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Fire Emissions Inventories for Regional Haze Planning: Methods and Results

PREPARED FOR:
WESTERN REGIONAL
AIR PARTNERSHIP

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1.0 INTRODUCTION

This report is a summary of the activity data sources and calculation methods used to develop fire emissions inventories prepared for the Western Regional Air Partnership (WRAP) Fire and Smoke Workgroup (FSWG)[1]. These emissions inventories (EIs) are part of WRAP's efforts to provide technical support for its members to prepare State Implementation Plan (SIP) updates for Regional Haze, due by July 31, 2021.

The fire EIs described here were provided digitally to the WRAP Regional Technical Operations Work Group (RTOWG) as text files in two distinct formats: Flat File 10 (FF10), which includes PTINV and PTDAY files by fire type for CMAQ; and comma-delimited (CSV), which includes a daily activity and emissions file, and an hourly file containing plume rise and diurnal profile parameters for CAMx.

1.1 Background – Fire EIs for the Round 1 Regional Haze SIPs

The WRAP, through the Fire Emissions Joint Forum (FEJF), provided technical assistance and developed policies to assist western states with developing Regional Haze SIPs during the period 1999–2008[2]. Wildland and agricultural fires were a key source category for the Attribution of Haze Project[3], which apportioned natural and anthropogenic pollution sources impacting Class I Areas. Other key outcomes from the FEJF included defining a policy on the contribution of fire to natural background[4], gathering and publishing information about Emission Reduction Techniques (ERTs)[5], and developing a policy for and implementing a regional fire tracking system, the FETS[6].

Key Data Elements for a Point-Based Fire EI

- Date
- Location (Latitude/Longitude)
- Size (Acres)
- Type (Wildfire, Prescribed, Ag)
- Fuel loading (Tons/acres)

To include Wildland and Agricultural fire in the source apportionment process, a point-based EI for the year 2002 was created using fire activity records provided by Federal Land Managers (FLMs) and state air quality agencies. GIS techniques were used to assign metadata to each record for calculating emissions, estimating plume height, and to assign each record as a "Natural" (NAT) or "Anthropogenic"

NAT and ANTH Assignment by Fire Type

Wildfire:	Always Natural
Agricultural Fire:	Always Anthropogenic*
Prescribed Fire:	Dependent on vegetation characteristics

*Except for Tribal ceremonial uses

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[1] https://www.wrapair2.org/FSWG.aspx

[2] https://www.wrapair.org/forums/fejf/index.html

[3] https://www.wrapair.org/forums/aoh/index.html

[4] https://www.wrapair.org/forums/fejf/documents/nbtt/NBTT.html

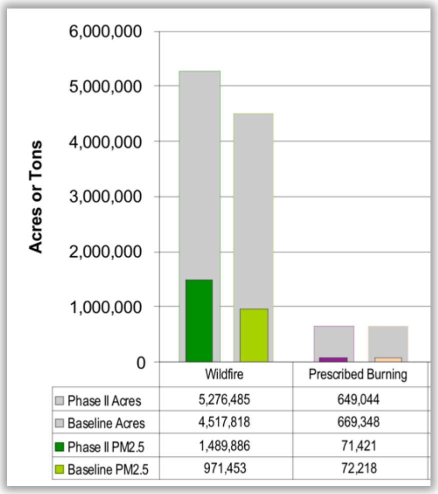
[5] https://www.wrapair.org/forums/fejf/documents/ert/index.html

[6] https://www.wrapair.org/forums/fejf/documents/fts/fts.html

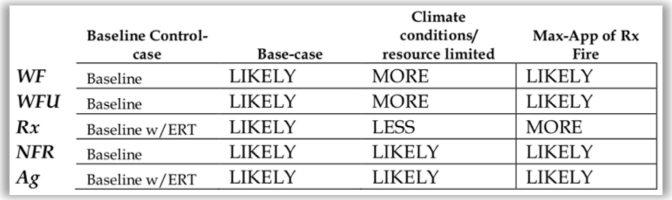
(ANTH) source. Emission factors were assigned based on information from EPA as well as refereed literature. An evaluation process included sending data summaries to key stakeholders (FLMs, state air quality staff, etc), which resulted in additional activity records being added from state and regional databases (Air Sciences 2005) and fuel loadings for large fire being adjusted in some cases.

Once a Base Year fire EI was developed for the year 2002, planning year EIs were developed to compare impacts from a Baseline Period against future conditions. These planning EIs were not year-specific, but were meant to provide emissions representative of a multi-year monitoring data period.

For each type of fire (wild, prescribed, and agricultural), WRAP developed methods to determine what level of fire activity best represented the Baseline Period with the Base Year EI used as a starting point. Because of their inherent spatial and temporal variability, wildfires from the Base Year were compared against a long-term wildfire climatology to determine if Base Year activity was exceptionally high or low (Air Sciences 2007). Prescribed and agricultural fire activity was considered more stable year-to-year, so regional experts were consulted to determine if the Base Year activity was unusual for those two types.



	Wildfire	Prescribed Burning
▨ Phase II Acres	5,276,485	649,044
▨ Baseline Acres	4,517,818	669,348
🟩 Phase II PM2.5	1,489,886	71,421
🟩 Baseline PM2.5	971,453	72,218



	Baseline Control-case	**Base-case**	**Climate conditions/ resource limited**	**Max-App of Rx Fire**
WF	Baseline	LIKELY	MORE	LIKELY
WFU	Baseline	LIKELY	MORE	LIKELY
Rx	Baseline w/ERT	LIKELY	LESS	MORE
NFR	Baseline	LIKELY	LIKELY	LIKELY
Ag	Baseline w/ERT	LIKELY	LIKELY	LIKELY

Future Year scenarios were developed by examining known policy decisions and regulations predicted to affect future activity and/or emissions, and, for each fire type, developing "LESS," "LIKELY," and "MORE" datasets that were combined in various ways to explore potential scenarios (e.g. Climate conditions and Maximum Application of Prescribed Fire). Some policy changes were "baked-in," such as the increased use of Emission Reduction Techniques (ERT) for prescribed burning, which scaled emissions downward for the same level of activity.

For datasets that were scaled up ("MORE"), virtual events were created at centroids of modeling grid squares and given the metadata attributes of the centroid coordinates. Size, timing, and grid square was determined by using averages from the size, temporal, and spatial distributions of fires in the Phase II dataset (e.g., the average acres within a size bin, or the average number of events in a given month).

1.2 Fire and Smoke Analysis for the Round 2 Regional Haze SIPs

The WRAP, in the 2018-19 Workplan[7] of April 2018 and subsequent update[8] of April 2019 and developed to support Round 2 Regional Haze planning, identified an objective to promote understanding of role of fire and smoke in regional and local air quality plans. As with Round 1 Regional Haze work on fire and smoke, the Workplan identifies that fire emissions, both natural and anthropogenic, are important pollution sources across the western U.S. and are expected to increase in both intensity and duration for a variety of reasons, including accumulated fuels, climate change, drought, and other factors. Estimating and tracking fire emissions will improve the understanding of the role of fire and smoke in NAAQS attainment and for Regional Haze planning, both now and in the future. Modeling a range of future fire emissions will help constrain future impacts from this sector.

Both natural, unplanned wildfires and long-standing practices of planned, prescribed fire are important air pollution sources in the western United States. For wildfire, the length of the fire season and the duration and intensity of individual fires are increasing due to the build-up of natural fuels after years of public policy for restricting wildfire spread and a warming climate. With a better understanding of the role of natural fire in maintaining the health of natural landscapes, public policy is evolving to balance the need for natural fires with the need for protection of human infrastructure and public health through application of prescribed fire. Additionally, climate change is resulting in altered weather patterns, shifts in the types and composition of natural landscape communities, and increased threats from biological pests on weakened and transitioning ecosystems. Periodic and sustained drought and pressure to expand human communities into the wildland-urban interface heighten the importance of understanding wildfire in the western United States. In recognition of the increasing of wildfire smoke to ambient air quality, the western states have formed cooperative tracking systems that are the technical basis for improved understanding of smoke from uncontrolled wildfires.

The WRAP Workplan established the FSWG to focus on analysis and planning activities related to improving activity data to support emissions inventories for fire and smoke emissions, begin scoping work to assess current and future year contributions of natural sources such as fire, undertake evaluation of Smoke Management Programs, survey and compile information about Exceptional Events demonstrations, review the treatment of fire and smoke emissions in modeling studies, and improve coordination between state, tribal, and federal agencies. Several of these activities involved close coordination with other WRAP Work Groups. FSWG activities equally supported Round 2 Regional Haze planning and associated regional analysis technical support for Exceptional Events demonstrations and NAAQS SIPs and TIPs.

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[7] https://www.wrapair2.org/pdf/2018-2019 WRAP Workplan - Board approved April_4_2018.pdf

[8] https://www.wrapair2.org/pdf/2018-2019 WRAP Workplan update Board Approved April.3.2019.pdf

1.3 Evolution of Methods and Data Sources

Fire activity data sources and emissions calculation methods have evolved considerably since the 2002 fire EI was developed. Beginning with 2008 and every three years since, the Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) has produced a daily, event-based fire EI as part of the triennial National Emissions Inventory (NEI), known as the NFEI. Due to time and resource constraints, the EIs described in this report rely on the 2014 NFEI as a starting point. However, modifications were necessary to overcome some limitations of the NFEI stemming from automated processing and inferences made to the activity data sources' metadata.

The other major difference in methods compared to the Round 1 regional haze fire EIs is the development of the Baseline Period and Future Year Scenarios. The Round 1 methods relied on the 2002 Base Year daily fire activity as a source of "seed data." These seed fires were then duplicated or excluded from the fire datasets used to calculate emissions according to state-specific five-year averages of total acres burned. These methods were extended to the Future Scenarios. There were two primary limitations to this approach, including[9]:

- For states with fire activity in 2002 *below* the 5-year average, activity records were duplicated to make up the difference, in effect artificially doubling the size of some fires. This effect is further exacerbated in areas with increased fire activity in a Future Year scenario.
- By looking at state averages, the variation due to differing fire regimes was obscured.

Section 3 describes an alternative approach to creating the Baseline Period EI that sought to overcome (or at least mitigate) these limitations.

1.4 Project Partners and Contributors

Many people made this work possible. Contributors included:

- Members of the Fire and Smoke Work Group
- Members of the Representative Baseline and Future Fire Scenario subcommittee
- Sara Strachan, Idaho DEQ, FSWG co-chair
- Josh Hall, USDA Forest Service, FSWG co-chair
- Paul Corrigan, USDA Forest Service, FSWG co-chair
- Robert Kotchenruther, EPA Region 10, FSWG co-chair
- Mark Fitch, National Park Service
- Tom Moore, WESTAR/WRAP
- State and tribal air quality agency staff that provided QC review of the draft EIs
- Smoke management program staff that provided QC review of the draft EIs

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[9] Despite being a limitation from an inter-annual wildfire activity perspective, keeping spatial and temporal patterns consistent between baseline and future EIs is a necessary feature for regional have modeling.

2.0 THE 2014 BASE YEAR FIRE EI

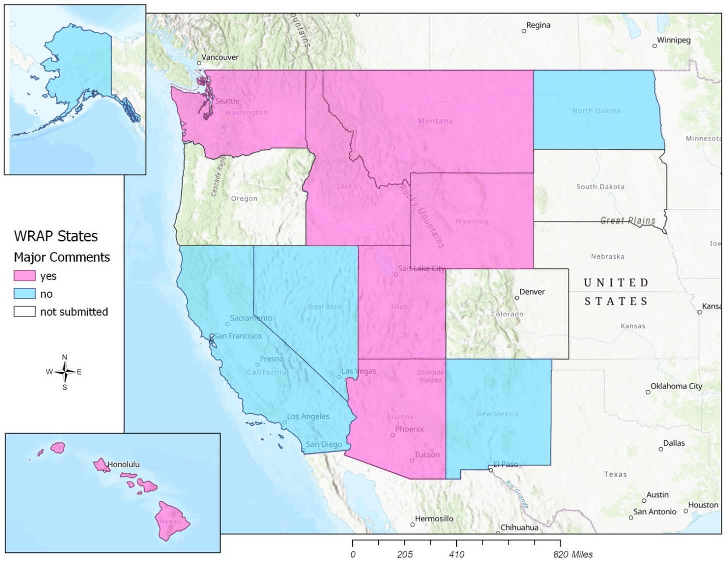
Development of the 2014 Base Year fire EI began with EPA's 2014 Wildland Fire EI, version 2[10]. To provide WRAP region stakeholders the opportunity to review and comment on the data prior to using it for the Base Year, a review tool[11] was developed that allowed the data to be grouped and summarized in a variety of ways. An email request (included in Appendix A) was distributed to the primary state regional haze contacts on 9/4/2018 with a deadline to respond by 10/17/18.

Figure 1 below shows the states that responded with feedback. Table 1 summarizes the major issues reported; these issues informed the alterations made to the EI. In addition to the issues listed below, the data for Georgia[12] and Washington required additional post-processing since those states submitted their own data.

Table 1. Summary of Issues with 2014 NFEI Reported by WRAP Members

Issue	S/L/Ts Affected
1. Urban Land Use Class Fuel Loading and Fire Type	All
2. Agricultural fires submitted by SMPs not included	All (ID, NPT, CA)
3. Timing/Magnitude issues with Rx burning; general concern with satellite-derived fires	MT, ID, AZ, UT, WY

Figure 1. Comments received from WRAP region states regarding the 2014 NFEIv2 dataset



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[10] ftp://newftp.epa.gov/air/nei/2014/doc/2014v2_supportingdata/wild_and_prescribed_fires/. Accessed August 23, 2018.

[11] http://fire.airsci.com/fire_eval_2014

[12] Georgia is outside the WRAP region, but it was necessary to post-process this dataset to create a complete EI for the model domain.

2.1 Alterations to the 2014 NFEI v2 Dataset

A primary source of activity data used to develop the 2014 NFEI was NOAA's Hazard Mapping System (HMS), which collates fire events algorithmically detected by multiple thermal imaging remote sensing platforms, performs manual quality control with a team of analysts, and publishes the results as a spatial layer every 4 hours of every day. This data source is extremely useful for,

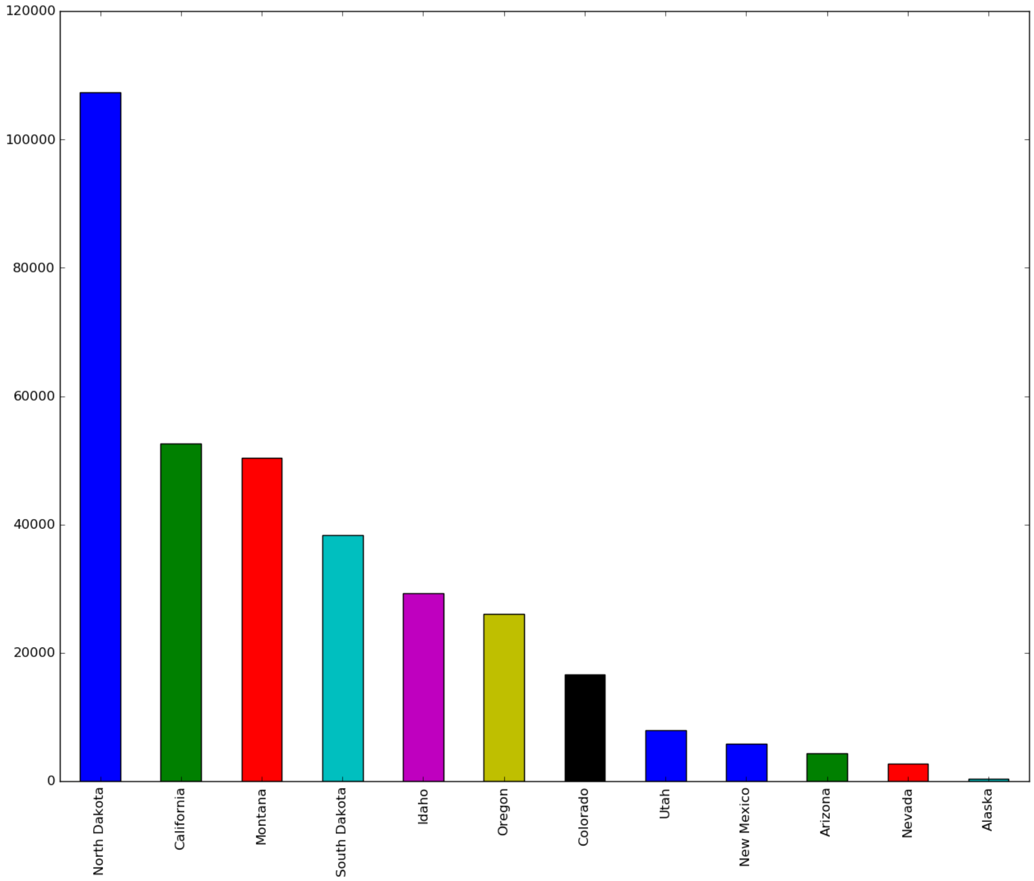
- Detecting fires in areas with poor reporting or without a smoke management program
- Quantifying daily acres burned for large, multi-day fires
- Filling in data gaps in areas with smoke management programs due to regulatory or jurisdictional limits

Unfortunately, beyond knowing the time and place that a fire did occur, nothing else is known about each event (in the case of isolated, single detects, even size is not known). The NFEI methodology tries to infer the characteristics of these events based on land use, geography, and input from air agency staff from the states in which they occur, or by reconciling them with nearby reported information. For the fire events that relied solely on the HMS, we refer to them as "HMS-only."

One of the issues immediately apparent when reviewing the 2014 NFEI dataset was the large number of HMS-only fires—totaling 350,000 acres—classified with an "Urban" land use-land cover (LULC) (Figure 2). The LULC layer used in the 2014 NFEI was the Fuel Characteristics Classification System (FCCS), which defines Urban as, "barren, developed, or agricultural land." This ultimately revealed two issues: 1) Urban-classified fires were given generic fuels characteristics not reflective of the surrounding area, and 2) were overwhelmingly classified as prescribed burns. These burns ended up being the source of issues 1 and 3 in Table 1. Concerns expressed by states about the timing of prescribed burns turned out to be from this subset of HMS-only, Urban-classified prescribed burns.

In addition to the "misclassified" fire events described above, other records had incomplete or missing metadata. The two primary goals, then, for re-processing the 2014 NFEI prior to formatting as model-ready files, were to repair the misclassified burns and ensure all records had complete and correct metadata.

Figure 2. Acres of "Urban" fires by state, 2014 NFEI



2.1.1 Processing misclassified fire events

A step-wise approach was developed to re-assess the HMS-only, Urban-classified prescribed fires. The general approach was to find proximate burns in space and time, find a single "best match" event for each misclassified fire, and replace the fuels, emissions, and burn type with those of the matched event. The detailed steps are outlined in Table 2.

Table 2. Steps to reclassify HMS-only Urban-classified fire events

Step	Notes
Isolate events where *sources* = "HMS_2014_noag_3", *fccs_number*= "0, and *scc* in ("2811015001"," 2811015002")	
Find the five closest burns within +/- two weeks of target	Loosened to +/- 30 days if no events returned
Eliminate burns nearby in time >25 km away	In rare cases, buffer was increased to up to 50km in areas of sparse activity
Determine dominant fire type (AG, RX, or WF) and best match	Prefer agricultural burns Prefer time over distance
Assign SCC, fuel loading of match to target	New column, *transform_id*, to track burn *eventid* matched to target
Recalculate heat flux and emissions based on assigned fuel loading	

Values in italics are column names from the 2014 NFEI dataset.

