

# Documentation for Estimation of PM<sub>2.5</sub> in western US: Total and Attributed to Wildfires and Prescribed Fires

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# **1 Abstract**

The objective of this project is to estimate  $\text{PM}_{2.5}$  concentrations by day and ZIP code for the western US during 2008-2018 and categorize  $\text{PM}_{2.5}$  concentrations as non-fire and by type of fire.

## **1.1 Key Words**

## 2 Introduction

The increase in frequency and severity of wildfires occurring in the western US (Dennison et al., 2014; Steel et al., 2015) has led to higher air pollution levels than would be expected without the fires (O'Dell et al., 0). Prescribed fires (deliberate, controlled fires) are used as a management tool to reduce fuel loads and the risk of large uncontrolled wildfires while allowing ecological benefits of fire. Previous research indicates that prescribed fires impact air quality less than wildfires on a per-fire basis (Liu et al., 2017), however differences in chemical composition of the smoke could result in different health impacts from these two types of fires. To our knowledge, previous studies have not considered if air pollution from prescribed fires and wildfires pose differential risks to public health. Wildfire smoke is a complex mixture of gases and particles, but most studies of wildfire smoke and health focus on one air pollutant, particulate matter with aerodynamic diameter smaller than  $2.5 \mu\text{m}$  ( $\text{PM}_{2.5}$ ), which is the predominant pollutant of concern to health in wildfire smoke (Sapkota et al., 2005).

Recent extremely large fires such as the Camp Fire in Paradise, CA and the 2017 fires in Santa Rosa, CA have burned not only vegetation but also many buildings. We hypothesize that these urban-invasive fires could have different air pollution chemistry which could affect population health differently than wildfires that burn predominantly forests or grasses. Compared to our understanding of the health impacts of other sources of air pollution, we know much less about the health impacts of wildfire smoke exposure. Recent review articles document that wildfire smoke exacerbates asthma, although the evidence is less consistent for other respiratory and cardiovascular outcomes (Reid and Maestas, 2018; Reid et al., 2016a; Liu et al., 2015), despite clearer associations found with other sources of air pollution (Requia et al., 2018). It is possible that differences in findings across studies could be due to the type of fuels burned or other characteristics of each wildfire, or they could be due to the prevalence of chronic disease within the exposed populations (Liu et al., 2015; Rappold et al., 2011; Tinling et al., 2016). To date, however, no one has investigated what is driving heterogeneity of effects in wildfire-health studies. Given the increased risk of wildfires in the western US (Westerling, 2016b; Schoennagel et al., 2017) and the increased population living within the wildland-urban interface (Radeloff et al., 2018), it is increasingly important to understand whether different kinds of wildfires pose differential health risks and if wildfires exert more health concerns in areas with higher pre-existing health burdens. As a pre-requisite to such a study, this paper presents the exposure data necessary.

Our interdisciplinary team has experience modeling fire emissions and trajectories of smoke plumes (Thelen et al., 2013), estimating spatiotemporal air pollution exposures (Thelen et al., 2013; Reid et al., 2015a), and analyzing epidemiological relationships between air pollution and health (Reid et al., 2016b; Crooks et al., 2016). Our proposal addresses the following **Specific Aims**:

**AIM 1:** Determine whether there are differential associations between  $\text{PM}_{2.5}$  and respiratory hospitalizations and emergency department (ED) visits during prescribed fires compared to wildfires.

**Aim 1a** – For a list of 200 wildfires and 150 prescribed fires that occurred in our study area (AZ, CA, CO, NM, OR, UT, WA) during 2008-2018, estimate the background and fire-affected  $\text{PM}_{2.5}$  concentrations for each affected ZIP code-day.

**Aim 1b** – Using Poisson generalized estimating equations (GEE) models assess associations between prescribed fire  $\text{PM}_{2.5}$  and wildfire  $\text{PM}_{2.5}$ , separately, with respiratory hospitalizations and ED visits, adjusted for pertinent confounding variables.

**AIM 2:** Assess whether associations between  $PM_{2.5}$  during wildfires and respiratory and cardiovascular hospitalizations and ED visits differ by wildfire characteristics (e.g., predominant fuel type, size, duration, etc.).

**Aim 2a** – For each fire, estimate the association between daily wildfire-affected  $PM_{2.5}$  and daily counts of respiratory and cardiovascular hospitalizations and ED visits using Poisson GEE models, adjusted for pertinent confounding variables.

**Aim 2b** – Using meta-regression of the individual regressions by fire from Aim 2a, quantify the role of fire characteristics in describing the heterogeneity in relationships between  $PM_{2.5}$  and respiratory and cardiovascular hospitalizations and ED visits across the study fires.

**AIM 3:** Assess whether associations between  $PM_{2.5}$  during wildfires and respiratory and cardiovascular hospitalizations and ED visits differ by population health characteristics (e.g., prevalence of chronic disease or health behaviors).

**Aim 3a** – Using meta-regression of the individual regressions by fire from Aim 2a, quantify the role of population health characteristics in describing the heterogeneity in relationships between  $PM_{2.5}$  and respiratory and cardiovascular hospitalizations and ED visits across the study fires.

### 3 Materials and Methods

#### 3.1 Phase 1: Data Sources and Points of Interest for Machine Learning

For the creation of the spatiotemporal daily exposure surface via machine learning, a large number of data sets will be collected as discussed below. The dependent variable will be daily 24-hour  $PM_{2.5}$  from monitoring data.



Figure 1: Map of 11-state study area.

### 3.1.1 PM<sub>2.5</sub> Monitor data from US EPA AQS Air Data Query Tool

#### To Do

1. Download the 2018 data again - the complete 2018 data should be available by July 2019.

#### Data Source

- **Contact** Can email the Air Quality Analysis Group (U.S. EPA Office of Air Quality Planning and Standards) on their website at <https://www.epa.gov/outdoor-air-quality-data/forms/contact-us-about-outdoor-air-quality-data>
- **Citation/Link**  
United States Environmental Protection Agency. *Pre-Generated Data Files: Daily Summary Files, PM<sub>2.5</sub> FRM/FEM Mass (88101) and PM<sub>2.5</sub> non FRM/FEM Mass (88502), 2008-2018*. [https://aqs.epa.gov/aqsweb/airdata/download\\_files.html#Daily](https://aqs.epa.gov/aqsweb/airdata/download_files.html#Daily). Download spreadsheet listing all AQS monitors with datums ([https://aqs.epa.gov/aqsweb/airdata/aqs\\_monitors.zip](https://aqs.epa.gov/aqsweb/airdata/aqs_monitors.zip)) from "Monitor Listing" at [https://aqs.epa.gov/aqsweb/airdata/download\\_files.html#Meta](https://aqs.epa.gov/aqsweb/airdata/download_files.html#Meta). The file name is aqs\_monitors.csv in the AQS\_Daily\_Summaries folder in the S3 data.
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent** 2008 through 2018. The 2018 file was downloaded June 14, 2019, and it is possible that more 2018 data will become available after this date.
- **Acknowledgment** EPA

#### Brief Description

##### Data File Names

1. daily\_88101\_2008.csv
2. daily\_88101\_2009.csv
3. daily\_88101\_2010.csv
4. daily\_88101\_2011.csv
5. daily\_88101\_2012.csv
6. daily\_88101\_2013.csv
7. daily\_88101\_2014.csv
8. daily\_88101\_2015.csv
9. daily\_88101\_2016.csv
10. daily\_88101\_2017.csv
11. daily\_88101\_2018.csv \* this is only part of 2018 - the rest will need to be downloaded once it becomes available
12. daily\_88502\_2008.csv
13. daily\_88502\_2009.csv
14. daily\_88502\_2010.csv
15. daily\_88502\_2011.csv
16. daily\_88502\_2012.csv
17. daily\_88502\_2013.csv
18. daily\_88502\_2014.csv
19. daily\_88502\_2015.csv
20. daily\_88502\_2016.csv
21. daily\_88502\_2017.csv

22. daily\_88502\_2018.csv \* this is only part of 2018 - the rest will need to be downloaded once it becomes available

### **Script Names**

1. process\_PM25\_EPA\_data\_source\_function.R (called from Process\_PM25\_data\_step1.R)



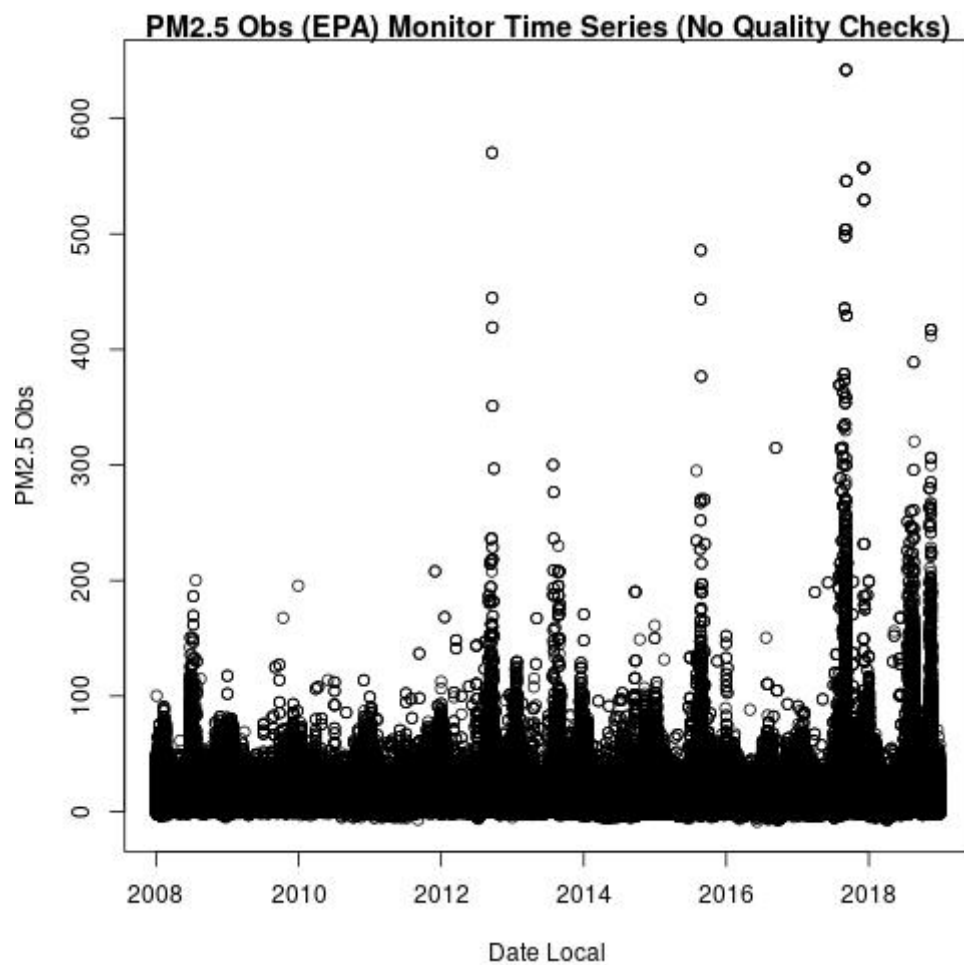


Figure 2: EPA Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)

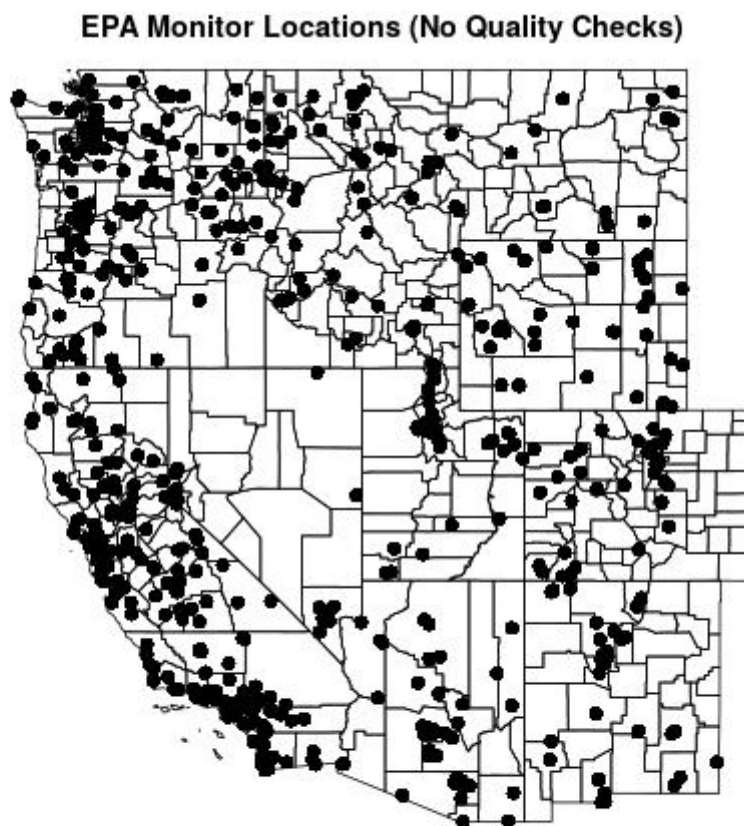


Figure 3: EPA Monitor Locations (No Quality Checks; PM2.5 Processing Step 1)

### 3.1.2 PM<sub>2.5</sub> data from the Fire Cache Smoke Monitor Archive

#### Data Source

- **Contact** Josh Walston at 775-673-7624; Amber Ortega directed us to the website and Scott Landis suggested that a good person to contact about the page would be Mike Broughton from the US Forest Service ([michaelbroughton@fs.fed.us](mailto:michaelbroughton@fs.fed.us))
- **Citation/Link** <https://wrcc.dri.edu/cgi-bin/smoke.pl>
- **Data (local)** PM<sub>2.5</sub> data from the Fire Cache Smoke Monitor Archive
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

#### Notes

#### File Formats

.CSV

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

- 1.
- 2.

#### Quality Control

#### Script Names

process\_PM25\_Fire\_Cache\_data\_source\_function.R (called from Process\_PM25\_data\_step1.R)

#### Processed/Cleaned Data File Names

- 1.
- 2.

