid infrastructure components at the (a.) transmission network, (b.) sub-transmission network, and (c.) distribution network levels.

a. Transmission Network

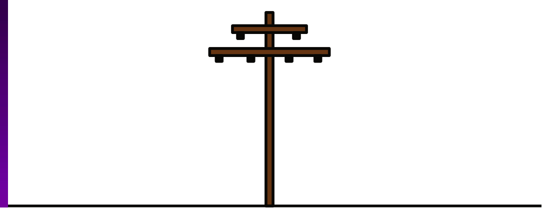




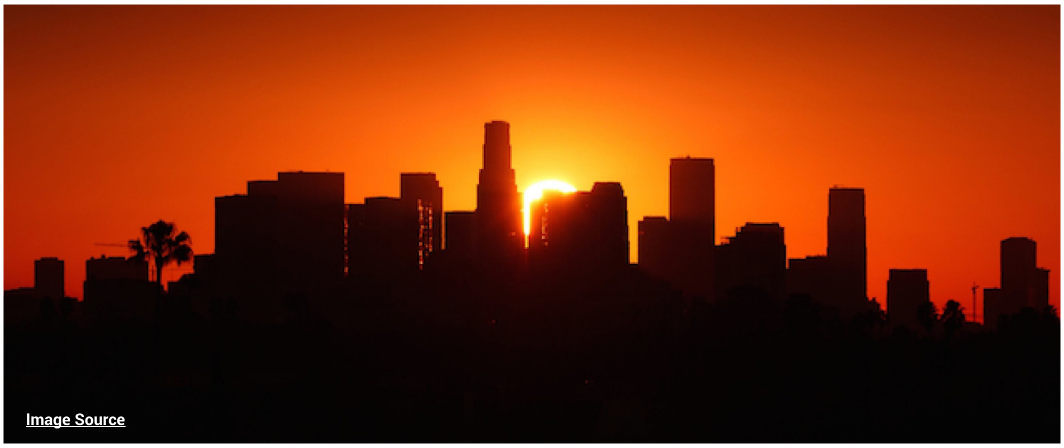
b. Sub-Transmission Network



c. Distribution Network



Local Trends in Extreme Heat



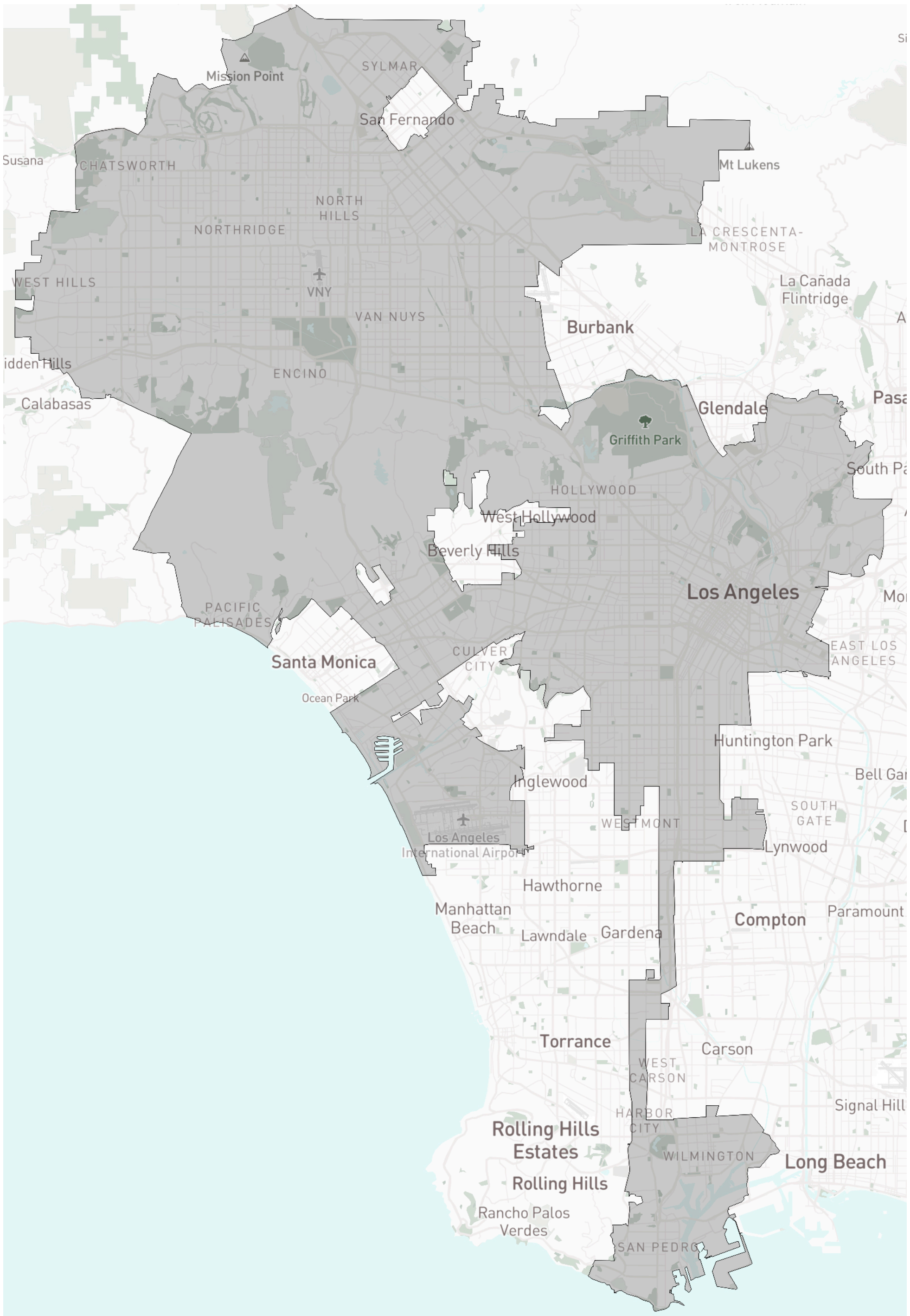
In the following section we shall present a series of more detailed analyses which graphically illustrate spatial and temporal variations in recent extreme heat events that have recently been experienced throughout the LA area. These analyses have been developed using historical weather data which were obtained from Oregon State University's PRISM Climate Group. PRISM weather data are available at a daily time interval since 1981 for the entire contiguous United States and have been modeled using climatologically aided interpolation (CAI) (Daly et al. 2013). This is a numerical technique which uses the long-term average pattern (i.e., the 30-year normals) as first-guess of the spatial pattern of climatic conditions for a given month or day. CAI is robust to wide variations in station data density, which is necessary when modeling long time series with a regular spatial resolution. For more information please visit the PRISM Group's website where the data and supporting documentation can be freely accessed at:

https://prism.oregonstate.edu/

The subset of PRISM data which has been analyzed corresponds to a 16-year time series from 2005-2020 and spanning 147 sample locations, which correspond to a regularly spaced 2km^2 grid, distributed across the entire LA area. While a 16-year time series is insufficient to observe significant changes in climate, it is useful for illustrating some of the shifting patterns in extreme weather that LA has recently been experiencing. These trends in weather will provide insights into future challenges that must be overcome in order to maintain the health of the electric power system.

