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Supporting Information for

Rapid Growth of Large Forest Fires Drives the Exponential Response of Annual Forest-Fire Area to Aridity in the Western United States

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Introduction

For this and future work, we developed a new database of locations and sizes of individual fires in the western United States (US), which we refer to as the Western US MTBS-Interagency (WUMI) wildfire database. Below we describe the database in further detail.

Text S1. Database production

The cornerstone of the WUMI wildfire database is the set of high-resolution maps of large wildfires (≥4.04 km^2) provided by the Monitoring Trends in Burn Severity (MTBS) program (Eidenshink et al., 2007). The MTBS program uses Landsat satellite imagery to map burned areas at 30-m resolution for thousands of large wildfires across the western US. As of September 2021, the MTBS database extended from 1984-2019. We excluded prescribed fires from our database.

The NWCG dataset has been used in several other western US fire-climate studies (e.g., Westerling et al., 2011; Keeley & Syphard, 2018; Williams et al., 2019) and is a compilation of fire records from six federal government agencies: the Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS), US Fish and Wildlife Service (FWS), and US Forest Service (FS).

The records together are referred to as the "Interagency" databases. These NWCG records cover 1972-2019 for FS and FWS, cover 1972-2017 for BIA, BLM, BOR, and NPS, and contain point locations for each fire. NWCG records also include for each fire, the date that suppression activities began—which we treat as the ignition date, an estimate of the area burned, and fire's name. Because MTBS records are critical to our dataset, we excluded NWCG fires prior to the beginning of the MTBS dataset in 1984. We also excluded prescribed fires with "RX", "RXBURN", or "PSBURN" in the fire name, and multi-agency assists where a fire in another agency's database will be labeled with an agency name and a number, e.g., "USFS 1".

We performed rigorous quality control to remove duplicate fires through a multi-step process. Duplicate fires were first identified as multiple fires with all the same fields. Then, we identified more duplicates as fires with similar names, locations, and/or sizes. For example, if two fires with the same name occurred within 300 km and 10 days of each other, they were flagged as duplicates. Or, if two fires with different names occurred in the exact same location and date, those fires were also assumed to be duplicates. Other duplicates were identified by flagging fires with combinations of very similar names (e.g., "ST FRANCIS" vs. "SAINT FRANCIS"), similar dates (e.g., ≤2 days to ≤10 days), similar locations (e.g., ≤0.01 degrees to ≤1 degrees), and similar sizes (e.g., within 20% to 50% of the fire's reported size), and then manually deciding if they are duplicates. When duplicates were identified, the fire with the largest-recorded burned area record and/or the earliest ignition date were retained because often an agency records the burned area only where and when a fire event occurred within their jurisdiction. For some fire records, we often kept the FS fire size record but retained the fire name from a different Interagency database that was consistent with other Interagency and MTBS records. While the BIA, BLM, BOR, and NPS data only come through 2017, we considered records through 2019 in this study of forest fire because the vast majority of fires in forested areas are in the FS dataset (Figure S3).

The NWCG database was merged with fires ≥1 km^2 from the California Department of Forestry and Fire Protection (CalFire) Fire and Resource Assessment Program, which includes dates and perimeters of fires across most of California from the early 20^{th} century through 2020. We also identified duplicates between NWCG and CalFire databases. Because the CalFire records are produced by an agency specifically focused on fire, include fire perimeters, and extend beyond 2017, we prioritized the CalFire records over the NWCG records in cases of duplicates. Use of CalFire fire perimeters undoubtedly leads to a bias toward enhanced accuracy of forest-area burned in California relative to the rest of the western US, especially among smaller fires not

represented in the MTBS database, but we determined that enhanced accuracy in part of the study region is a net positive contribution to the quality and usefulness of our WUMI database.

