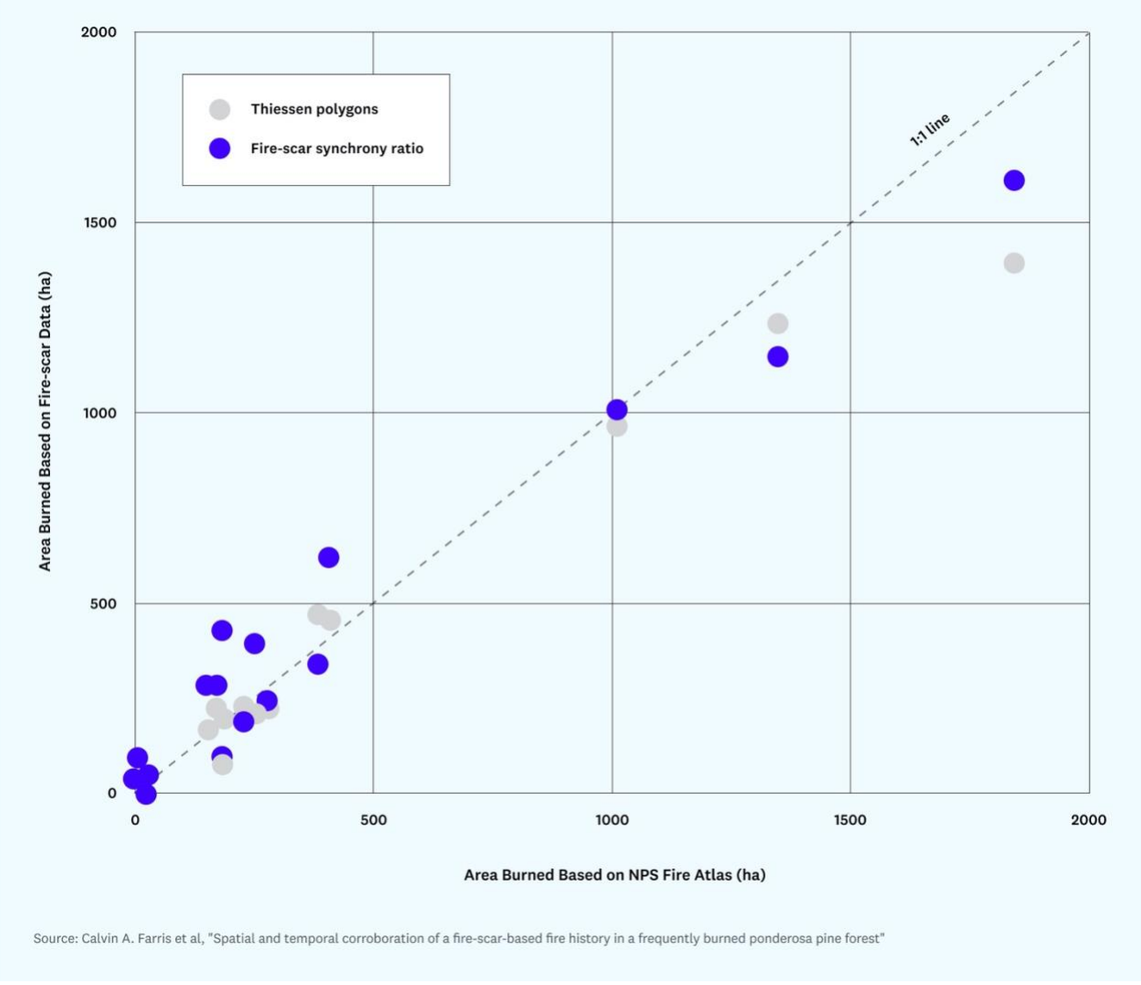
from José Luis Ricón
for https://future.a16z.com/why-california-burns-the-data-behind-the-flames

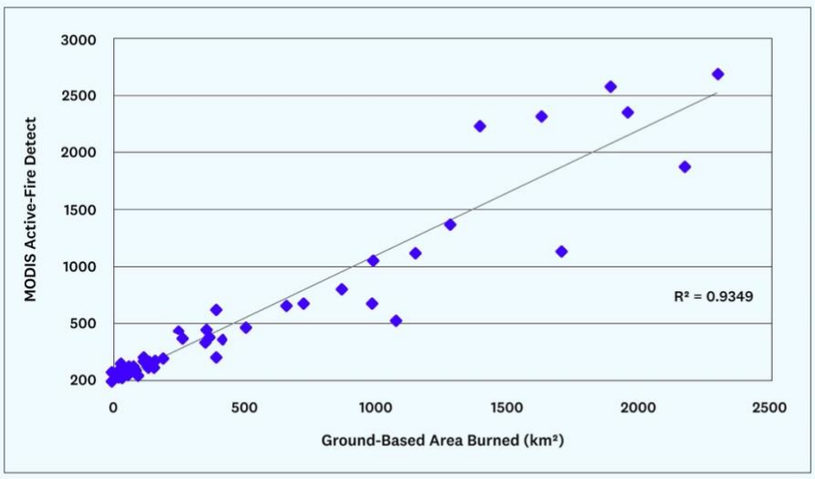
Section: Are we sure it's worse?

"Taken together, this data — derived from satellite imagery, airborne cameras, and written records — seems to make clear that wildfires became increasingly more destructive in the years 1950-2020."

- The main source of data on acreage burned in the last few decades is images taken by Landsat satellites, developed by NASA and others; researchers can compare pictures from before and after fires, draw a polygon, and measure areas to determine burned acreage. Results from different satellites tend to be very similar (Edwards et al., 2018). There is no satellite data for fires prior to 1972, when the first Landsat satellite was launched; pre-1972 data is derived from written records, aerial imagery, and soil sampling and charcoal accumulation measurement (a method that has been used to reach back over a millennium).
- The analysis of fire scarring in trees yields potentially useful data going back to about 1700. Inferring data from fire scarring is an imperfect metric for multiple reasons: Trees may not have scars even if they burned, trees may all just die and not leave a trace of the fire, or the composition of a given forest may have changed (if a handful of trees are found with fire scars, it could be a sign of a small fire, or of a larger fire in which the rest of the forest died). Statistical techniques can be used to correct for these factors. There are some studies that aim to measure how well fire scars correlate with the written record for old fires (Fule et al., 2003). This is what the correlation for the written record and fire scar-derived data (by two different methods) looks like, showing reasonable agreement in one area studied over the period 1937–2000 (Farris et al., 2010; for a less optimistic view, see Shapiro-Miller 2007, though in the latter study a lack of good written records rather than misleading fire scars could be a factor).



- Satellite data matches ground-based data as well, although we can only see this for more recent data when we have satellite imagery (Soja et al., 2006).



Comparison of area burned during the extreme 2004 fire season in Alaska. MODIS data are taken from June, July and August 2004 when the fires are most active and the fire scars sizes are reported for the entire fire season. The linear relationship show that MODIS data are able to accurately estimate the amount of area burned, particularly for large fires.

Source: Amber Soja et al, "How well does satellite data quantify fire and enhance biomass burning emissions estimates?"