### Download instructions

1. For each file:
  - (a) <https://wrcc.dri.edu/cgi-bin/smoke.pl>
  - (b) Hover over the appropriate drop-down menu and click on the monitor you want to download e.g., “Cache Monitors” then “Smoke #11”
  - (c) On the left-side menu, click on “Data Details”
  - (d) Set the starting date: January 1, 2008 (or as far back as it goes if it doesn’t go back to 2008)
  - (e) Set the ending date: Last date possible
  - (f) Elements (ignore - default is to include all elements)
  - (g) Options
    - i. Excel (.xls) (It had html code in the file if I chose other options.)
    - ii. Data Source: Original
    - iii. Represent missing data as: -9999.
    - iv. Include data flags: Yes

- v. Date format: MM/DD/YYYY hh:mm
- vi. Time format: LST 0-23
- vii. Table Header: Column header short descriptions
- viii. Field Delimiter: comma (,)
- ix. Select the Units: Metric
  - x. Leave Sub interval windows set to: January 01, December 31, Hours: 00 and 24
- xi. Submit Info
- (h) Open in excel (this takes several seconds and sometimes there is an alert dialog box, answer yes)
- (i) Check the following:
  - i. The name of the monitor is in cell A1
  - ii. The header is spread across rows 2-4
  - iii. There are 34 columns of data (goes through columns “AH” in excel)
  - iv. Concentration in the 11th (“K”) columns
- (j) Save as: Fire\_Cache\_Smoke\_DRI\_\*.csv Where \* is the monitor name with spaces replaced with underscore and # symbols replaced with the letter “N”, e.g., the file name for monitor “Smoke #11” is “Fire\_Cache\_Smoke\_DRI\_Smoke\_N11.csv”. If a window pops up asking whether to keep the csv format, answer yes.
- (k) List the file names in the latex documentation (PM25\_Fire\_Cache\_Smoke\_Monitor\_Archive.tex)

## 2. Once all files are downloaded locally

- (a) Upload file to S3 bucket in the Earthlab-reid-group folder within the Fire\_Cache\_Smoke\_DRI subfolder <https://732215511434.signin.aws.amazon.com/console>

## **Original Data File Names and notes about monitors (downloaded February 26-27, 2019 unless otherwise noted)**

### 1. Cache Monitors

- 1 Smoke #11: August 2010 – December 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N11.csv
- 2 Smoke #13: January 2010 – February 2019; Fire\_Cache\_Smoke\_DRI\_Smoke\_N13.csv
- 3 Smoke #15: August 2010 – December 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N15.csv
- 4 Smoke #16: June 2011 – June 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N16.csv
- 5 Smoke #17: September 2010 – July 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N17.csv
- 6 Smoke #19: August 2010 – October 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N19.csv
- 7 Smoke #20: June 2011 – October 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N20.csv
- 8 Smoke #21: April 2011 – December 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N21.csv
- 9 Smoke #22: February 2011 – November 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N22.csv
- 10 Smoke #23: March 2011 – June 2019; Fire\_Cache\_Smoke\_DRI\_Smoke\_N23.csv \*  
This file seems to have a few rows of data shifted by two columns. Those rows look like they could be problematic, so I’ll leave them as-is and let the processing scripts remove them. Downloaded June 14, 2019
- 11 Smoke #24: March 2011 – October 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N24.csv  
\* This file seems to have a few rows of data shifted by two columns. Those rows look like they could be problematic, so I’ll leave them as-is and let the processing scripts remove them.
- 12 Smoke #65: March 2013 – August 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N65.csv

- 13 Smoke #66: March 2012 – October 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N66.csv
- 14 Smoke #67: January 2012 – June 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N67.csv
- 15 Smoke #68: March 2012 – November 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N68.csv
- 16 Smoke #69: January 2012 – October 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N69.csv
- 17 Smoke #84: March 2013 – July 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N84.csv \*  
This file seems to have a few rows of data shifted by a few columns. Assuming those rows could be problematic, I'll leave them as-is and let the processing scripts remove them.
- 18 Smoke #215: January 2014 – October 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N215.csv
- 19 Smoke #216: January 2014 – February 2019; Fire\_Cache\_Smoke\_DRI\_Smoke\_N216.csv
- 20 Smoke # 217: January 2014 – October 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_N216.csv  
\* This file seems to have a few rows of data shifted by a few columns. Assuming those rows could be problematic, I'll leave them as-is and let the processing scripts remove them.
- 21 Smoke # 456: December 2018 – March 2019; Fire\_Cache\_Smoke\_DRI\_Smoke\_N456.csv  
Downloaded June 14, 2019.
- 22 Smoke E-BAM 231: November 2014 – December 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_231.csv
- 23 Smoke E-BAM 418: July 2017 – November 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_418.csv Downloaded June 14, 2019
- 24 Smoke E-BAM 591: July 2017 – September 2017; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_591.csv Downloaded June 14, 2019
- 25 Smoke E-BAM 592: July 2017 – August 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_592.csv Downloaded June 14, 2019
- 26 Smoke E-BAM 840: October 2014 – February 2019; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_840.csv
- 27 Smoke E-BAM 866: November 2014 – November 2018; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_866.csv
- 28 Smoke E-BAM 882: July 2017 – September 2018 Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_882.csv Downloaded June 14, 2019
- 29 Smoke E-BAM 925: November 2014 – February 2019; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_925.csv \* This file seems to have a few rows of data shifted by a few columns. Assuming those rows could be problematic, I'll leave them as-is and let the processing scripts remove them.
- 30 Smoke E-BAM 969: July 2017 – September 2017; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_969.csv Downloaded June 14, 2019

## 2. Cache Monitors that did not operate during 2008-2018

- 1 Smoke #209 - started operation in March 2019.
- 2 Smoke #210 - started operation in March 2019.
- 3 Smoke #454 - started operation in March 2019.
- 4 Smoke #455 - started operation in March 2019.
- 5 Smoke #457 - started operation in March 2019.
- 6 Smoke E-Bam #787 - started operation in March 2019
- 7 Smoke E-Bam #794 - started operation in March 2019

### 3. USFS Regional Monitors

- 1 Smoke USFS R1-39: February 2013 – October 2018; Fire\_Cache\_Smoke\_USFS\_R1-39.csv
- 2 Smoke USFS R1-52: January 2013 – February 2019; Fire\_Cache\_Smoke\_USFS\_R1-52.csv
- 3 Smoke USFS R1-53: February 2013 – February 2019; Fire\_Cache\_Smoke\_USFS\_R1-53.csv
- 4 Smoke USFS R1-306: November 2014 – February 2019; Fire\_Cache\_Smoke\_USFS\_R1-306.csv
- 5 Smoke USFS R1-307: November 2014 – September 2017; Fire\_Cache\_Smoke\_USFS\_R1-307.csv
- 6 Smoke USFS R2-69: May 2013 – February 2019; Fire\_Cache\_Smoke\_USFS\_R2-69.csv
- 7 Smoke USFS R2-78: April 2013 – October 2017; Fire\_Cache\_Smoke\_USFS\_R2-78.csv
- 8 Smoke USFS R2-264: November 2014 – October 2017; Fire\_Cache\_Smoke\_USFS\_R2-264.csv
- 9 Smoke USFS R2-265: December 2014 – October 2018; Fire\_Cache\_Smoke\_USFS\_R2-265.csv
- 10 Smoke USFS R2-922: June 2015 – June 2018; Fire\_Cache\_Smoke\_USFS\_R2-922.csv
- 11 Smoke USFS R2-923: June 2015 – October 2016; Fire\_Cache\_Smoke\_USFS\_R2-923.csv
- 12 Smoke USFS R2-924: June 2015 – February 2019; Fire\_Cache\_Smoke\_USFS\_R2-924.csv (website claims August of 1941 has data, but this is highly dubious.)
- 13 Smoke USFS R3-28: March 2013 – October 2018; Fire\_Cache\_Smoke\_USFS\_R3-28.csv \* This file seems to have a few rows of data shifted by a few columns. Assuming those rows could be problematic, I'll leave them as-is and let the processing scripts remove them.
- 14 Smoke USFS R3-86: March 2018 – February 2019; Fire\_Cache\_Smoke\_USFS\_R3-86.csv
- 15 Smoke USFS R5-39: June 2013 – July 2014; Fire\_Cache\_Smoke\_USFS\_R5-39.csv
- 16 Smoke USFS R5-49: June 2013 – July 2016; Fire\_Cache\_Smoke\_USFS\_R5-49.csv \* concentrations are all 0 or -9999 ug/m3. Air Flow is correspondingly 0 or -9999 L/min, so all of these data will be removed by the processing scripts.
- 17 Smoke USFS R8-33: December 2014 – January 2017; Fire\_Cache\_Smoke\_USFS\_R8-33.csv
- 18 Smoke USFS R8-34: September 2015 – August 2016; Fire\_Cache\_Smoke\_USFS\_R8-34.csv (website claims August of 1941 has data, but this is highly dubious.)
- 19 Smoke USFS R8-35: August 2016 – July 2017; Fire\_Cache\_Smoke\_USFS\_R8-35.csv
- 20 Smoke USFS R8-55: November 2016 – July 2017; Fire\_Cache\_Smoke\_USFS\_R8-55.csv Downloaded June 14, 2109
- 21 Smoke USFS R8-56: November 2016 – July 2017; Fire\_Cache\_Smoke\_USFS\_R8-56.csv Downloaded June 14, 2109
- 22 Smoke USFS R9-15: February 2013 – April 2018; Fire\_Cache\_Smoke\_USFS\_R9-

- 15.csv
- 23 Smoke USFS R9-16: February 2013 – May 2018; Fire\_Cache\_Smoke\_USFS\_R9-16.csv
- 24 Smoke USFS R9-17: February 2013 – May 2018; Fire\_Cache\_Smoke\_USFS\_R9-17.csv
- 25 Smoke USFS R9-60: October 2012 – July 2018; Fire\_Cache\_Smoke\_USFS\_R9-60.csv  
\* This file seems to have a few rows of data shifted by a few columns. Assuming those rows could be problematic, I'll leave them as-is and let the processing scripts remove them.
- 26 Smoke USFS 3015: December 2015 – February 2019; Fire\_Cache\_Smoke\_USFS\_3015.csv
- 27 Smoke USFS 3016: May 2016 – February 2019; Fire\_Cache\_Smoke\_USFS\_3016.csv  
(website claims 1941 has data, but this is highly dubious.)
- 28 Smoke USFS R9-3017: December 2015 – February 2017; Fire\_Cache\_Smoke\_USFS\_R9-3017.csv
- 29 Smoke USFS R9-3018: January 2016 – February 2017; Fire\_Cache\_Smoke\_USFS\_R9-3018.csv

#### 4. Miscellaneous Monitors

- 1 Smoke #25: January 2011 – September 2015; Fire\_Cache\_Smoke\_DRI\_Smoke\_N25.csv  
\* This file seems to have a few rows of data shifted by a few columns. Assuming those rows could be problematic, I'll leave them as-is and let the processing scripts remove them.
- 2 Smoke #86: October 2012 – February 2019 Fire\_Cache\_Smoke\_DRI\_Smoke\_N86.csv
- 3 Smoke E-BAM 52: April 2012 – April 2015; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_52.csv
- 4 Smoke E\_BAM 65: June 2013 – September 2015; Fire\_Cache\_Smoke\_DRI\_Smoke\_E-BAM\_65.csv \* This file seems to have a few rows of data shifted by a few columns. Assuming those rows could be problematic, I'll leave them as-is and let the processing scripts remove them.
- 5 FWS Smoke #1: June 2012 – November 2018; Fire\_Cache\_Smoke\_DRI\_FWS\_Smoke\_N1.csv
- 6 Smoke NCFS E-BAM #1: June 2014 – December 2016; \* This file has 10 fewer columns of data than most of the files, which have 34, and the ordering of the columns that are there is different. Not sure if this will cause a problem when compiling the data. Fire\_Cache\_Smoke\_DRI\_Smoke\_NCFS\_E\_BAM\_N1.csv
- 7 Smoke NCFS E-BAM #2: June 2014 – February 2015; Fire\_Cache\_Smoke\_DRI\_Smoke\_NCFS\_E-BAM\_N2.csv \* This file has 10 fewer columns of data than most of the files, which have 34, and the ordering of the columns that are there is different. Not sure if this will cause a problem when compiling the data. It is a short file and doesn't appear to have any days of data that will pass the quality checks (negative concentrations, too few hourly observations within a day).
- 8 Smoke NCFS E-BAM #3: June 2014 – February 2015; \* This file has 10 fewer columns of data than most of the files, which have 34, and the ordering of the columns that are there is different. Not sure if this will cause a problem when compiling the data.  
Downloaded June 14, 2019
- 9 Smoke NPS Yosemite 01 California: September 2014 – September 2018; Fire\_Cache\_Smoke\_DRI\_Sm

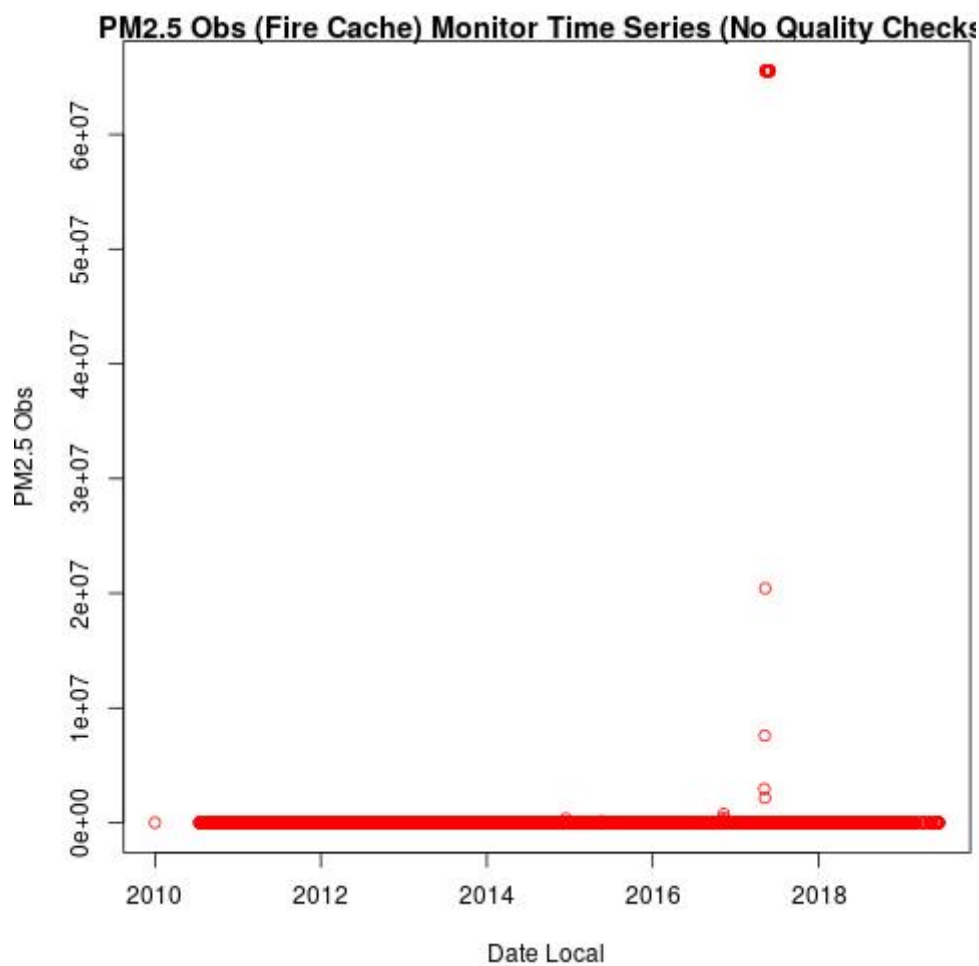


Figure 4: Fire Cache Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)

- 10 RSF Smoke Monitor 1: November 2015 – July 2016; Fire\_Cache\_Smoke\_DRI\_RSF\_Smoke\_Monitor
- 11 Lolo NF Smoke Monitor #1: February 2016 – October 2018; Fire\_Cache\_Smoke\_Lolo\_NF\_Smoke\_M  
Downloaded June 14, 2019
- 12 Lolo NF Smoke Monitor #2: February 2016 – April 2016; Fire\_Cache\_Smoke\_Lolo\_NF\_Smoke\_Mon  
Downloaded June 14, 2019



**Fire Cache Monitor Locations (No Quality Checks)**

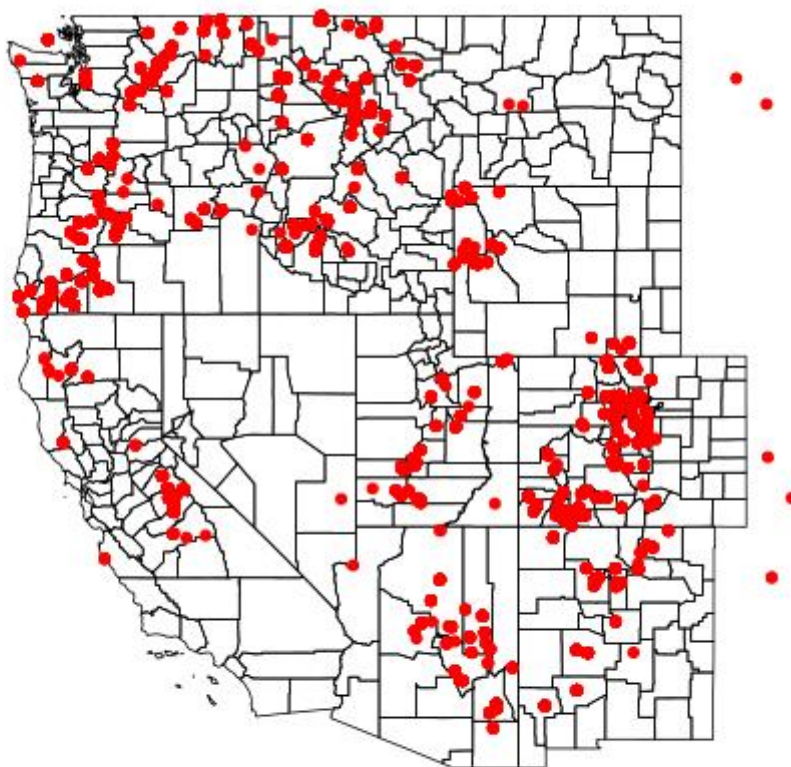


Figure 5: Fire Cache Monitor Locations (No Quality Checks; PM2.5 Processing Step 1).