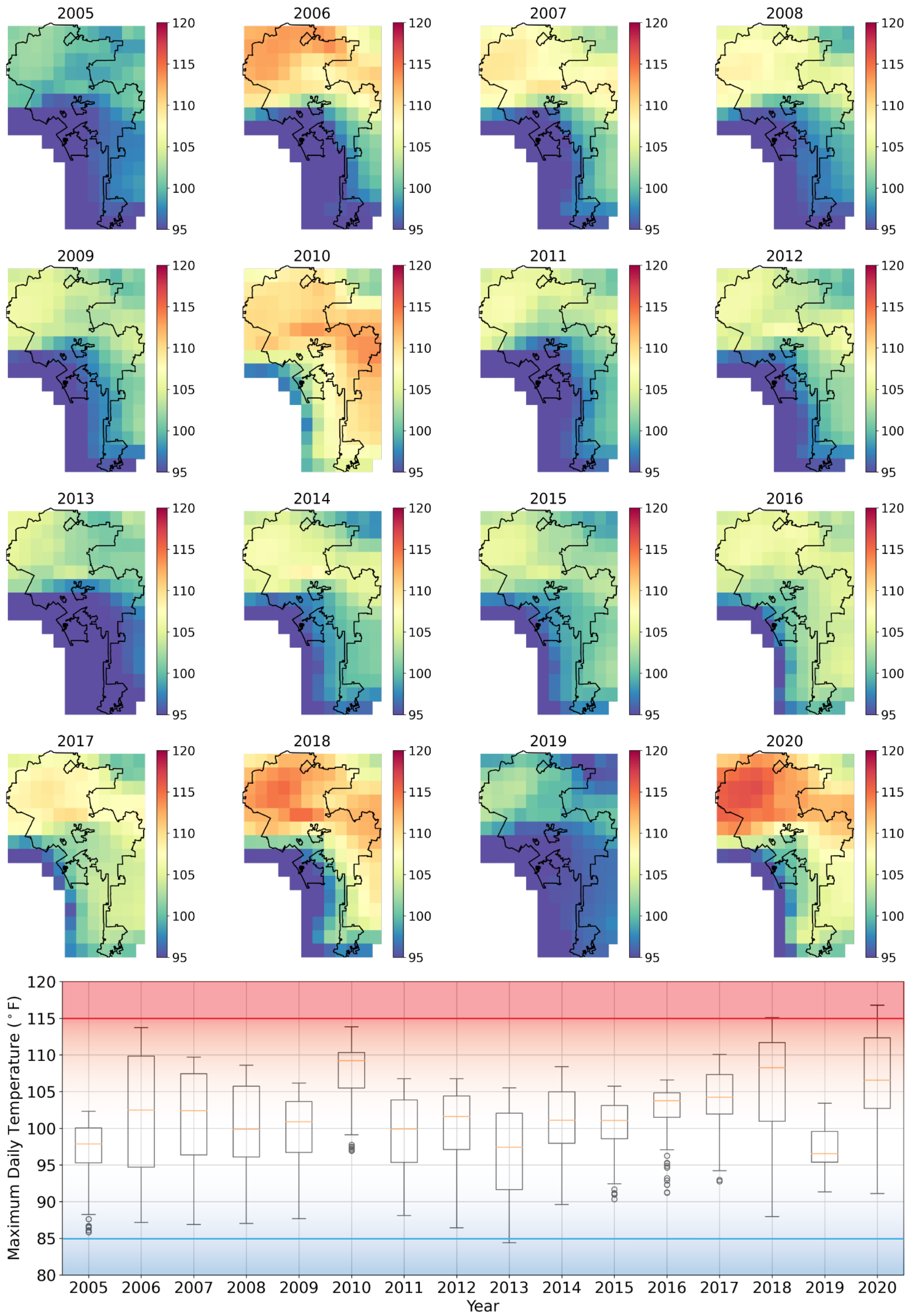
The three metrics that we will be focusing on here involve recent trends in the extremity, frequency, and duration of extreme heat events. In each case, the data describing these trends are represented both spatially, using a set of map panels, and temporally, using a time series of box-plots. A detailed local context map which shows the locations of various communities, highways, points of interest, and the location of the Los Angeles Department of Water and Power's (LADWP's) in-basin service territory is provided to the right for reference. This same reference boundary is plotted in all of the subsequent map panels.

Context Map: Administrative boundaries of the City of Los Angeles.



Map Data: https://www.mapbox.com/

Extreme Heat: Annual maximum temperatures (°F) (2005-2020).



Weather Data: Copyright ©, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Figure created July 2021.

This first figure (preceding page) illustrates spatial and temporal trends in the maximum daily temperatures experienced at each sampled location within the LA area for each year from 2005-2020. Looking first at the map panels, one feature of note which immediately stands out is the growing severity of the levels of extreme heat being experienced in LA's inland valley communities. These areas of concern include the San-Fernando Valley in the North and, increasingly, the San Gabriel Valley to the East. In 2020, roughly a quarter of the land area in the LA area experienced maximum high temperatures in excess of 115F. The geographic scope of such extreme heat is without precedent in the recent past.