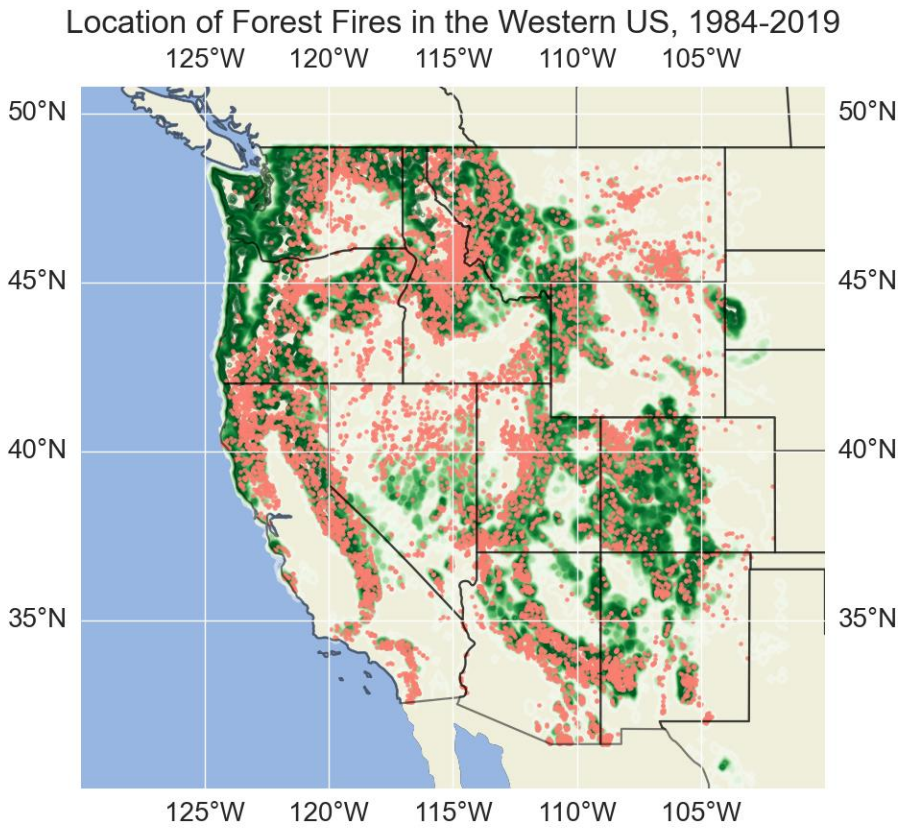
Finally, the NWCG-CalFire database was combined with MTBS data, prioritizing MTBS records in cases of duplicates. Often times, a single fire in the MTBS database is actually composed of numerous smaller fires. For example, the large 1988 burned area that occurred from many fires in in and around Yellowstone National Park are represented by just four fires in the MTBS dataset (e.g. the Storm Creek fire, mt4507511010219880619). Therefore, we chose not to replace any fires between the Interagency databases and the MTBS database, but we instead "link" fires (sometimes multiple fires) from the NWCG-CalFire database to a single MTBS fire event using the following steps. First, we identified and linked fires with the exact same name within 10 days and 300 km. Next, we identified complex fires (with "COMPLEX" in their name) within a 0.1-degree buffer of the bounding box of an MTBS fire's satellite footprint and/or within 50 km and (2) within 180 days of the MTBS fire ignition date. We identified noncomplex fires as fires (1) within a 0.1-degree buffer of the MTBS satellite footprint bounding box ignited within 20 days of the MTBS fire's ignition date, or (2) fires located within 20 km of the center of the MTBS fire ignited within 1 day of the MTBS fire's ignition date. A final step identified and linked fires between the MTBS database and the NWCG-CalFire database using combinations of similar location (e.g. within 0.05-2 degrees), similar ignition dates (e.g. within 3-9 days), similar names (e.g. matching first 2 characters), and similar fire size (e.g. within 50%-80% of the current size).

In cases when multiple non-duplicate fires in the NWCG-CalFire database were linked to an MTBS fire, we distributed the burned area as recorded by MTBS across the multiple NWCG-CalFire fires, maintaining the proportional differences in fire sizes originally reported by NWCG-CalFire. For fires originating from MTBS, burned areas were aggregated to 1-km resolution by directly summing groups of 30-m resolution maps of burned area. For CalFire, we determined the

area within each 1-km grid cell that fell within each fire perimeter. For NWCG fires, fire perimeters were assumed to be circular and centered around the point locations provided.