### 3.1.3 PM<sub>2.5</sub> data from the Federal Land Manager Environmental Database

#### To Do

1. Check again to see if the 2018 data is available (as of February 2019, it was not available)

#### Data Source

- **Contact** Bret Schichtel
- **Citation/Link** <http://views.cira.colostate.edu/fed/DataWizard/Default.aspx>
- **Download Date** March 15, 2018
- **Data (local)** PM<sub>2.5</sub> data from the Federal Land Manager Environmental Database
- **Geographic Extent** Nationwide
- **Temporal Extent** January 1, 2008 - Decemer 31, 2017
- **Acknowledgment** - need to fill in

We downloaded IMPROVE PM<sub>2.5</sub> data from the Federal Land Manager Environmental Database maintained by CIRA and Colorado State University. The IMPROVE monitors capture air quality information in more rural areas (US EPA, 2017c). We are including any of the following parameter codes: 88101, 88500, 88502, 81104 (US EPA, 2017a,b,d).

The data does not come with datum information. When processing the data, the datum is input as WGS84 per an email from Bret Schichtel on October 22, 2018.

A few sites only had only two decimal places for latitude and/or longitude. I contacted Bret Schichtel (bret.schichtel@colostate.edu), who put me in contact with Scott Copeland (scott.copeland@colostate.edu) and Anthony Prenni (anthony\_prenni@nps.gov). Scott Copeland sent Site\_Meta\_Master\_10\_2018.csv, a master file of the IMPROVE sites and Anthony Prenni referred me to the “Current Site List” at <http://vista.cira.colostate.edu/Improve/improve-data/>. The Current Site List seems to have the most decimal places for location information, but does not have all sites. This file is used first and then locations are filled in from Site\_Meta\_Master\_10\_2018.csv. Latitude and Longitude data from the main data files are ignored. See process\_PM25\_IMPROVE\_data\_source\_functions.R.

Downloading IMPROVE Aerosol, RHR II (New Equation) data (one parameter at a time):

1. Reports: Raw data
2. Datasets: “IMPROVE Aerosol, RHR II (New Equation)”
3. Sites: select all
4. Parameters:
  - 1 Mass, PM2.5 (Fine): Code MF, Type PM2.5, Units ug/m<sup>3</sup> LC AQS ID 88101
  - 2 Mass, PM2.5 Reconstructed (Fine): Code RCFM, Type PM2.5 Units ug/m<sup>3</sup> LC, AQS ID 88401
5. Select Dates: By Years and Months: 2008-2017; select all months
6. Aggregations: Non-aggregated
7. Fields: Select All

8. When 2008-2014 data was downloaded: Options: Text File; Generate one file containing all the data; Comma delimited, Standard (“wide” format); Data & Metadata, Display Column Headers, Don’t Display Section Titles, String Quotes: Double Quotes, Missing Values (blank); Date Format: 3/14/2002; Display Results: In a separate browser window; Show Report Log
9. When 2008-2017 data was downloaded: Options: Text File; Generate one file containing all the data; Comma delimited, Standard (“wide” format); Data & Metadata, String Quotes: Double Quotes, Missing Values (blank); Date Format: 3/14/2002; Display Results: In a separate browser window;
10. Submit

Repeat the downloading steps above, except replace step #2 with these Datasets and parameters:

1. IMPROVE Aerosol, RHR III (DRAFT - Preliminary Most Impaired Days dataset)

1 Mass, PM2.5 (Fine) is listed twice

After downloading data, save each file as \*\_top\_removed.csv and remove all rows above the main section of data (approximately 270 rows).

## **File Formats**

csv

## **Original Data File Names**

1. Federal\_Land\_Manager\_IMPROVE\_RHR\_II\_88101\_201922513514530P22rMs.csv
2. Federal\_Land\_Manager\_IMPROVE\_RHR\_II\_88401\_20192251356232212121t.csv
3. Federal\_Land\_Manager\_RHR\_III\_88101\_first\_param\_2019225135946946xJ0L22.csv



Figure 6: IMPROVE RHR II 88101 Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)

**IMPROVE RHR II 88101 Monitor Locations (No Quality Checks)**

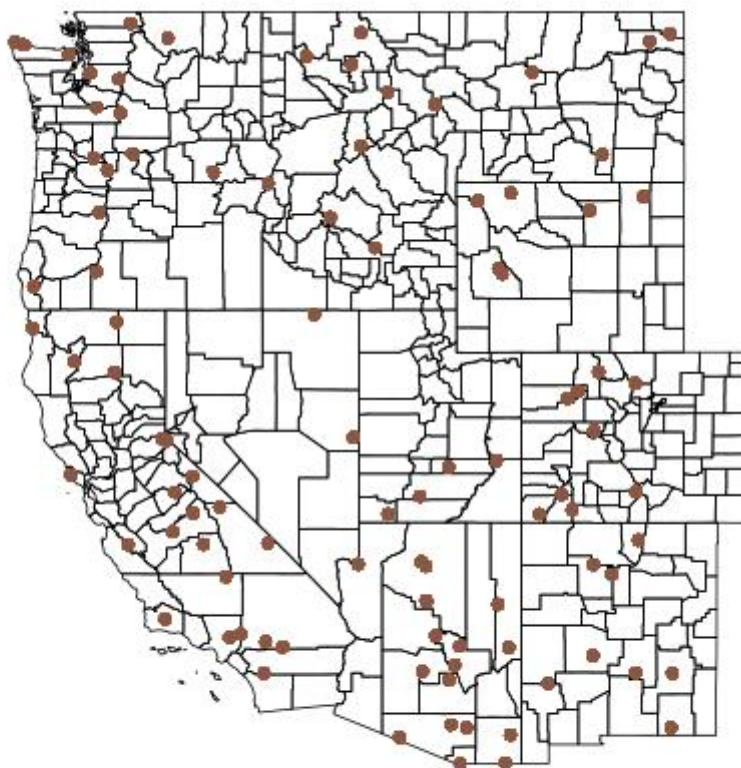


Figure 7: IMPROVE RHR II 88101 Monitor Locations (No Quality Checks; PM2.5 Processing Step 1)

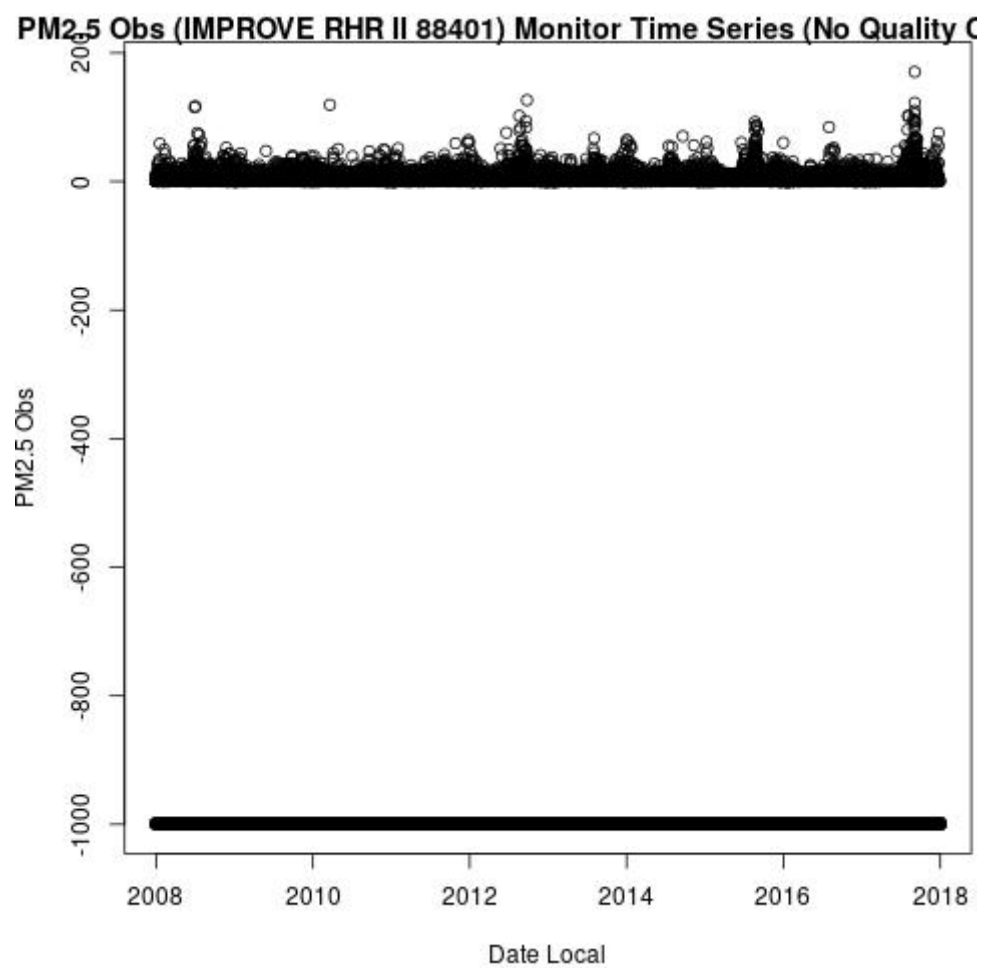


Figure 8: IMPROVE RHR II 88401 Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)

**IMPROVE RHR II 88401 Monitor Locations (No Quality Checks)**



Figure 9: IMPROVE RHR II 88401 Monitor Locations (No Quality Checks; PM2.5 Processing Step 1)



Figure 10: IMPROVE RHR III 88101 Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)



**IMPROVE RHR III 88101 Monitor Locations (No Quality Checks)**

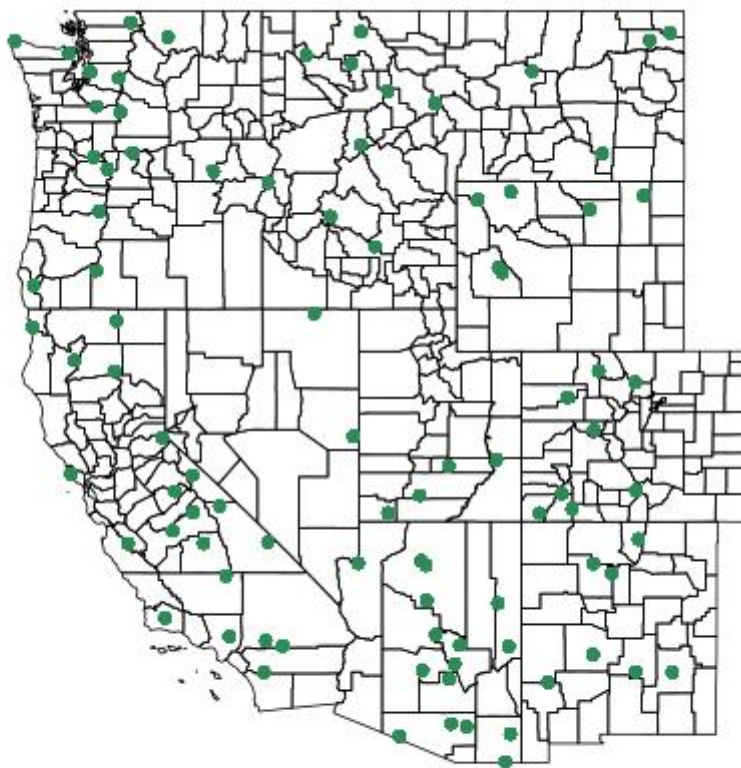


Figure 11: IMPROVE RHR III 88101 Monitor Locations (No Quality Checks; PM2.5 Processing Step 1)

### 3.1.4 PM<sub>2.5</sub> data from the California State Air Quality and Meteorological Information System (AQMIS)

#### To Do

1. Check for availability of 2015-2018 data

#### Data Source

- **Contact** Denise Odenwalder, Denise.Odenwalder@arb.ca.gov
- **Citation/Link** To AQMIS: <https://www.arb.ca.gov/aqmis2/aqmis2.php>
- **Data (local)**
- **Geographic Extent** Whole state of California, wherever there are monitors
- **Temporal Extent** 2008-2014, daily averages
- **Acknowledgment** California Air Resources Board was very helpful in gathering and sending us this data.

#### Brief Description

- PM<sub>2.5</sub> measurements at all monitoring stations in CA
- Some entries are 24-hour measurements while others are the average of hourly measurements
- One entry per 3 days

#### Notes

Reached out to [aqmis@arb.ca.gov](mailto:aqmis@arb.ca.gov) after determining that there was data being collected in CA that is not published on the EPA AQS website. They emailed us within a week, with a file of the data we requested.

#### File Formats

xlsx spreadsheet

#### Data Filtering and Processing

##### Final Variable(s)

##### Methods

- 1.
- 2.

#### Quality Control

##### Script Names

- 1.

##### Original Data File Names

- 1.
- 2.

##### Processed/Cleaned Data File Names

- 1.
- 2.