"Data derived from written records from Cal Fire and the U.S. Forest Service dating back to 1919 show that wildfires, far from increasing, have actually declined over the last 100 years"

- “Historians have generally been confident in these early California fire records (Brown 1945; Show 1945; Clar 1969; Cermak 2005). J. E. Keeley examined all of the California fire-related materials stored at the state and federal archives and believes that collectively, they show managers have always been conscientious about reporting accuracy and completeness. For example, beginning in 1905, USFS recordkeeping required 15 items of information on the fire reporting Form 944, including the specific cause (Donoghue 1982b). On state-protected lands there was an incentive in that the 1911 Federal Weeks Law provided fiscal aid to states based on statistics of fire protection (see http://www.calfire.ca.gov/ about/about_calfire_history2, accessed May 23, 2018). In 1919, the California state legislature appropriated money for fire prevention and suppression, and records in the state archive show that by 1920 there were more than 400 fire wardens distributed throughout the state who were charged with firefighting and fire reporting. In 1920, there were 800 flights of the Army’s 9th Aero Squadron fire patrol that covered 426,500 kilometers during the five-month California fire season (Cermak 1991).” (Keeley & Syphard 2018).

"... the website of the National Interagency Fire Center previously noted that fires were at their very worst a century ago."

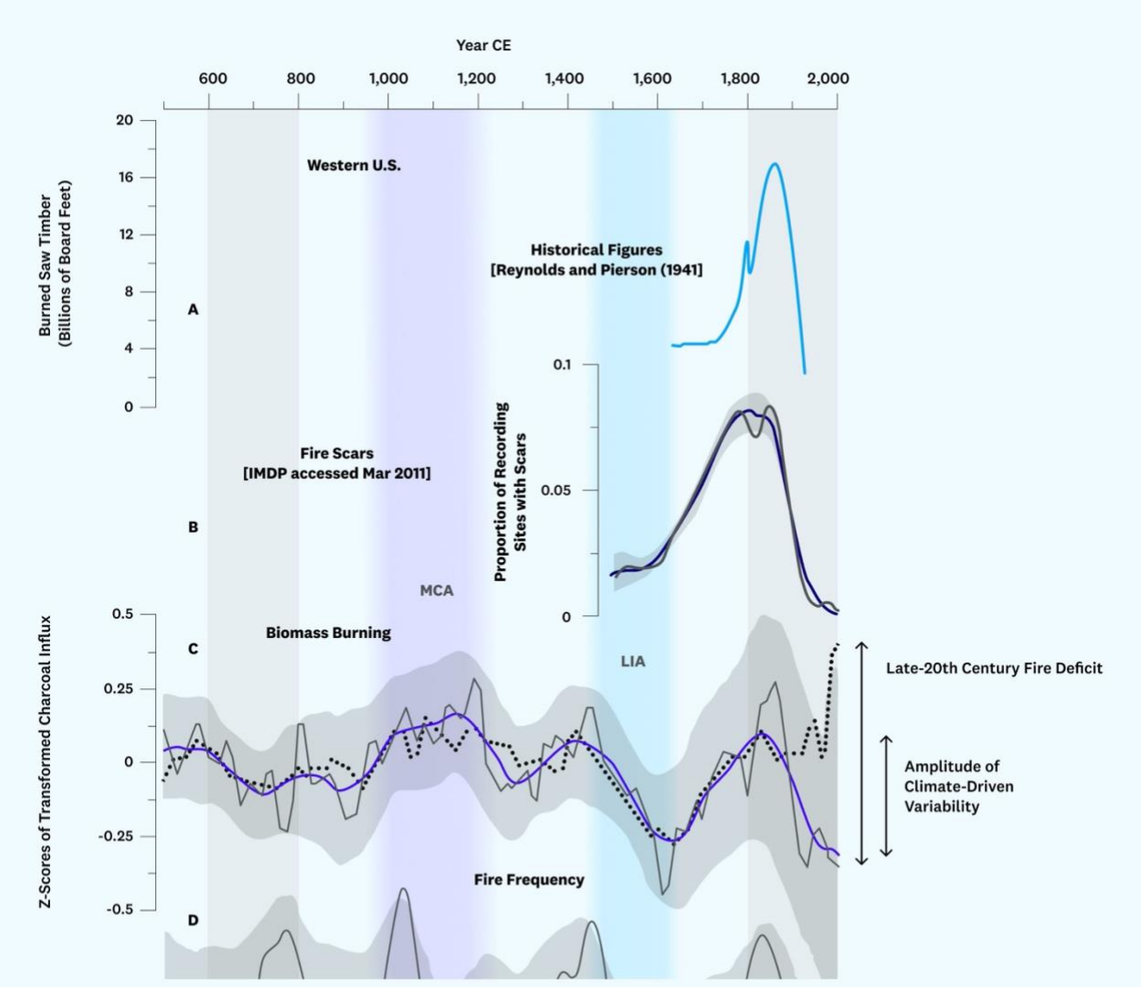
- The NIFC has since removed pre-1983 data from its site; currently the site notes that “(p)rior to 1983, the federal wildland fire agencies did not track official wildfire data using current reporting processes. As a result, there is no official data prior to 1983 posted on this site.”

"The data on the overall, century-long trend suggest that most of the 20th century represented an unusually low amount of fire, and what we're seeing now is a return to the 'normal' levels of fire of the early 1900s.Syphard & Keeley (2016)."

- The figure extracted refers to the Sierra Nevada area and is in thousands of hectares of burned units. “FRAP” is the State of California Fire and Resource Assessment Program. “FPA FOD” is Fire Program Analysis, Fire-Occurrence Database, a national interagency dataset covering 1992-2013. Written records: “California is noteworthy for its extensive written fire history for state and federal lands (Keeley & Syphard 2015). These data are available as annual summaries of fire frequency and area burned for United States

Forest Service (USFS) forests (1910-present) and for individual counties protected by the state agency California Department of Forestry and Fire Protection (Cal Fire) (1919-present). These data include all fires and their size that were recorded each year by county (Cal Fire) or forest (USFS)." Keeley and Syphard cite the written record as the broadly more accurate one of the three sources over long spans of time, as FRAP and FPA FOD are official databases that tend to undercount smaller fires, or do not include fires at all where the perimeter was uncertain. The authors do not dispute the underlying data (i.e. they agree that there is no secular increasing trend of wildfires in the state).

- There's some work going even further into the past: Marlon et al. (2011) say that considering even longer time scales, while there was a peak in fire activity around 1890, that wasn't the situation all the way into the past. Prior to that there was, it is true, more fire than there is now, but not as much as that intermediate era. Marlon et al. note that there is, as of the date of writing the paper, a "fire deficit" (noted also by Baker, 2015) relative to what one would expect from historical climatic patterns: not enough was burning in recent decades. A decade later, we're perhaps now seeing how that gap is being closed by means of the most damaging fire seasons ever.