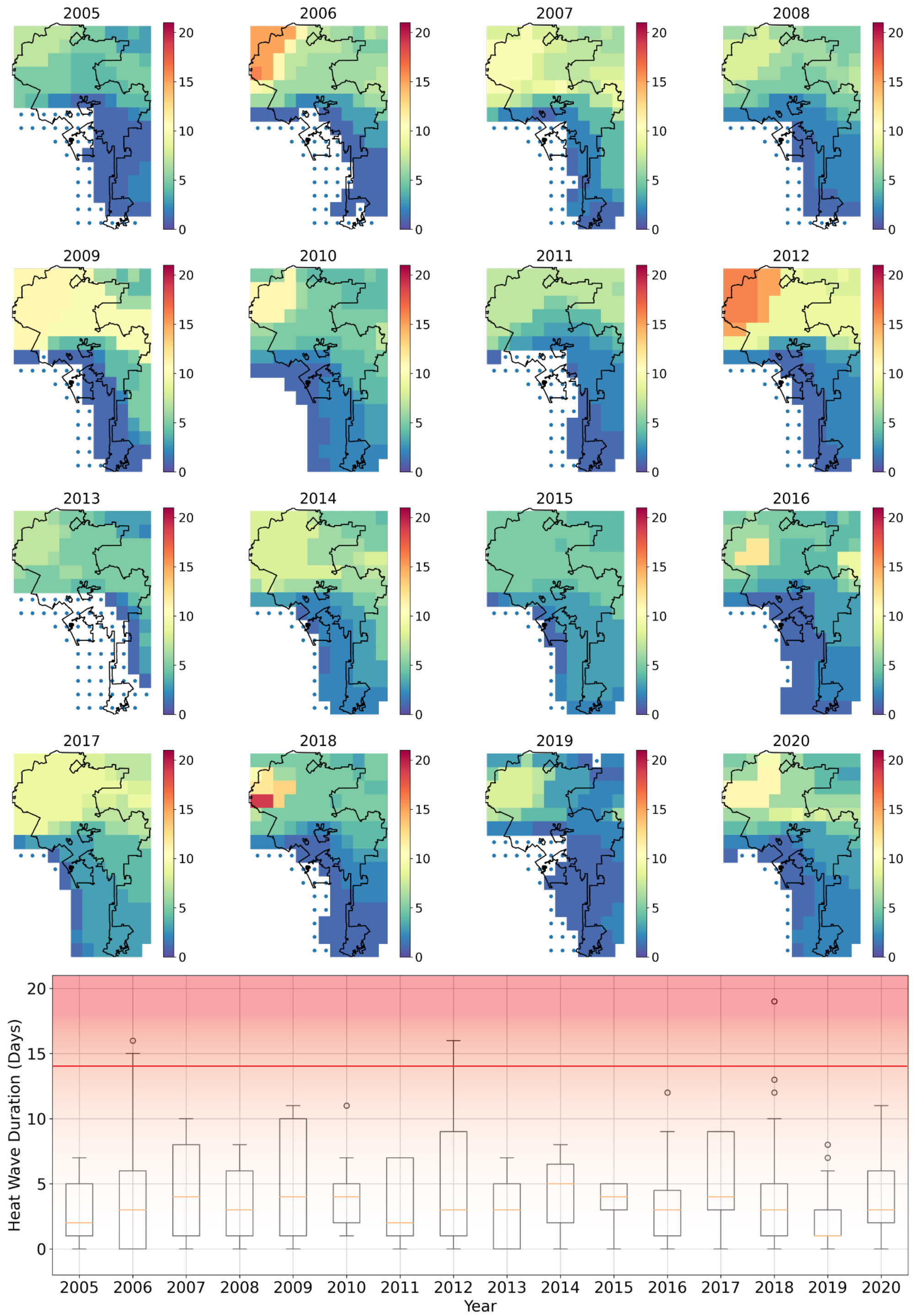
Another important observation which can be gleaned from these map panels is the degree to which LA's coastal communities are increasingly being impacted by the experience of extreme heat. As recently as a decade ago, LA's coastal regions (i.e., areas within ~2 miles of the water) would rarely experience temperatures above 95F and almost never see a single 100F day. This is largely due to the thermal regulating effects of ocean waters on local ambient air temperatures. Large bodies of water function like radiators, absorbing and dissipating heat through evaporation.

During the past few years however, a worrying trend has begun to emerge whereby these >100F high temperatures have been creeping towards the coast. And while these coastal communities tend to be more affluent – suggesting that they should have a greater capacity to cope with this type of heat – any time that extreme temperatures begin to be experienced in areas where they have historically been absent, there are potential risks not only to human health but also to the health of the power system, which may have difficulties responding to rapid changes in seasonal energy demand.