2.1.2 Processing steps to ensure consistent metadata

Certain metadata fields were missing from agricultural events, and from events in Georgia and Washington. For some fields, values were easily calculated but others required inference and calculating average values from similar data. These steps are outlined in Table 3.

Table 3. Steps to reclassify HMS-only Urban-classified fire events

Step	Purpose
Overlay GA and WA data with FCCS layer	FCCS codes were needed for next step
Calculate consumption, heat release, and emissions for missing pollutants in GA and WA files	Calculate average consumption and emission factors by FCCS code for neighboring states and apply to events. Ensure EC + OC emissions <= PM2.5
Assign dummy FCCS codes and eventids to Ag data	Required for FF10 file format
Calculate additional pollutants for Ag dataset	Not all pollutants were calculated for ag data. Used emission factors from the FETS database (Air Sciences 2005)
Calculate fuel loading for Ag dataset	Needed to calculate heat release. Calculated by multiplying pre-burn fuel loading and combustion completeness
Calculate heat release for Ag dataset	Multiply fuel loading, acres, and heat content of wood (8000 BTU/ton)
Back-calculate emission factors for all events	Divide by acres and fuel loading. Used for diagnostic purposes.

3.0 THE BASELINE PERIOD FIRE EMISSIONS INVENTORY

The Western Regional Air Partnership (WRAP) Fire and Smoke Work Group formed a technical working group to examine methods used to incorporate fire into the regional haze modeling process[13]. A primary goal was to evaluate and develop methods for building a representative single-year fire EI to be used for planning purposes, based on the "typical" activity observed during the Baseline Period (2014–2018). These methods are described in this section.

3.1 Wildfire activity data

Wildfire activity across the United States can vary greatly from year to year across three primary degrees of freedom: space, time, and magnitude. Therefore, building a single-year, composite EI dataset that captures "average" wildfire activity over the multi-year Baseline Period is difficult: assessing average total acres burned across the domain is straightforward, but not so for the timing, location, and size of the constituent events.

Previous research has demonstrated (Malamud et al. 1998; Malamud et al. 2005) that wildfire activity in the United States (and perhaps more generally) obeys the phenomenon of self-organized criticality (SOC)[14]. Malamud, et al. (2005) expressed the frequency of fires of a given area as

$$\boldsymbol{f(A_F) = \alpha A_F^{-\beta}} \tag{1}$$

with frequency density $f(A_F)$, the number of wildfires with A_F area burned, and α and β as constants. Interestingly, this relationship holds over many spatial scales, but the resulting constants will change. Malamud, et al (2005) developed solutions for the constants for each Bailey ecoregion division (Bailey 1976) in the United States using a 30-year wildfire dataset (1970–2000) *for Forest Service lands only*. The resulting derived curves showed unique patterns of burning across the ecoregions, capturing the variability of different fire regimes.

The relationship shown in Equation 1 was used as the basis for developing the Representative Baseline (RB) wildfire EI, which is in effect a "virtual year," and included the follow steps:

1. Create a source of seed data, i.e., simulated fire events
2. Sample seed data to create a set of wildfire events for the RB virtual year
3. Determine the start day-of-year, and duration of each simulated fire event
4. Assign a unique location, as latitude-longitude coordinates, to each simulated fire event
5. Calculate daily emissions for each simulated event

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[13] https://www.wrapair2.org/RBFFSWG.aspx

[14] https://en.wikipedia.org/wiki/Self-organized_criticality

3.1.1 Create a source of seed data

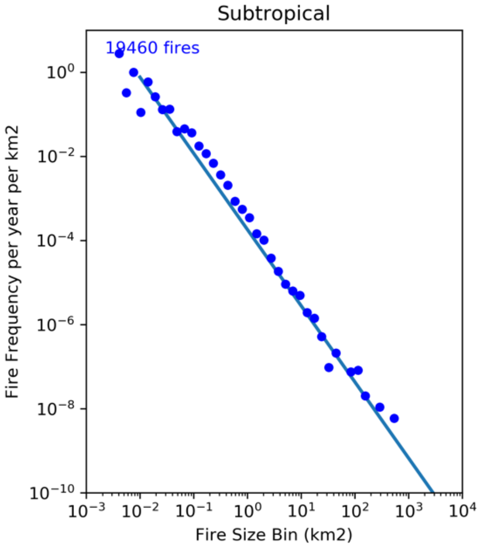

Figure 3. Example area-frequency plot comparing FSRDA data (dots) to the derived curve from Malamud et al. (2005).

A more recent dataset compiled by the Forest Service, the Forest Service Research Data Archive (FSRDA)[15], covers the period 1992–2015, includes events on all federal lands as well as some state-reported events, and was evaluated for duplicates and other errors. We evaluated this dataset against the equations derived in Malamud, et al. (2005) by extracting events on Forest Service lands and plotting the data against the derived curves (Figure 3). We found excellent agreement between the derived curves and the FSRDA data *for all ecoregion divisions*, which was somewhat surprising given the apparent recent increases in fire activity across the United States. We derived new curves based on the full FSRDA dataset to capture non-Forest Service lands. See Appendix B for more detail.

Using newly derived frequency curves based on the FSRDA dataset for each ecoregion division allows for the variability across fire regimes to be captured in simulated data sets used to determine a Baseline Period EI. The next step was to transform the derived frequency curves into empirical probability distributions for each ecoregion division. Using these probability distributions, it is possible to generate a population of fire events representing a simulated, hypothetical year, where the number of fires, distribution of fire sizes, fire-start months, and burn durations are all randomly determined within bounds and according to distributions derived from the historical data. The specific method and order of determination for each fire characteristic are outlined below.

Note that each time a population of baseline year fire events is generated for an ecoregion, the exact distributions of component fire characteristics will be different. For example, one dataset may contain a 600,000-acre fire among the others, making up a large percentage of the total area (based on the upper limit) for that ecoregion. However, on average, if multiple simulated data sets are generated, these extreme cases will appear much less frequently than more common cases. In other words, for each simulated year, the resulting dataset is one possible fire population outcome. This will produce results which tend to generally reflect historical observations while still allowing for the possibility of statistical anomalies (i.e. mega-fires). By generating multiple simulated "years" for each ecoregion, the variability and extremes in reasonable potential fire event populations for each ecoregion can be explored.

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[15] Short, Karen C. 2017. Spatial wildfire occurrence data for the United States, 1992-2015 [FPA_FOD_20170508]. 4th Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.4

3.1.2 Sample seed data to build RB virtual year dataset

3.1.2.1 Determine the number of fires that occur in a simulated year

The first step in building a single, simulated fire year is to determine an appropriate total number of events to simulate. For each ecoregion, an empirical probability distribution for number of fires in a year was developed from the FSRDA dataset. For a given annual simulation, the number of fires to be included by ecoregion (i.e., the number of times to sample the frequency-area curves) in a simulation run was determined via a single random selection from each distribution.

3.1.2.2 Sample frequency-area curves to create a simulated annual activity dataset

Using the selected number of fires by ecoregion determined in 3.1.2.1, randomly sample the empirical probability distributions described in 3.1.1. This results in an annual fire activity dataset with two columns, acres and ecoregion division.

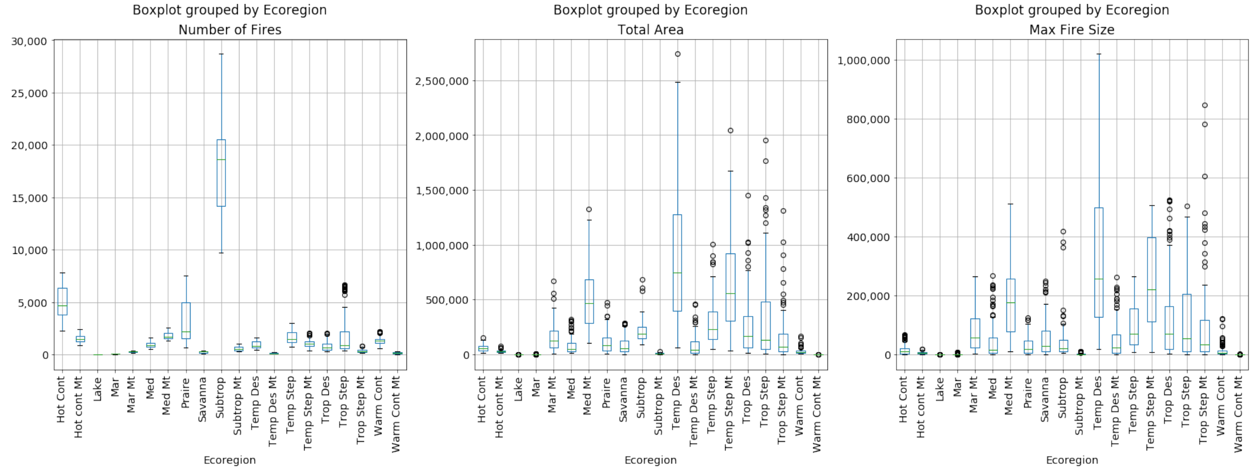
3.1.2.3 Build a population of simulated annual activity datasets

Repeat the steps in 3.1.2.1 and 3.1.2.2 100 times to build a population of simulated annual fire activity datasets. The result of this is a database table with the following columns:

- **run_id**. Foreign key tied to a table that records settings such as random seed used, distribution bin sizes, date of run, etc).
- **simulation_id**. Unique identifier within the run_id. All fire events with the same simulation_id make up a single virtual year. Values from 1–100.
- **event_id**. Unique identifier for fire events within a given simulation_id.
- **area_burned**. Total size of the fire event.
- **size_class**. Federal fire size class. Values from A–G.
- **division**. Ecoregion division where the fire occurred.

Figure 4 shows distributions of the simulation results by ecoregion from three perspectives: number of fires, total annual area burned, and maximum fire size. A single annual fire activity was then selected for each ecoregion to build the final RB virtual year. To do this, the 5-year annual average acres burned by ecoregion for the period 2012-2015 was calculated from the FSRDA dataset, and the simulation with total acres burned that most closely matched that value for each ecoregion was selected. This resulted in a set of simulation_id-division pairs that were carried forward for subsequent calculations to build a daily fire EI for the RB.

Figure 4. Boxplots of annual fire activity simulation population characteristics



3.1.3 Determine the start day and duration of each fire event

The set of fire events queried from the simulation_id-division pairs identified in 3.1.2.3 for the RB fire EI need a start date and duration in order to calculate daily emissions. Two sets of probability distributions were constructed from the FSRDA to do this: counts of fire starts in each month for each ecoregion and fire size class, and counts of fires by duration in days for each ecoregion, fire size class, and month.

The sampling is performed in sequence in order to utilize an appropriate probability distributions dependent on previously determined characteristics. At each level, the probability distribution sampled is based off an increasingly specific subset of the historical data, to ensure that simulated characteristics are consistent with past observations (see Figure 5). A fire event is first assigned a total burn area (and associated size class) based on the ecoregion fire size distribution. Then a start month is assigned based on ecoregion and size class. Finally, a burn duration is assigned based on ecoregion, size class, and start month.

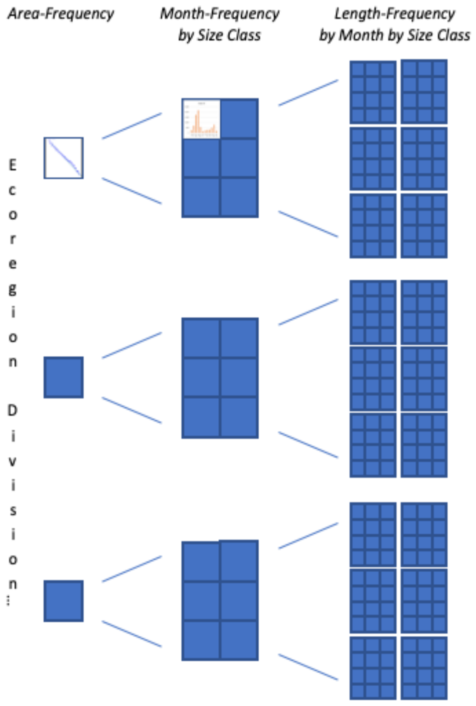


Figure 5. Diagram of the distributions used, by ecoregion, to derive fire event attributes. At each step, values derived at the previous step inform the selection.

3.1.3.1 Fire duration missing data and outlier analysis

The burn duration for each fire in the historical data is calculated from the fire's recorded start date and end date. However, the fire end dates in the historical record can be unreliable compared to other records. Bad fire end date data falls primarily into two categories, each addressed in a different way:

1. Missing data: For many fires, an end date is simply not recorded, making it impossible to determine a fire duration based on start and end dates. In these cases, the event with a missing end date was assigned an estimated fire duration equal to the average duration observed for events of the same fire size class and the same start month.

2. Inaccurate data: Especially for smaller fires, some fire records appear to be "closed out" and assigned an arbitrary end date well past what would be a reasonably expected burn duration for the fire size. For these cases, the calculated fire duration is inaccurately large. These outlying duration data points were identified using a median absolute deviation (MAD) test on the (log-transformed) duration data for each region, fire size class, and month. Fire durations with a modified z-score greater than 3.5 were classified as anomalous and not utilized to develop duration probability curves.

3.1.4 Assign a unique location to each fire event

Events derived from Steps 1–4 have a highly generalized location attribute, the ecoregion division. The frequency-area distributions are intended to build a "most likely" composite of when and how much burning occurs within their respective ecoregions, but the fires must be distributed across the landscape to provide a reasonable representation of activity. However, the ecoregions themselves are contiguous areas covering the whole of North America and do not discriminate where fires are able or unable to burn within those areas.

To obtain locations, one could sample actual coordinates of fires from the FSRDA dataset to ensure that the derived fire events fall within burnable areas. However, historical fire locations are a poor predictor of where burns will occur in the future. The 140 million acres burned in the 24-year period covered by FSRDA represent less than 1% of the estimated total burnable area in the Contiguous United States[16], so it would seem more likely that future burns will occur in new locations. This is important to consider for building future fire scenarios, which shares the same methods as the Baseline Period EI. Therefore, we chose a Monte Carlo method to randomly distribute derived burns within their respective ecoregions rather than rely on historical burn coordinates.

For the Monte Carlo approach the Fuel Characteristics Classification System (FCCS) 30m fuel grid was used as a starting point to isolate burnable areas within each ecoregion. "Non-

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[16] Estimated by adding up the total area of FCCS 30m grid cells with a non-zero fuel loading, about 1.6 billion acres.

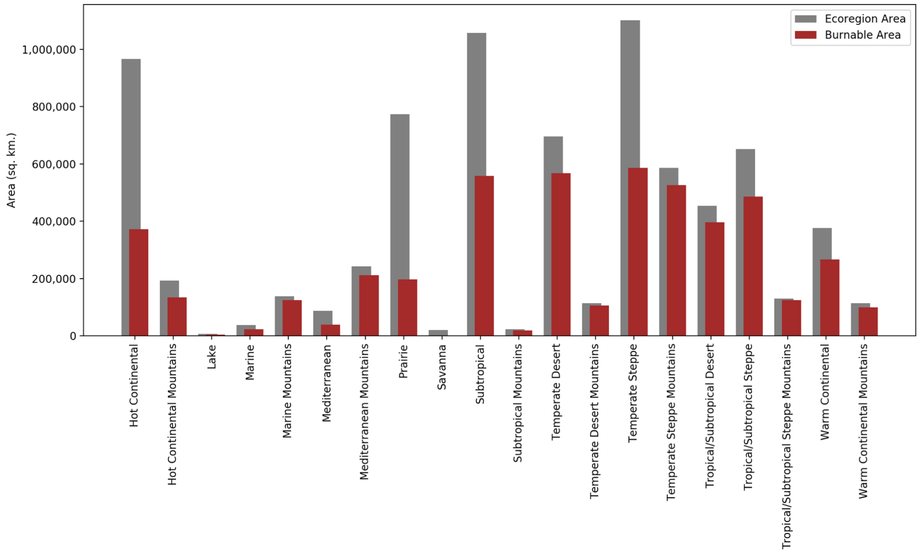
burnable area" grid cells were defined for the grid with the following ruleset that incorporated additional national datasets:

- Reclassify as 0 (non-fuel area) all FCCS pixels that overlap National Hydrographic Dataset vector polygons classified as lake, pond, marsh, swamp, river, or canal
- Reclassify as 0 all FCCS pixels that overlap state and federal highways (vector polyline layer)
- Reclassify as 0 all FCCS pixel that overlap the 2014-2018 Cultivated Land grid from the National Agricultural Statistics Service (NASS)
- Exclude FCCS pixel values < 1 and > 799[17]

Figure 5 shows the total area of each ecoregion division (gray) and the calculated burnable area (red) by summing reclassified FCCS grid cells with value between 1 and 800 (see Appendix B for an ecoregion map key). To assign a location for each burn, the following steps were executed for each fire event:

- Determine ecoregion division of event
- Use Monte Carlo technique to generate a random X-Y coordinate within ecoregion polygon extent.
  - If coordinate falls outside ecoregion polygon, start over.
  - Calculate a buffer around point based on total fire size.
  - If < 75% of the pixels are "burnable," start over
- After 5,000 failed attempts to assign coordinates, reduce the minimum burnable area threshold by 5%

Figure 6. Derived burnable area by ecoregion.



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[17] Pixels classified as 0 in the original FCCS layer include anything without a defined fuelbed, such as developed land, agricultural land, or barren land. Values ≥ 800 include water, snow/ice, etc.

3.2 Prescribed and agricultural fire activity

Prescribed and agricultural fire activity was carried forward from the 2014 Base Year dataset as-is. After consultation with the FSWG and various stakeholders, it was concluded that the inter-annual variations in activity for these two sources was not large enough to warrant exploring alterations. In contrast to wildfires, prescribed and agricultural burns are planned and lit intentionally and vary according to annual weather patterns (i.e. opportunities to burn), policy and available resources. Therefore, the approach to developing the wildfire dataset is not applicable. In addition, consistent, multi-year activity data for these fire types are not readily available, making it resource-intensive to make refinements to the 2014 dataset without introducing many assumptions.

3.3 Calculate daily emissions for each fire event

The process to calculate emissions for the Baseline Period EI is outlined in Figure 7. Starting with the final dataset from 3.1.4 (shown in the white box at far left in Figure 7), additional attributes were added using spatial overlays (for FCCS fuelbed information) and database lookup tables (for fuel loading, biomass type, emission factors, and consumption completeness). Emissions were calculated using the basic equation:

$$\boldsymbol{E}[\boldsymbol{tons}] = \boldsymbol{area}[\boldsymbol{acres}] \times \boldsymbol{loading}\left[\frac{\boldsymbol{tons}}{\boldsymbol{acre}}\right] \times \boldsymbol{EF}\left[\frac{\boldsymbol{g}}{\boldsymbol{kg}}\right] \times \mathbf{0.001}\left[\frac{\boldsymbol{kg}}{\boldsymbol{g}}\right] \times \boldsymbol{CC}[\boldsymbol{unitless}] \qquad (2)$$

For each event, fuel loading was derived by calculating an area buffer equal to the size of the event and overlaying the FCCS grid. Non-zero fuelbed values were grouped and summed to create an array of fractional acres by fuel type. Fractional emissions were calculated for each area fraction-fuelbed and summed to calculate total emissions. Note that if non-fuel grid cells were present inside the buffer, emissions were not calculated for that fraction of the area.

The 2014 Base Year EI utilized emission factors from the Fire Emission Production Simulator (FEPS) software, which has only one value per pollutant per combustion phase, relying on a consumption algorithm (Consume 4) to characterize emissions for different fuelbeds and fire types. Since our approach does not include a consumption algorithm, and to better capture the variation in emissions per pollutant for different fuel types, we opted instead to use the recently compiled emission factors from the Fire INventory from NCAR (FINN)[18] version 2.2 (McDonald-Buller et al. 2019), which are fully documented and compatible with using biomass type to map emission factors for different fire types (Table 4). Agricultural fire emissions were calculated using emission factors reported with the 2014 NFEI, with supplemented emission factors for elemental carbon (EC) and organic carbon (OC) from previous WRAP work (Air Sciences 2005).