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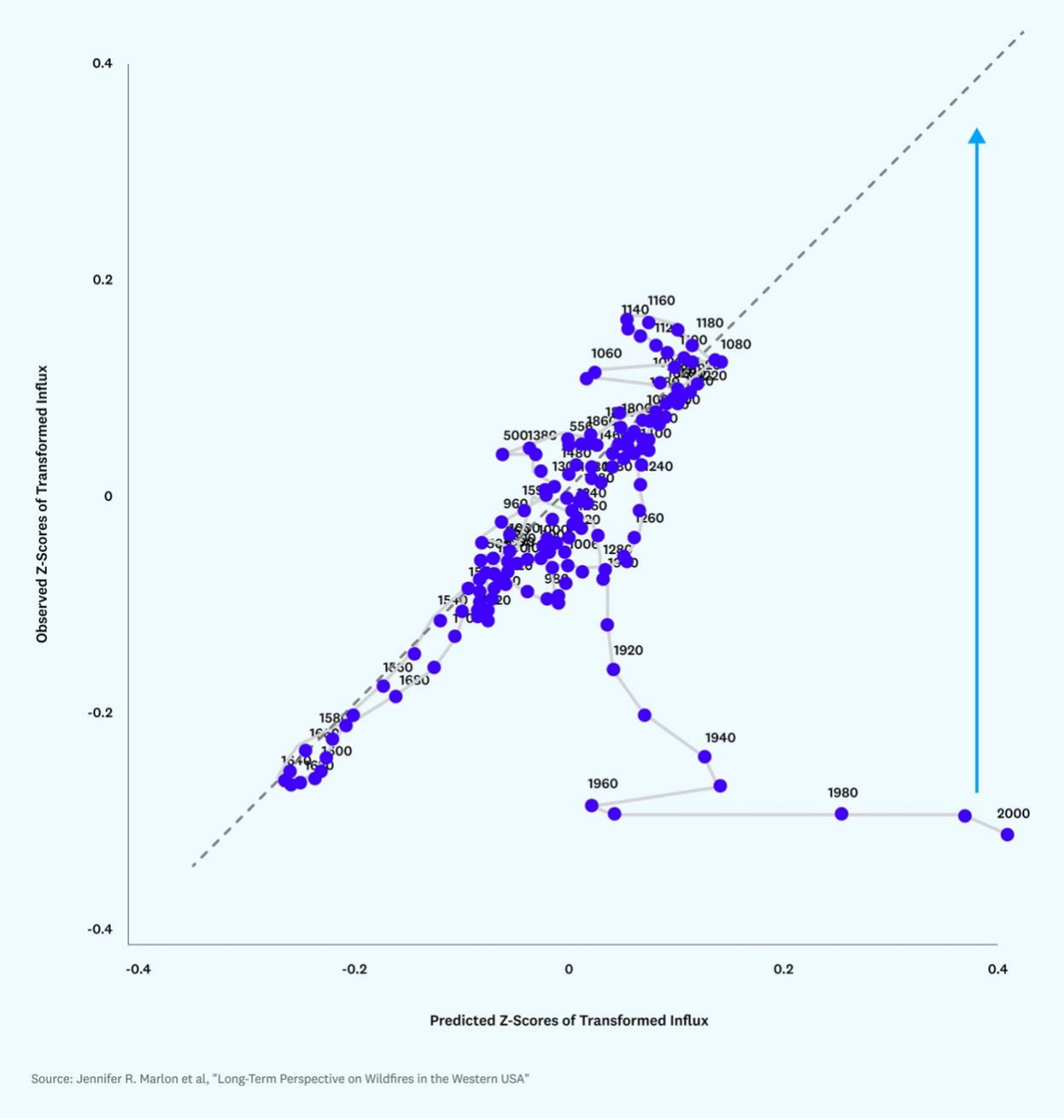
- This fire deficit is even more striking if one plots (as Marlon et al. did, in the supplement) the historical record of predicted charcoal influx (a proxy for fire) using climate and the observed record.



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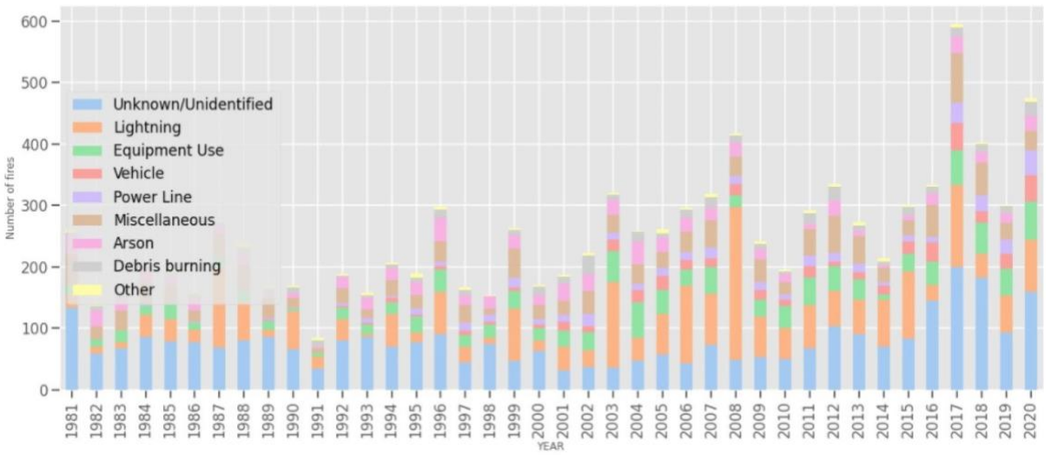
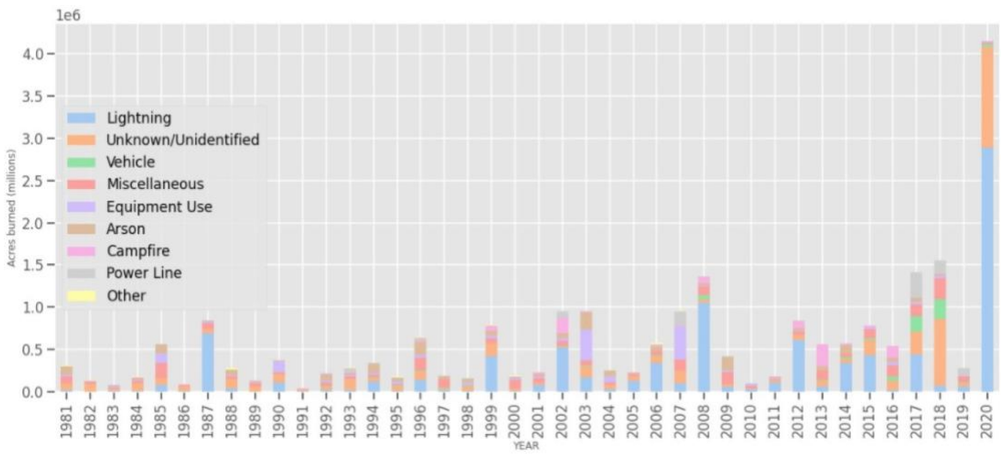
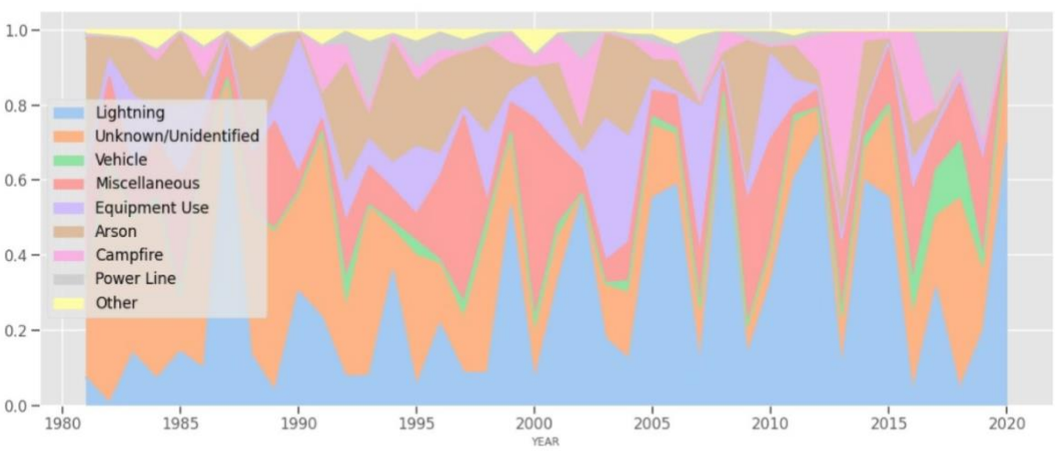
Section: What causes wildfires?