Turning next to the box-plots, an overarching trend towards increasing maximum temperatures is clearly visible. This is evident in the upward shifts in both the medians and extremes of the box-plot's tails. There are many ways to assess the "hotness" of a given year. Some of these include the average maximum temperature, the highest maximum temperature, the highest minimum temperature, etc. However, by virtually any measure, 2018 and 2020 can be considered among the two hottest years in LA's history with some of the most widespread and severe high temperatures ever experienced. And as we shall see, these unwelcome developments in terms of the scope and extremity of high-heat events are being accompanied by troubling changes in their frequency and duration as well.


Image Source

Heat Wave Duration: Annual largest number of consecutive days in which maximum temperatures exceeded 95 °F (2005-2020).

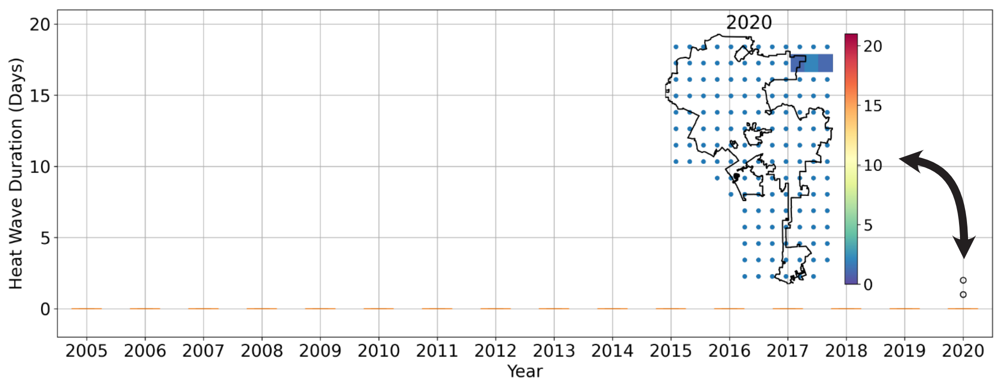


Weather Data: Copyright ©, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Figure created July 2021.

The impacts of extreme heat on public health and energy infrastructure can become significantly amplified as the duration of an event increases. This is because both people and grid components are not given adequate time to “cool down” and dissipate excess heat accumulating during the highest temperature periods. For grid infrastructure components, which are overwhelmingly designed to be passively cooled, this accumulation of heat can be as problematic, if not more-so, than the absolute temperature extremes endured over the course of a given high heat event. The figure above plots spatial and temporal patterns in the maximum duration of “heat wave” events experienced throughout the LA area for each year from 2005-2020. Relative to the data in these plots, a heat wave has been defined as multiple consecutive days in which the maximum temperature at a location exceeded 95F. Within the map panels, small blue dots are plotted at locations where annual maximum temperatures of 95F were not experienced for even a single day within a given year.