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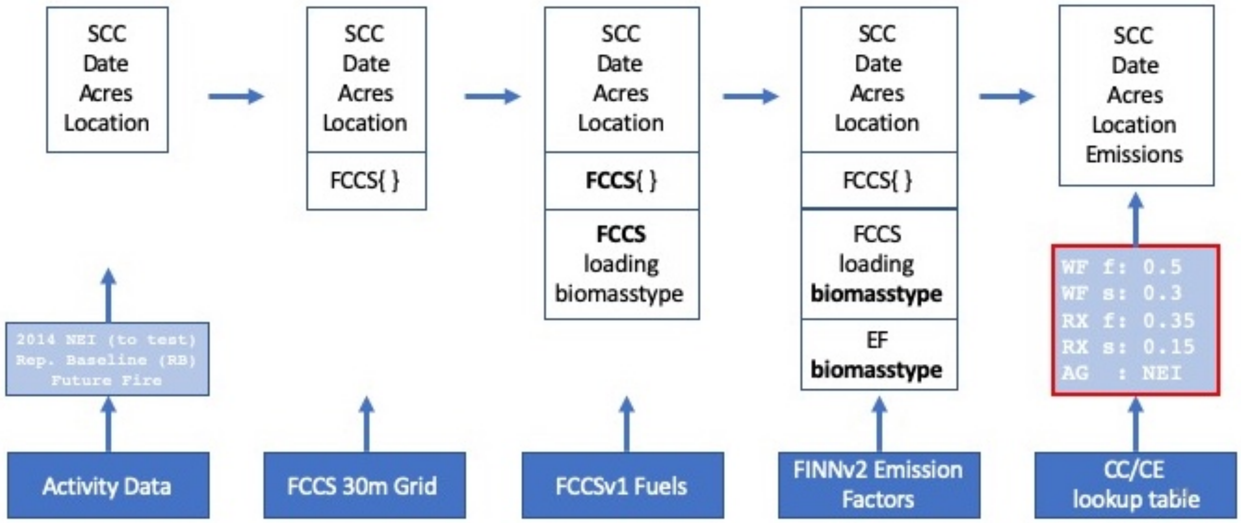
[18] We pulled in the EFs directly from the FINN open-source codebase located here: https://github.com/mbjoseph/finnemit. Accessed on August 7, 2019.

Figure 7. Baseline Period Fire EI calculation steps.



CC/CE lookup table fractions "f" for flaming, "s" for smoldering

Table 4. Emission Factors from FINN version 2.2, g/kg

Biomass Type	CO_2	CO	CH_4	NMOC	NO_x as NO	SO_2	$PM_{2.5}$	OC	BC	NH_3	NO	NO_2	PM_{10}
Boreal Forest	1565	111	6	48.5	0.95	1	18.4	7.8	0.2	1.8	0.83	0.63	18.4
Tropical Forest	1643	93	5.1	51.9	2.6	0.4	9.9	4.7	0.52	1.3	0.9	3.6	18.5
Temperate Forest	1510	122	5.61	56	1.04	1.1	15	7.6	0.56	2.47	0.95	2.34	16.97
Chaparral	1681	67	3	24.8	3.645	0.68	7.1	3.7	1.31	1.2	0.77	2.58	11.4
Savanna	1686	63	2	28.2	3.9	0.9	7.17	2.6	0.37	0.56	2.16	3.22	7.2
Crop Residue	1444	91	5.82	51.4	2.43	0.4	6.43	2.66	0.51	2.12	1.18	2.99	7.02
Extratropical Forest	1623	112	3.4	49.3	1.96	1.1	17.9	7.6	0.56	1.17	0.95	2.34	18.4
Pasture Maintenance	1444	91	5.82	51.4	2.43	0.4	6.43	2.66	0.51	2.12	1.18	2.99	7.02

4.0 THE FUTURE YEAR FIRE SCENARIOS

The Western Regional Air Partnership (WRAP) Fire and Smoke Work Group formed a technical working group to examine wildland fire emissions based on predictions of future conditions, both from a land management and climate change perspective, to inform regional haze modeling examining Reasonable Rate of Progress (RRP) for SIP updates. For this modeling exercise, the year 2028 was chosen to estimate the RRP toward regional haze goals. Two Future Fire Scenarios (FFS) were chosen based on discussions within the working group, summarized in Table 5. Each scenario scaled *acres burned* at the individual event level for one fire type. Methods of scaling differed for wildfire and prescribed fire; agricultural fires were left unchanged in both scenarios. Other aspects of future conditions, such as fuel loading or average consumptions, were not considered.

Table 5. Summary of FFS and changes by fire type

Fire Type	Scenario 1: Future Wildfire	Scenario 2: Future Rx
Wildfire	Scaled from modeled future biomass burning	Unchanged from RB
Prescribed	Unchanged from RB	Scaled based on expert input
Agricultural	Unchanged from RB	Unchanged from RB

4.1 Future Scenario 1: Climate Forced Wildfire Activity

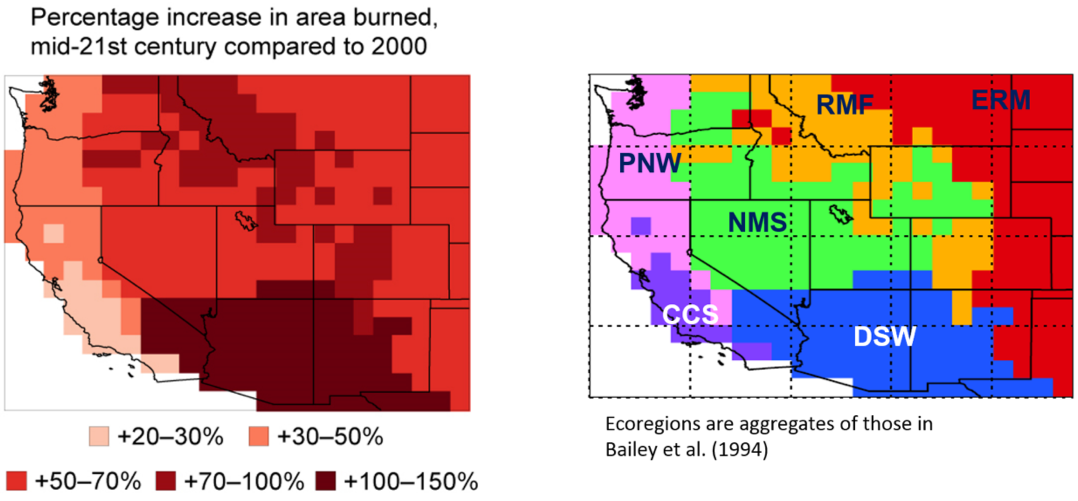
Scenario 1 developed scaled wildfire emissions for 2028 using the same set of simulation populations (Figure 4) described in Section 3.0. Recall that the simulation chosen for each ecoregion for the Representative Baseline was based on the most recent 5-year average acres burned from the FSRDA. To select simulations for 2028, those 5-year averages were scaled based on predictions made in Yue, et al. (2013), which outlined increases in biomass burning for the western United States for aggregated Bailey ecoregions (Figure 8) based on mid-century ensemble climate model outcomes. Table 6 summarizes the percent increases by aggregated ecoregion for c. 2050 scaled to 2028 using a linear interpolation with 2012 as a baseline as shown in Equations 3, 4, and 5.

$$scalar_{2028} = \left((m \times (2028 - 2012) + b) - 1\right) * 100 \tag{3}$$

$$b = \left(1 - \frac{scalar_{2050}}{100 \times 38}\right) * \frac{38}{37} \tag{4}$$

$$m = 1 - b \tag{5}$$

Figure 8. Predicted percent increases in biomass burning c. 2050 (left) in aggregated ecoregions (right). From Yue et al. (2013)



Ecoregions are aggregates of those in Bailey et al. (1994)

Table 6. Aggregated ecoregions and percent increase in burning in 2050 scaled to 2028

Ecocode	Description	Scalars (%) 2050	Scalars (%) 2028	Linear Interpolation Slope	Linear Interpolation Offset
DSW	Desert Southwest	125	51	0.034	0.966
RMF	Rocky Mountains Forest	85	34	0.023	0.977
ERM	Eastern Rocky Mountains/Great Plains	60	24	0.016	0.984
NMS	Nevada Mountains/Semi-desert	60	24	0.016	0.984
CCS	California Coastal Shrub	25	10	0.007	0.993
PNW	Pacific Northwest	40	16	0.011	0.989

Table 7. Aggregated ecoregions mapped to Bailey ecoregion divisions

Bailey Ecoregion Division	Ecocode
Marine	PNW
Marine Mountains	PNW
Mediterranean	CCS
Mediterranean Mountains	CCS
Temperate Desert	NMS
Temperate Desert Mountains	NMS
Temperate Steppe	ERM
Temperate Steppe Mountains	RMF
Tropical/Subtropical Desert	DSW
Tropical/Subtropical Steppe	DSW
Tropical/Subtropical Steppe Mountains	DSW

Solutions for *m* (slope) and *b* (offset) are shown in Table 6. The aggregated ecoregions were mapped back to the Bailey ecoregions such that each division was only associated with one ecocode (Table 7; see Appendix B for ecoregion maps). New simulations were selected that most closely matched the scaled 5-year average for each ecoregion multiplied by the 2028 scalars (for ecoregions outside of the domain in Figure 8, the same simulations from the RB were used).

The modeling analyses performed to help determine RRP for SIP updates will compare impacts for a fixed set of dates and locations in order to estimate the effect that changes in emissions have on aerosol concentrations. Therefore, members of the FSWG and the EPA expressed the desire for the wildfire events in the FFS to have the same spatial and temporal characteristics as events in the RB. Therefore, to build a final daily EI for FFS Scenario 1, instead of following the methods outlined in Sections 3.1.3 and 3.1.4, the new simulation-based events were instead given the metadata (start date, duration, and location) of matched RB simulation events. This was done by rank-ordering the simulation data for each ecoregion division by total fire size and matching ranks between the FFS and RB events. If the FFS simulation had more events than the RB simulation for a given ecoregion division, the "extra" events were dropped from the dataset. If the FFS simulation had fewer events than the RB, all FFS events were matched and any additional RB events were dropped. Table 8 illustrates the rank-ordering for the ten largest fires of an example ecoregion division. Green columns are the data that were carried forward to build the final EI.

Table 8. Example of mapping temporal metadata from RB simulation data to the FFS

FFS Fire Size km^2	RB Fire Size km^2	RB Start Day of Year	RB Duration Days	FFS fire_id Unique ID	RB fire_id Unique ID
452.88	603.19	143	25	1040	830
282.79	404.69	68	6	6097	1500
231.48	290.34	172	5	665	118
227.33	282.36	111	3	1136	3455
211.93	109.60	85	5	4767	2222
148.80	89.82	46	1	3165	1007
138.26	83.84	114	2	1494	3598
132.23	59.61	149	8	476	591
71.59	41.69	84	5	2367	1373
57.54	38.25	193	9	249	2889

4.2 Future Scenario 2: Management-Driven Prescribed Fire Activity

The working group engaged regional and national land managers from the four federal agencies that engage in the majority of prescribed burning on federal lands to obtain "most likely" estimates of changes in activity over the next decade. The results of these discussions are summarized in Table 9. To develop the EI for this scenario, the location of each prescribed fire event in the RB dataset was overlaid on a federal lands map. Events falling on federal land were then overlaid on either the ecoregion division map (BLM, FWS, NPS) or the Forest Service Administrative Regions map to extract a scalar to adjust the acres for that event. Emissions were then recalculated using the new acres value. All other aspects of the RB dataset were left intact. Note that for all agencies other than the Forest Service, only western regions were scaled.

Table 9. Percent increases in prescribed fire acres by federal agency and geographic area.

Agency	Ecocode or USFS Region	Scalar (%)	Geographic Description
BLM	CCS	0	Central CA
	DSW	0	So. CA, AZ, NM
	ERM	0	Great Plains
	NMS	0	Arid regions of NV, OR, ID, WY
	PNW	0	OR and WA Cascades
	RMF	0	Rocky Mountains
FWS	CCS	0	
	DSW	0	
	ERM	50	
	NMS	50	
	PNW	0	
	RMF	0	
NPS	CCS	100	
	DSW	100	
	ERM	5	
	NMS	0	
	PNW	75	
	RMF	100	
USFS	01	75	MT, ND, No. ID
	02	170	SD, WY, CO
	03	60	AZ, NM
	04	300	So. ID, NV, UT
	05	90	CA
	06	85	OR, WA
	08	15	SE US
	09	60	NE US

5.0 RESULTS AND DISCUSSION

5.1 2014 Base Year fire EI results

Detailed activity and emissions calculations methodology and results for the 2014 NFEI have been reported elsewhere (EPA 2018). Processing the dataset for the 2014 Base Year consisted of metadata clean-up and the reclassification of certain satellite-detected fire events (see 2.1). Figure 9 shows the result of the reclassifications, by fire type. In the WRAP region, the only significant change in $PM_{2.5}$ emissions was a 30% drop in North Dakota due to a large proportion of the fires there being reclassified from prescribed to agricultural, which generally have lower fuel loadings.

Figure 9. $PM_{2.5}$ emissions by fire type before and after reclassifying HMS-only "urban" fires

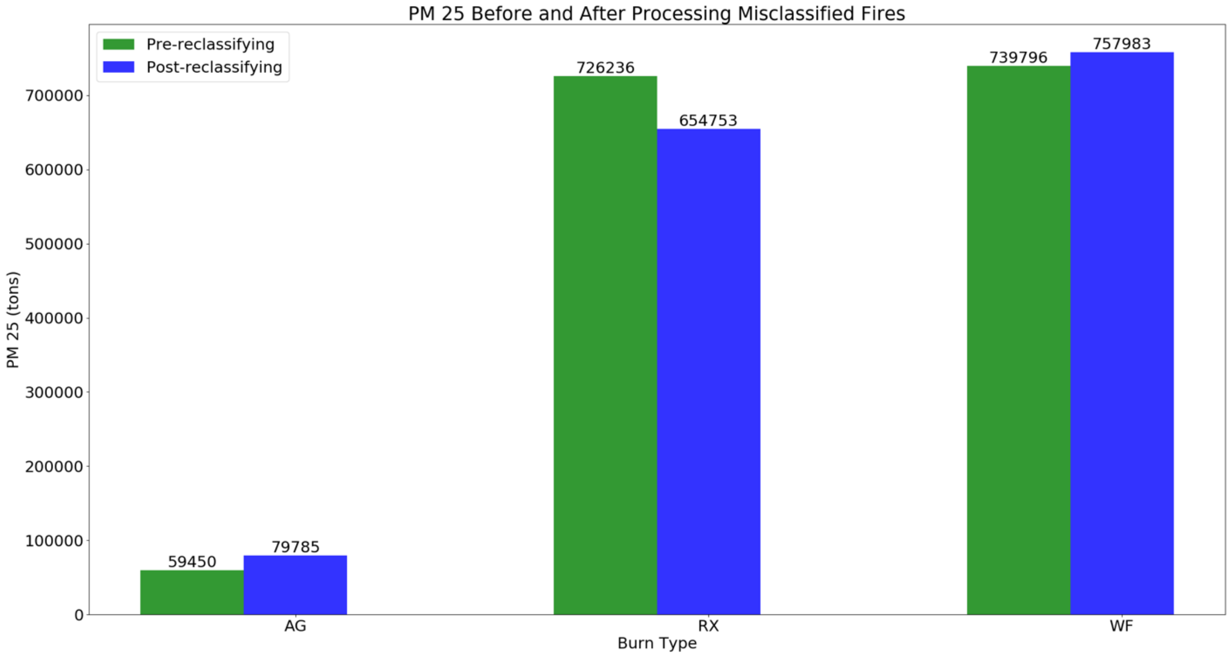


Table 10. 2014 Base Year fire EI activity and $PM_{2.5}$ emissions by WRAP region state for all fire types

	Wildfire				Prescribed Burning				Agricultural Burning			
State	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$
AZ	3,362	354,706	2,621,451	26,388	609	142,645	638,313	7,427	153	12,480	20,300	192
CA	6,887	636,867	21,660,269	272,512	1,004	135,257	1,950,028	23,271	2,327	279,010	488,014	3,951
CO	3,455	36,014	93,704	901	374	48,732	433,731	5,181	229	21,590	42,148	355
ID	2,612	234,067	3,059,453	35,340	1,827	138,061	1,616,842	19,863	963	114,619	189,045	1,754
MT	1,071	38,104	511,160	6,895	1,481	161,093	1,714,531	22,352	1,336	172,756	282,052	2,701
NV	461	89,835	789,821	8,649	94	15,670	63,168	774	31	1,420	2,296	24
NM	802	74,933	722,479	8,265	258	88,247	306,877	3,410	126	10,080	16,270	184
ND	61	2,830	33,953	365	215	39,248	371,386	4,540	3,703	266,604	486,921	3,538
OR	3,831	1,059,531	9,031,676	106,301	2,524	302,044	3,261,628	41,813	903	108,452	177,084	1,855
SD	750	18,127	208,315	2,375	395	64,668	1,035,733	12,691	879	62,610	132,124	984
UT	1,257	51,250	296,725	3,064	224	71,512	368,401	3,990	98	5,060	8,731	83
WA	2,477	513,889	5,957,096	104,950	1,275	123,157	1,559,674	14,176	1,018	122,160	204,828	1,818
WY	554	16,286	123,491	1,500	283	43,306	409,202	5,212	159	14,270	24,216	261
Total	27,580	3,126,438	45,109,592	577,505	10,563	1,373,641	13,729,515	164,700	11,925	1,191,111	2,074,029	17,699

5.2 Representative Baseline fire EI results

Daily fire emissions were calculated across the continental United States (CONUS) using simulated wildfire events (see 3.1) and prescribed and agricultural events from the 2014 Base Year EI (see 3.2). The simulated wildfires totaled 6.3 million acres, of which 4.5 million were inside CONUS WRAP region states. A summary of activity and $PM_{2.5}$ emissions for CONUS WRAP region states is shown in Table 11. There are differences between agricultural activity and emissions compared to the 2014 Base Year due to additional QC checks that removed 11 events totaling 1,000 acres.

There are significant differences in prescribed burning emissions due to aligning the emissions calculations for the RB with the methods for the simulated wildfires, described in 3.3. The RB emissions calculation pathway is insensitive to additional fuels information such as moisture, recent precipitation events, and site characteristics that are available in Consume 4, the consumption model used by EPA for the 2014 NFEI (EPA 2018). Despite the more resolved approach of calculating fractional emissions by fuelbed and excluding non-fuel areas, emissions were overall much higher, possibly due to the assumption of 50% fuel consumption (see Figure 7) for every prescribed fire.

Figure 10 and Figure 11 show monthly totals of simulated wildfire acres burned and $PM_{2.5}$ emissions normalized by area for the RB EI compared to the 2014 Base Year. These plots show the magnitude and seasonality of activity for the RB EI while revealing deviations from 2014 data. Overall, the patterns of simulated wildfire activity appear reasonable, with distinct peaks in the summer months. Normalized $PM_{2.5}$ emissions show a distinct positive bias in the shoulder seasons in some states when compared to 2014, likely due to the insensitivity to fuel moisture[19]. Other, sporadic differences are likely due to differing fuelbeds burning between the two years.