"According to Cal Fire, 6 out of the top 20 most destructive fires since 1991 (by structures burned and deaths) were due to faulty power lines. However, power lines are still fairly low on the list when looking at overall acres burned since 2000. (I created this Github repository for supporting data.)"

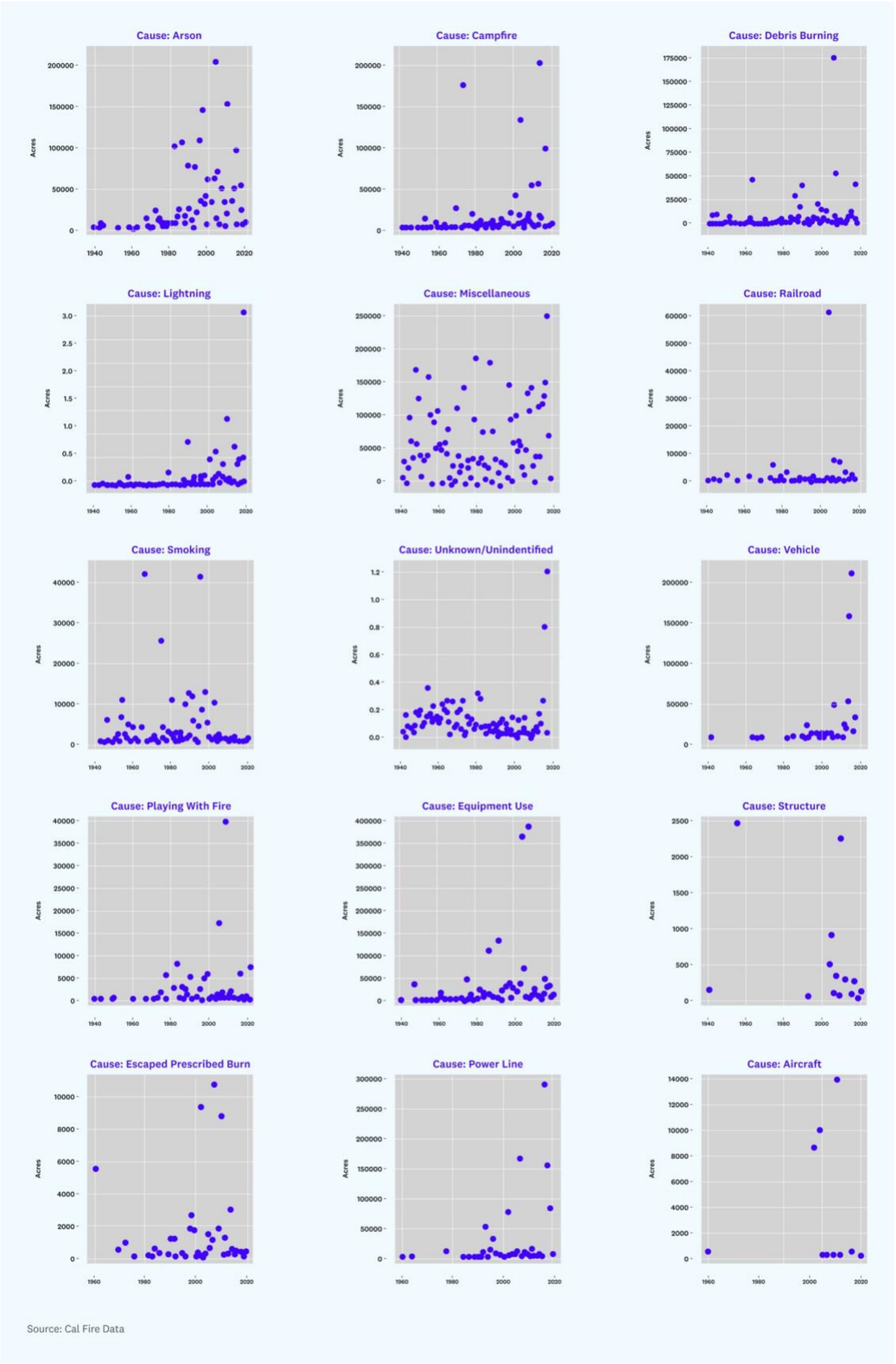
- Note that this dataset, covering 2000 to the present, focuses on the largest fires and not all fires. The difference between FRAP and other data sources is documented in Syphard & Keeley 2016, though FRAP data may now be more up to date.