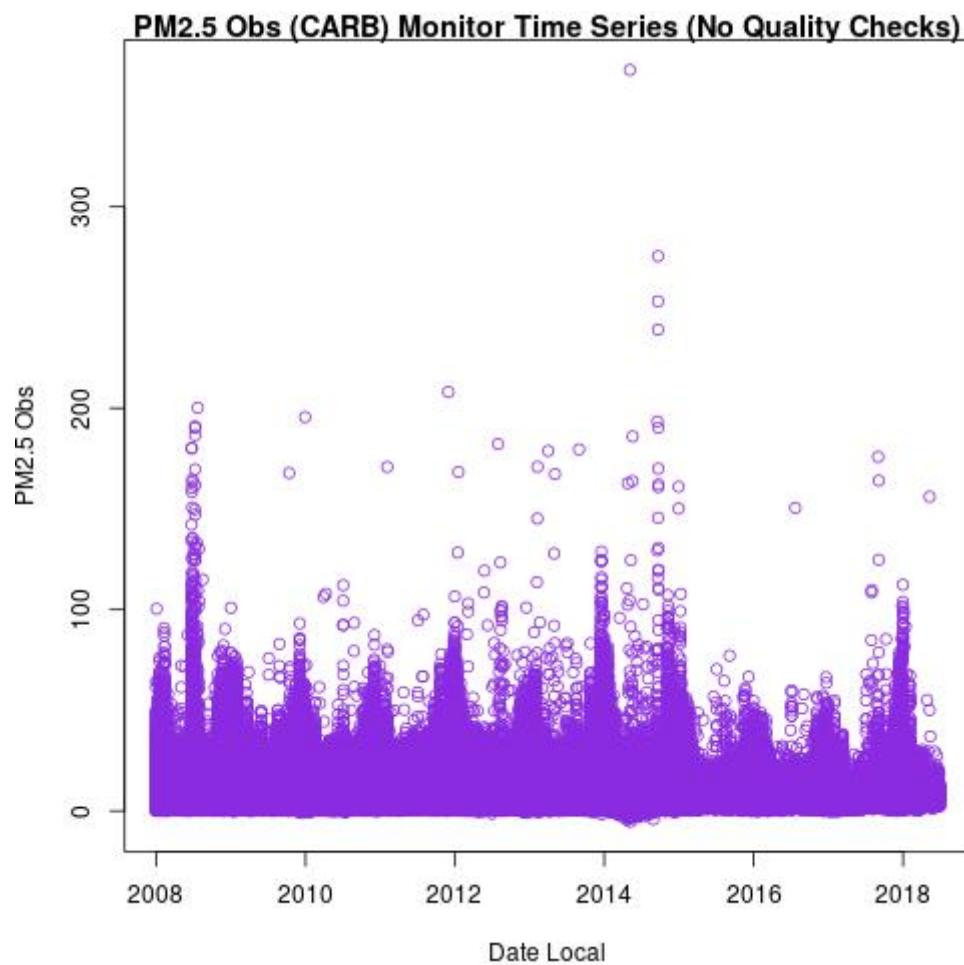


Figure 12: CARB Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)

**CARB Monitor Locations (No Quality Checks)**

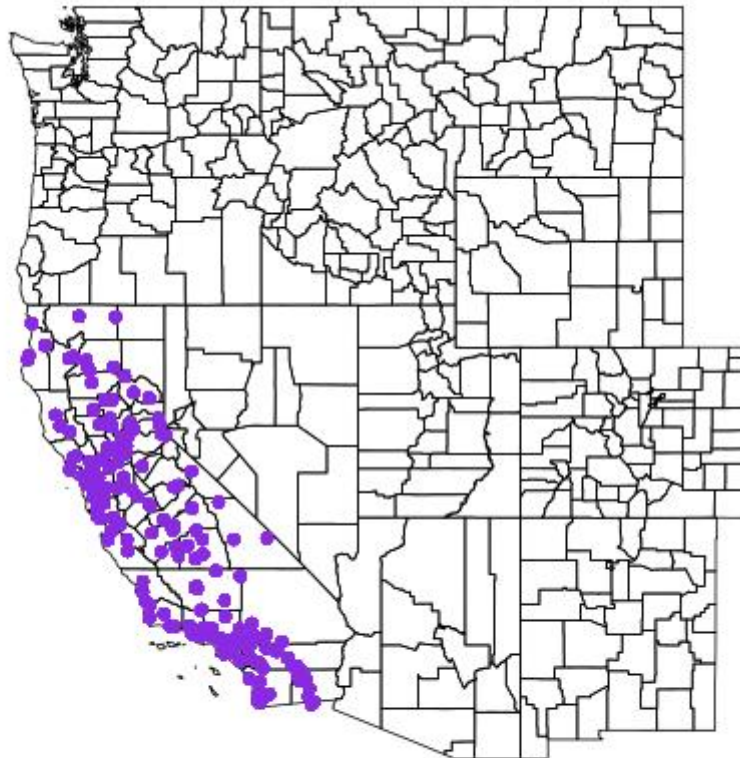


Figure 13: CARB Monitor Locations (No Quality Checks; PM2.5 Processing Step 1)

### 3.1.5 PM<sub>2.5</sub> data from the CARB Mobile Monitoring Network

#### Data Source

- **Contact** Charles Pearson, Manager, California Air Resources Board, Incident Air Monitoring Section [charles.pearson@arb.ca.gov](mailto:charles.pearson@arb.ca.gov) and Joseph McCormack, Air Pollution Specialist, (916) 445-3621, [joseph.mccormack@arb.ca.gov](mailto:joseph.mccormack@arb.ca.gov)
- **Citation/Link**
- **Data (local)** PM<sub>2.5</sub> data from the CARB Mobile Monitoring Network
- **Geographic Extent** California
- **Temporal Extent** 2013 – early 2019
- **Acknowledgment**

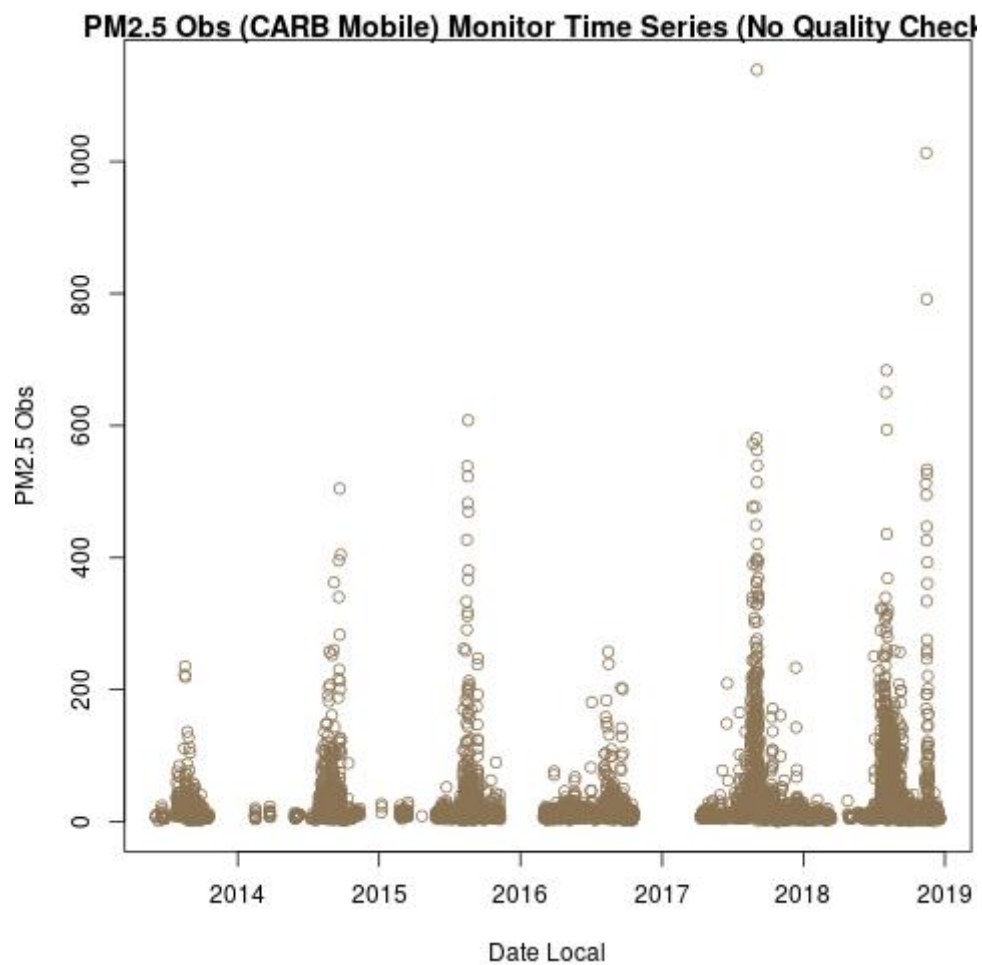


Figure 14: CARB Mobile Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)

**CARB Mobile Monitor Locations (No Quality Checks)**

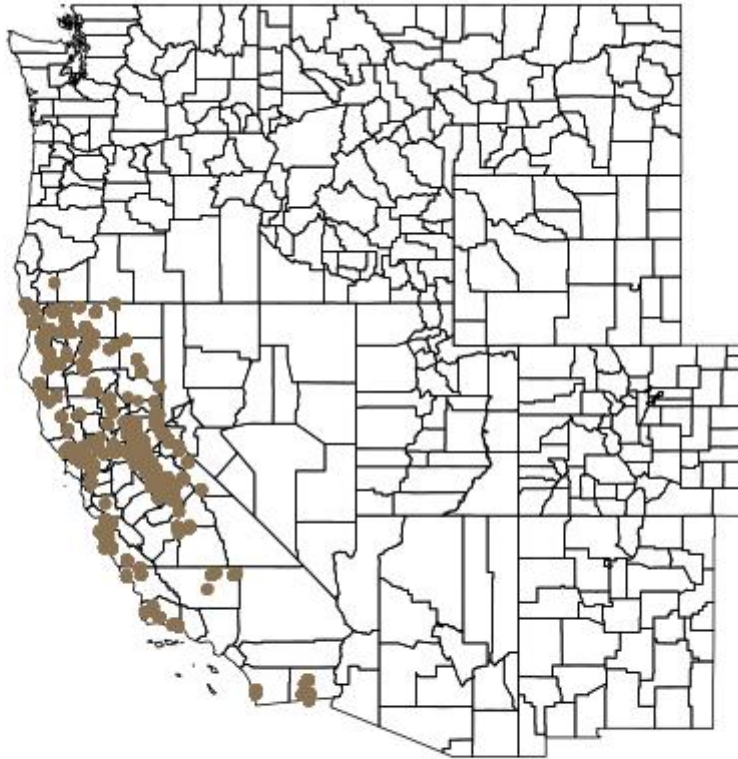


Figure 15: CARB Mobile Monitor Locations (No Quality Checks; PM2.5 Processing Step 1).

### 3.1.6 PM<sub>2.5</sub> Monitor data from Uintah Basin

#### To Do

1. Check to see if there is any more recent data available - email sent June 17, 2019

#### Data Source

- **Contact** Seth Lyman [seth.lyman@usu.edu](mailto:seth.lyman@usu.edu)
- **Citation/Link** <https://usu.app.box.com/s/rigadr7yt7ipir4gzj75vfaazoe8u8mt>
- **Data (local)** PM<sub>2.5</sub> measurements from 10 sites in Uintah Basin, Utah
- **Geographic Extent** Uintah Basin, Utah
- **Temporal Extent** October 2009 - March 2017
- **Acknowledgment** PM<sub>2.5</sub> data from the Uintah Basin were provided by Seth Lyman at Utah State University.

#### Brief Description

PM<sub>2.5</sub> data were provided by Seth Lyman at Utah State University via email on January 16, 2018. The .xlsx file has PM<sub>2.5</sub> data from 10 stations during 2009-2017. The .png file has the longitude and latitude of each site.

#### Notes

Additional information from Seth's email:

"I've attached most of the PM<sub>2.5</sub> observations that have ever been collected in the Uintah Basin. What are in the Excel file are 24-hr average data. Data from Roosevelt, Vernal, Ouray, Red Wash, Myton, and Rangely are from the EPA AQS database.

Data from Horsepool are from a BAM 1020 monitor that we operate every winter. Data in Ft. Duchesne and Randlett are 24-hr filter samples that were analyzed gravimetrically. Data from Rabbit Mountain are from a BAM 1020, and data through mid-2013 are in the AQS database.

I have hourly data from Horsepool and Rabbit Mountain if you'd rather have that.

Site locations are given in the list of monitoring stations for the Basin below."

The .png file is easier to read in some programs than others, e.g., it looks fine in "Paint," but not "Photos."

#### File Formats

Excel and png

#### Data Filtering and Processing

FinalPM2.5\_multiyear\_thruwint2017\_sheet1.csv is the first sheet of FinalPM2.5\_multiyear\_thruwint2017.xlsx converted to .csv, and the second row of the header was merged into the first (24hr avg PM<sub>2.5</sub>).

FinalPM2.5\_multiyear\_thruwint2017\_GISSheet.csv is the third sheet of FinalPM2.5\_multiyear\_thruwint2017.xlsx converted to .csv and gives the latitude and longitude of each site. This sheet originally did not have location information from the Rangely site, so this was filled in by hand with the numbers from UintahBasinSiteLocations.png.



**Final Variable(s)****Methods**

- 1.
- 2.

**Quality Control****Script Names**

- 1.

**Original Data File Names**

1. FinalPM2.5\_multiyear\_thruwint2017.xlsx
2. UintahBasinSiteLocations.png

**Processed/Cleaned Data File Names**

1. FinalPM2.5\_multiyear\_thruwint2017\_sheet1.csv
2. UintahBasinSiteLocations.png

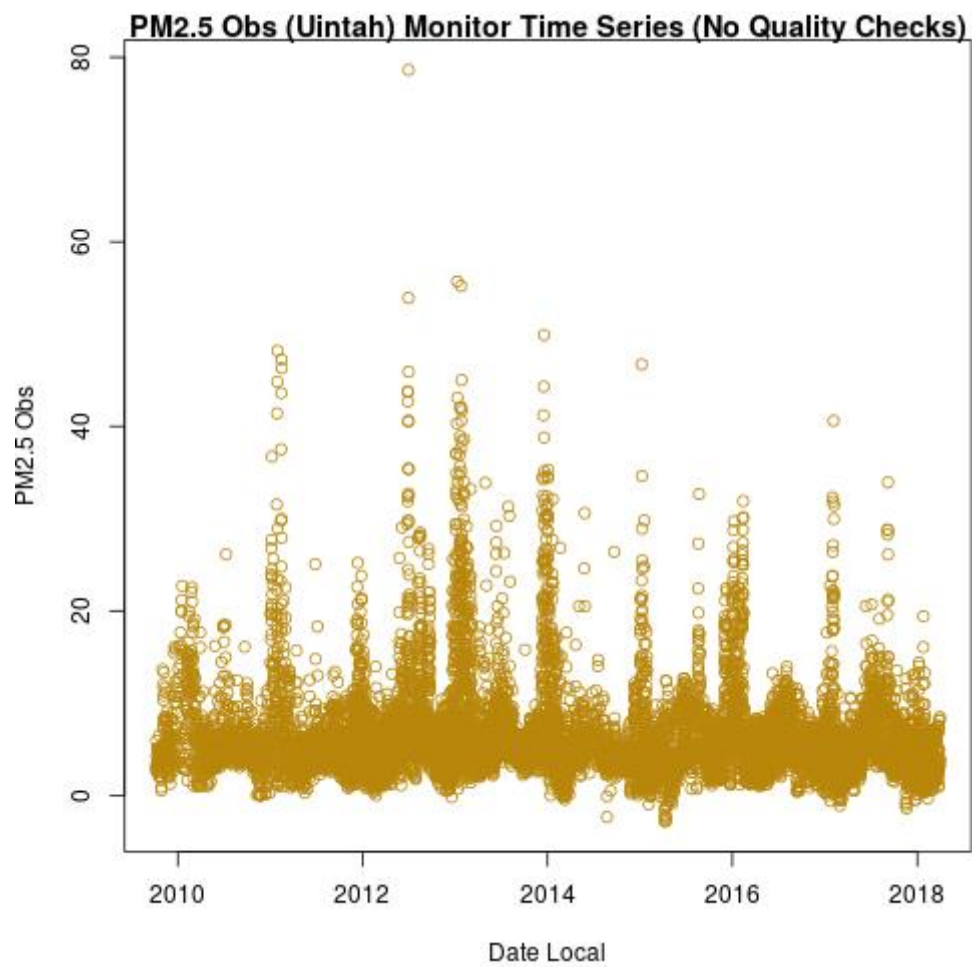


Figure 16: Uintah Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)

**Uintah Monitor Locations (No Quality Checks)**



Figure 17: Uintah Monitor Locations (No Quality Checks; PM2.5 Processing Step 1)

### 3.1.7 PM<sub>2.5</sub> data from PCAPS in the Salt Lake Valley

#### Data Source

- **Contact** Dr. Geoff Silcox in Chemical Engineering at the University of Utah ([geoff@chemeng.utah.edu](mailto:geoff@chemeng.utah.edu))
- **Citation/Link** Publication: <https://www.sciencedirect.com/science/article/pii/S1352231011011204> [Silcox et al. \(2012\)](#) (Data was received from Dr. Silcox via email on February 6, 2018.)
- **Data (local)** PM<sub>2.5</sub> data from the Persistent Cold Air Pool Study (PCAPS)
- **Geographic Extent** Salt Lake Valley
- **Temporal Extent** January - February, 2011
- **Acknowledgment** Dr. Geoff Silcox

#### Brief Description

#### Notes

#### File Formats

.xlsx

#### Data Filtering and Processing

PCAPS\_Site\_Locations.csv is the same data as Table 1 of final\_publication.pdf, and has the site locations and elevation.