Forested area burned was estimated by multiplying each fire's 1-km map of area burned by a corresponding 1-km map of forest fractional coverage using the forest-type map from Ruefenacht et al. (2008). The Ruefenacht map has a 250-m spatial resolution and covers the coterminous US and Alaska. Ruefenacht et al. (2008) used observations from the US Forest Inventory and Analysis (FIA), remotely sensed imagery, the National Land Cover Dataset, and maps of soils and climate characteristics to classify each 250-m grid cell as forest or non-forest, and, for forested grid cells, they classified the dominant forest type to be one of 141 forest types, which included woodland areas composed of piñon-juniper, oak, or mesquite. For each 1-km grid cell in our forest coverage map, we calculated the fraction of 250-m grid cells within that were classified by Ruefenacht et al. (2008) as forest.

Our fire database consists of 18,368 western US fire events from 1984 through 2019. A text file (west_US_fires_1984_2020.txt) provides a list of each fire event, including the fire's name, discovery date, point location, total area burned, and forested area burned (see the corresponding readme.txt file for column labels). We also include NetCDF files of the 1-km map of forest fractional coverage and the 1-km maps of monthly burned area over 1984–2019.



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91 **Figure S1. Location of forest fires >1 km^2 in the western United States (US)**. Fire locations
92 are shown as red point locations representing a central latitude/longitude for each fire event
93 recorded in the Western US MTBS-Interagency (WUMI) wildfire database, overlaid on forest
94 area fraction, in green. Point locations are not scaled to fire size.
95