Source: Cal Fire Data



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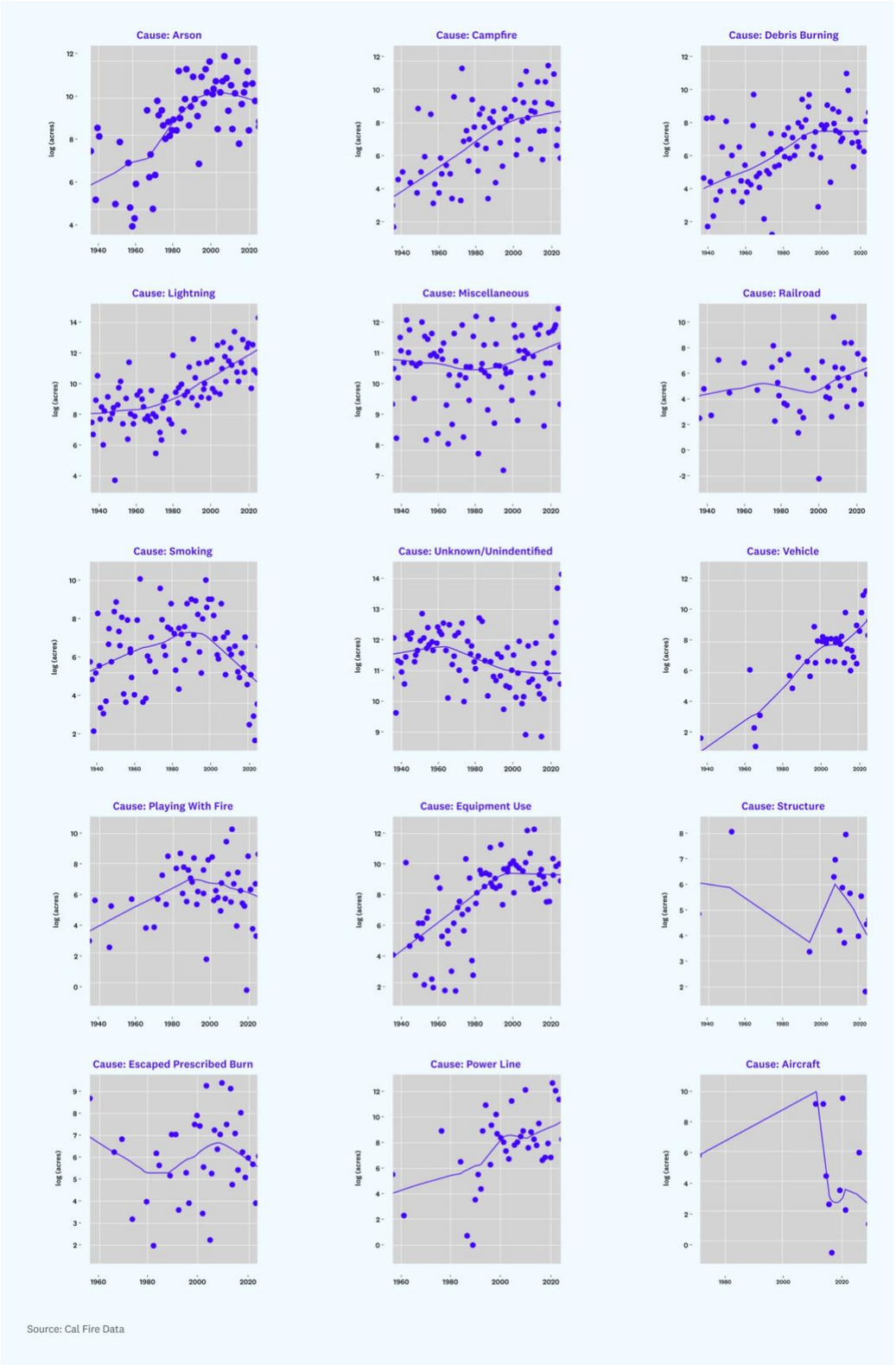
Same data as above but in logarithmic scale, so it's easier to appreciate the trend (albeit at the cost of de-emphasizing the outlier status of the last few years).



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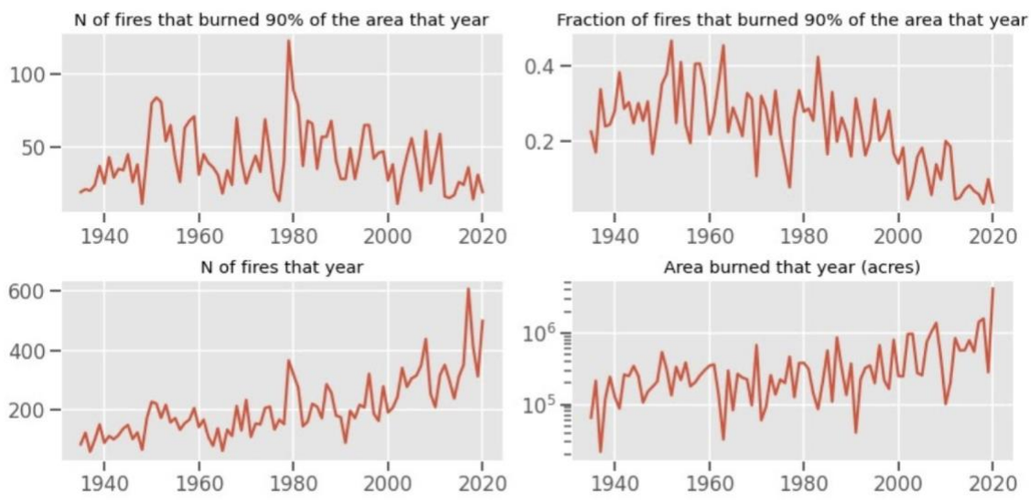
Section: How significant are human causes (and impacts)?

"From analyzing this dataset, it's clear there is a trend toward more area burned and more fires, as well as toward an increase in the largest fires. Whereas 30% of the fires were responsible for 90% of the area burned in a given year in the 1940-2020 period, now less than 10% of the fires (recently, less than 25 fires in a given year) account for most of the area burned."



Source: José Luis Ricón/Cal Fire data

Section: Measuring the deeper health impacts

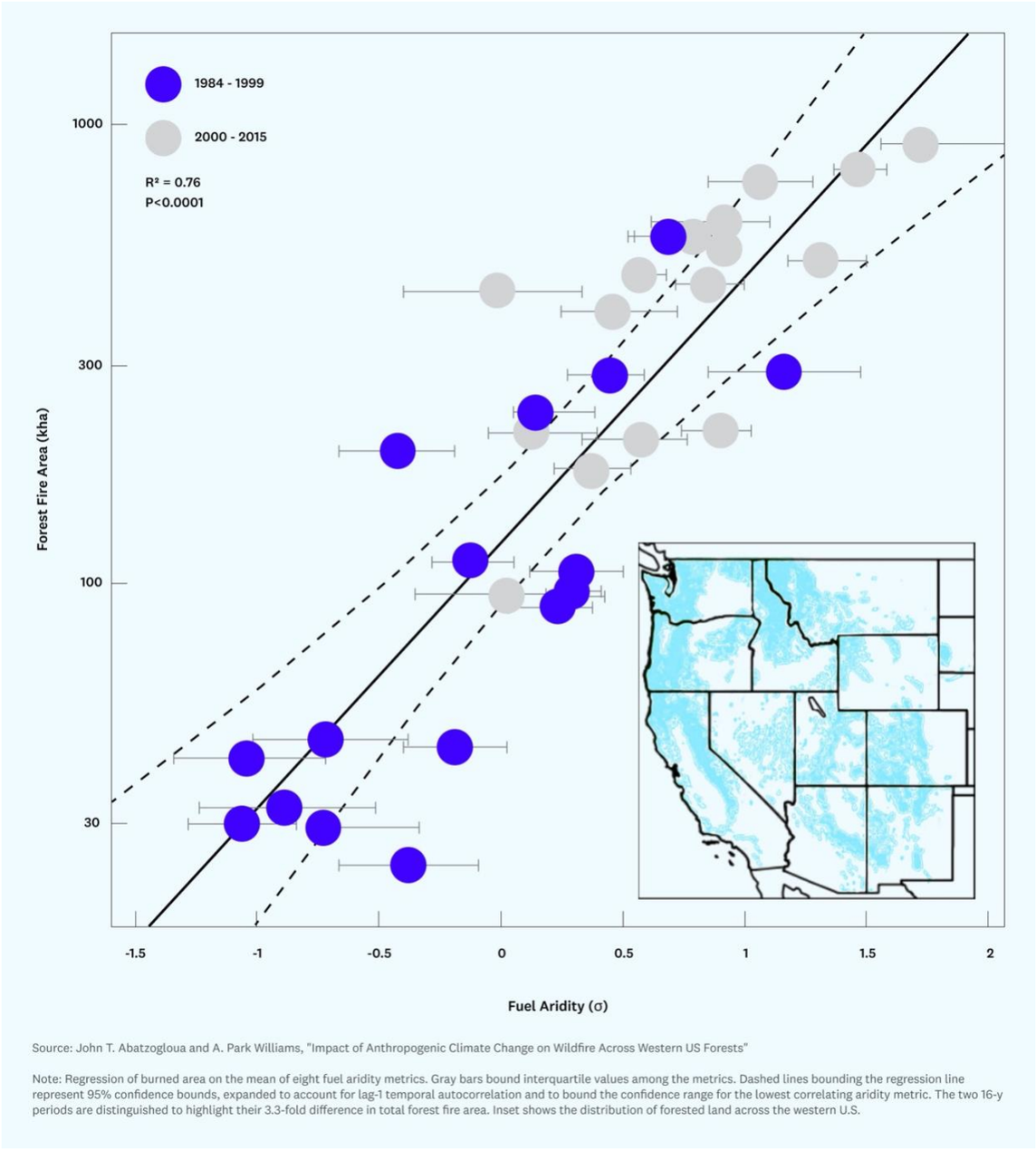
"There is work attempting to quantify the impact of wildfire-produced air pollution on health; Wang et al. (2021) estimate that the California wildfires of 2018 alone, via increases in mortality risk, caused the death of 3,652 people, which is 35 times more than the lives lost directly due to the fires."