Additional summary comparison plots are shown in Appendix C. These focus on spatial patterns of activity and emissions for the 2014 Base Year and RB. There are distinct differences in spatial patterns between the two inventories, for several reasons:

- Large wildfires in the 2014 EI have unique locations each day, enabled by satellite detection, whereas the RB EI places wildfires at one point regardless of size
- The distribution of fires in the RB is only limited by masking layers that identify where burns cannot go, but does not weight likelihood of ignition beyond that.
- In some states, such as Arizona, distinct clustering patterns emerge due to additional reported datasets from, for example, state transportation departments.
- The RB EI has more events overall, especially very small events.

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[19] Note that Figure 11 represents the ratio of emissions:acres burned. Months with very few events (e.g., winter in Idaho) may not register in Figure 10 but still produce a result in Figure 11.

Table 11. Representative Baseline fire EI activity and $PM_{2.5}$ emissions by WRAP region state for all fire types

	Wildfire				Prescribed Burning				Agricultural Burning			
State	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$
AZ	2,810	219,779	554,371	7,238	595	141,195	907,285	13,533	145	11,740	19,140	180
CA	7,004	822,112	30,274,941	450,970	993	130,965	2,197,780	32,518	2,330	279,270	486,747	4,195
CO	2,103	209,106	6,014,389	89,965	374	48,732	475,867	7,070	230	21,650	39,888	355
ID	2,082	331,911	2,977,946	42,601	1,824	137,990	1,905,385	28,367	945	112,459	187,003	1,716
MT	3,443	345,932	3,368,691	43,866	1,481	161,093	1,837,448	25,822	1,336	172,756	284,142	2,701
NV	1,540	268,607	643,098	7,437	95	16,270	72,430	1,013	30	1,380	2,243	23
NM	4,418	543,192	893,910	9,760	258	88,247	511,013	7,530	125	10,000	16,148	183
ND	377	8,007	90,876	774	214	39,193	197,939	2,013	3,703	266,604	475,674	3,540
OR	2,583	558,944	10,731,358	157,441	2,525	302,136	4,218,348	61,808	912	109,552	178,802	1,876
SD	891	321,681	4,649,179	49,242	394	64,568	1,062,962	15,449	876	62,390	121,443	980
UT	1,382	295,023	1,257,384	17,174	224	71,512	486,573	7,116	98	5,060	8,590	83
WA	1,566	184,553	9,378,215	140,516	1,278	123,228	1,540,525	22,864	1,025	122,980	206,488	1,828
WY	2,478	367,253	1,098,031	10,982	283	43,306	421,667	6,021	159	14,270	23,827	261
Total	32,677	4,476,101	71,932,389	1,027,966	10,538	1,368,436	15,835,221	231,125	11,914	1,190,111	2,050,136	17,924

Figure 10. Wildfire acres burned by month between 2014 Base Year (red) and RB (green).

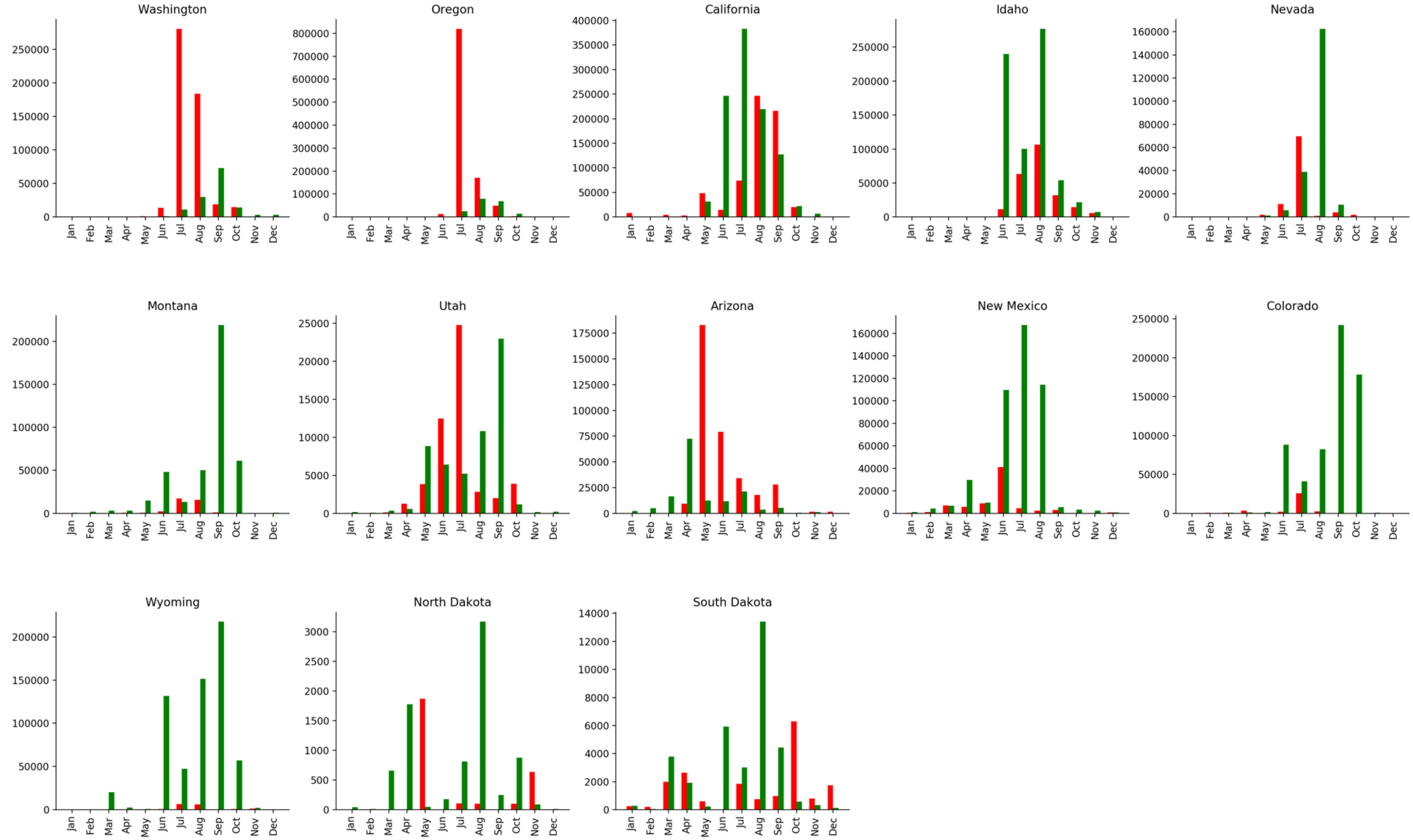
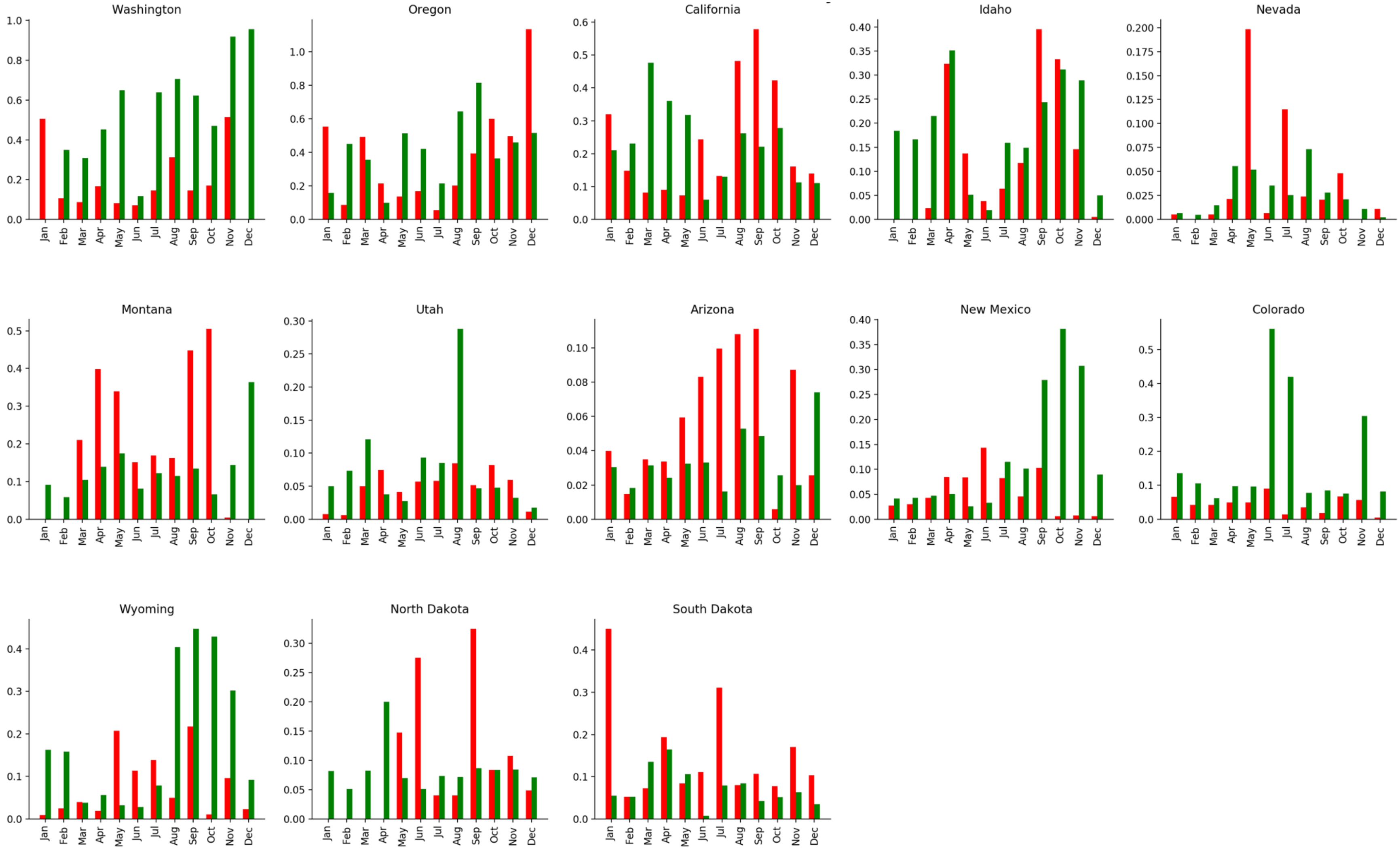


Figure 11. Wildfire $PM_{2.5}$ emissions normalized by area between 2014 Base Year (red) and RB (green).



5.3 Future Fire Scenarios Results

Daily fire emissions for two future scenarios were calculated across the continental United States (CONUS) using simulated wildfire events (see 3.1 and 4.1), scaled prescribed fire events, and agricultural events from the Representative Baseline (RB) EI (see 3.2 and 4.2). The simulated wildfires were scaled only in the western US, roughly coinciding with the CONUS WRAP region. A summary of wildfire and prescribed fire activity and $PM_{2.5}$ emissions for CONUS WRAP region states is shown in Table 12 compared to the RB EI (agricultural fires were unchanged).

5.3.1 Future Wildfire Results

Wildfire activity in the CONUS WRAP region increased by 1.2 million acres between the RB and FFS 1. However, the changes were highly variable within each state and the differences in emissions were also much smaller than may be expected, but there are reasons for these differences. The process of rank-ordering fires between the RB and FFS wildfire simulation datasets occurred at the ecoregion level, and therefore a state with a 50,000-acre fire in the RB EI may have matched to a 20,000-acre fire in the FFS if there were fewer large fires in the FFS dataset. In addition, because the size of a fire at a given location may have changed dramatically between the two EI's, the distribution of fuels consumed also changes. In Idaho, for example, despite a 6% increase in total acres, emissions *fell* by 59% because on average the largest fires mapped to locations with lower fuel loadings (sagebrush scrub versus conifer forest).

Another interesting feature of the wildfire FFS was a systematic (albeit variable) decrease in the number of events (-12.5% overall) despite the increase in acres, but again this is to be expected, since the maximum number of burns possible for each ecoregion is the value from the RB, so only the ecoregions with fewer burns reveal any variation. This is best illustrated in Table 13, which summarizes the difference in wildfire activity between FFS1 and the RB by ecoregion instead of state: for a given ecoregion, the count of events is always FFS1 ≤ RB.

Taking a closer look at Table 13, the percent difference in acres by ecoregion is always positive, which is what we would expect since the scaling was done by ecoregion. Variations still exist since, contrary to the method of scaling prescribed burning acres, the nearest *simulation* is selected which is unlikely to exactly match the RB simulation multiplied by its 2028 scalar. An interesting consequence of this is how the simulation distribution by total acres burned for each ecoregion (the middle boxplot in Figure 4) leads to larger departures from the "target" in some cases. For example, the 5-year average for Tropical/Subtropical Desert ("Trop Des" in Figure 4) was already approaching the 75th percentile for the RB, so an additional 50% increase in acres pushed the total acres into a small group of outliers, with the simulation nearest the scaled value being 70% higher than the RB. Despite these variations, however, when comparing the weighted average 2028 scalar (based on acres burned in the RB) to the actual percent increase in acres burned between the RB and FFS across all ecoregions, it is within 4% (27% actual vs 31% weighted-average scalar).

5.3.2 Future Prescribed Fire Results

The changes in prescribed fire activity and emissions, on the other hand, were much more straightforward: because each individual event was simply scaled based on its location, acres burned and emissions increased by a similar amount overall. There were still interesting results, however. Utah, for example, saw by far the biggest jump in activity because of prescribed fire activity concentrated on Forest Service and National Park Service lands. The one fewer fire in the FFS dataset was likely filtered out due to acreage scaling that tipped its dominant biomass type to "peatland," for which there were no emission factors and resulted in a handful of small fires being dropped from the final dataset.

Table 12. FFS 1 and 2 for scaled fire types. Colored values are percent differences from the RB EI.

	Wildfire (Scenario 1)					Prescribed Burning (Scenario 2)				
State	Events	Acres		Tons $PM_{2.5}$		Events	Acres		Tons $PM_{2.5}$	
Arizona	2,461	278,146	27%	7,168	-1%	595	185,102	31%	18,491	37%
California	6,502	1,058,201	29%	434,630	-4%	993	184,688	41%	48,672	50%
Colorado	1,816	88,746	-58%	19,970	-78%	374	88,032	81%	14,674	108%
Idaho	1,908	350,939	6%	17,495	-59%	1,824	268,469	95%	53,594	89%
Montana	3,016	585,817	69%	75,799	73%	1,480	201,931	25%	35,679	38%
Nevada	1,233	221,413	-18%	9,169	23%	95	22,369	37%	1,872	85%
New Mexico	3,298	914,977	68%	11,131	14%	258	113,215	28%	11,039	47%
North Dakota	317	7,582	-5%	784	1%	214	47,591	21%	2,375	18%
Oregon	2,453	822,417	47%	239,672	52%	2,525	378,621	25%	77,827	26%
South Dakota	740	292,610	-9%	43,847	-11%	394	112,840	75%	33,795	119%
Utah	1,194	478,045	62%	24,057	40%	224	220,746	209%	22,939	222%
Washington	1,500	243,934	32%	192,062	37%	1,278	147,728	20%	28,087	23%
Wyoming	2,187	347,097	-5%	10,175	-7%	283	70,749	63%	12,624	110%
Total	28,625	5,689,923	27%	1,085,959	6%	10,537	2,042,079	49%	361,670	56%

Table 13. Comparison of wildfire activity and emissions between FFS1 and RB by ecoregion division

Ecoregion Division	2028 Scalar	Percent Difference		Future Fire Scenario 1			Representative Baseline		
		Acres	Tons	Events	Acres	Tons Fuel Consumed	Events	Acres	Tons Fuel Consumed
Marine	16%	9%	13%	275	460	25,485	275	423	22,464
Marine Mountains	16%	20%	22%	2,095	303,053	17,094,042	2,095	252,882	14,040,600
Mediterranean	10%	2%	-4%	1,614	27,645	549,136	1,614	27,053	572,008
Mediterranean Mountains	10%	9%	-12%	5,221	663,976	20,920,142	5,760	611,097	23,905,698
Temperate Desert	24%	24%	31%	3,132	1,567,661	11,661,524	3,641	1,264,480	8,883,257
Temperate Desert Mountains	24%	27%	12%	505	67,629	434,530	734	53,152	389,533
Temperate Steppe	24%	11%	-2%	4,105	669,914	6,363,261	5,076	602,236	6,469,697
Temperate Steppe Mountains	34%	32%	8%	6,555	1,285,448	17,625,810	7,135	973,558	16,332,192
Tropical/Subtropical Desert	51%	70%	38%	664	727,770	1,126,364	664	427,460	817,819
Tropical/Subtropical Steppe	51%	29%	43%	8,085	846,312	2,460,166	8,085	657,510	1,718,223
Tropical/Subtropical Steppe Mountains	51%	38%	-36%	1,548	457,205	403,001	3,018	331,598	627,325
Totals	31%[a]	27%[b]	7%[c]	33,799	6,617,072	78,663,461	38,097	5,201,448	73,778,816

[a] Average scalar weighted by RB acres burned

[b] Percent difference based on total acres burned

[c] Percent difference based on total tons consumed

6.0 DELIVERABLES

The workflow to build each fire EI consists of a series of Python functions that source and export data to a PostgreSQL database hosted by Amazon Web Services (AWS). The database contains base geographic layers such as ecoregions, political boundaries, and Weather Information Management System (WIMS) station locations; fire activity datasets including the FSRDA, Monitoring Trends in Burn Severity (MTBS), and 2014 NFEI; and lookup tables for emissions calculations such as emission factors, fuel loadings, consumption completeness scalars, and plume height parameters. In addition, the database stores settings used to "tune" the EI building process—consumption and activity scalars, area-frequency curve constants, random number generator seeds—so that each scenario is repeatable[20]. Plots, maps, and charts are generated at each major step of the Python code to provide visual QA/QC tools. Final daily datasets are stored in the database and were delivered as PTINV, and PTDAY files in Flat File 10 (FF10) format, as well as CSV files with hourly plume characteristics. Table 14 summarizes the emissions inventory files delivered to the modeling group, including date of delivery.

---

[20] Keeping the random seed consistent means that the outcomes of the simulations are the same each time the code is run. However, locations of fires change each time the Monte Carlo process is run.