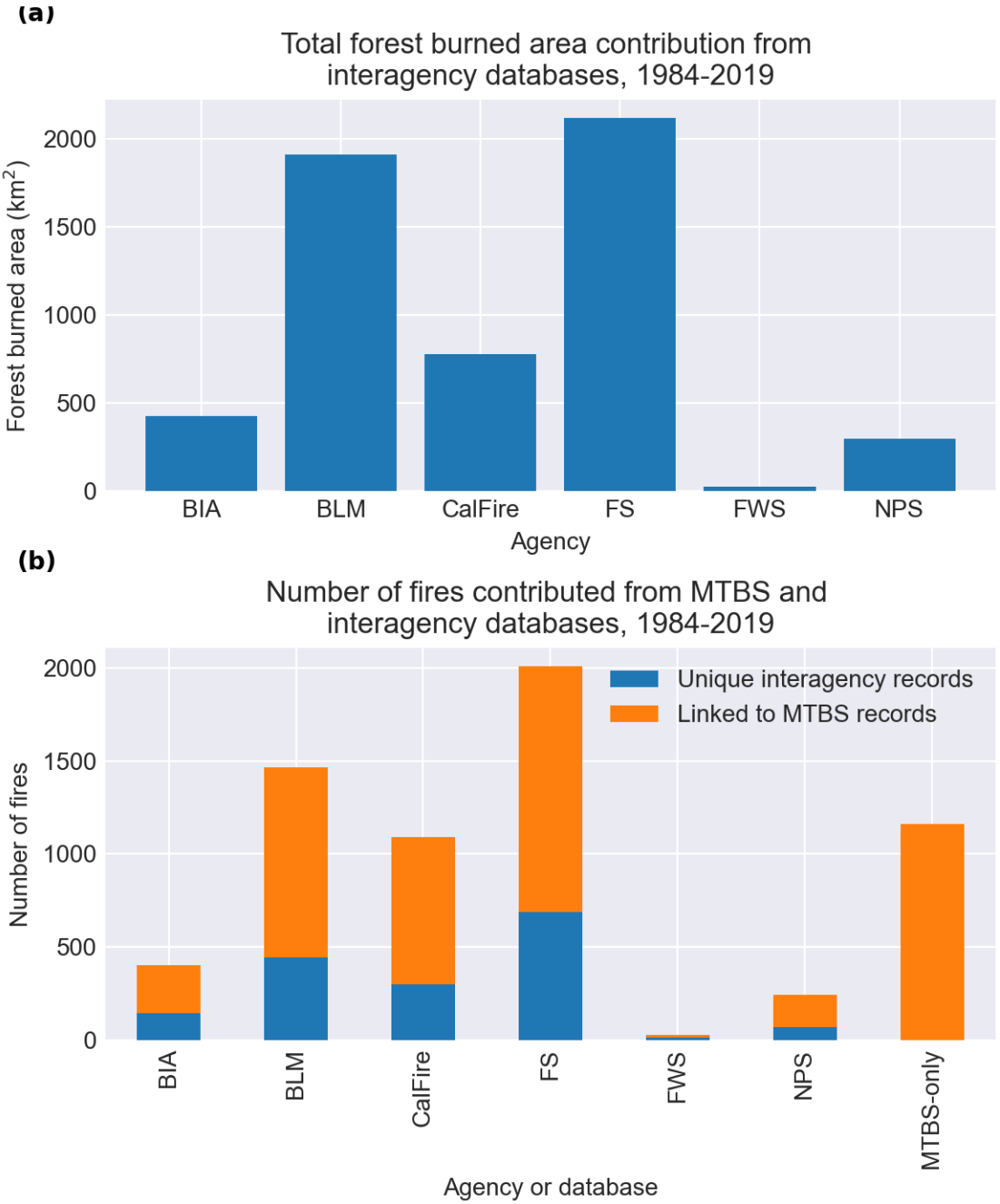

Figure S2. Total forest burned area and number of fires contribution from NWCG-CalFire interagency databases. (a) Sums of forest fire area burned for unique fire event records in the Bureau of Indian Affairs (BIA), Bureau of Land Management (BLM), California Department of Forestry and Fire Protection (CalFire), US Forest Service (FS), US Fish & Wildlife Service (FWS), and National Park Service (NPS) in the WUMI wildfire database. The records shown are unique ones that are not associated with a Monitoring Trends in Burn Severity (MTBS) record. **(b)** Number of forest fires for fire event records unique to the interagency databases (in blue), interagency records that are linked to MTBS records for a single fire event (in orange), or forest-fire events unique to MTBS (MTBS-only, in orange).

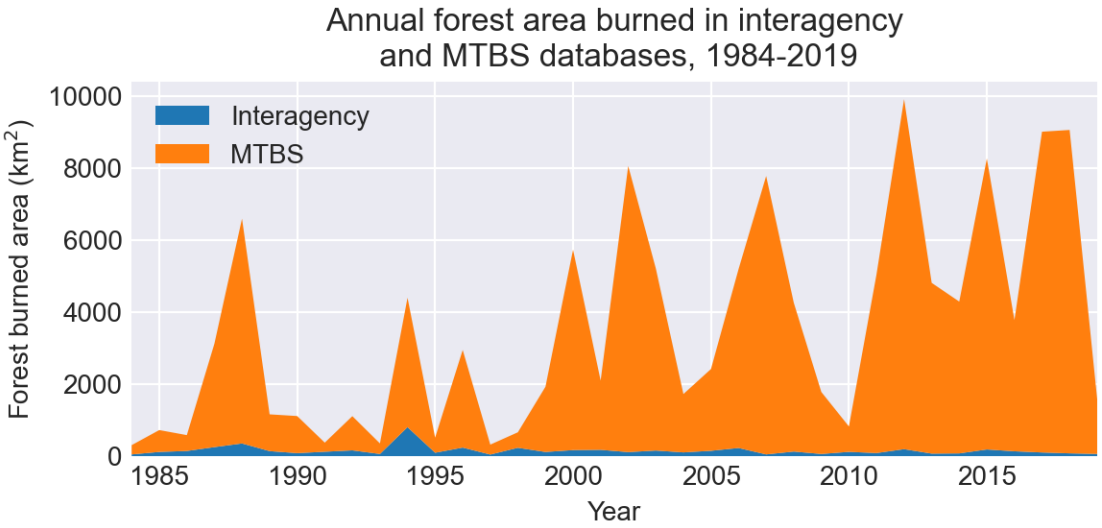

Figure S3. Annual forest area burned in Interagency (NWCG-CalFire) and MTBS databases. Stacked sums of annual forest area burned in the combined Interagency databases (in blue) and Monitoring Trends in Burn Severity (MTBS) database (in orange) for all fire events >1 km^2.