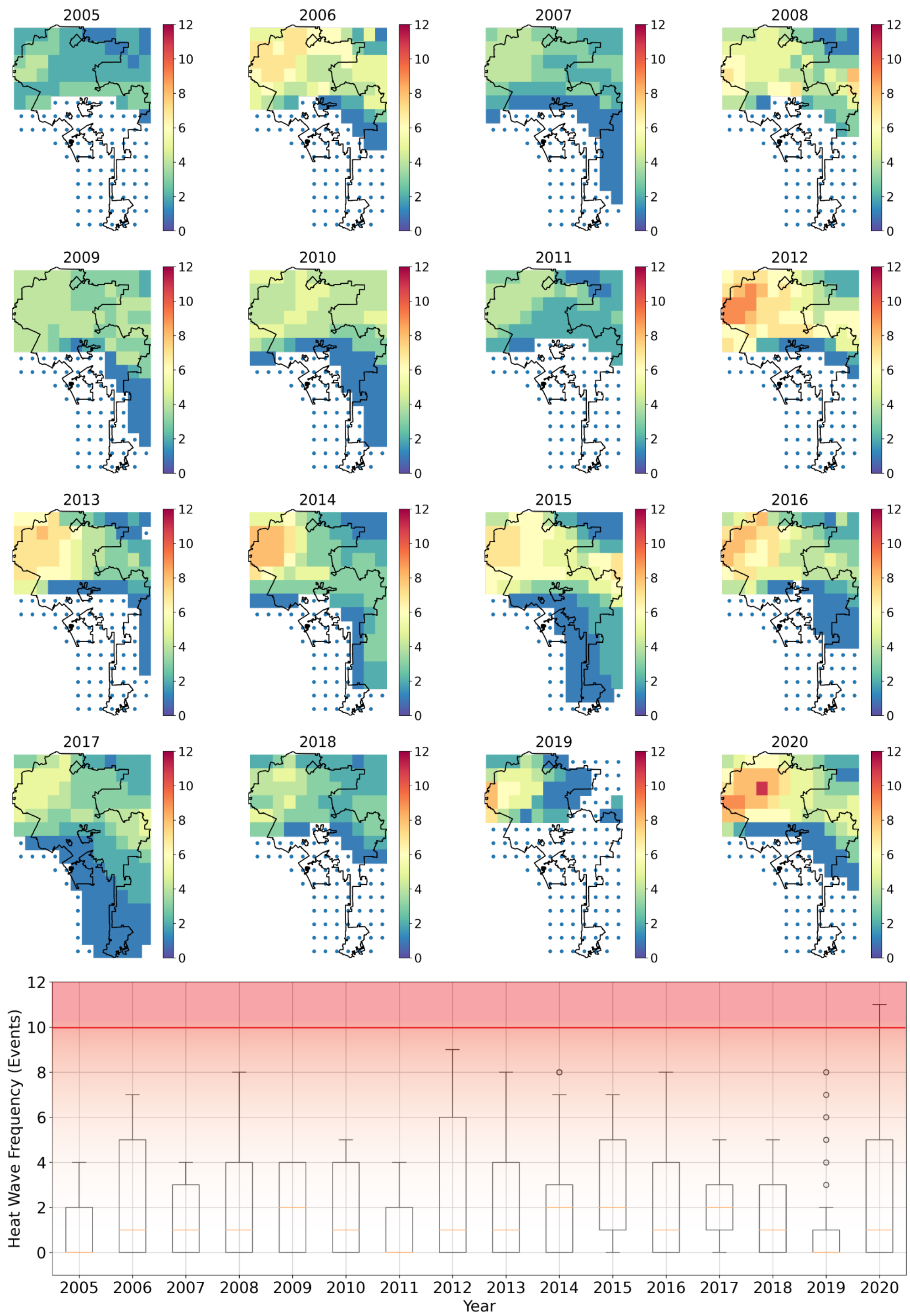
The first thing that is noticeable in the figure’s map panels is that the number of these blue dots has been steadily decreasing over time. This corresponds to the previous trend that was observed around the encroachment of high heat conditions into the region’s coastal areas. Contrary to the previous discussion of absolute temperature extremes however, no similarly clear year-over-year trend can be observed in terms of the average duration of high heat events. Despite this however, there is evidence that recent years have seen an uptick in the overall maximum duration of heat waves experienced throughout the LA area. For example, in 2018 there were isolated locations in the central San Fernando Valley that endured as many as 19 consecutive days with high temperatures in excess of 95F. This is a full three days longer than the longest duration events experience anywhere throughout the basin in previous years.

Heat Wave Non-Abatement: Annual largest number of consecutive days in which the minimum temperatures did not drop below 85 °F (2005-2020). The blue dots plotted in the map inset depict all of the locations where such conditions never occurred.



Extreme high temperatures usually abate overnight, providing some measure of relief, especially during prolonged periods with consistently high daytime temperatures. This suggests that another useful way of looking at this issue of heat wave duration is to instead focus on the number of consecutive days in which the minimum temperatures did not drop below some given threshold, even overnight. This perspective can provide an alternative metric of heat non-abatement. Using 85F as a threshold temperature for the calculation of this metric, we can in the figure above that 2020 was the first year in the time series in which there were at least some areas within the LA area where there were multiple consecutive days in which the minimum overnight temperatures did not drop below the cutoff. This is a significant new development, one that will effect both the demands for cooling energy within the summer months as well as the strain which will be placed upon the grid’s infrastructure in order to supply it.

Heat Wave Frequency: Annual number of events with three or more consecutive days in which maximum temperatures exceeded 95 °F (2005-2020).



Weather Data: Copyright ©, PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. Figure created July 2021.

The final dimension of extreme heat that we analyzed involves the changing frequency of heat wave events. Here, we define a heat wave event as three or more consecutive days year where the maximum temperatures at a given location exceeded 95F. The plots contained in the figure above show spatial and temporal patterns in the frequency of these types of heat wave events throughout the LA area from 2005-2020.