#### Final Variable(s)

#### Methods

- 1.
- 2.

#### Quality Control

#### Script Names

- 1.

#### Original Data File Names

1. final\_publication.pdf (Publication of paper)
2. MiniVol\_data.xlsx

#### Processed/Cleaned Data File Names

1. MiniVol\_data.csv
2. PCAPS\_Site\_Locations.csv

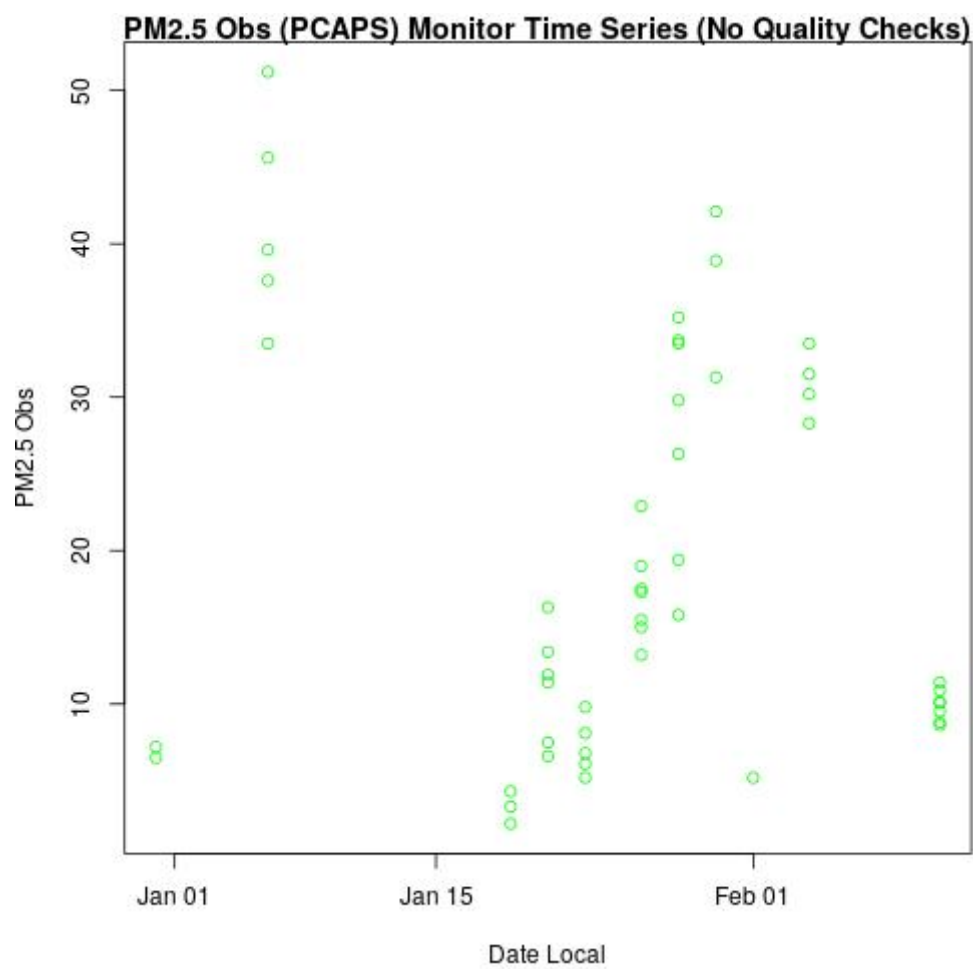


Figure 18: PCAPS Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1); 2010-12-31 - 2011-02-11

**PCAPS Monitor Locations (No Quality Checks)**



Figure 19: PCAPS Monitor Locations (No Quality Checks; PM2.5 Processing Step 1).

### 3.1.8 PM<sub>2.5</sub> data from the Utah Department of Environmental Quality

#### To Do

1. check for data availability between 2014-2018

#### Data Source

- **Contact**
- **Citation/Link** <http://www.airmonitoring.utah.gov/dataarchive/archpm25.htm>
- **Data (local)**
- **Geographic Extent** Varies...
- **Temporal Extent** Hourly Value CSVs
- **Acknowledgment**

#### Brief Description

PM<sub>2.5</sub> data from all monitoring stations in Utah

#### Notes

There was a lot of overlap with the EPA AQS data, so we took data only from the PM<sub>2.5</sub> stations not reported by the EPA. This ended up being one or more of three stations (NP, HC, and RS) for 2009, 2010, 2012, and 2013.

Information about the monitoring stations: <http://www.airmonitoring.utah.gov/network/Counties.htm>

Meta information about monitors obtained from <http://www.airmonitoring.utah.gov/dataarchive/2016DailyMaxPM25.pdf>

#### File Formats

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

- 1.
- 2.

#### Quality Control

#### Script Names

- 1.

#### Original Data File Names

- 1.
- 2.

#### Processed/Cleaned Data File Names

- 1.
- 2.

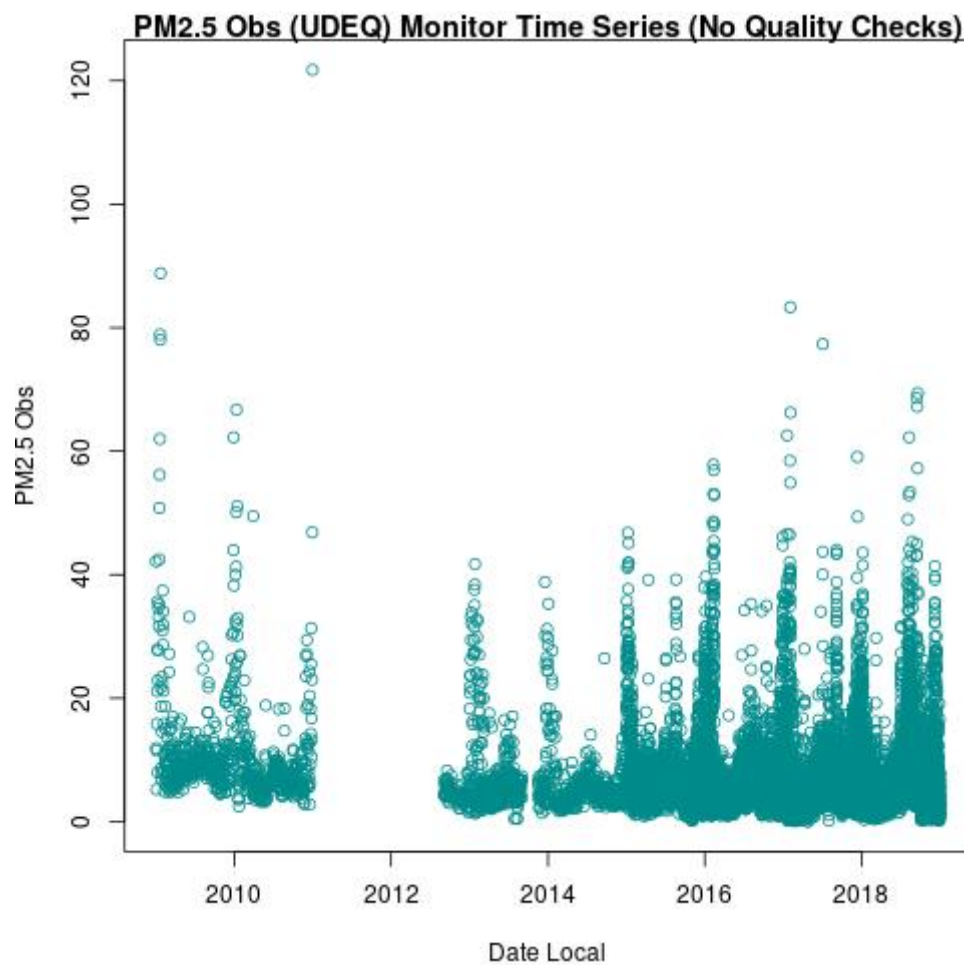


Figure 20: UDEQ Monitor Time Series (No Quality Checks; PM2.5 Processing Step 1)



**UDEQ Monitor Locations (No Quality Checks)**

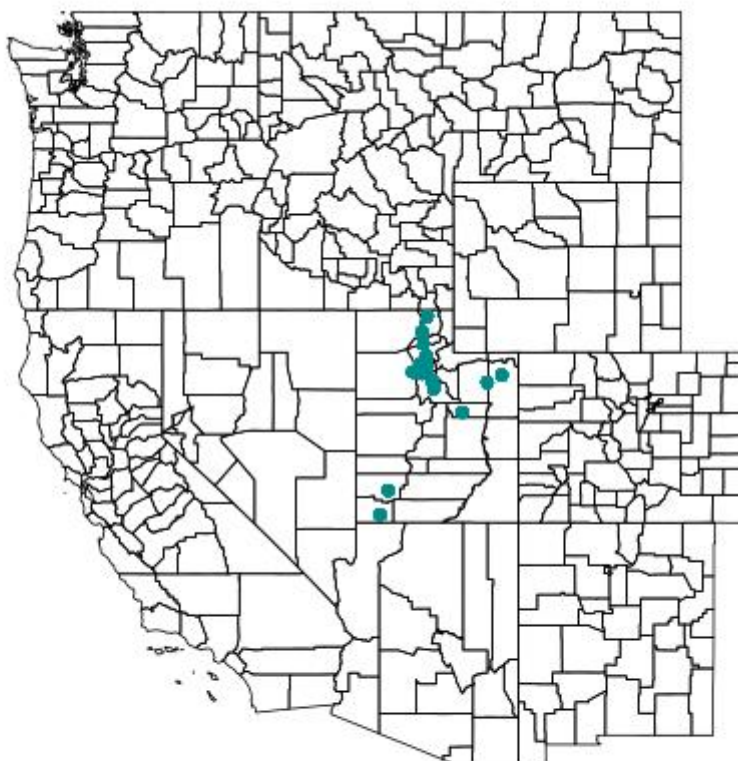


Figure 21: UDEQ Monitor Locations (No Quality Checks; PM2.5 Processing Step 1)

### 3.1.9 Processing PM<sub>2.5</sub> data

Below are the scripts that process and compile the PM<sub>2.5</sub> data. The “\*” in each of the file names refers to the current “processed\_data\_version” (set in general\_project\_functions.R) since compiling the data is an ongoing process.

1. Script1\_Install\_Pkgs.R » install packages
2. Process\_PM25\_data\_step1.R » compiles the various PM<sub>2.5</sub> data sources into a single data frame. Data eliminations to the data are:
  - 1 EPA: remove states that are not in our study area
  - 2 CARB Mobile :
    - i. remove hourly observations that have negative concentrations
    - ii. remove rows with NA values for Latitude, Longitude, date, PM<sub>2.5</sub>, RHi, Flow, and voltage
  - 3 DRI:
    - i. remove hourly observations that have negative concentrations

Update time frame of study if necessary (set in general\_project\_functions.R). The output from this script is a csv file and sink .txt for each PM<sub>2.5</sub> data source as well as a file with all of the PM<sub>2.5</sub> data sources merged together (“PM25\_Step1\_part\_\*.csv”). This script takes about 10 minutes to run on a laptop (3 cores). The script runs in parallel, with each data source sent to a different processor. Output files:

- 1 PM25\_Step1\_part\_\*.csv (the main data file)
- 2 PM25\_CARB\_Step1\_part\_\*.csv
- 3 PM25\_CARB\_Step1\_part\_\*\_combining\_sink.txt
- 4 PM25\_EPA\_Step1\_part\_\*.csv
- 5 PM25\_EPA\_Step1\_part\_\*\_combining\_sink.txt
- 6 PM25\_FireCacheDRI\_Step1\_part\_\*.csv
- 7 PM25\_FireCacheDRI\_Step1\_part\_\*\_combining\_sink.txt
- 8 PM25\_IMPRHR2MF88101\_10010\_Step1\_part\_\*.csv
- 9 PM25\_IMPRHR2MF88101\_10010\_Step1\_part\_\*\_combining\_sink.txt
- 10 PM25\_IMPRHR2RCFM88401\_10010\_Step1\_part\_\*.csv
- 11 PM25\_IMPRHR2RCFM88401\_10010\_Step1\_part\_\*\_combining\_sink.txt
- 12 PM25\_IMPRHR3MF88101\_10006\_Step1\_part\_\*.csv
- 13 PM25\_IMPRHR3MF88101\_10006\_Step1\_part\_\*\_combining\_sink.txt
- 14 PM25\_PCAPS\_Step1\_part\_\*.csv
- 15 PM25\_PCAPS\_Step1\_part\_\*\_combining\_sink.txt
- 16 PM25\_UintahBasin\_Step1\_part\_\*.csv
- 17 PM25\_UintahBasin\_Step1\_part\_\*\_combining\_sink.txt
- 18 PM25\_UtahDEQ\_Step1\_part\_\*.csv
- 19 PM25\_UtahDEQ\_Step1\_part\_\*\_combining\_sink.txt
- 20 PM25\_CARBMobile\_Step1\_part\_\*.csv
- 21 PM25\_CARBMobile\_Step1\_part\_\*\_combining\_sink.txt
- 22 Time series of raw data and map of locations for each data source (writes to estimate-pm25/LaTeX\_documentation/Code\_Outputs/ folder)

Notes that are useful when incorporating new data:

- 1 Process\_PM25\_data\_step1.R: change n\_data\_sets to higher number if adding new data

source

- 2 For the Federal Land Manager Database (IMPROVE) data: Download data as described in Section 3.1.3. Edit “skip\_n\_files” in process\_PM25\_parallel\_wrapper\_function.R so that FMLEdata\_Parameter\_MetaData will load the row with the header ‘DatasetID, Parameter, Code, AQSCode, Units, Description’ for each IMPROVE file.