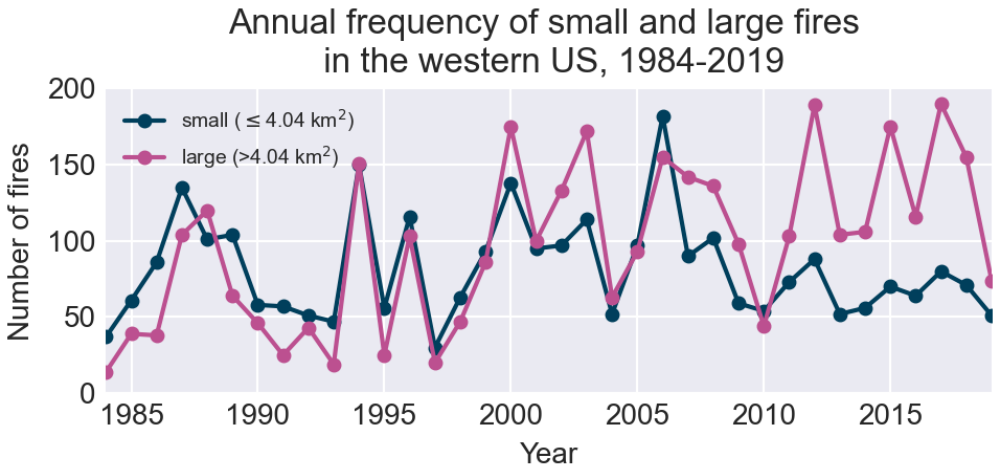

Figure S4. Annual frequency of small and large fires in the western US. Line plots of small (1-4.04 km^2, in blue) and large (>4.04 km^2, in purple) fires in the WUMI wildfire database.