As the figure's box-plots illustrate, 2020 was the year in the time series in which heat waves were experienced with the largest frequency at some isolated individual locations within the LA area. Looking to the map panels, we can see that these areas include the central San Fernando Valley communities of Chatsworth, Northridge, and Van Nuys – many of the same locations which were previously observed to be experiencing high heat events of growing extremity and duration. This is a worrying pattern as future simultaneous growth in the severity of these three dimensions of extreme heat is likely to create conditions that will be very challenging for maintaining the health of grid infrastructure.

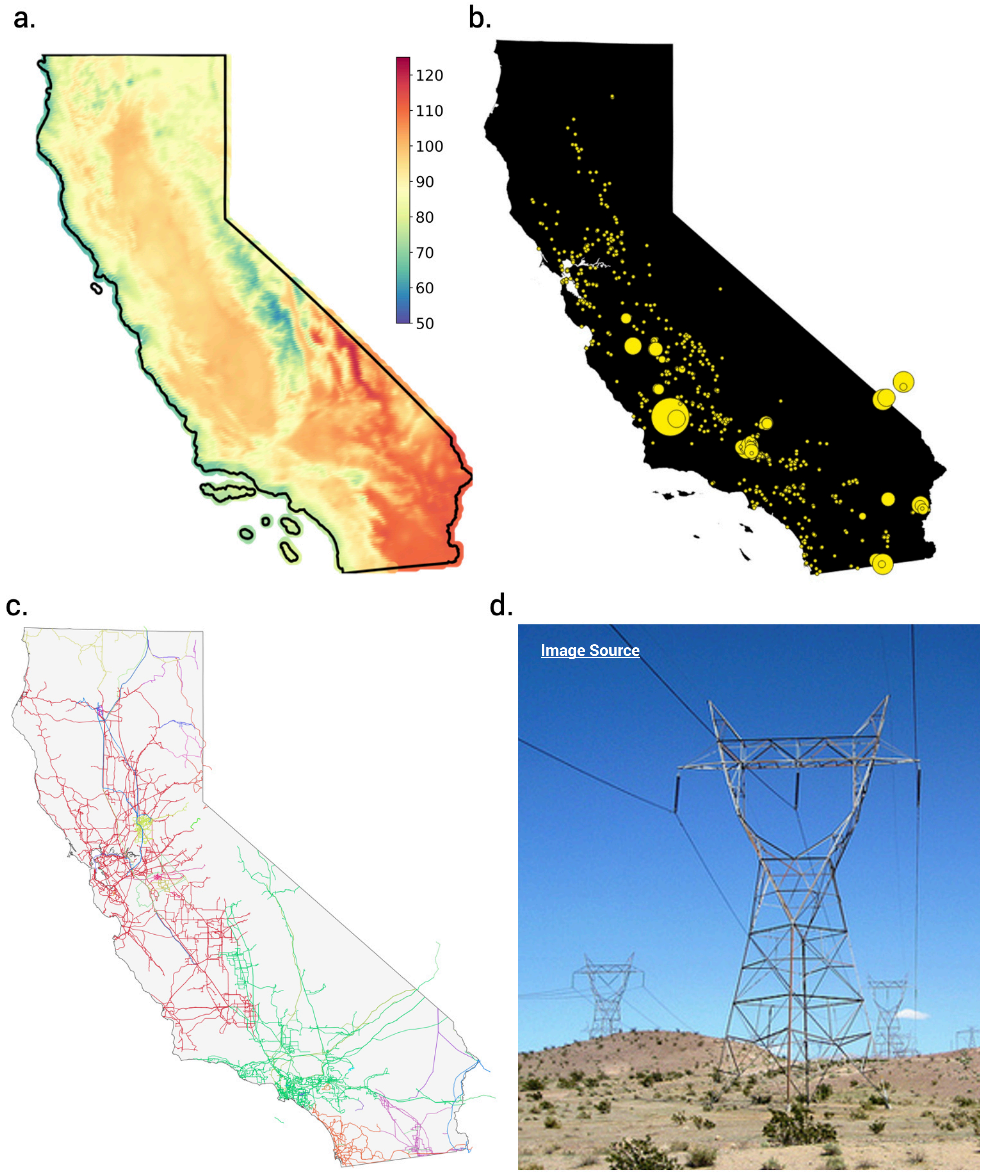
In terms of the most geographically widespread occurrence of heat wave events, 2017 stands out as being a significant year, with more than 2/3rd of the LA area's experiencing at least one 3-day heat wave with temperatures in excess of 95F. This is an important observation as pertains to the health of the energy system because many strategies for dealing with peak power demand rely on the import of electricity from nearby areas where demand is more moderate. **As the geographic scope of heat waves widen, across both the LA region and multiple western states, options to provide additional energy supply can become limited."**