Note about flag added to data:

- 1 For DRI and CARB Mobile data, put in flags for voltage data outside the range 12.5-14.4 V. This range was suggested by Joseph McCormack at CARB. Flags for relative humidity and flow were also added. Thresholds are defined in the code in general\_project\_functions.R.
3. Process\_PM25\_data\_step2.R » cleans the data. This script takes about 5 minutes on a laptop. This script outputs the following files:
  - 1 PM25\_Step2\_part\_\*.csv (main cleaned data file)
  - 2 PM25\_Step2\_part\_\*\_sink.txt (description and summaries of the data at each step of the quality cutting)
  - 3 PM25\_Step2\_part\_\*\_Locations.csv (list of unique locations from main cleaned data file)
  - 4 PM25\_Step2\_part\_\*\_Locations\_Dates.csv (list of unique locations/dates from main cleaned data file)
  - 5 Data\_Removed\_in\_PM25\_Step2\_part\_\*.csv (all data that was removed from the cleaned file and the reason for removal of each data point is indicated)

The following is a list of the quality cuts and changes made to the data:

- 1 Replace “UNKNOWN” datum in EPA data with “NAD27” per Colleen’s advice.
- 2 Remove negative and NA PM<sub>2.5</sub> concentrations. This includes removing all data for a monitor on a given day if any of the hourly observations were negative.
- 3 For the hourly data, remove monitor-days that do not have at least 18/24 observations.
- 4 For DRI and CARB Mobile data, remove data with voltage flags.
- 5 For DRI and CARB Mobile data, remove data with flow flags. Different flow thresholds were set for these data sets.
- 6 for DRI and CARB Mobile data, remove data with humidity flags - **Still need to clarify with CARB whether RH<sub>i</sub> is internal or ambient RH. RH<sub>i</sub> is currently fed into the Relative humidity column in input\_mat, but it might be better to put it in the internal sensor RH. RH<sub>i</sub> is the variable that should have the threshold, not RH<sub>x</sub>.**
- 7 June 6, 2014 24-hr average PM<sub>2.5</sub> concentration from monitor “Smoke NCFS E-BAM #1” (Fire\_Cache\_Smoke\_DRI\_Smoke\_NCFS\_E\_BAM\_N1.csv) is 24,203 ug/m<sup>3</sup>. There’s nothing apparent wrong with the hourly data, however, this is the only day of data that made it through the other quality checks from this data file. This suggests that this monitor is suspect, and will be removed.
- 8 Remove data points with lat/lon outside this box: (50,-126) to (25,-101). These values are defined in general\_project\_functions.R.
- 9 Remove data outside the study period (defined in general\_project\_functions.R).
- 10 Remove data with “Event\_Type” = “Excluded”
- 11 Remove data with more than 0.001 degrees variation in Lat/lon within a day

- 12 Remove data from monitor “USFS R2-265” (Fire\_Cache\_Smoke\_USFS\_R2-265.csv) between October 2016 - May 2017. The concentrations (some higher than 65,000,000 ug/m3) and the behavior of the concentrations (frequently changing by exactly 1000 ug/m3 from one hour to the next) are unrealistic. The data outside this time frame look more reasonable.
  - 13 Remove data from monitor “USFS R2-264” (Fire\_Cache\_Smoke\_USFS\_R2-264.csv”) between October 2016 - October 2017. The behavior of the concentrations (frequently changing by exactly 1000 ug/m3 from one hour to the next) are unrealistic. The data outside this time frame look more reasonable.
  - 14 Remove data from monitor “FWS Smoke #1” (Fire\_Cache\_Smoke\_DRI\_FWS\_Smoke\_N1.csv) between February 11-14, 2017. The behavior of the concentrations (frequently changing by exactly 1000 ug/m3 from one hour to the next) are unrealistic. The data outside this time frame look more reasonable.
  - 15 Remove data from monitor “Smoke #22” (Fire\_Cache\_Smoke\_DRI\_Smoke\_22.csv) on June 15, 2012. The behavior of the concentrations (frequently changing by exactly 1000 ug/m3 from one hour to the next) are unrealistic. The data outside this time frame look more reasonable.
  - 16 Removing data from monitor “USFS-R2-69” during August 31, 2016 - September 5, 2016 because the concentrations look unrealistic and can shift by more than 10,000 ug/m3 from one hour to the next. The data outside this time frame look more reasonable.
  - 17 Removing data from monitor “USFS-R1-307” during May 4-19, 2015 because the concentrations look unrealistic and can shift by more than 10,000 ug/m3 from one hour to the next. The data outside this time frame look more reasonable.
  - 18 Removing data from monitor “Smoke # 216” during May 16- June 17, 2018 because the concentrations look unrealistic and are constant at 851 ug/m3 for extended hours at a time. The data outside this time frame look more reasonable.
  - 19 Removing data from monitor “Smoke USFS R2-922” during July 26-28, 2016 because the concentrations look unrealistic and can shift by thousands of ug/m3 from one hour to the next. The data outside this time frame look more reasonable.
  - 20 Remove data from monitor “ARB 1027” (ARB 1027 2018 Historical Data.csv) during August 2-9, 2018. Starting late on August 2, 2018, the data values have a constant value through August 9, 2018, which is unrealistic. The data outside this time frame look more reasonable.
4. Process\_PM25\_data\_step3.R » convert all PM2.5 data to the same datum (NAD83). Take the converted location info and put it into the data frame with the daily PM<sub>2.5</sub> data. This script also rounds all lat/lon info to 5 digits. This script takes several minutes on a laptop. This script also outputs the dates/locations with 7 day lags (used for active fire points data extraction). This script outputs these files:
- 1 PM25\_Step3\_part\_\*\_NAD83.csv (main data file)
  - 2 PM25\_Step3\_part\_\*\_Locations\_NAD83\_include\_old\_projection.csv
  - 3 PM25\_Step3\_part\_\*\_Locations\_NAD83.csv
  - 4 PM25\_Step3\_part\_\*\_Locations\_Dates\_NAD83\_include\_old\_projection.csv
  - 5 PM25\_Step3\_part\_\*\_Locations\_Dates\_NAD83.csv
  - 6 PM25\_Step3\_part\_\*\_Locations\_Dates\_NAD83\_wLags.csv

5. Process\_PM25\_data\_step4\_parallel.R » composite replicate data and data where there are co-located monitors. This script produces two different versions of the data:
  - 1 PM25\_Step4\_part\_\*\_de\_duplicated\_aves\_ML\_input.csv takes the averages of all available co-located data
  - 2 PM25\_Step4\_part\_e\_de\_duplicated\_aves\_prioritize\_24hr\_obs\_ML\_input.csv prioritizes data that was originally a 24-hour observation (typically FRM/filter-based measurements) over the data that was an average of hourly observations.

Calls these functions:

- 1 PM25\_station\_deduplicate\_aves\_parallel.fn
- 2 PM25\_station\_deduplicate\_aves\_parallel.fn
- 3 prioritize\_daily\_obs\_over\_hourly.fn (only called if de\_duplication\_method is set to “prioritize\_24Hour\_Obs”)
- 4 fill\_input\_mat\_aves.fn
  - i. concatenate\_within\_column\_function.R
  - ii. concatenate\_vector\_of\_strings.fn

Step 4 is ran on EC2 (AWS) with these settings (see also the instructions on google docs):

- 1 2019-03-13-earthlab-docker
- 2 m5a.4xlarge Type
- 3 30 GiB storage
- 4 rstudio security group
- 5 earthlab/r-reidgroup docker container

6. Process\_PM25\_data\_create\_report.R » map locations of monitors by data source/year

### **3.1.10 Determine which dates/locations are new to most recent “processed\_data\_version”**

See Merging\_loc\_dates.R

1. part a: early version created while writing code. Disregard.
2. part b: first batch of PM2.5 data that was used to extract predictor data, years 2008-2014
3. part c: county centroids, 2008-2014. This work flow has now been moved to the “Locations\_of\_interest”.
4. part d: second batch of PM2.5 data, adds AQS data for 2015-2018.
5. part e: updates IMPROVE and Fire Cache data to include 2008-2018 (whatever portion of that was available for download)
6. part f: add 37 mobile monitors from CARB (2013-2018), add more data from Fire Cache Data, EPA, CARB, UT DEQ, and Uintah Basin

### **3.1.11 Notes about very high data points**

Only one data point with concentrations above 1000 ug/m3 made it through all of the quality checks (without any flags):

1. ARB 1013 (1013.250 ug/m3 on 2018-11-14)

This observation was located between Paradise and Chico, CA and occurred during the Camp Fire.

## 3.2 MODIS AOD

### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

### Brief Description

We will use AOD estimates from the Deep Blue retrieval algorithm for AOD from the MODIS instrument on the NASA Terra and Aqua satellites (MOD04\_L2 and MYD04\_L2) ([Sayer et al., 2013](#)). The MODIS product is available twice daily at a 10 km spatial resolution for cloud-free scenes and is available longer than our 2008-2014 study period ([NASA LAADS DAAC, 2017a,b](#)).

AOD products use cloud filtering algorithms that often remove pixels in the center of the smoke plumes because they are assumed to be clouds due to high reflectivity ([Kondragunta and Seybold, 2009](#)). Given that these can be in the middle of smoke plumes, often the locations most heavily impacted by smoke have missing data for a key variable, AOD. In our previous work in summer in California when rain clouds are incredibly rare, we could be confident that missing values not along the coast were not clouds. However, for this larger study region and time period, this will be a bigger challenge. We will attempt to isolate smoke plumes from true clouds using satellite imagery and smoke plume polygons from NOAA's Hazard Mapping System Fire Smoke Product ([NOAA OSPO, 2017](#)). We will then estimate missing values within validated smoke plumes, but not within clouds, using radial basis functions as was done in our previous work ([Reid et al., 2015b](#)). Radial basis functions are exact interpolation functions that will return observed AOD values where they exist but can interpolate higher values than nearby observations in missing locations, which is needed since the missing values were removed due to their high reflectivity ([Reid et al., 2015b](#)).

### Notes

### File Format

.hdf

### Data Filtering and Processing

### Final Variable(s)

### Methods

1. Step 1: Download the MODIS AOD data sets from both Terra and Aqua sensors:

Using the [NASA EarthData online search tool](#), search for the 'MOD04' (Terra) data set. Set temporal extent by drawing polygon and set spatial extent by adjusting the appropriate filter on the web interface. Select the collection and proceed to download data. For data download options, specify "Stage for Delivery" through the "FTPPull" distribution option. Specify the email address for orders to be sent to. Orders will be sent to your email with instructions on how to connect to the FTP server and pull the ordered data into your local workspace through the command line. Because the amount of data being requested is large, the orders will come through several separate emails. Repeat this step for the 'MYD04'

(Aqua) data set. All of the raw downloaded data from this step will be in .hdf file format.

2. Step 2: Set up file system for data processing:

Create a directory locally named 'collected\_data'. In this directory, make two child directories named "MOD04\_terra" and "MYD04\_aqua". Follow instructions in email to download data through FTP into the appropriate MODIS directory ('MOD04\_terra' or 'MYD04\_aqua') depending on whether the order is from the Terra or Aqua sensor.

3. Step 3: Extract lat, long, and aod values from .hdf files and save into .csv files

Run script 'modis\_aod\_create\_csv\_file.py'. This script will take all the .hdf files that you have downloaded and store the lat, long and aod value for non-null pixels from the 'Deep\_Blue\_Aerosol\_Optical\_Depth\_550\_Mid\_Resolution' SDS. A .csv file will be created for each corresponding .hdf file.

4. Step 4: Create .shp file for each .csv file

Run 'modis\_aod\_convert\_csv\_to\_shapefile.py'. This script will read in the .csv files and convert them to .shp files using multiprocessing, which speeds up the process.

5. Step 5: Project .shp files to US Albers Equal Area Conic

Run 'modis\_aod\_project\_to\_albers.py'. This script will reproject the .shp files to be US Albers Equal Area Conic (ESRI:102003).

6. Step 6: Combine .shp files for same date and convert to raster with 10km resolution

Run 'modis\_aod\_create\_daily\_averages.py'. This will combine all .shp files from the same date and then produce a raster for each with a 10km resolution. Then, the interpolated grids are clipped to the 11 western states (our study area) with a 100km buffer.

7. Step 7: Extract MODIS AOD value at EPA monitor locations

Using ExtractValuesToPoints tool in ArcGIS.

## **Quality Control**

### **Script Names**

1. modis\_aod\_create\_csv\_file.py
2. modis\_aod\_convert\_csv\_to\_shapefile.py
3. modis\_aod\_project\_to\_albers.py
4. modis\_aod\_create\_daily\_averages.py

### **Data File Names**

1. western\_states\_merge.shp

### 3.3 GASP-West AOD

#### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

We will use AOD estimates from the Geostationary Operational Environmental Satellite West (GOES-West) Aerosol Smoke Product (GASP-West AOD). The GASP product is available at a 4 km resolution at nadir with retrievals every 30 minutes during daylight hours and is available from 2006 onward ([NOAA NCEI, 2017](#)).

AOD products use cloud filtering algorithms that often remove pixels in the center of the smoke plumes because they are assumed to be clouds due to high reflectivity ([Kondragunta and Seybold, 2009](#)). Given that these can be in the middle of smoke plumes, often the locations most heavily impacted by smoke have missing data for a key variable, AOD. In our previous work in summer in California when rain clouds are incredibly rare, we could be confident that missing values not along the coast were not clouds. However, for this larger study region and time period, this will be a bigger challenge. We will attempt to isolate smoke plumes from true clouds using satellite imagery and smoke plume polygons from NOAA's Hazard Mapping System Fire Smoke Product ([NOAA OSPO, 2017](#)). We will then estimate missing values within validated smoke plumes, but not within clouds, using radial basis functions as was done in our previous work ([Reid et al., 2015b](#)). Radial basis functions are exact interpolation functions that will return observed AOD values where they exist but can interpolate higher values than nearby observations in missing locations, which is needed since the missing values were removed due to their high reflectivity ([Reid et al., 2015b](#)).

#### Notes

websites: <https://www.ncdc.noaa.gov/data-access/satellite-data/satellite-data-access-datasets>  
<https://www.ncdc.noaa.gov/data-access/satellite-data/satellite-data-access-datasets>

Order form for data: <https://www.ncdc.noaa.gov/has/has.dsselect>

<https://www.ncdc.noaa.gov/doclib/index.php?choice=dsi&searchstring=3635&submitted=1&submitted=Search>

#### File Format

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

##### 1. Download Data

Navigate to NCEI's [Archive Information Request System \(AIRS\)](#). Scroll down and click on 'Satellite' to expand menu. Click on 'Goes Products' to expand menu. Click on 'Order Data'. Select GOES-West for satellite ID, GASP-AOD-GZ for data type, and appropriate start and end date. Select "Yes" for Submit Batch. Enter email address and submit order. You



will get emails later on with FTP links to your data. Run ‘Generic\_FTP\_download\_to\_S3.py’ on an EC2 instance passing in the FTP url as the argument. This will download the data and upload it to S3 (and then delete it off the EC2 instance).

## **Quality Control**

### **Script Names**

1. Generic\_FTP\_download\_to\_S3.py

### **Data File Names**

- 1.

### **3.4 Hazard Mapping System (HMS)**

#### **Data Source**

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### **Brief Description**

See ? and references therein (especially Rolph et al 2009) to see descriptions of HMS data.

#### **Notes**

#### **File Formats**

#### **Data Filtering and Processing**

#### **Final Variable(s)**

#### **Methods**

- 1.
- 2.

#### **Quality Control**

#### **Script Names**

- 1.

#### **Original Data File Names**

- 1.
- 2.