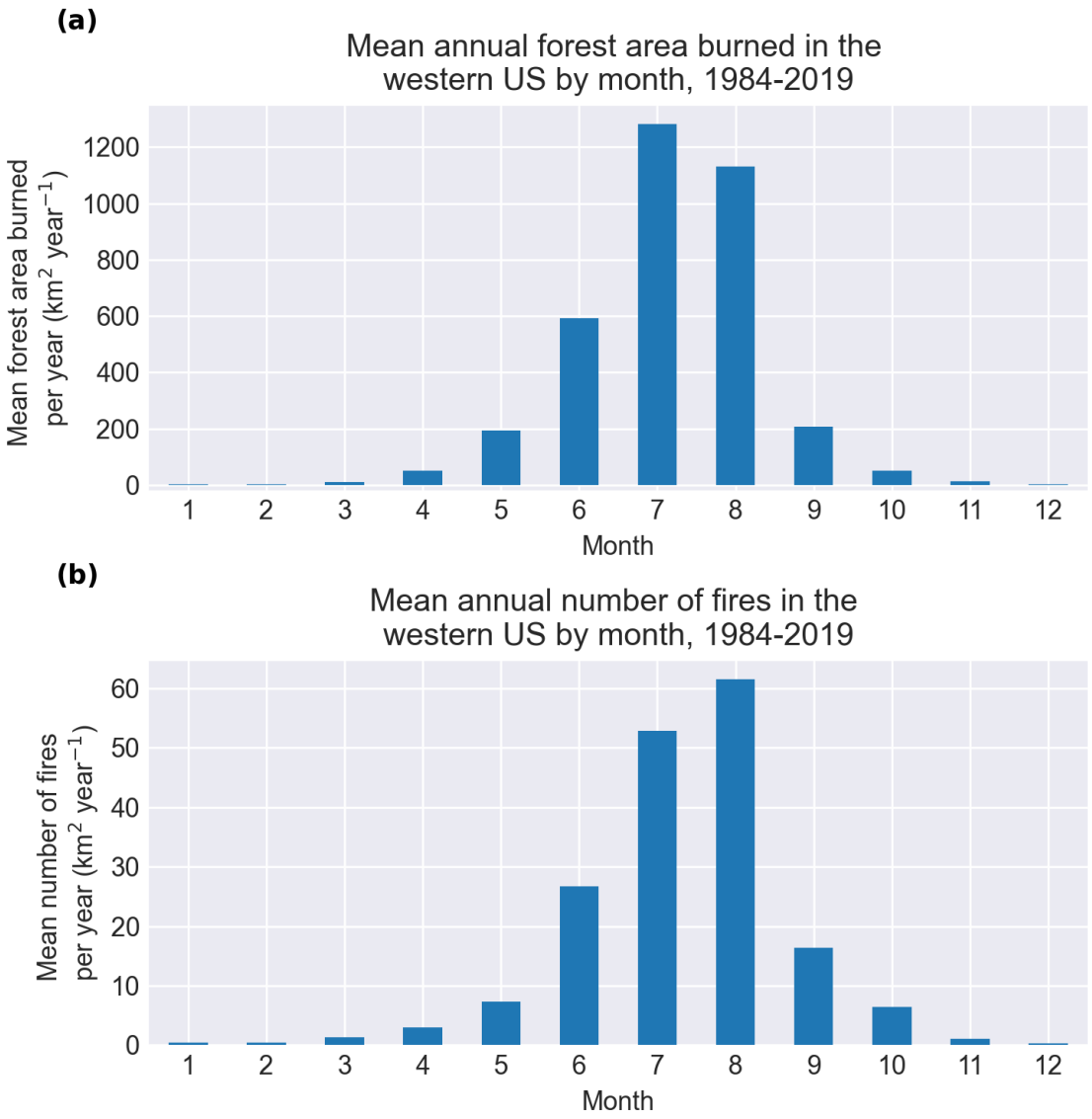

Figure S5. Mean annual forest fire activity by month in the western US. (a) Mean forest area burned per year, classified by month. (b) Mean number of forest fires in the western US per year, classified by month. Both panels are averaged over the time period 1984-2019.

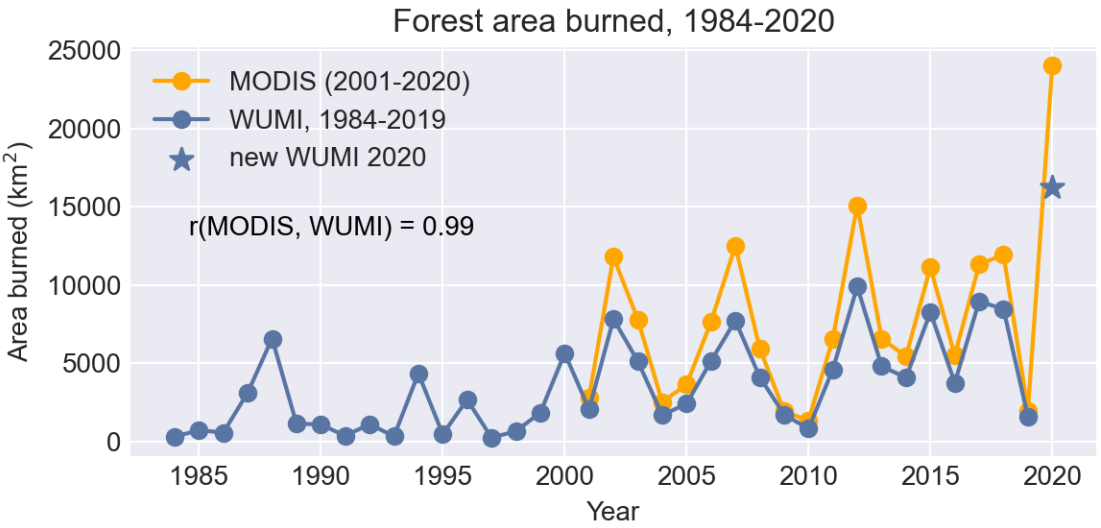

Figure S6. Western US annual forest area burned, in MODIS satellite data and WUMI database. Timeseries of forest area burned for the Western US MTBS-Interagency (WUMI) database (1984-2019, in blue) and the Moderate Resolution Imaging Spectroradiometer (MODIS) v6 Burned Area Product (Giglio et al., 2016) (2001-2020, in yellow). MODIS data were used to extend the WUMI forest burned area measurement through 2020 using a linear relationship between 2001-2019 MODIS and WUMI data with a correlation coefficient of 0.99. The resulting 2020 burned area for 2020 is shown with a blue star.