Future Implications for the Energy System

The increasing extremity, frequency, duration, and geographic scope of high heat events due to climate change is something which should explicitly be considered as we plan for major new grid infrastructure investments. Over the next 25 years California will be engaged in an ambitious statewide effort to decarbonize the sources of its electricity supply. And if recent trends hold, there is every indication that solar PV, and to a lesser extent wind, will constitute the dominant class of renewable generation technologies that will be relied on to displace the output of existing fossil fuel generators. One important question that remains in terms of the implementation of this transition, however, is to what extent this new renewable generation capacity will be developed out-of-basin, according to a more traditional, centralized model, or within-basin, using a more modern, decentralized approach.

Historically, the architecture of the grid has relied heavily upon the use of long distance, high-voltage transmission lines to move power from the locations where it is produced, typically in more remote, sparsely populated areas, to the more densely populated locations where it is consumed. This transmission infrastructure is not only aging but also coming under increased threat of disruption from high heat and related threats, such as wildfires. Renewable generation technologies, and in particular, solar PV, have the benefit of being able to be deployed at installations that span a wide range of capacity scales (from as little as 10 Watts to as many as 1,000,000,000 Watts). Moreover, across this entire deployment capacity range, there is no concern about any potential harmful impacts to adjacent human populations either due to the release of harmful emissions byproducts or the threat of a catastrophic accident.

Renewable Generation Deployment: [a.] Statewide maximum temperatures (°F) in 2020 [b.] locations of large scale (>5 MW) solar PV generation facilities in 2020 (Data: CEC), [c.] existing electricity transmission infrastructure in 2020 (Data: CEC), [d.] photograph of a typical high voltage transmission line support structure.



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Grid Generator Data: https://data.ca.gov/dataset/california-power-plants2
Transmission Infrastructure Data: https://data.ca.gov/dataset/california-electric-transmission-lines2

These characteristics will provide significant resilience benefits if future solar development is prioritized in-basin and preferably on existing structures. Doing so would provide a significant measure of insurance against the possibility of widespread grid outages occurring due to the experience of high-heat or other related natural hazards. This is because distributed generation functions to diversify the geographic sources energy supply and also locates them in closer proximity to sources of energy demand.

Unfortunately, however, the state has historically favored the development of larger scale, more centralized, renewable generation facilities. Some arguments which are commonly invoked to support this centralized strategy include: better unit-economics - due to hardware economies of scale and reduced land acquisition costs - and more predictable deployment timelines - due to reduced uncertainty of development schedules.

The figure above plots, as of the year 2020, [a.] statewide maximum temperatures, [b.] the location of large scale (>5 MW) solar PV generation facilities, and [c.] the location of existing high-voltage electricity transmission lines. Looking at the spatial overlap we can see that LA is likely to be in an increasingly precarious situation if its primary sources of energy generation continue to be developed in far flung locales which necessitate the continuous availability of transmission infrastructure to deliver power into the basin. This is especially true given recent trends in the changing frequency, duration, and intensity of high heat events and the associated risks that they pose to the health of grid infrastructure. **The central point here is the proportionality of risks associated with any individual component's failure: if a pole-top transformer fails then a city block or neighborhood may be adversely affected. However, if a transmission tower fails then an entire city or even a large portion of a state may become severely impacted.**

In light of all these factors, we believe that new accounting methods must be adopted which explicitly quantify the resilience benefits which can be provided by decentralized renewable development strategies. This is an absolutely necessity if we are to be able to properly weigh the costs and benefits associated with different future investment approaches – i.e., centralized vs. decentralized. Failure to do so may result in a situation where significant future investments in out-of-basin new renewable generation capacity (and likely also, new high voltage transmission lines) may increasingly become stranded for prolonged periods of time as new climate hazards emerge. Recent experiences have demonstrated the potential for long duration power outages to create significant human suffering, health impacts, mortality, as well as spoilage of food and other financial losses - all of which can and should be avoided.

References

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