- The study appears robust, with some potential caveats. At one point the authors use random forests to estimate the background PM2.5 (airborne particulate matter) over California. The authors use a statistical value of life of $8.8 million, which is not unreasonable. Even when assuming differential value per age and assuming that most of the risk is borne by older people, it would still be a large number. They used a model called BenMAP, produced by the EPA, to predict the health impacts of fire-derived particulates. (I did not examine the model directly.)

Section: Conditions for more damaging fires

"What the authors find is that half of the increase in aridity of the fuels present in western forests, including those in California, was due to anthropogenic climate change, with the rest being natural variation (possibly the oscillations described earlier)."

- There's a more conservative estimate in the paper that would reduce the contribution of climate change by 19%; that means that instead of 55% more burned area we got 40% more burned area due to climate change.
- Aridity is strongly correlated with burned area in a given year:

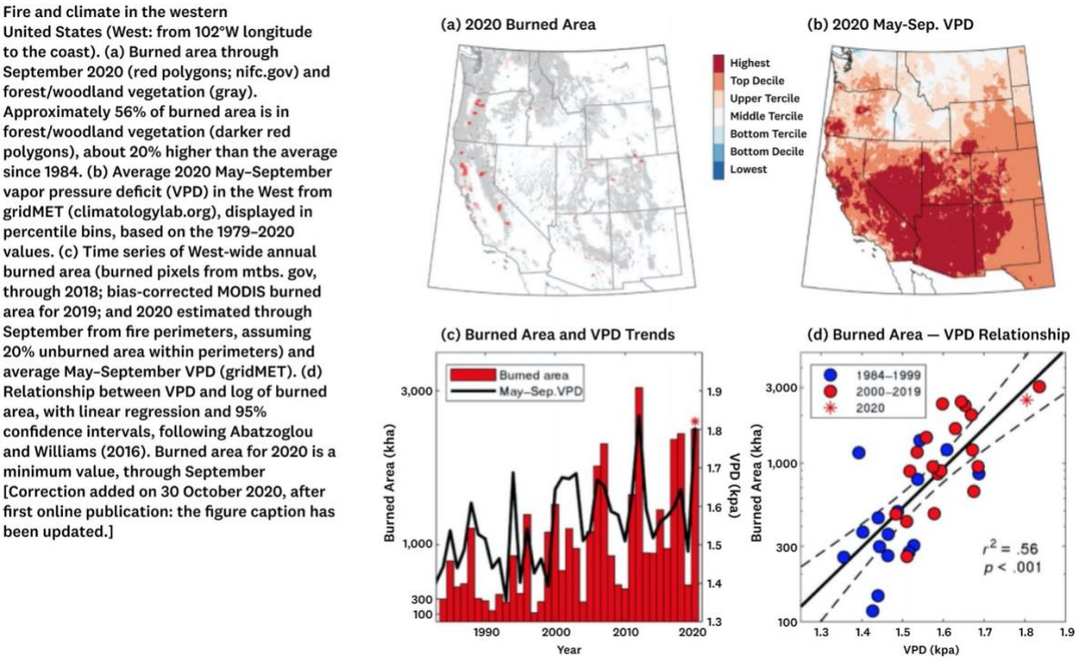


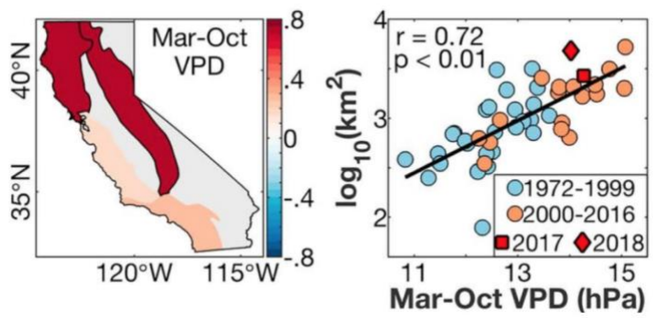
Source: John T. Abatzogloua and A. Park Williams, "Impact of Anthropogenic Climate Change on Wildfire Across Western US Forests"

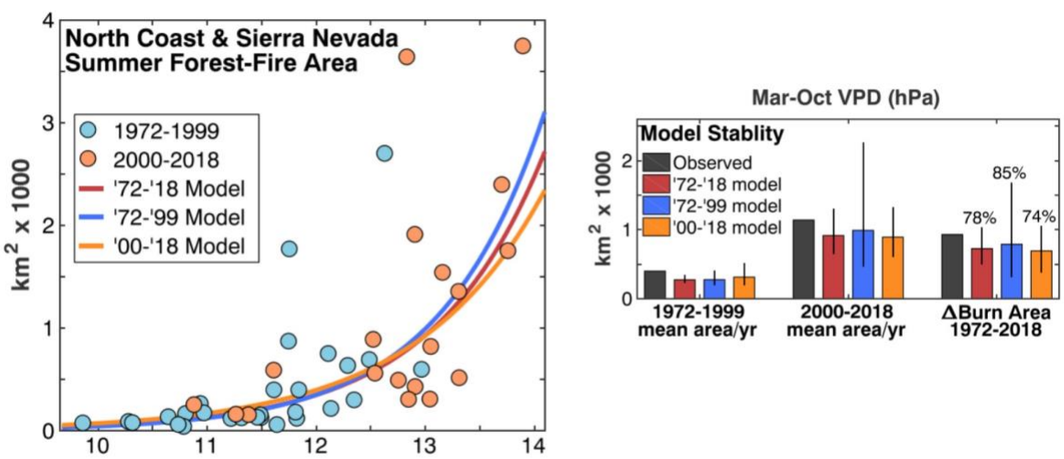
Note: Regression of burned area on the mean of eight fuel aridity metrics. Gray bars bound interquartile values among the metrics. Dashed lines bounding the regression line represent 95% confidence bounds, expanded to account for lag-1 temporal autocorrelation and to bound the confidence range for the lowest correlating aridity metric. The two 16-y periods are distinguished to highlight their 3.3-fold difference in total forest fire area. Inset shows the distribution of forested land across the western U.S.