Table 14. List of deliverables and delivery dates

Inventory	File Names	File Format	Date Delivered
2014 Base Year	Agricultural PTINV & PTDAY	FF10	January 19, 2019
	Prescribed flaming PTINV & PTDAY	FF10	
	Prescribed smoldering PTINV & PTDAY	FF10	
	Wildfire flaming PTINV & PTDAY	FF10	
	Wildfire smoldering PTINV & PTDAY	FF10	
	Agricultural daily and hourly	CAMx-ready CSV	
	Prescribed flaming daily and hourly	CAMx-ready CSV	
	Prescribed smoldering daily and hourly	CAMx-ready CSV	
	Wildfire flaming daily and hourly	CAMx-ready CSV	
	Wildfire smoldering daily and hourly	CAMx-ready CSV	
Representative Baseline	Agricultural PTINV & PTDAY	FF10	November 22, 2019
	Prescribed flaming PTINV & PTDAY	FF10	
	Prescribed smoldering PTINV & PTDAY	FF10	
	Wildfire flaming PTINV & PTDAY	FF10	
	Wildfire smoldering PTINV & PTDAY	FF10	
	Agricultural daily and hourly	CAMx-ready CSV	
	Prescribed flaming daily and hourly	CAMx-ready CSV	
	Prescribed smoldering daily and hourly	CAMx-ready CSV	
	Wildfire flaming daily and hourly	CAMx-ready CSV	
	Wildfire smoldering daily and hourly	CAMx-ready CSV	
Future Fire Scenario 1	Agricultural PTINV & PTDAY	FF10	February 28, 2020
	Prescribed flaming PTINV & PTDAY	FF10	
	Prescribed smoldering PTINV & PTDAY	FF10	
	Wildfire flaming PTINV & PTDAY	FF10	
	Wildfire smoldering PTINV & PTDAY	FF10	
	Agricultural daily and hourly	CAMx-ready CSV	
	Prescribed flaming daily and hourly	CAMx-ready CSV	
	Prescribed smoldering daily and hourly	CAMx-ready CSV	
	Wildfire flaming daily and hourly	CAMx-ready CSV	
	Wildfire smoldering daily and hourly	CAMx-ready CSV	
Future Fire Scenario 2	Agricultural PTINV & PTDAY	FF10	February 28, 2020
	Prescribed flaming PTINV & PTDAY	FF10	
	Prescribed smoldering PTINV & PTDAY	FF10	
	Wildfire flaming PTINV & PTDAY	FF10	
	Wildfire smoldering PTINV & PTDAY	FF10	
	Agricultural daily and hourly	CAMx-ready CSV	
	Prescribed flaming daily and hourly	CAMx-ready CSV	
	Prescribed smoldering daily and hourly	CAMx-ready CSV	
	Wildfire flaming daily and hourly	CAMx-ready CSV	
	Wildfire smoldering daily and hourly	CAMx-ready CSV	

7.0 REFERENCES

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Appendix A – 2014 NFEI Data Review Request

The 2014 National Fire Emissions Inventory, version 2 (NFEIv2), was downloaded from the EPA website and compiled into a single dataset. An interactive plotting tool was created to summarize the dataset in various ways. The intention is to show, down to the level of States, Tribes, or counties, the characteristics of NFEIv2 regarding total acres, emissions, temporal variations, the breakdown of wildfire, prescribed, and agricultural burning, and the data sources used to build the inventory. In addition, a meta-data field required for regional haze modeling was added and may be reviewed. Below are instructions for navigating the tools and some initial questions to consider to begin evaluating the NFEIv2 results.

Evaluation Tool Instructions

Access the tool here: http://fire.airsci.com/fire_eval_2014

To update the plot,

1. Start with the top row, choosing either States or Tribes. You may choose one or more State/Tribe to compare, and one or more counties. Counties overlapping Tribal lands are provided as an optional organizational tool.
2. Set the X and Y axes, and, if desired, an optional Additional Comparison for each X axis category. Not all combinations are available depending on the X and Y axis chosen.
3. You may download the data visible in the plot by clicking the "Download CSV" button. You may also save the plot graphic by clicking the grey floppy-disk icon to the right of the plot.
4. If the plot stops responding, simply reload the page and start over. It's a good idea to reload the page if you leave it idle for more than a few minutes.

Questions to Consider

1. Natural vs. Anthropogenic Classifications[21]
    a. Compare Natural vs. Anthropogenic by Month, Location and Size Class for your State/Tribe[22]. Are the data consistent with what you'd expect in terms of location, timing, magnitude, and distribution of acres burned? Please document any concerns.
    b. Compare Natural vs. Anthropogenic by FCCS. Are the data consistent with what you'd expect in terms of fuel consumed and emissions magnitude? Are any fuel types represented that should not be or that are significantly over estimated (ignore any that are less 1,000 acres). Please document any concerns.

2. Compare Data Sources against acres by Fire Type for your State/Tribe. Refer to the attached Data Source dictionary.

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[21] NAT/ANTH was assigned by mapping FCCS codes listed in Table 2 here. Remaining events classified by overlaying VCC: Ia–IIa assigned NAT; IIb+ assigned ANTH

[22] Tribal fire associations were done by EPA for WF and RX. Agricultural burns were overlaid with a Tribal Lands layer from the National Map buffered to 1km to account for spatial errors in satellite detection.

c. Are the data sources used for your State/Tribe consistent with what was submitted?
d. Are the data sources used for your State/Tribe representative of available datasets?
e. Compare data source HMS_2014_no_3 (with no other sources) acres by fire type against other, reconciled data sources (e.g., HMS_2014_no_3 combined with additional sources). Are the HMS-only acres redundant with reported events, or do they seem to account for additional, unreported burns in your area? Keep in mind that HMS cannot detect a burn smaller than ~20 acres.
Example: Oregon →All Counties →Data Source →Acres →Wildfire vs. Prescribed vs. Agricultural. There are 209,000 acres of HMS-only prescribed fire acres. Is this reasonable, especially considering that pile burns were removed from reported datasets? Almost half the acres come from SE Oregon where there is a significant amount of unreported rangeland burning.

3. In general, as you explore the data please identify any concerns that may affect the emissions, in terms of timing, magnitude, or location.

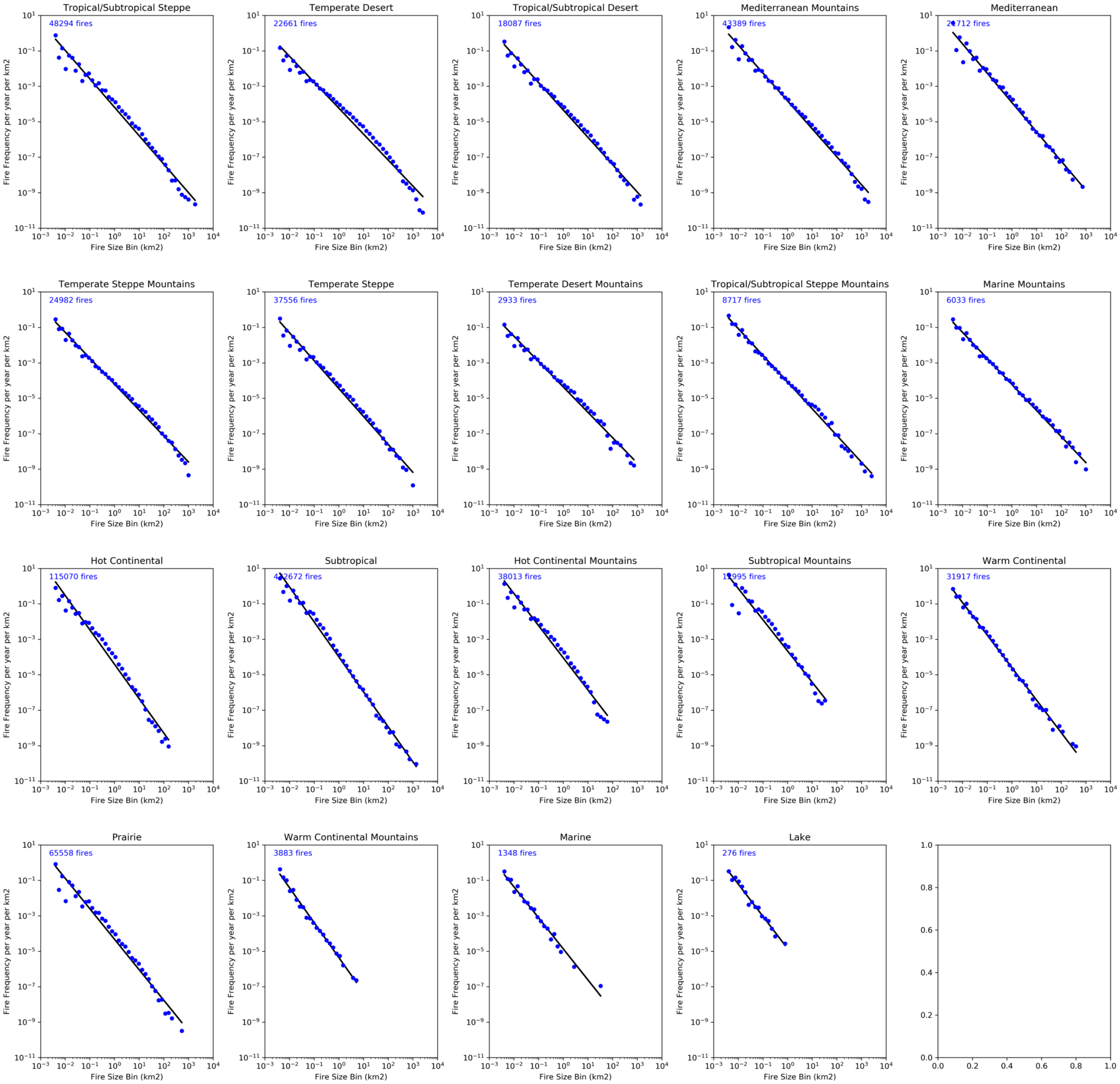
Data Sources Dictionary

The date sources listed below are usually represented in various combinations. This is due to the reconciliation process in SMARTFIRE2 that combines and reconciles multiple data sources to attempt to extract the maximum amount of information about each fire.

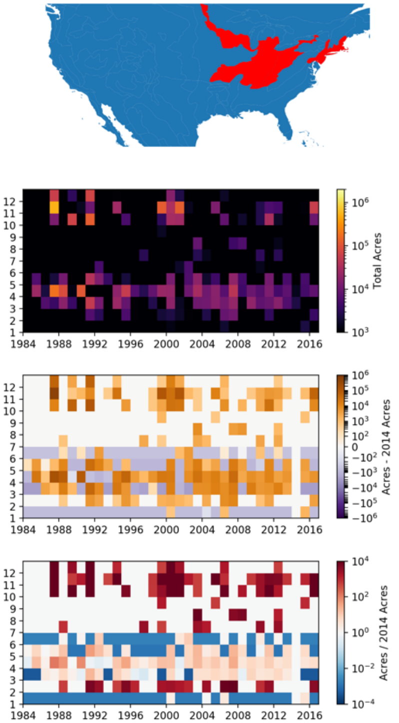
- **AVHRR; GOES-EAST; GOES-WEST; MODIS**. These are for agricultural data only, and represent the individual satellite platforms that were used to build the 2014 National Agricultural Emissions Inventory.
- **FETS2014_v2; State2014_SupplementAll_correct; wa_state_data.** As a result of the data collected and assessed, fire activity data from 22 states and one Indian Nation (32 individual data sets and FETS data) were included in the 2014 NEI. *ALL PILE BURNS WERE REMOVED FROM THESE DATASETS.*
- **HMS_2014_noag_3**. Hazard Mapping System (HMS) data published by the National Oceanic and Atmospheric Administration (NOAA)were acquired and agricultural fires were removed. See Section 4.11 on agricultural fires for more a description as to what was done and why.
- **ICS_2014_normal; ICS_2014_simple_correct**. Incident Status Summary (ICS-209) Reports in application (.exe) format were acquired via the National Fire and Aviation Management Web Applications website. Upon execution, the application file created a Microsoft Access database containing the fire activity data. Data from two tables in the database were merged and used: the SIT209_HISTORY_INCIDENT_209_REPORTS table contained daily 209 data records for large fires, and the SIT209_HISTORY_INCIDENTS table contained summary data for additional smaller fires.
- **FWS_2014_correct**. U.S. Fish and Wildlife Service (USFWS) fire information data were provided by the USFWS.
- **NASF_2014_2_nonj.** National Association of State Foresters (NASF) fire information data were downloaded from the National Fire and Aviation Management Web Applications website. Only wildfire data were included.
- **FACTS_2014.** Forest Service Activity Tracking System (FACTS) fire information data were supplied by the USFS. Only fuel treatment data were included.
- **GeoMAC_2014_3.** Geospatial Multi-Agency Coordination (GeoMAC) fire perimeter data were downloaded via the USGS GeoMAC wildland fire support website.
- **NFPORS_2014_correct**. U.S. Department of the Interior (DOI) prescribed fire data were extracted from the National Fire Plan Operations and Reporting System (NFPORS) and supplied by the USFS. This is a new data source that was not used in previous efforts. See [ref 1] for more details.

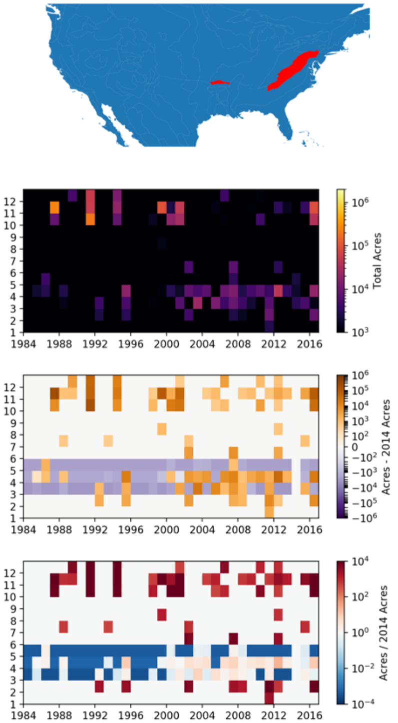
Appendix B – Representative Baseline Seed Data Derivation Plots

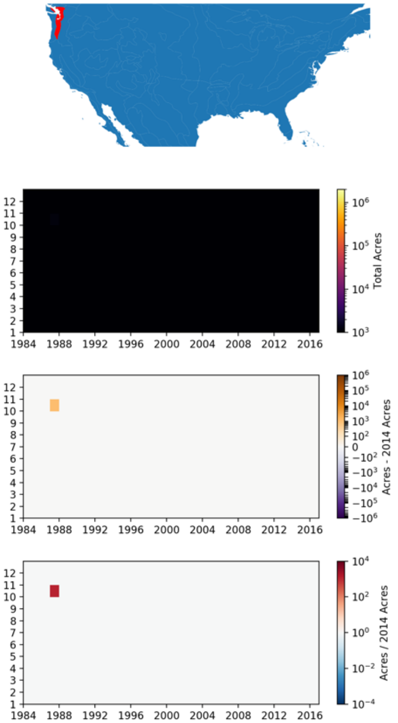
The plot below shows the derived frequency-area relationships for each CONUS ecoregion division using FSRDA data. Individual fire events from the FSRDA dataset are binned according to fire size (km^2), shown on the x-axis. Y-axis values are derived by calculating the frequency of binned events per year per area of the ecoregion (yr^{-1} km^{-4}). Because the curve represents a power law function it appears linear in log-log space.

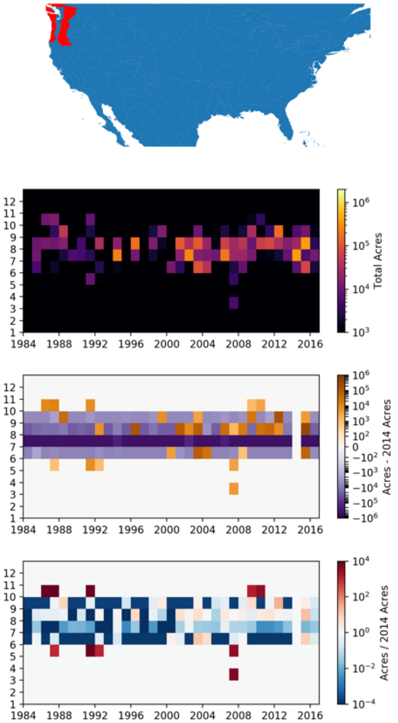


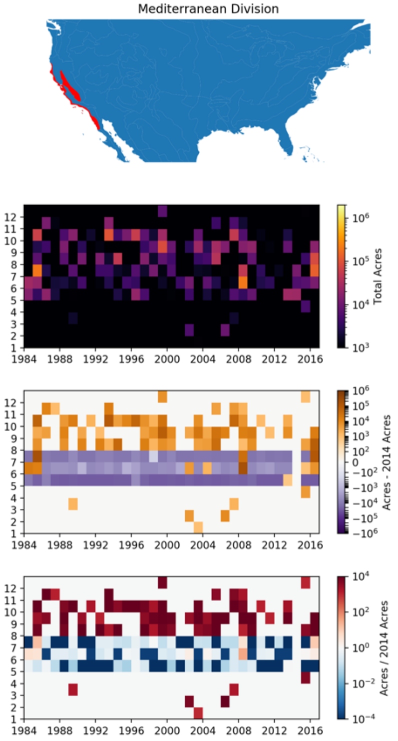
The following plots provide a reference for each CONUS ecoregion division, and show patterns of wildfire acres burned for the period 1984-2016. The y-axis of each heat map is month of year. Differences between each year and 2014 are shown to illustrate the inter-annual differences between the base year and past years. Also evident are increases in fire activity over time in some divisions (e.g., Prairie, page B-3, and all three Tropical/Subtropical divisions, page B-6). These plots were used to help assess the validity of using a long-term wildfire climatology dataset to represent contemporary patterns of burning.

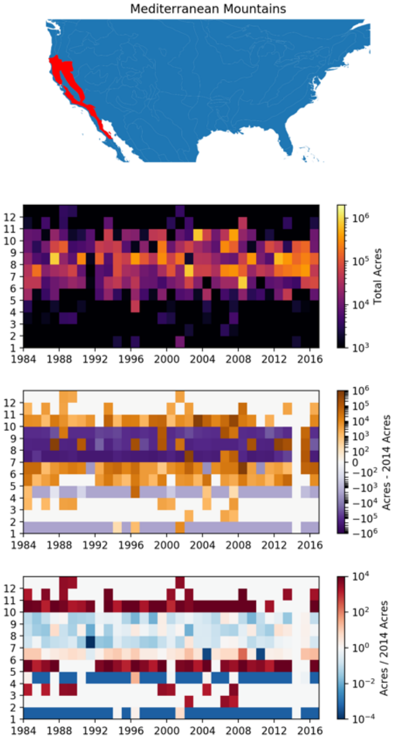

Hot Continental Division

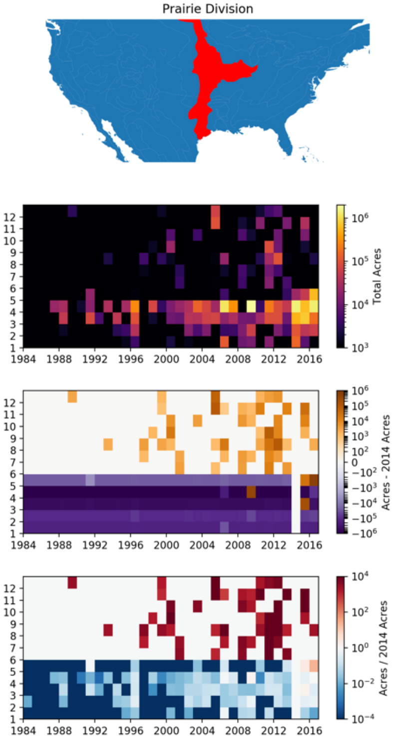

Hot Continental Mountains

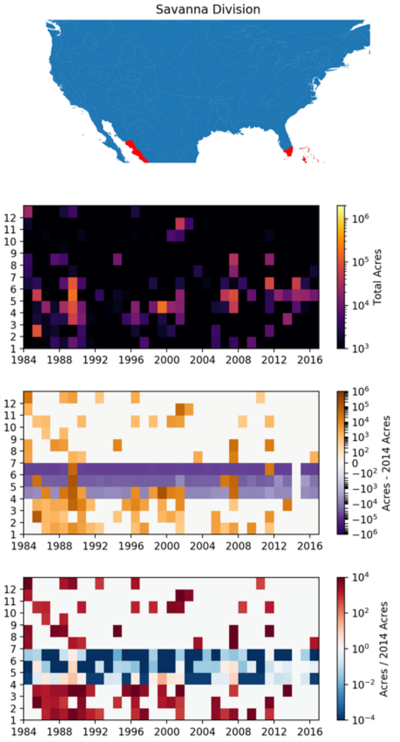

Marine Division

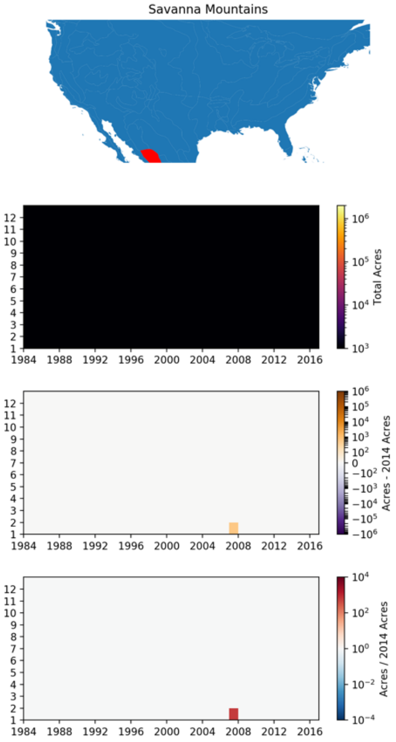

Marine Mountains


Mediterranean Division
Total Acres
Acres - 2014 Acres
Acres / 2014 Acres
1984 1988 1992 1996 2000 2004 2008 2012 2016
1 2 3 4 5 6 7 8 9 10 11 12
10^3 10^4 10^5 10^6
-10^6 -10^5 -10^4 -10^3 -10^2 0 10^2 10^3 10^4 10^5 10^6
10^{-4} 10^{-2} 10^0 10^2 10^4