#### **Processed/Cleaned Data File Names**

- 1.
- 2.

### **3.5 MERRA-2**

#### **Data Source**

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### **Brief Description**

#### **Notes**

#### **File Formats**

#### **Data Filtering and Processing**

#### **Final Variable(s)**

#### **Methods**

- 1.
- 2.

#### **Quality Control**

#### **Script Names**

- 1.

#### **Original Data File Names**

- 1.
- 2.

#### **Processed/Cleaned Data File Names**

- 1.
- 2.

### 3.6 MODIS Thermal Anomalies/Fire Daily L3 Global 1km (MCD14DL)

#### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

We will collect data about fire detection locations, size, and fire radiative power from the MODIS Thermal Anomalies/Fire Daily L3 Global 1km (MOD14 and MYD14) ([Giglio et al., 2006](#); [Hawbaker et al., 2017](#)). Using GIS techniques, we will create daily clusters of fire points and use these to calculate: (1) the distance to the nearest fire cluster by day and (2) the sum of Fire Radiative Power (FRP) of the nearest clusters of fires by day as it is likely that smoke levels are higher closer to fires. The MODIS product spans longer than our study period (2008-2014) at daily temporal resolution and has a spatial resolution of 1 km.

#### Notes

#### File Format

.shp

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

1. Navigate to the [NASA EarthData FIRMS Archive Download site](#)
2. Select "Create new Request"
3. In the dropdown for region, select "Custom Region" and draw a bounding box around study area
4. In the dropdown for fire data source, select "MODIS C6"
5. Select dates for study time period
6. In the dropdown for file type, select "Shapefile (.shp)"
7. Enter your email address
8. You will get an email with a download link containing a zipfile with the data
9. Run `active_fire.py` with the required arguments. This script will spatially join the fire data with the timezone data. This is a necessary step for adjusting the timestamp from UTC to local in the next step.

10. Create fields "ACQ\_TIME" and "ACQ\_DATE" in ArcMap, QGIS, or any other method of your choosing in the output shp file from the previous step. Extract the time and date from the "adj\_time" column to populate these new fields.
11. Run buffers.py with the required arguments. This script will take in a csv file with lat, lon, and dates (the PM2.5 stations/points of interest), a shp file with buffers around each of these observation (specified as arguments), the fire shp file that was edited in the previous step, and an output csv filename. The output is a csv file similar to the input csv, but with an additional columns that includes the number of active fires in each buffer. Note: the buffer shp file used in this study was created with geodesic buffering due to the large buffer sizes used (25km, 50km, 100km, 500km radiuses). We decided that it would be better to use geodesic buffering for large areas (as opposed to planar buffering) because they will not be affected by distortion introduced from the projection, which is a bigger issue with larger areas.
12. Run merge\_with\_zeros.py with the required arguments. This merges the dataframe created in the previous step with the original dataframe of station locations and dates with over 1 million rows. It matches the rows with fire counts and give a value of 0 for all else.

## **Quality Control**

### **Script Names**

1. active\_fire.py
2. buffers.py
3. merge\_with\_zeros.py

### **Data File Names**

1. timezones\_western\_us.json

### 3.7 Landsat-derived burned area essential climate variable (BAECV) fire activity data

#### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

We will collect data about fire detection locations, size, and fire radiative power from the Landsat-derived burned area essential climate variable (BAECV) fire activity data, ([LP DAAC, 2017](#)). Using GIS techniques, we will create daily clusters of fire points and use these to calculate: (1) the distance to the nearest fire cluster by day and (2) the sum of Fire Radiative Power (FRP) of the nearest clusters of fires by day as it is likely that smoke levels are higher closer to fires. The BAECV can detect fires larger than 4 km<sup>2</sup> and provides an estimate of the date of the fire and is available from 1984-2015.

#### Notes

#### File Format

.shp

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

1. BAECV data set already downloaded by EarthLab fire group. Navigate to the ‘earthlab-ls-fire’ S3 bucket, then the v1.1 subdirectory. Here you will find yearly .tar.gz files. Have not spent time decompressing files and exploring data yet but my guess is that within each yearly file, we will find more detailed, daily burn data.

#### Quality Control

#### Script Names

1. n/a

#### Data File Names

1. n/a

### 3.8 MODIS/Terra and Aqua Burned Area Monthly L3 Global 500 m SIN Grid V006 (MCD64A1)

#### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

We will collect data about fire detection locations, size, and fire radiative power from MODIS/Terra and Aqua Burned Area Monthly L3 Global 500 m SIN Grid V006 (MCD64A1) ([Schroeder et al., 2014](#)). Using GIS techniques, we will create daily clusters of fire points and use these to calculate: (1) the distance to the nearest fire cluster by day and (2) the sum of Fire Radiative Power (FRP) of the nearest clusters of fires by day as it is likely that smoke levels are higher closer to fires.

#### Notes

#### File Format

.hdf

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

1. Run script 'MODIS\_FTP\_download.py' and pass two arguments: the first is the data set name and the second is the local directory path to save files to (i.e. "MCD64A1" "C:/Users/User/MCD64A1\_"). Update: 'MODIS\_FTP\_download.py' is obsolete because NASA LAADS decommissioned their FTP site in favor of HTTPS. So, a new all-purpose script will need to be written to do this download that does HTTPS retrievals instead.

#### Quality Control

#### Script Names

1. MODIS\_FTP\_Download.py

#### Data File Names

- 1.

### 3.9 Visible Infrared Imaging Radiometer Suite (VIIRS) (VNP14IMGTDL\_NRT)

#### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

We will collect data about fire detection locations, size, and fire radiative power from the Visible Infrared Imaging Radiometer Suite (VIIRS) (VNP14IMGTDL\_NRT) ([Schroeder et al., 2014](#)). Using GIS techniques, we will create daily clusters of fire points and use these to calculate: (1) the distance to the nearest fire cluster by day and (2) the sum of Fire Radiative Power (FRP) of the nearest clusters of fires by day as it is likely that smoke levels are higher closer to fires. The MODIS product spans longer than our study period (2008-2014) at daily temporal resolution and has a spatial resolution of 1 km. VIIRS was launched in 2011 and has 12 h temporal resolution with 750 m resolution. The BAECV can detect fires larger than 4 km<sup>2</sup> and provides an estimate of the date of the fire and is available from 1984-2015.

#### Notes

#### File Format

.csv

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

1. Navigate to the [NASA EarthData FIRMS Archive Download site](#)
2. Select "Create new Request"
3. In the dropdown for region, select "Custom Region" and draw a bounding box around study area
4. In the dropdown for fire data source, select "VIIRS"
5. Select dates for study time period
6. In the dropdown for file type, select "Shapefile (.shp)"
7. Enter your email address
8. You will get an email with a download link containing a zipfile with the data
9. Progress stopped here, as we chose to proceed with the MODIS Thermal Anomalies dataset for the active fire input for the project as of Fall 2018. But, follow along in the steps for



the MODIS Thermal Anomalies workflow to continue. The steps are the same, as the data comes from the same source.

### **Quality Control**

#### **Script Names**

1. n/a

#### **Data File Names**

1. fire\_archive\_V1\_2770.csv

### 3.10 Classified land cover information from the Landsat-derived NLCD 2011

#### Data Source

- Contact
- Citation/Link
- Data (local)
- Geographic Extent
- Temporal Extent
- Acknowledgment

#### Brief Description

Classified land cover information from the Landsat-derived NLCD 2011 ([Homer et al., 2017](#)) will be used to calculate estimates of the percentage of urban development (codes 22, 23, and 24), agriculture (codes 81 and 82), and vegetated area other than agricultural land (codes 21, 41, 42, 43, 52, and 71) within buffer radii of 100 m, 250 m, 500 m, and 1000 m around each monitor. The buffer distance that is most highly correlated with  $PM_{2.5}$  will be entered into each model. NLCD 2011 has a spatial resolution of 30 m and uses circa 2011 Landsat satellite data.

#### Notes

Use special Albers projection to create the buffers (can import the projection from existing file on S3).

#### File Format

.shp

#### Data Filtering and Processing

##### Final Variable(s)

##### Methods

1. Navigate to the [National Map Viewer](#) and find products for "National Land Cover Database (NLCD)" at the National extent. From the search results, download "NLCD 2011 Land Cover (2011 Edition, amended 2014)". This will download a zipfile with the data.
2. Run `nlcd_process.py` with the required arguments. This script computes zonal statistics between a buffer shp file and an classified raster tif (in our use case, a reclassified NLCD raster). The computed value is percent area of developed high density land cover in each buffer. The output is another csv, which is the input csv with an extra column denoting the data. Note: the buffer shp file used in this study consisted of 1km, 5km, and 10km radius buffers using planar buffering.

#### Quality Control

##### Script Names

1. `nlcd_process.py`

##### Data File Names

1. n/a

### 3.11 MODIS Snow Cover Daily L3 Global 500m Grid, Version 6 (MOD10A1 and MYD10A1)

#### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

We will use snow cover data from the MODIS Snow Cover Daily L3 Global 500m Grid, Version 6 (MOD10A1 and MYD10A1) ([Hall and Riggs, 2016](#)) because snow coverage is a known contributor to wintertime PM<sub>2.5</sub> concentrations in mountain valleys ([Whiteman et al., 2014](#)). Daily MOD10A1 and MYD10A1 data are available since 2002 and have 500 m spatial resolution.

#### Notes

#### File Format

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

1. Step 1: Download the MODIS AOD data sets from both Terra and Aqua sensors:

Using the [NASA EarthData online search tool](#), search for the 'MOD10A1' (Terra) data set. Set temporal extent by drawing polygon and set spatial extent by adjusting the appropriate filter on the web interface. Select the collection and proceed to download data. For data download options, specify "Stage for Delivery" through the "FTPPull" distribution option. Specify the email address for orders to be sent to. Orders will be sent to your email with instructions on how to connect to the FTP server and pull the ordered data into your local workspace through the command line. Because the amount of data being requested is large, the orders will come through several separate emails. Repeat this step for the 'MYD10A1' (Aqua) data set. All of the raw downloaded data from this step will be in .hdf file format.

#### Quality Control

#### Script Names

- 1.

#### Data File Names

- 1.

### 3.11.1 Elevation

#### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### Brief Description

Elevation can influence  $PM_{2.5}$  concentrations; for example,  $PM_{2.5}$  can accumulate in mountain valleys during persistent cold air pools (commonly referred to as inversions) during winter (Whiteman et al., 2014). We will get elevation data from the 3D Elevation Program, which has resolution of 1 arc-second. This resolution is approximately 30 m north/south and varies east/west with latitude (USGS, 2017).

#### Notes

#### File Format

#### Data Filtering and Processing

#### Final Variable(s)

#### Methods

1. Navigate to the <https://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEPView> National Map Viewer site and find products for Elevation Products (3DEP), 1 arc-second DEM, IMG file format. Once results are returned, select "Save as Text", which will download a text file containing server links to each NED tile.
2. Download the data using the [download\\_tiles.py](#) script, which will access the text file that you just downloaded.
3. Extract the elevation values using the [extract\\_values\\_to\\_points.py](#) script. Step-by-step instructions:
  - 1 Start t2.medium EC2 instance on AWS with 250 BG storage
  - 2 `docker pull earthlab/estimate-pm25`
  - 3 `docker run -d earthlab/estimate-pm25`
  - 4 `docker ps`
  - 5 `docker exec -it [docker_name] /bin/bash`
  - 6 `aws configure`
  - 7 `mkdir NED`
  - 8 `cd NED`
  - 9 `mkdir data`
  - 10 `aws s3 cp s3://earthlab-reid-group/NED/data/ /home/jovyan/NED/data/ --recursive`

- i. This step takes a few hours
- 11 `aws s3 cp s3://earthlab-reid-group/Processed_Data/PM25_Locations_Dates/ /home/jovyan/NED/ --recursive`
- 12 `git clone https://github.com/earthlab/estimate-pm25.git`
- 13 `cd estimate-pm25`
- 14 `cd download-earth-observations/NED/`
- 15 `python extract_values_to_points.py --NED_directory "/home/jovyan/NED/data/" --input_csv_file "/home/jovyan/NED/Part_e_not_in_bd_Locations.csv" --output_csv_file "/home/jovyan/NED/ned_pa`
- 16 See also: <https://docs.google.com/document/d/1IysKoAS8l1WH6nN4lksWe9MWqNZEOG5DQD9DY/edit?usp=sharing>

## Quality Control

### Script Names

1. `download_tiles.py`
2. `extract_values_to_points.py`

### Data File Names

1. n/a

## 3.12 MODIS Normalized Difference Vegetation Index (MOD13A3)

### Data Source

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

### Brief Description

MODIS NDVI description

### Notes

Need to use the monitors' projected coordinates (ESRI 102003) for the `extract_to_values.py` script.

### File Format

### Data Filtering and Processing

### Final Variable(s)

### Methods

1. Download data using the [MODIS\\_HTTPS\\_download.py](#) script with required arguments.
2. Translate, mosaic, and reproject data using the [translate\\_mosaic\\_reproject.py](#) script with required arguments.
3. Extract to points using the [extract\\_to\\_values.py](#) script with required arguments.

### Quality Control

### Script Names

1. `MODIS_HTTPS_download.py`
2. `translate_mosaic_reproject.py`
3. `extract_to_values.py`

### Data File Names

1. n/a

### 3.13 Meteorological Data

#### Data Source

North American Mesoscale, Analysis (NAM)

- **Contact**
- **Citation/Link** <https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/north-american-mesoscale-analysis>  
<https://nomads.ncdc.noaa.gov/data/namanl/>
- **Geographic Extent** North America
- **Temporal Extent** Available March, 2004 - present with slight delay. Not all files online all the time.
- **Acknowledgment**

#### Brief Description

We will obtain meteorological data from the North American Mesoscale, Analysis (NAM) because it includes all of the standard meteorological variables, including planetary boundary layer height, which has proved to be an important variable for converting AOD to PM<sub>2.5</sub> (Liu et al., 2005). We will calculate 24-hour averages from 6-hourly data for temperature, relative humidity, sea level pressure, surface pressure, planetary boundary layer height, dew point temperature, precipitation, snow coverage, and the U and V components of wind speed. NAM has 12 km resolution and is available 2004 onward.

#### Notes

##### File Format

Prior to 2018, the files are in \*.grb (“grib1”) format, while 2018 data is in \*.grib2 (“grib2”) format.