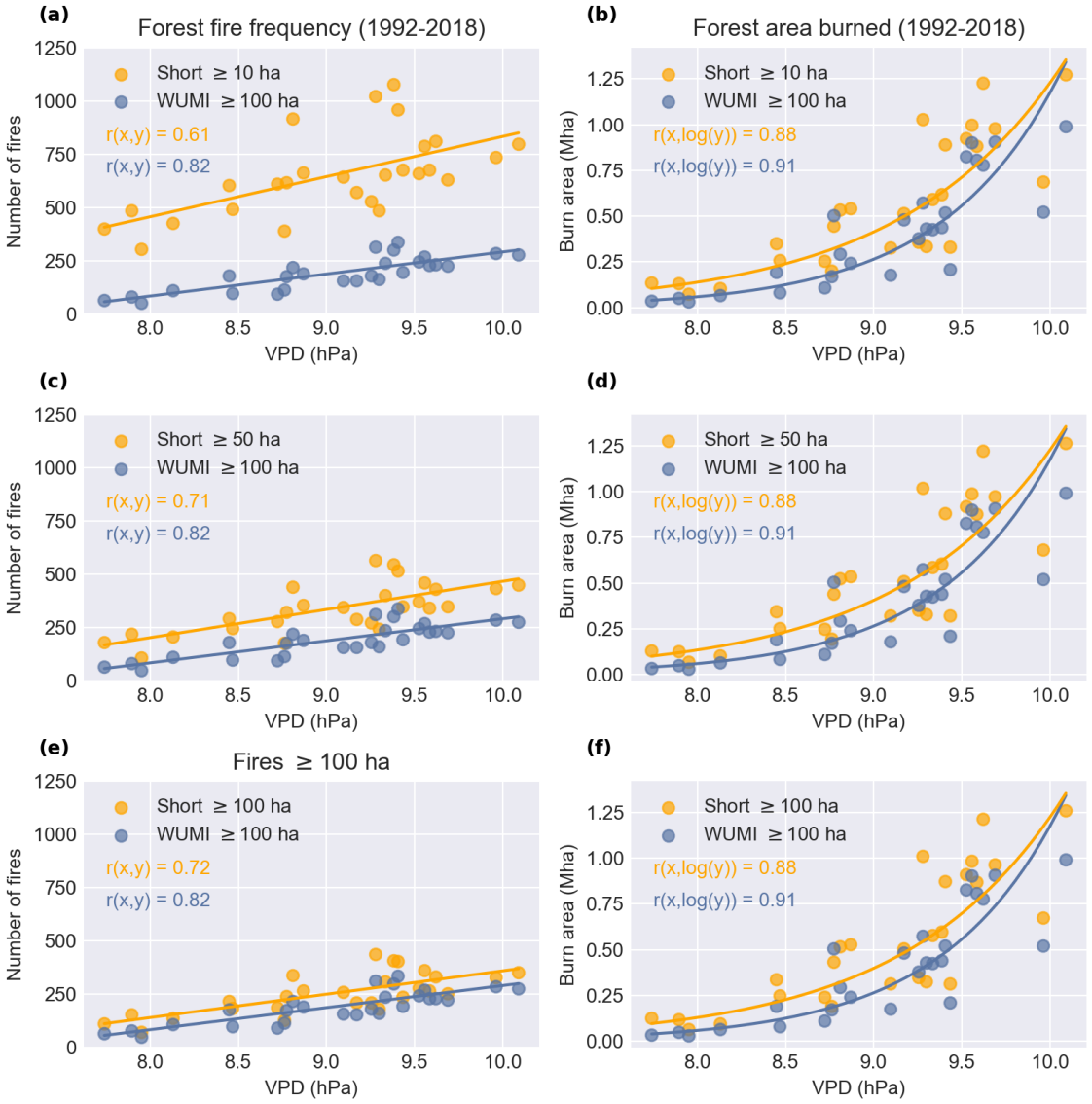

Figure S7. Database comparison using forest fire frequency and area burned versus vapor-pressure deficit (VPD) relationships, including Short (2021) forest fires ≥10 ha, ≥50 ha, and ≥100 ha (≥0.1 km^2, ≥0.5 km^2, and ≥1 km^2). The Short (2021) database of forest fires (in yellow) is compared with forest fires in the Western US MTBS-Interagency (WUMI) wildfire database (in blue) for the same period of time, 1992-2018. **Left column: (a), (c), and (e)** show fire frequency vs. VPD for WUMI fires ≥100 ha and Short (2021) fires ≥10 ha, ≥50 ha, and ≥100 ha, respectively. **Right column: (b), (d), and (f)** show forest area burned (in Mha, millions of hectares) versus VPD for WUMI and Short fires. Records of burned area appear visually identical but are different in (b), (d), and (f) because including smaller fires contributes a very tiny fraction to overall forest area burned. Least-square regression lines for number of fires and $\log_{10}$(burn area) and their *r*-values are also shown for both databases.

Table S1. Readme. A file uploaded with the WUMI database to describe the data columns.

Dataset: Western US MTBS-Interagency (WUMI) Wildfire database

Format: TXT

Last updated: 08/16/2021

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How to read this dataset:

Columns labeled "intagncy" store information from six federal government agencies: BIA, BLM, BOR, NPS, FWS, and FS; and from one state agency database: CalFire. Collectively, these are referred to as interagency databases.

Columns labeled "MTBS" store information from the Monitoring Trends in Burn Severity (MTBS) database.

Columns labeled "final" are the data used in our investigations. The final fire name, location, and size used in our main investigation were decided on by order of priority (MTBS, CalFire, and then interagency databases), and included in the WUMI fire database labeled “final”. Each row in the database is for one fire event, which contains information about the fire as listed in the interagency databases, the associated information from the MTBS database for the same fire, and the final information that was used for analysis.