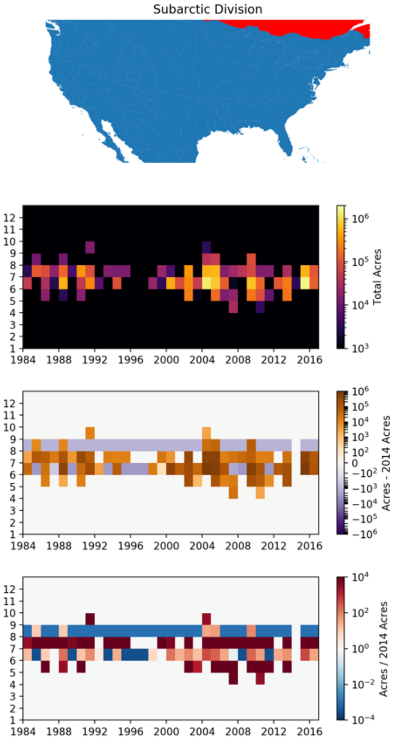

Mediterranean Mountains
Total Acres
Acres - 2014 Acres
Acres / 2014 Acres
1984 1988 1992 1996 2000 2004 2008 2012 2016
1 2 3 4 5 6 7 8 9 10 11 12
10^3 10^4 10^5 10^6
-10^6 -10^5 -10^4 -10^3 -10^2 0 10^2 10^3 10^4 10^5 10^6
10^{-4} 10^{-2} 10^0 10^2 10^4


Prairie Division
Total Acres
Acres - 2014 Acres
Acres / 2014 Acres
1984 1988 1992 1996 2000 2004 2008 2012 2016
1 2 3 4 5 6 7 8 9 10 11 12
10^3 10^4 10^5 10^6
-10^6 -10^5 -10^4 -10^3 -10^2 0 10^2 10^3 10^4 10^5 10^6
10^{-4} 10^{-2} 10^0 10^2 10^4

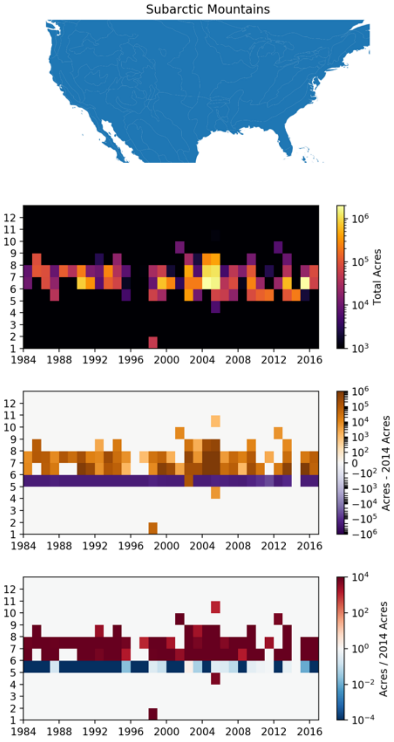

Savanna Division
Total Acres
Acres - 2014 Acres
Acres / 2014 Acres
1984 1988 1992 1996 2000 2004 2008 2012 2016
1 2 3 4 5 6 7 8 9 10 11 12
10^3 10^4 10^5 10^6
-10^6 -10^5 -10^4 -10^3 -10^2 0 10^2 10^3 10^4 10^5 10^6
10^{-4} 10^{-2} 10^0 10^2 10^4