- Aridity here is a mean of eight different metrics of "fuel aridity." Four metrics were calculated from monthly data for 1948–2015: (i) reference potential evapotranspiration (ETo), (ii) VPD, (iii) CWD, and (iv) Palmer drought severity index (PDSI). The other four metrics are daily fire danger indices calculated for 1979–2015: (v) fire weather index (FWI) from the Canadian forest fire danger rating system, (vi) energy release component (ERC) from the U.S. national fire danger rating system, (vii) McArthur forest fire danger index (FFDI), and (viii) Keetch-Byram drought index (KBDI).
- As an aside, if we pick one of them, like vapor pressure deficit, we get the same results. VPD measures the difference between the amount of moisture in the air and how much moisture the air could potentially hold when it's saturated. It's often measured in pounds per square inch (psi) or kilopascal (kPa). A high VPD (greater than 1.0 kPa) means that the air can still hold a large amount of water. High VPD means that rather than droplets of water staying on or in plants, they will be sucked up into the air (warmer air can carry more water), thus high VPD leads to drier terrains and drier terrains leads to, in general, more fire. VPD also correlates reasonably well with burned area across the Western United States in general and California specifically (Higuera & Abatzoglou, 2020, Park Williams et al. 2019). The relationship seems exponential: More VPD, exponentially more fires:

Fire and climate in the western United States (West: from 102°W longitude to the coast). (a) Burned area through September 2020 (red polygons; nifc.gov) and forest/woodland vegetation (gray). Approximately 56% of burned area is in forest/woodland vegetation (darker red polygons), about 20% higher than the average since 1984. (b) Average 2020 May–September vapor pressure deficit (VPD) in the West from gridMET (climatologylab.org), displayed in percentile bins, based on the 1979–2020 values. (c) Time series of West-wide annual burned area (burned pixels from mtbs. gov, through 2018; bias-corrected MODIS burned area for 2019; and 2020 estimated through September from fire perimeters, assuming 20% unburned area within perimeters) and average May–September VPD (gridMET). (d) Relationship between VPD and log of burned area, with linear regression and 95% confidence intervals, following Abatzoglou and Williams (2016). Burned area for 2020 is a minimum value, through September [Correction added on 30 October 2020, after first online publication: the figure caption has been updated.]

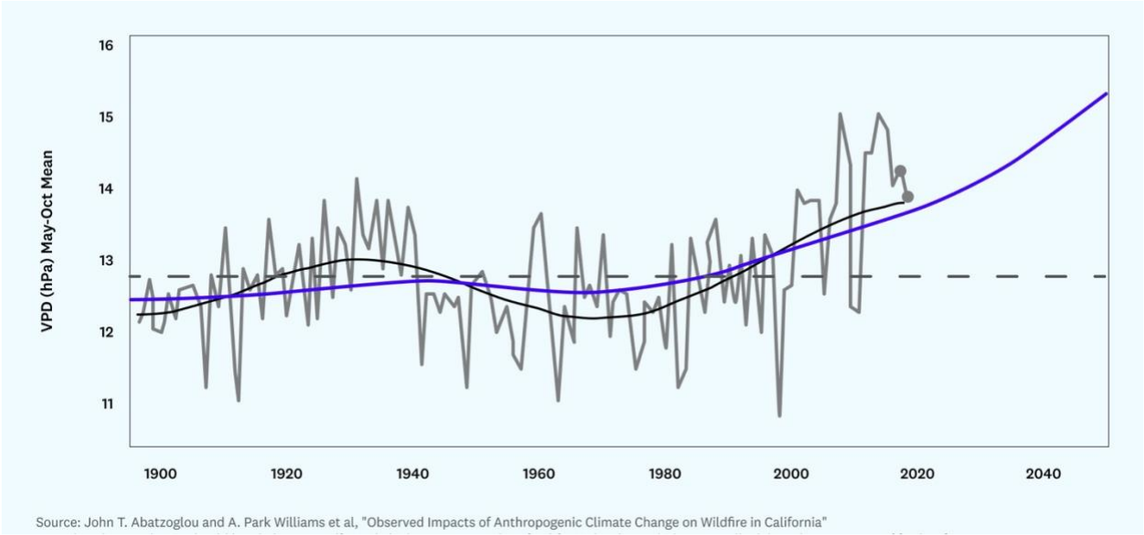






Source: John T. Abatzoglou and A. Park Williams et al, "Observed Impacts of Anthropogenic Climate Change on Wildfire in California"

- It won't be too surprising to say that VPD is going up as temperatures rise, but note, in the below graphic, that it also presents an oscillatory component (black) that is not well captured by the CMIP5 climate model ensemble (blue). This oscillation may help explain why there were so many fires pre-1950, why there was so little fire in the intermediate years, and why there is so much fire now. Eyeballing the period of the oscillation, it may be caused by the Pacific Decadal Oscillation. If so, we may have reached a peak and will get some relief from the rising trend from a few years, but given the underlying rising trend from climate change, that won't be more than a temporary slowdown of the increase rather than an absolute respite:



- Note that the correlation should break down at sufficiently high VPDs: once a lot of California has burned, that naturally delays the occurrence of further fires.

"Even this analysis, which adds a layer of nuance to the "is climate change to blame" question, focuses on the direct impacts of anthropogenic climate change on fuel aridity and does not address several other pathways by which it may have affected wildfire activity (either in a positive or negative direction), according to the authors."

- "In focusing exclusively on the direct impacts of ACC on fuel aridity, we do not address several other pathways by which ACC may have affected wildfire activity. For example, the fuel aridity metrics that we used may not adequately capture the role of mountain snow hydrology on soil moisture. Nor do we account for the influence of climate change on lightning activity, which may increase with warming. We also do not account for how fire risk may be affected by changes in biomass/fuel due to increases in atmospheric CO2 (41), drought-induced vegetation mortality, or insect outbreaks. Additionally, we treat the impact of ACC on fire as independent from the effects of fire management (e.g., suppression and wildland fire use policies), ignitions, land cover (e.g., exurban development), and vegetation changes beyond the degree to which they modulate the relationship between fuel aridity and forest fire area. These factors have likely added to the area burned across the western US forests and potentially amplified the sensitivity of wildfire activity to climate variability and change in recent decades. Such confounding influences, along with nonlinear relationships between burned area and its drivers, contribute uncertainty to our empirical attribution of regional burned area to ACC. Our approach depends on the strong observed regional relationship between burned area and fuel aridity at the large regional scale of the western United States, so the quantitative results of this attribution effort are not necessarily applicable at finer spatial scales, for individual fires, or to changes in nonforested areas."