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Column headers in the WUMI wildfire database:

Column Name	Type and units	Description
intagncy_agency	Text	Agency abbreviation for the database entry used
intagncy_name	Text	Fire name as listed in the interagency database(s)
intagncy_year	Numeric, 4 digits	Fire discovery date, year
intagncy_month	Numeric, 1 to 12	Fire discovery date, month
intagncy_day	Numeric, 1 to 31	Fire discovery date, day
intagncy_lon	Numeric, decimal degrees (-180 to 180 °E)	Location of the fire center provided by the agency, longitude
intagncy_lat	Numeric, decimal degrees (-90 to 90 °N)	Location of the fire center provided by the agency, latitude
intagncy_area_ha	Numeric, in hectares (ha)	Fire size
intagncy_forest_area_ha	Numeric, in ha	Forested area fire size
MTBS_name	Text	Fire name as listed in the MTBS database
MTBS_year	Numeric, 4 digits	Fire discovery date, year
MTBS_month	Numeric, 1 to 12	Fire discovery date, month
MTBS_day	Numeric, 1 to 31	Fire discovery date, day
MTBS_lon	Numeric, decimal degrees (-180 to 180 °E)	Location of the fire center from MTBS polygon, longitude
MTBS_lat	Numeric, decimal degrees (-90 to 90 °N)	Location of the fire center from MTBS polygon, latitude
MTBS_area_ha	Numeric, in ha	Fire size
MTBS_forest_area_ha	Numeric, in ha	Forested area fire size
MTBS_filename	String of letters and numbers	Unique fire ID in the MTBS database
final_year	Numeric, 4 digits	Combined WUMI database fire discovery date, year
final_month	Numeric, 1 to 12	Combined WUMI database fire discovery date, month
final_day	Numeric, 1 to 31	Combined WUMI database fire discovery date, day
final_lon	Numeric, decimal degrees (-180 to 180 °E)	Combined WUMI database location of the fire center, longitude
final_lat	Numeric, decimal degrees (-90 to 90 °N)	Combined WUMI database location of the fire center, latitude
final_area_ha	Numeric, in ha	Combined WUMI database fire size
final_forest_area_ha	Numeric, in ha	Combined WUMI database forested area fire size

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