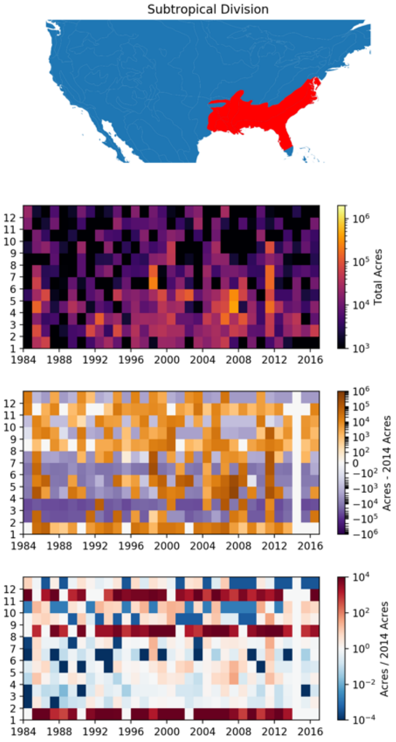
Savanna Mountains



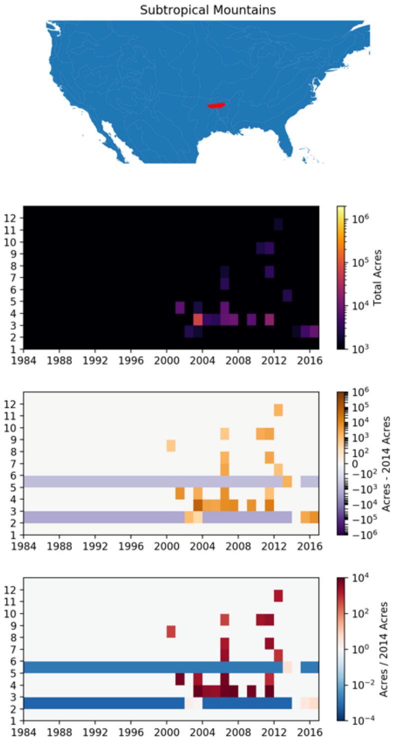
Subarctic Division

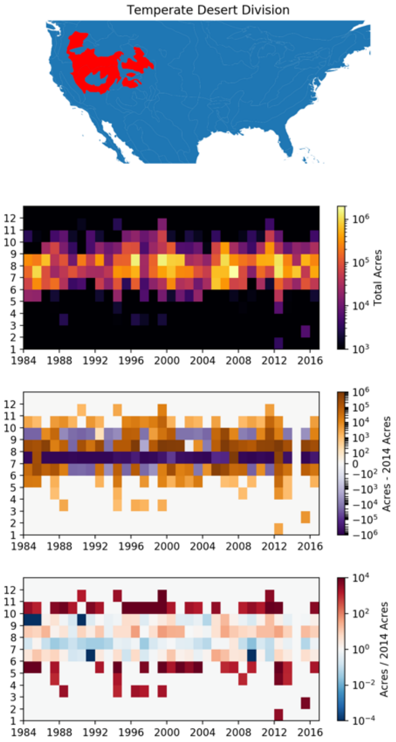


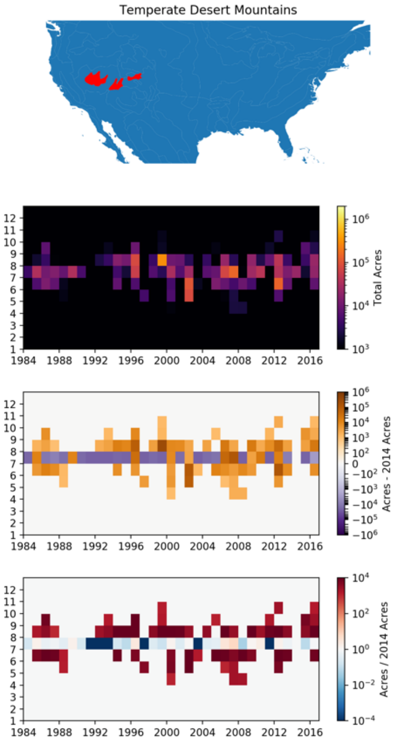
Subarctic Mountains

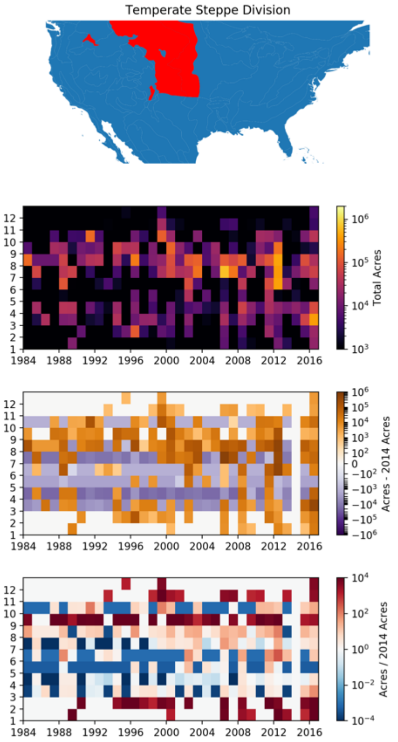


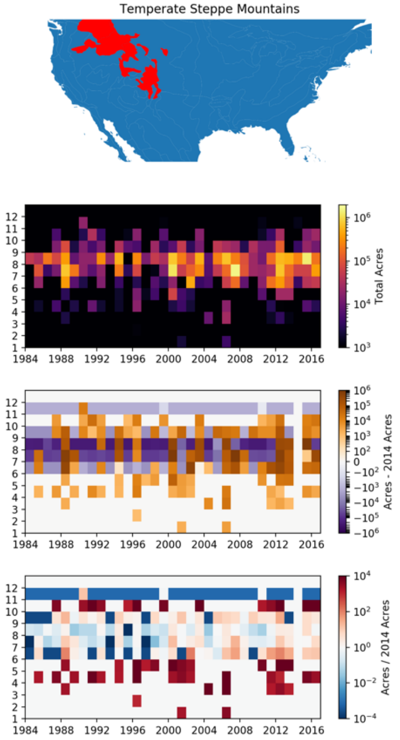
Subtropical Division

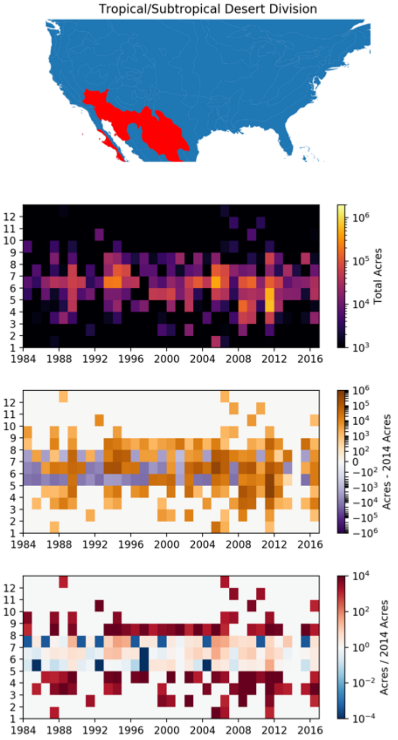

Subtropical Mountains

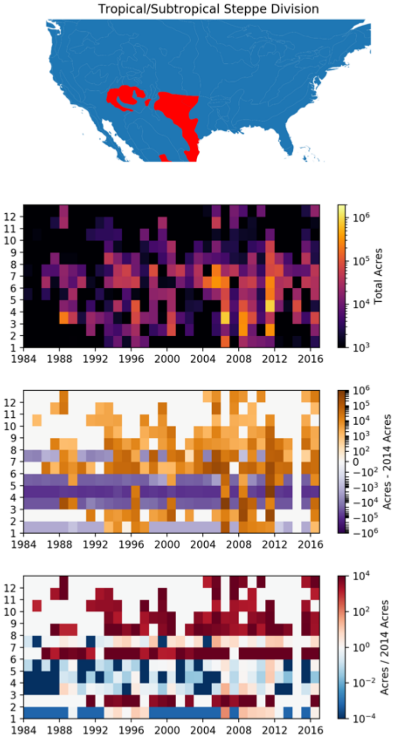

Temperate Desert Division

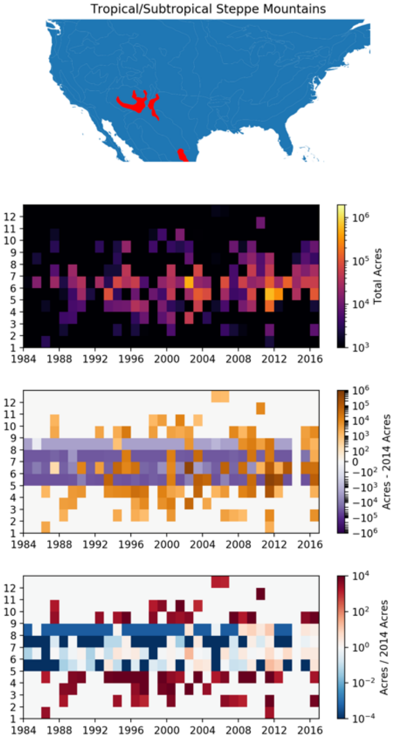

Temperate Desert Mountains

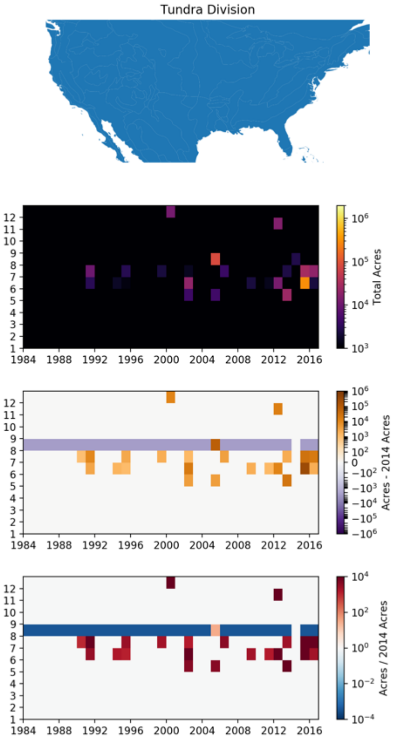

Temperate Steppe Division

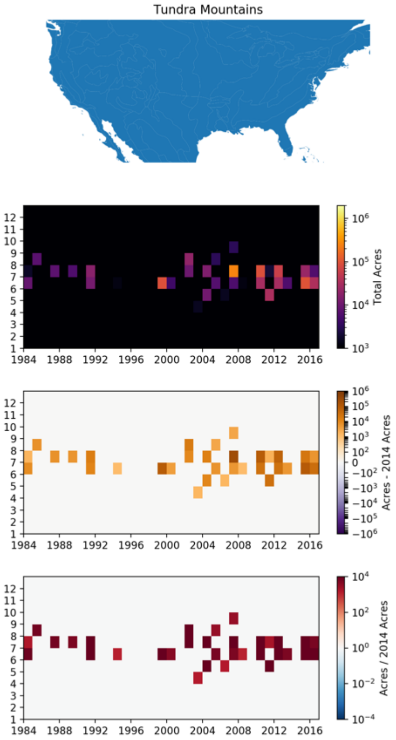

Temperate Steppe Mountains

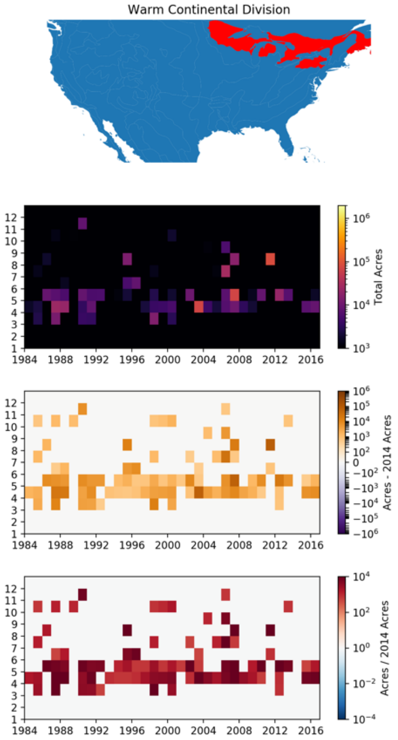

Tropical/Subtropical Desert Division

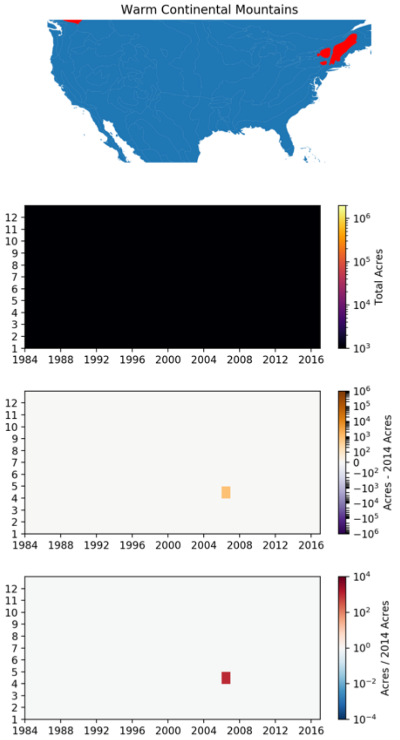

Tropical/Subtropical Steppe Division


Tropical/Subtropical Steppe Mountains


Tundra Division

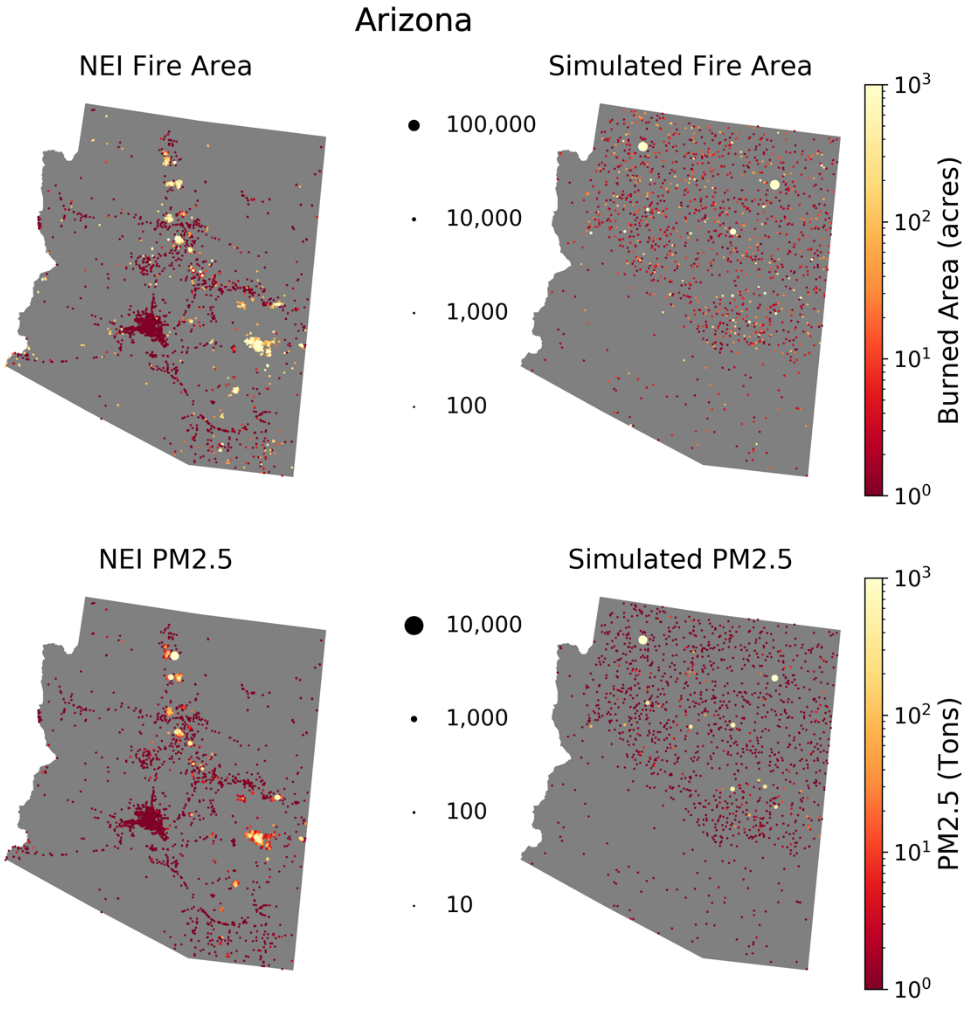

Tundra Mountains

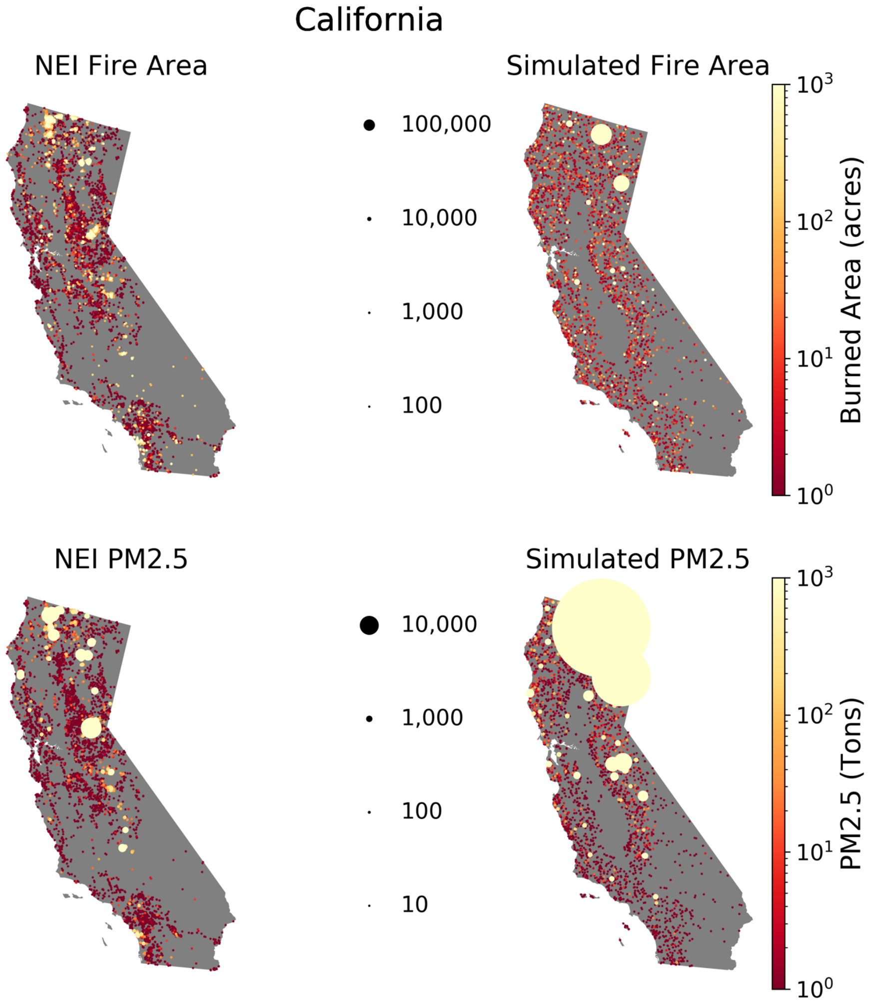

Warm Continental Division

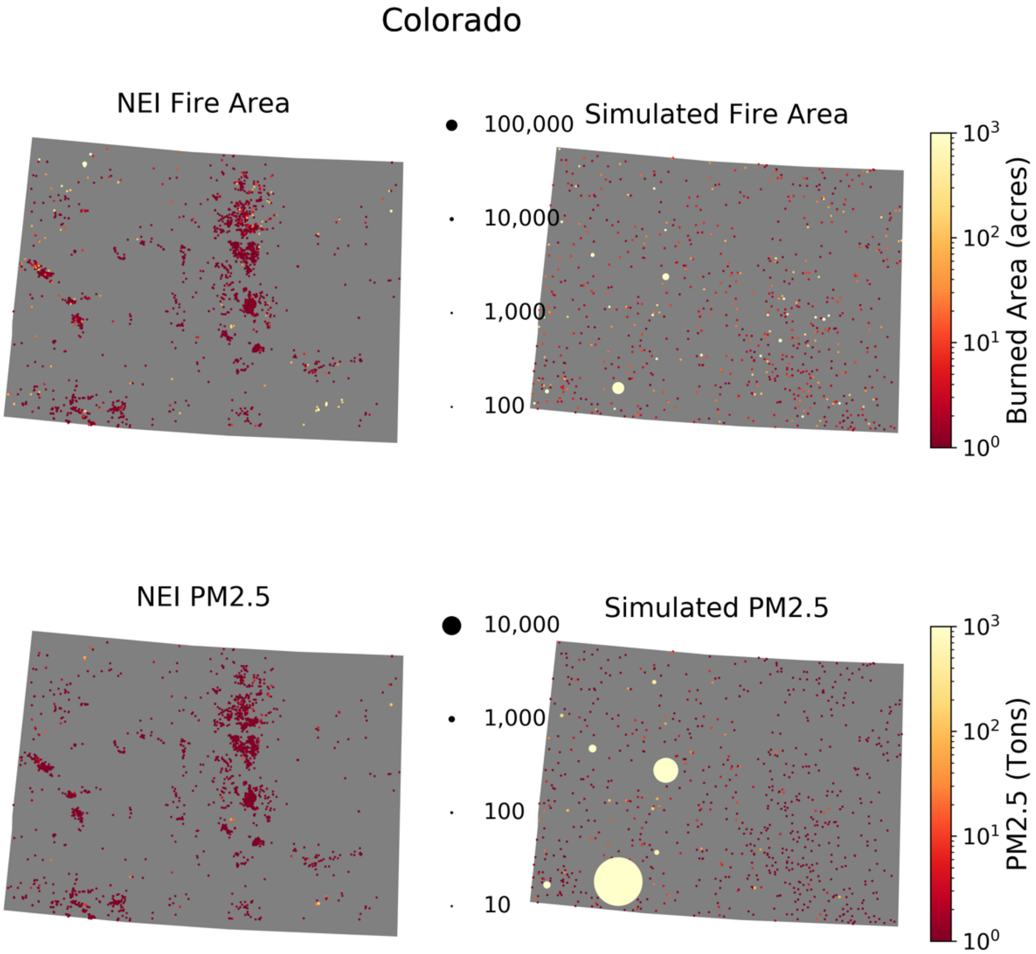

Warm Continental Mountains

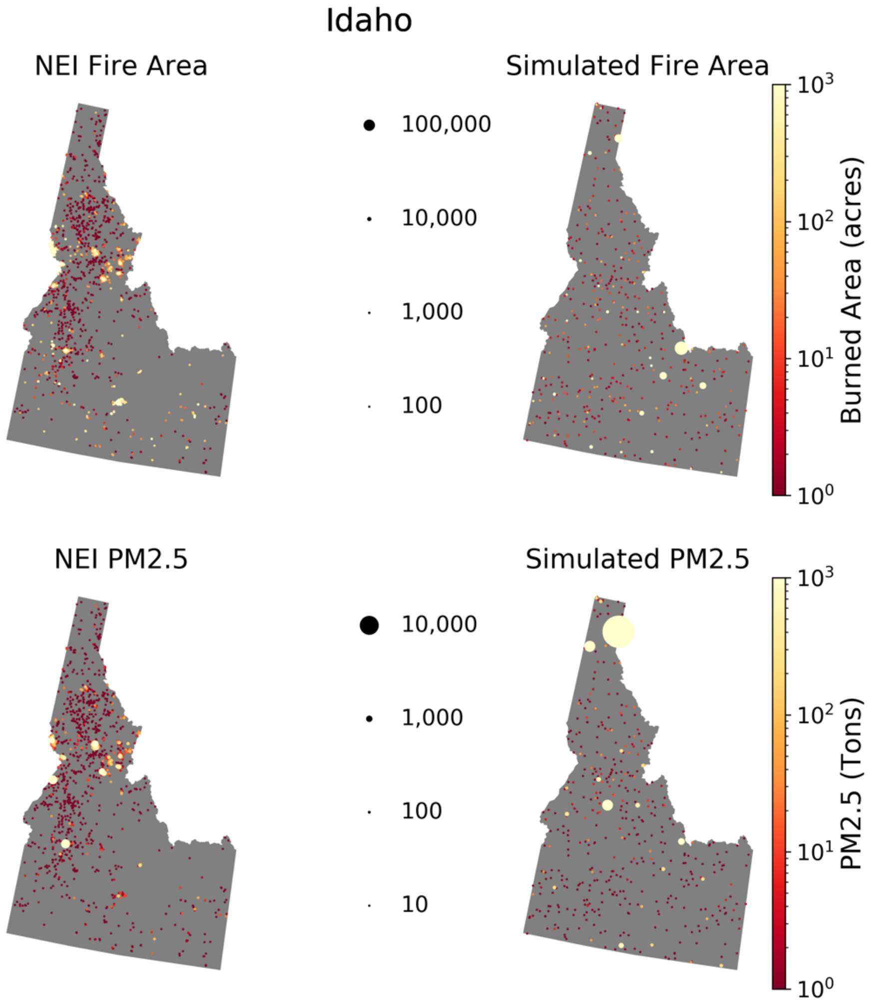
Appendix C – Representative Baseline Inventory Summary Graphics

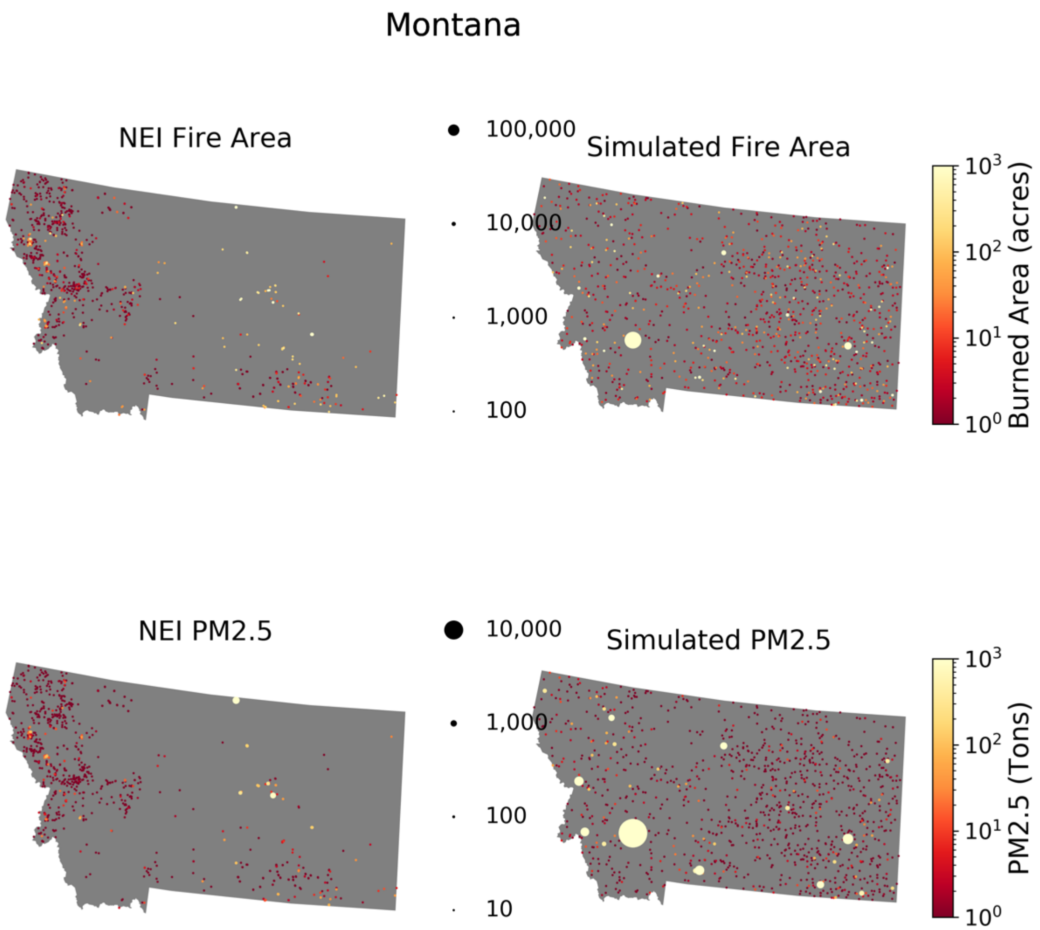
The following plots show location and magnitude differences of wildfire area burned and tons $PM_{2.5}$ consumed for the 2014 Base Year EI and the RB EI. The color scale saturates at 1,000 acres/tons, and the size scale picks up after that.

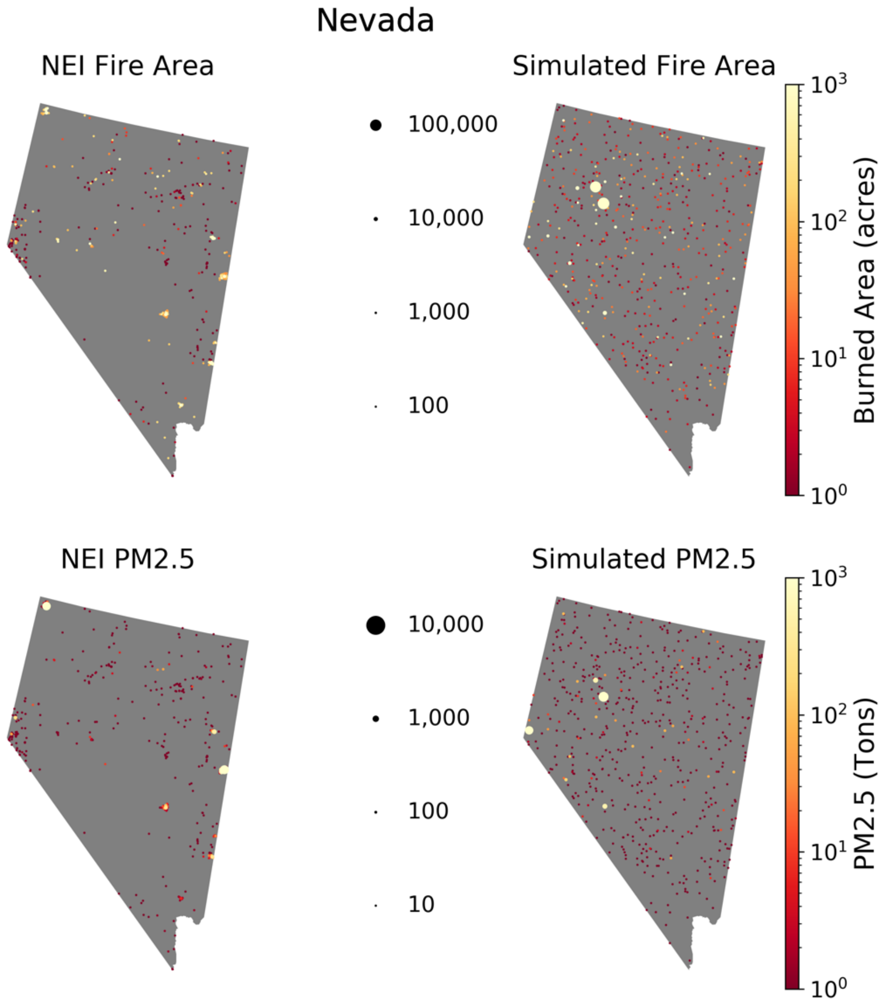


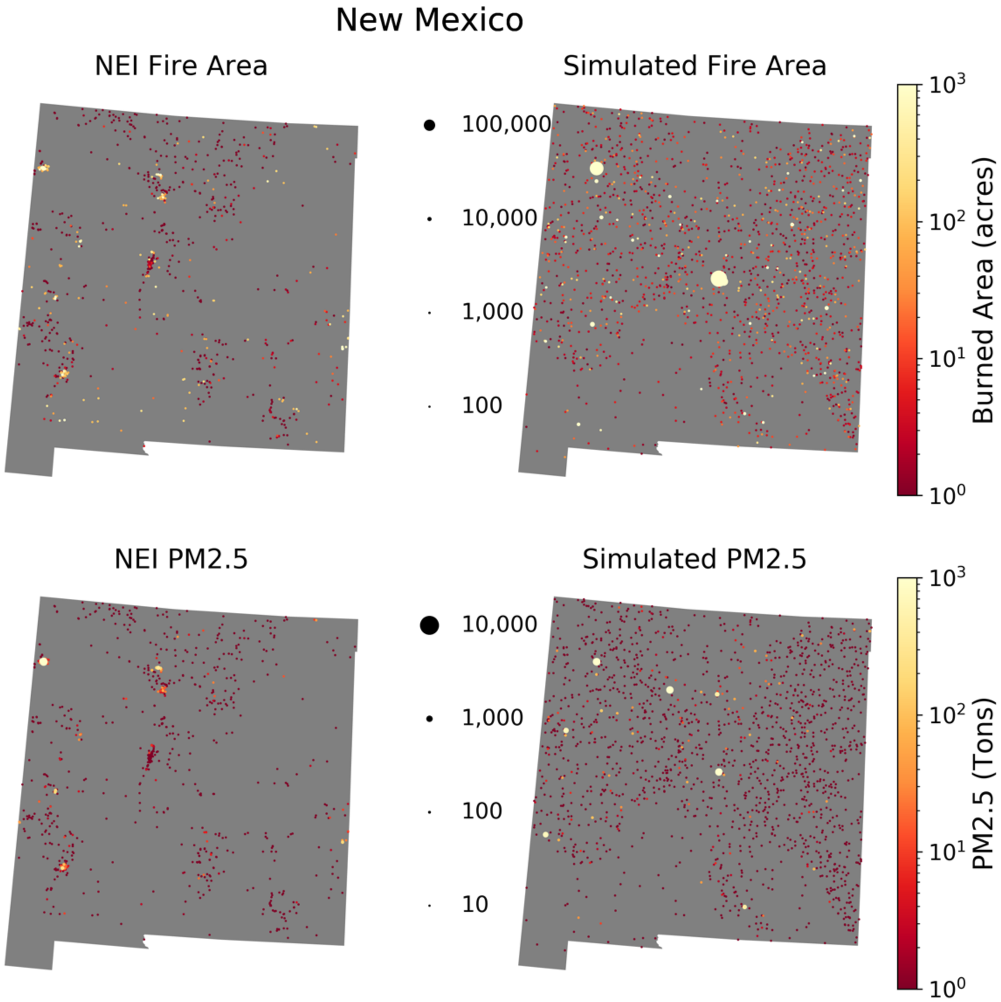

California
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
10^3
10^2
10^1
10^0
Burned Area (acres)
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
10^3
10^2
10^1
10^0
PM2.5 (Tons)


Colorado
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
Burned Area (acres)
10^3
10^2
10^1
10^0
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
PM2.5 (Tons)
10^3
10^2
10^1
10^0