Section: Land management policies

"After years of debate, the state decided against prescribed burns. Any fire was deemed too dangerous."

- Show & Kotok, 1924; see also Keeley, 2021, who notes that part of the reason the fire exclusion policy was put into place seems to be some amount of lobbying by the logging industry: burnt trees are less valuable. Now that logging and wood-related activities are a minor part (~1%) of California's GDP ($39 billion out of $3 trillion) this justification is weaker compared to other considerations like health and protecting life and property.

"In 1970 a reversal of these policies started, and now the consensus position is that prescribed burns can be a valuable tool (Stephens & Ruth, 2005)."

- "Shortly after the NPS revised its fire policy, the USFS did so as well. Henry Debruin, director of Fire and Aviation Management for the USFS, stated ''we are determined to save the best of the past as we change a basic concept from fire is bad to fire is good and bad'' (DeBruin 1974:12). While this statement represented a major shift in the philosophy of the USFS, fire suppression was still to dominate agency policy for the coming decades (Franklin and Agee 2003)." (Stephens & Ruth, 2005)

"Interviewees therefore underscored the importance of expanding prescribed burns, particularly on non-federal lands, to achieve the ecological benefits of fire."

- A point I encountered repeatedly is that Native Americans were engaging in prescribed burns before the arrival of Europeans in America. This may be an attempt to gain support for prescribed fires as a return to ancestral practices. But did Native Americans really use prescribed burns? Native Americans indeed used fire for various reasons, from religion to clearing land to increasing agricultural yield to reducing places where rival tribes could hide and ambush them (Keeley, 2002). But the extent to which these practices affected large swathes of territory remains debated. For what it's worth, Keeley does think that the practices did lead to substantial amounts of fire, enough to shape large parts of the region. What seems to be the authoritative book on the subject, *Indians, Fire, and the Land in the Pacific Northwest* (Boyd, 1999), says that indeed the Native Americans were not really engaged in the deliberate prevention of fire, but rather to the extent that they were causing there to be fewer larger fires, it was an accidental outcome of their use of fire for other purposes, Other ecological effects of burning and other traditional management practices that are apparent today may not have been so obvious or primary in the world of the Native Americans. The beneficial effects of understory and spot burning in several forest types as a preventive to wildfires, disease outbreaks, and extensive forest burns, now so apparent to Northwest forest managers, have become timely because of the ill-advised, unnatural, and culturally specific practice of fire suppression.
- I'm agnostic as to whether these practices were enough to substantially alter the landscape of California at large. Ultimately I think of the practice of prescribed burning as aiming not to give the environment what it "naturally needs"; nature does not do prescribed burning, rather it's an attempt to first undo what the longstanding fire suppression policy (also an alteration over the natural course of things) did, and make California a more livable place than what nature would let us have: maybe more fires, but in safer ways with less pollution and damage.

"If the approved burn window is missed, landowners (whether private owners or public agencies) have to reapply for approval."

- An example (thanks to Eli Dourado): An Environmental Impact Statement and Decision Notice was released in May of 2001. The project was subsequently appealed. At the appeals resolution meeting, eight individual landowners requested the appellants withdraw their appeal, which they did not. The project decision was upheld in August of 2001. The appellant filed a complaint with the Federal District Court to permanently enjoin the project, which was granted. A hearing date was set for October of 2003; however, in July of 2003 approximately 45% of the project area burned in a running crown wildfire. The chronology of this project shows how process and procedural delays hamper the ability to get on top of forest health restoration needs, especially when treatment needs are time-sensitive. Often delay is the objective of individuals or groups that do not want to see any trees harvested.

Section: Potential paths to progress

"Ease air quality regulations, including for prescribed fires. Temporary worsening on a schedule (so the affected population can prepare) is better than multi-month bad air quality."

- Those interviewed by Miller et al. declined to ask for weaker environmental regulations for prescribed fires. The California Air Resources Board is aware of the need for more prescribed fire, and back in 2019 it was calling to "significantly increase the number of acres treated with prescribed fire" and to "streamline regulatory and permitting processes." Currently, prescribed fires take place in favorable weather, which is why there is less of an impact to nearby populations (Xiaoxi et al., 2017), but burning all that is required to burn probably will require making occasional exceptions to these air quality regulations.

"Use market-oriented solutions in the WUI. California is preventing market mechanisms from fully operating to reduce construction in highly fire-prone areas."

- The closest we have to mandatory third-party insurance, or rather used to have, is the Cal Fire fee levied on habitable buildings on state land that is not incorporated. The problem with this fee is twofold: one, it's the same for everyone (unlike regular insurance), so higher-risk areas are not charged a higher premium. Second, it doesn't apply to everyone! While hot tub owners in Cobb would be paying the fee, those in South Lake Tahoe would not. The insurance mechanism on the victim side (paying

those who suffer from wildfire damage) is sadly broken due to government regulation. What should happen is that premiums should increase in areas prone to fire, which in turn would help dissuade new construction there on the margin. California's government, for example, prevents insurers from dropping coverage in wildfire-prone areas. Where they can, insurers are in fact dropping customers. Why would insurers want to drop valuable customers? Because again the California government doesn't let them increase premiums to actuarially fair levels: they have to ask for permission to raise them. Instead of a free market where insurers compete to fairly price risk, the imposition of price caps leads to the absence of service. There's a state-operated insurer of last resort, the FAIR plan, which fortunately offers less comprehensive coverage than the private plans (so it ends up being expensive; perhaps not as expensive as it should be, but better than it would be if it were more comprehensive). Of course, California being California, the plan is to move in the direction of more comprehensive, less expensive coverage, in effect offering a subsidy to those living in fire-prone areas.

"Enforce 'defensible space' around houses in the WUI."

- The creation of defensible space around a property, according to specific horizontal and vertical spacing criteria, is required by state law in State Responsibility Areas and in High Fire Hazard Severity Zones in Local Responsibility Areas, and/or by local ordinance. The specific requirements for defensible spaces are found in the Public Resources Code 4290- 4294 within California Building Code: Chapter 7A. Amendments to the CA building code in 2005, 2008 (SB 1595 Kehoe, Chapter 366, Statutes of 2008) and 2018 (AB 2911 Friedman, Chapter 641, Statutes of 2018) provided major updates to the code that increased defensible space requirements, including increasing the defensible space up to 100 feet and requiring more intense fuel management within the first 30 feet around a structure. State law applies fines of no less than $100 for a first infraction, increasing to a potential misdemeanor charge and a fine of no less than $500 for a third infraction. State law also allows insurance carriers to require more restrictive defensible space criteria than the 100-foot criteria in California's building code. **There is no statewide audit of defensible space compliance with the state requirement and anecdotal evidence suggests compliance is uneven. **(The Costs of Wildfire in California)

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