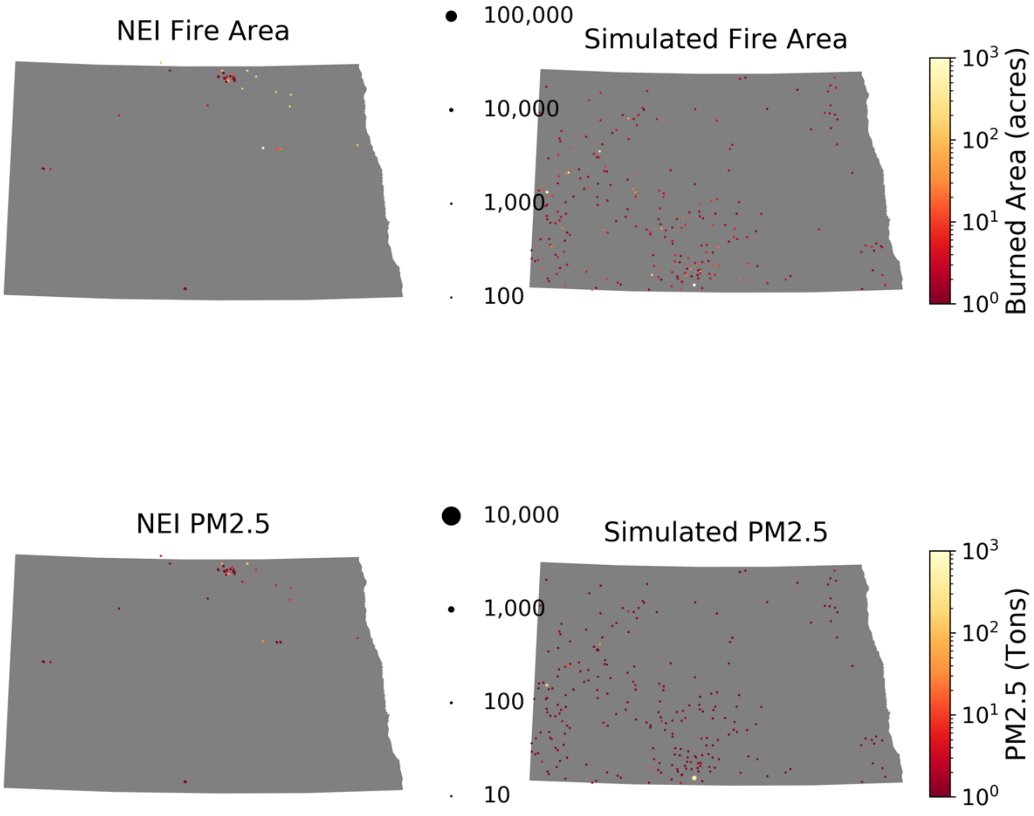

Idaho
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
Burned Area (acres)
10^3
10^2
10^1
10^0
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
PM2.5 (Tons)
10^3
10^2
10^1
10^0


Montana
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
10^3
10^2
10^1
10^0
Burned Area (acres)
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
10^3
10^2
10^1
10^0
PM2.5 (Tons)

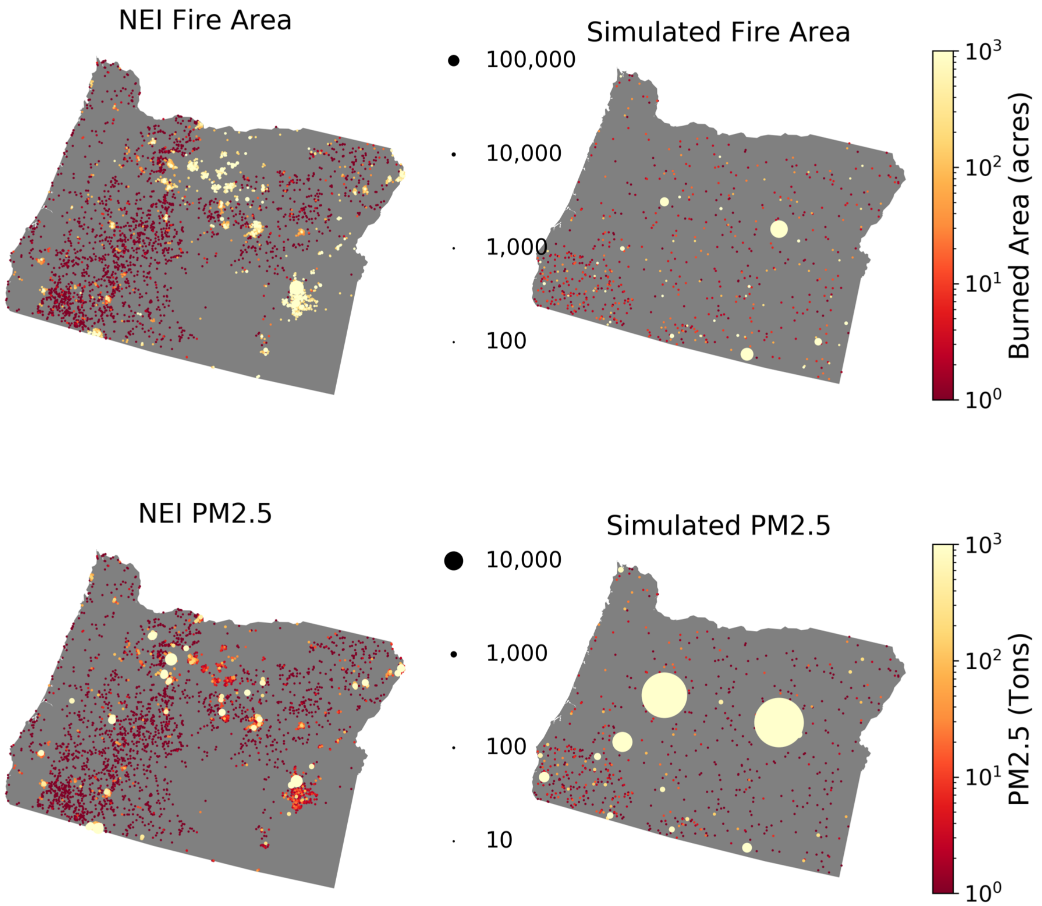

Nevada
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
10^3
10^2
10^1
10^0
Burned Area (acres)
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
10^3
10^2
10^1
10^0
PM2.5 (Tons)

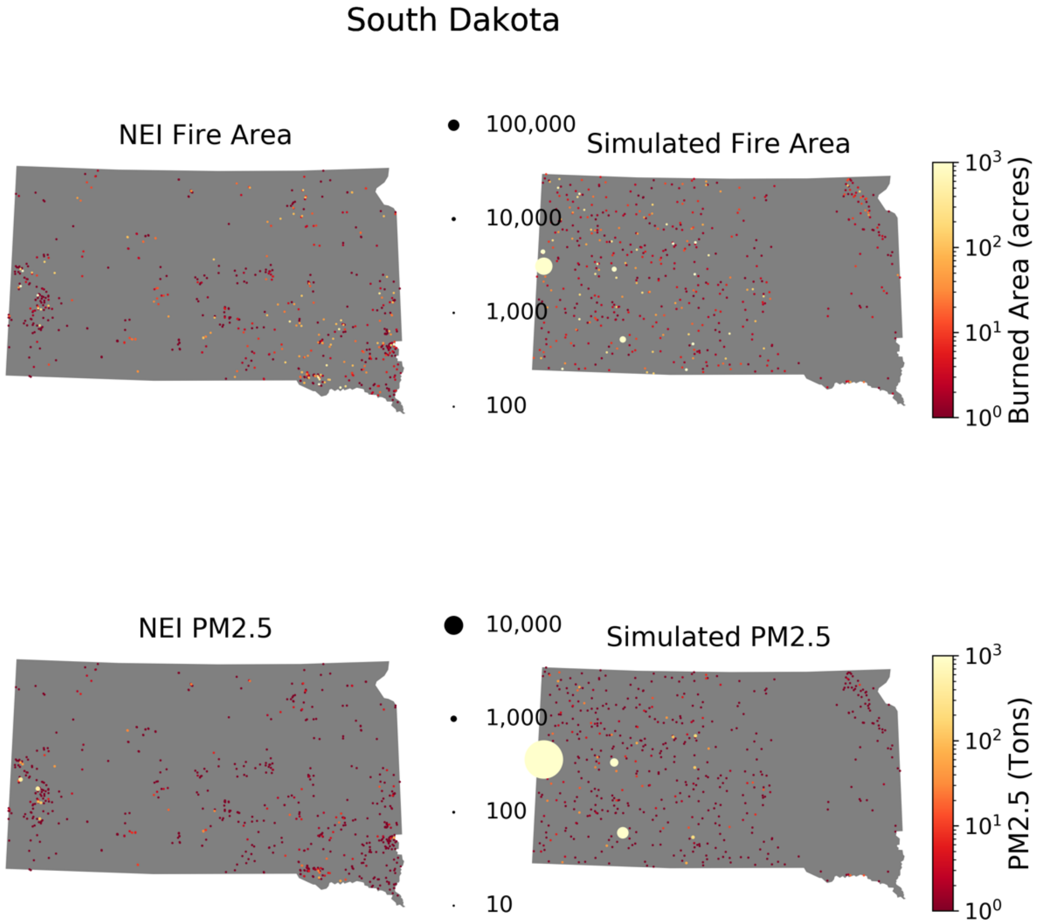

New Mexico
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
Burned Area (acres)
10^0
10^1
10^2
10^3
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
PM2.5 (Tons)
10^0
10^1
10^2
10^3

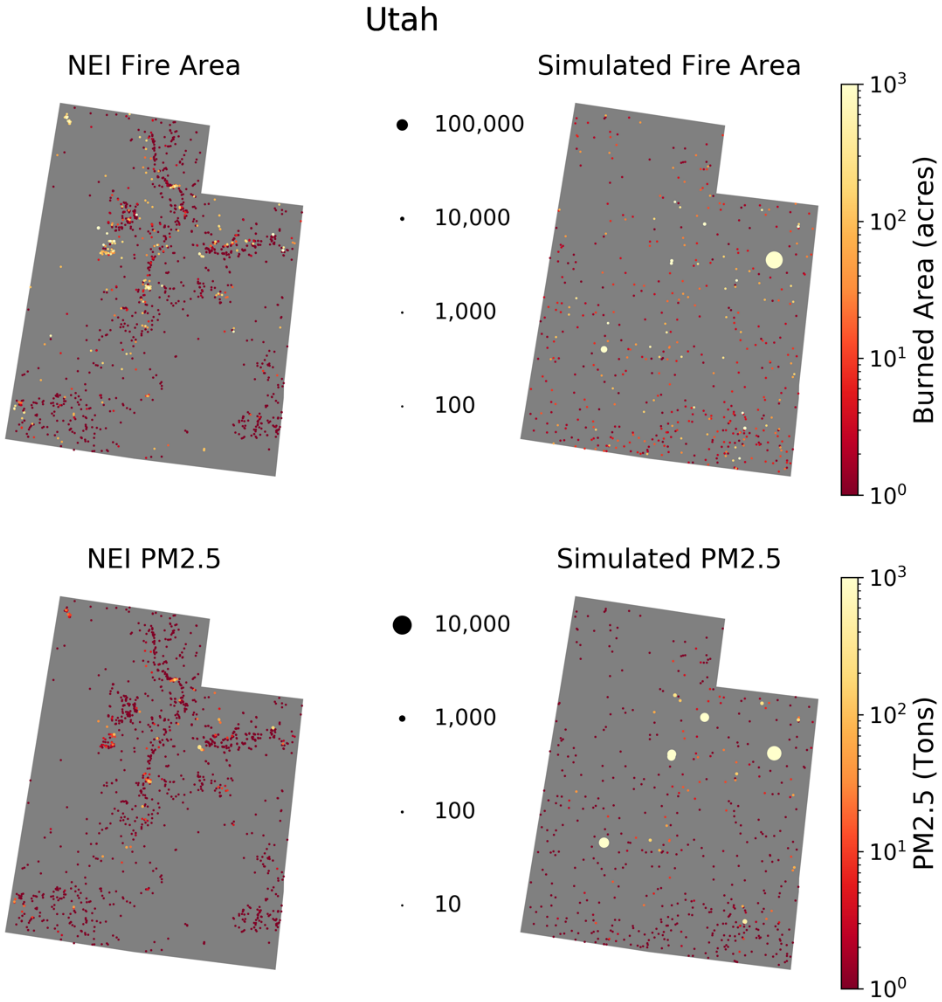
North Dakota

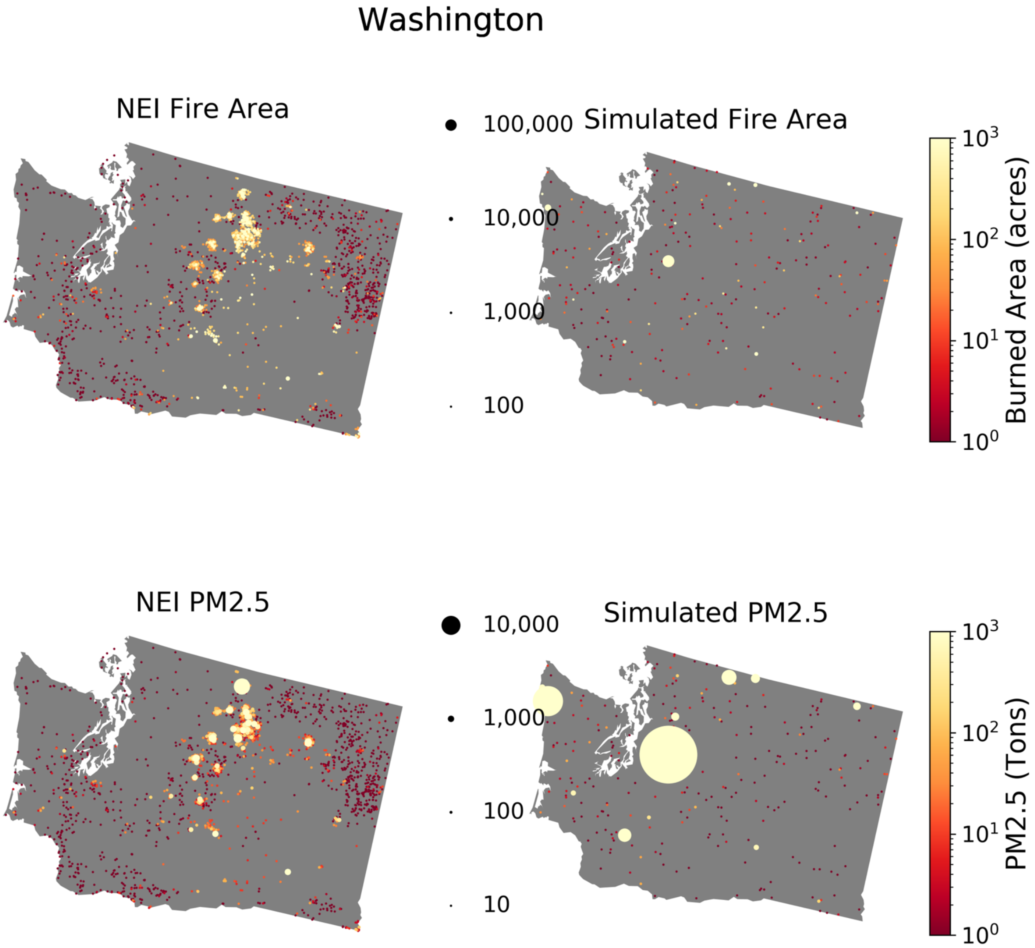


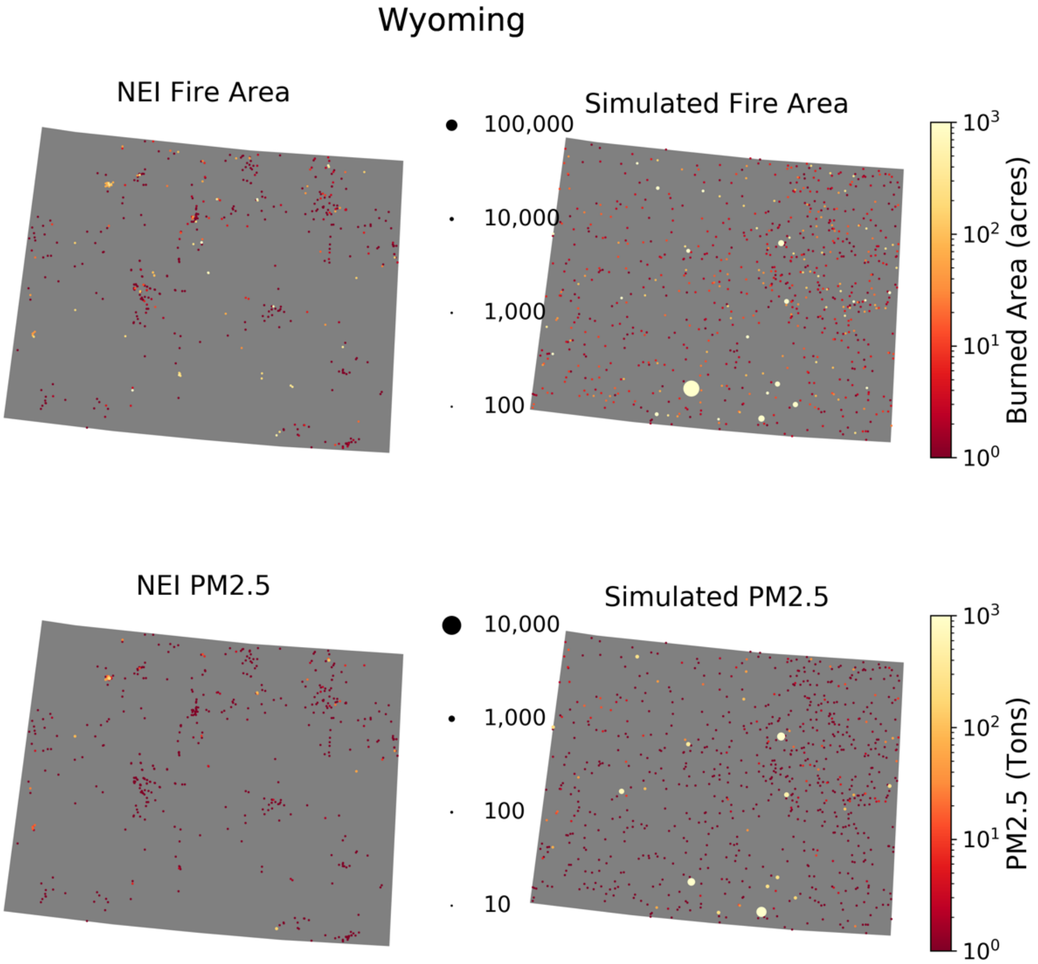
Oregon


NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
10^3
10^2
10^1
10^0
Burned Area (acres)
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
10^3
10^2
10^1
10^0
PM2.5 (Tons)


South Dakota
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
Burned Area (acres)
10^3
10^2
10^1
10^0
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
PM2.5 (Tons)
10^3
10^2
10^1
10^0


Utah
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
10^3
10^2
10^1
10^0
Burned Area (acres)
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
10^3
10^2
10^1
10^0
PM2.5 (Tons)


Washington
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
Burned Area (acres)
10^3
10^2
10^1
10^0
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
PM2.5 (Tons)
10^3
10^2
10^1
10^0


Wyoming
NEI Fire Area
Simulated Fire Area
100,000
10,000
1,000
100
Burned Area (acres)
10^3
10^2
10^1
10^0
NEI PM2.5
Simulated PM2.5
10,000
1,000
100
10
PM2.5 (Tons)
10^3
10^2
10^1
10^0