Resources about this file type:

- rNOMADS is an R package for accessing grb\* files. It is mostly geared for grib2 files.  
<https://cran.r-project.org/web/packages/rNOMADS/rNOMADS.pdf>
- Explanation of what grib files are: [http://www.cpc.ncep.noaa.gov/products/wesley/reading\\_grib.html](http://www.cpc.ncep.noaa.gov/products/wesley/reading_grib.html),
- wgrib program information: <http://www.cpc.ncep.noaa.gov/products/wesley/wgrib.html>

#### Data Filtering and Processing

1. Use the earthlab/r-reidgroup docker image, which has wgrib and wgrib2 <http://www.cpc.ncep.noaa.gov/products/wesley/wgrib.html> and wgrib2 <http://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/> installed on it.
  - 1 Start EC2-session on AWS (using m5a.xlarge session with 30 GB attached memory)
  - 2 Install and start the earthlab/r-reidgroup docker image, see <https://hub.docker.com/r/earthlab/r-reidgroup/>. See also <https://docs.google.com/document/d/1hQdZgbnwwBMACzVvTOqdcjA27JgyL4EtNyCyVa4/edit?usp=sharing>
2. Process\_NAM\_data\_step1.R reads in locations file and outputs the “\*\_NextDay” csv file, which includes the next day for each location/day listed in the first file. The purpose of this

is so all of the necessary NAM files can be processed. UTC dates can go into the next day for western US time zones. This script runs in serial and takes approximately 6 minutes to run. This step uses these input files and R packages and functions:

- 1 Input files:
    - i. PM25\_Step3\_part\_\*\_Locations\_Dates\_NAD83.csv
    - ii. CountyCentroid\_Locations\_Dates\_2008-01-01to2018-12-31.csv
  - 2 Packages:
    - i. (none)
  - 3 Files with custom functions:
    - i. general\_project\_functions.R
    - ii. NAM\_processing\_functions.R
  - 4 Output files:
    - i. NAM\_Step1\_part\_\*\_Locations\_Dates\_PM25\_Locations\_Dates\_wNextDay.csv
    - ii. NAM\_Step1\_part\_e\_Locations\_Dates\_CountyCentroid\_wNextDay.csv
3. Process\_NAM\_data\_step2\_parallel.R downloads each NAM file, extracts relevant data, and deletes the original NAM data. (All of the NAM files together would be about 1.6 Tb.) This file operates in parallel, and will use n-1 cores, where n is the number of cores on the computer. The output is 1 csv with all locations of interest for a given date and time step. The time steps for the NAM are 0Z, 6Z, 12Z, and 18Z. The output files have the format Locations\_Dates\_of\_PM25\_Obs\_DeDuplicate\_YYYY\_MM\_DD\_XXUTC.csv where XX refers to the timestep. Change the study start and stop dates for the dates to be processed. This step uses these input files and R packages and functions:

- 1 Input files:
  - i. NAM\_Step1\_part\_\*\_Locations\_Dates\_PM25\_Locations\_Dates\_wNextDay.csv
  - ii. NAM\_Step1\_part\_e\_Locations\_Dates\_CountyCentroid\_wNextDay.csv
- 2 Packages:
  - i. rNOMADS
  - ii. parallel
- 3 Files with custom functions:
  - i. general\_project\_functions.R
  - ii. NAM\_processing\_functions.R
  - iii. extract\_NAM\_data\_parallel\_function.R
  - iv. define\_project\_bounds\_function.R
  - v. loop\_NAM\_run\_times\_parallel\_function.R
  - vi. merging\_data\_functions.R
- 4 Output files:
  - i.



ii.

- 1 Locations\_Dates\_of\_PM25\_Obs\_DeDuplicate.csv - Data file with dates (local) and locations where you want the NAM data
  - 2 MeteoVariablesNAM.csv - listing of meteorological variables to be extracted from NAM data
  - 3 rNOMADS R package (which calls wgrib and wgrib2) <https://cran.r-project.org/web/packages/rNOMADS/rNOMADS.pdf>
  - 4 parallel R package
  - 5 grb1to2\_conversion\_prep\_function.R - This script downloads the files that will be necessary to run grb1to2.pl, created by the Climate Prediction Center <http://www.cpc.ncep.noaa.gov/products/wesley/grb1to2.html>
  - 6 loop\_NAM\_run\_times\_parallel\_function.R - this function loops through the time steps on a given day and calls function (listed below) to extract meteo data at locations of interest
  - 7 define\_project\_bounds\_function.R - the bounding box for the study area is defined in this function. The scripts can run faster if the entire NAM domain does not need to be loaded into memory.
  - 8 extract\_NAM\_data\_parallel\_function.R - this function extracts the NAM data at points of interest
  - 9 which\_type\_of\_grib\_file\_function.R - this function determines whether the data for a given time step are grib1 or grib2 format
  - 10 convert\_grib1to2\_function.R - convert file type from grib1 to grib2, unless it's already a grib2 file. This is essentially a wrapper for grb1to2.pl created by the Climate Prediction Center <http://www.cpc.ncep.noaa.gov/products/wesley/grb1to2.html>
- 
4. Process\_NAM\_data\_step3.R merges all of the files from step 2 into a single file and adds a column at the beginning giving the UTC time stamp. This script will take approximately 20 minutes (runs in serial).
  5. Process\_NAM\_data\_step4.R Add time zones and local times.
  6. Process\_NAM\_data\_step5.R merges the 4 time steps to give a 24-hr summary. Min, max, mean, etc. is set in MeteoVariablesNAM.csv. This script is expected to take a little over an hour on 16-cores.

### **Final Variable(s)**

See MeteoVariablesNAM.csv

### **Quality Control**

### **3.14 Dust Storms**

#### **Data Source**

- **Contact**
- **Citation/Link**
- **Data (local)**
- **Geographic Extent**
- **Temporal Extent**
- **Acknowledgment**

#### **Brief Description**

Dust storm records will be included in the machine learning algorithm because they can be a significant indicator of airborne particulate matter from sources other than fires. Dust storm records are available from 1993-2017. The spatial resolution varies, but includes either forecast zone or county ([US National Weather Service, 2017b,c,a](#)).

#### **Notes**

#### **File Format**

#### **Data Filtering and Processing**

#### **Final Variable(s)**

#### **Methods**

- 1.
- 2.

#### **Quality Control**

#### **Script Names**

- 1.

#### **Data File Names**

- 1.

## 3.15 Phase 2: Extraction to Observation Locations and Points of Interest

### 3.16 Locations of Interest

This section describes the code for identifying and compiling the predictor variables for locations of interest, such as county centroids.

#### 3.16.1 County Centroids

1. CountyCentroid\_CreateLatLonDateFiles.R » Create two csv files in the /home/Processed\_Data/CountyCentroid/ folder. This script takes approximately 6 minutes to run on a laptop.
  - 1 Locations of county centroids for the study area: CountyCentroid\_Locations.csv (~ 30 KB)
  - 2 Locations of county centroids for study area expanded across all dates in study period: CountyCentroid\_Locations\_Dates\_[Study Start Date]to[Study End Date].csv (~ 140 MB)
2. CountyCentroid\_PlotLocations.R » Plot centroid locations and create summaries of the locations-only and dates-locations centroids files in CountyCentroid\_Locations\_File\_Summary.txt, which is stored in the same folder as the data. This script takes a few seconds to run on a laptop.

#### 3.16.2 Population-weighted county centroids

1. Extract\_county\_pop\_centroids.R **To Do:** update this code to have a similar process as the geographic county centroid codes listed above.

### **3.17 Phase 3: Merge extracted data**

This phase both the input file for the ML training and the input file for the predictions to points of interest.

### 3.17.1 Predictor input files for points of interest

Once the predictor variables have been extracted to the points of interest, these need to be merged into a single input file for each type of point of interest (e.g., geometric county centroid, population-weighted county centroid, etc.).

1. ML\_PM25\_estimation\_merge\_predictors.R » Merge the various predictor variables together with the monitor data or dates/locations of interest.
2. Formatting data for testing.R » Add state and cosine Day-of-Year (CosDOY) variables; separate data into fire/not-fire files by year.
3. ML\_PM25\_estimation\_plot\_predictors.R » Plot the training input file
  - 1 predictor variables vs date
  - 2 predictor variables vs PM<sub>2.5</sub>
1. Merge\_predictors\_to\_points\_of\_interest.R » Merge the predictor variables to the locations of interest for each set of points of interest. The file names for the source files will need to be updated as more predictor data is processed. This script takes about 2 minutes on a laptop. This script calls this function:
  - 1 Merge\_predictors\_to\_points\_of\_interest\_parallel\_wrapper\_function.R
2. Plot\_Predictor\_Inputs.R » Plot prediction input files that were created with above script. This script takes several minutes to run on laptop.

### **3.18 Phase 4: Machine Learning Methods**

### 3.19 ML Techniques and Calculations

Need to describe how  $R^2$  is calculated.

setting aside a portion of the PM2.5 data set and then doing 10-fold cross validation on the rest of the data

see <http://www.cvent.com/events/nasa-aist-machine-learning-workshop/event-summary-1f5144a5d1734ca.aspx> and particularly the very end of <https://global.gotomeeting.com/public/recording-player.html?id=owZDmUustOjaW9sJGQ5u9cUG2pBa4D> for list of resources and papers to read.

### 3.20 ML Scripts

1. ML\_PM25\_estimation\_step1.R » ML training algorithms
2. ML\_PM25\_estimation\_step1.R » create data frame of the dates/locations for which we want to predict PM2.5

### **3.21 Phase 5: Predictions to Points of Interest**



## 4 Results

## **5 Discussion**

Discuss a comparison of temporal trends between our work and O'Dell et al ?.

## 6 Ideas, To Do, Resources, etc

code up fires by type of land coverage

Consider using the work of Westerling et al for a comprehensive fire history (up through 2012) <http://science.sciencemag.org/content/313/5789/940>, <http://www.pnas.org/content/108/32/13165>, <http://rstb.royalsocietypublishing.org/content/371/1696/20150178> Westerling (2016b,a) Also look into the fire histories referenced in Westerling Westerling (2016b,a): [http://fam.nwcg.gov/fam-web/weatherfirecd/fire\\_files.htm](http://fam.nwcg.gov/fam-web/weatherfirecd/fire_files.htm) and <http://fam.nwcg.gov/fam-web/kcfast/mnmenu.htm> See also <http://www.nifc.gov>

look into the Fire and Smoke Model Evaluation Experiment (FASMEE) <http://www.fasmee.net>

Compare our results with EPA Downscaler <https://www.epa.gov/air-research/downscaler-model-predicting->

Look at Kollanus et al. (2016) again for references for PM2.5 paper, especially the introduction.

Consider using NAAPS in our study.

read McClure and Jaffe (2018)

read Landis et al. (2018)

see also <https://www.5280.com/2018/09/can-colorado-burn-its-way-out-of-a-wildfire-crisis/>

Could we use inciweb to distinguish prescribed fires?

look up Global Fire Emissions Database (GFED3) - maybe it would be useful for our study as an input to the machine learning? see Liu et al. (2016b)

see Alman et al. (2016) for potential data sources for ML project

emissions vary by temperature <https://cires.colorado.edu/news/wildfire-temperatures-key-better-understand>

and <https://www.atmos-chem-phys.net/18/9263/2018/>

read Monitoring Trends in Burn Severity MTBS, 2014. Data Access: Fire Level Geospatial Data. US Department of Agriculture, Forest Service and US Department of Interior, Geological Survey. <http://mtbs.gov/data/individualfiredata.html/>.

Idea: look at ambulance calls and PM2.5, similar to what Salimi et al. (2016) did in Australia.

read Williamson et al. (2016)

Database of planned/proposed prescribed burns: WRAP's Fire Emissions Tracking System: <http://wrapfets.org/index.cfm>

See Di et al., 2016 and Johnston et al., 2012, Rappold et al., 2014 in Jones and Berrens (2017) - combine modelled and monitored/satellite data to estimate PM2.5

See page 11 of Hyde et al. (2017) for discussion of discrepancies related to burned area estimates

<http://www.ptep-online.com/ctan/symbols-a4.pdf>

US National Atlas [http://nationalmap.gov/small\\_scale/atlasftp.html](http://nationalmap.gov/small_scale/atlasftp.html)

Thought: Using DigitalGlobe for fire data compared to NASA: would have higher spatial resolution, but not consistently viewing all areas (no cost to CU people)

Look up Openair R package

Papers/resources to look into: [https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds\\_id=1293](https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1293)

[https://www.fs.fed.us/psw/publications/4451/psw\\_2009\\_4451-001.pdf](https://www.fs.fed.us/psw/publications/4451/psw_2009_4451-001.pdf)

<https://labcit.ligo.caltech.edu/~ethrane/Resources/UNIX/>

<https://community.tableau.com/thread/141548>

According to Liu et al. (2016a), GEOS-Chem “can be classified according to emission source”, that implies that we could tag the emissions as wildfire vs prescribed fire vs urban. Would there be

any advantages of this model over CAMx?

could analyze data with NAAQS and WHO PM2.5 standards

projection/datum info: <https://gis.stackexchange.com/questions/664/whats-the-difference-between-a-projection-and-a-datum>  
<http://resources.esri.com/help/9.3/arcgisengine/dotnet/89b720a5-7339-44b0-8b58-0f5bf2843393.htm>  
<http://grindgis.com/blog/wgs84-vs-nad83>

Monitoring Trends in Burn Severity (MTBS) MTBS, 2016: Data Access: Fire Level Geospatial Data. USDA Forest Service/U.S. Geological Survey, accessed 8 October 2016, <https://mtbs.gov/direct-download>. Eidenshink, J., B. Schwind, K. Brewer, Z.-L. Zhu, B. Quayle, and S. Howard, 2007: A project for monitoring trends in burn severity. *Fire Ecol.*, 3, 3–21, <https://doi.org/10.4996/fireecology.0301003>.

Idea: Maybe instead of just distance to closest fire, we should follow the example of [Baek2016] and do distributed lags with concentric circles with information about fires in each concentric circle... also, instead of just distance to fire, maybe we could come up with a variable that is something like [distance\*size of fire] since both are important.

Fire stats/records: [https://www.nifc.gov/fireInfo/fireInfo\\_statistics.html](https://www.nifc.gov/fireInfo/fireInfo_statistics.html)

See [Adelaine et al. \(2017\)](#) for description of fire perimeter data that perhaps we could use (CA only)

See [Vaidyanathan et al. \(2018\)](#) for info about MTBS and Active Fire Mapping Program and NWS smoke products. See also Lassman et al [Lassman et al. \(2017\)](#) cited therein.

Read these papers cited in [Lassman et al. \(2017\)](#): Yao and Henderson, 2014; Henderson et al 2011; Liu et al 2015; Gan et al 2017; and look at their sources of PM2.5 data to see if we could add any of those to our project.

## 7 PM2.5 Surface Paper Notes

Discussion of trends in anthro PM2.5: [Ridley et al. \(2018\)](#)

### 7.1 Papers published in Atmospheric Environment - use as style example

Need to go through these papers

- [Brokamp et al. \(2017\)](#) (partially done, done through intro)
- [Sampson et al. \(2013\)](#)
- [Anyenda et al. \(2016\)](#)
- [Torvela et al. \(2014\)](#)
- [Whiteman et al. \(2014\)](#)

Put in [Brokamp et al. \(2017\)](#); [Larsen et al. \(2017\)](#)

## 8 Papers to cite/discuss in Introduction and/or Discussion

[Westerling \(2016b,a\)](#)

try to find English version <http://80.24.165.149/webproduccion/PDFs/15CAP03.PDF>

For fire identification, consider using NOAA's Hazard Mapping System and BlueSky

## 8.1 Notes on Papers

See [J. et al. \(2016\)](#) for statistics about wildfires in western US, e.g., % started by humans, number of fires, etc.

## 9 Fire attribution paper

revisit [Schweizer et al. \(2017\)](#)

include [Long et al. \(2018\)](#) - does a good job of summarizing the debate about more vs less prescribed burns

sources of fire data ?, ?

will need to compare our work to ?

include [Westerling \(2016b,a\)](#) and [Abatzoglou and Williams \(2016\)](#)

See [Kaulfus et al. \(2017\)](#) for an alternative method of attributing PM<sub>2.5</sub> to wildfire smoke (instead of CAMx)

See Le et al 2014 ?

See Huff et al ?

See [https://eos.org/articles/new-eyes-on-wildfires?utm\\_source=eos&utm\\_medium=email&utm\\_campaign=EosBuzz050319](https://eos.org/articles/new-eyes-on-wildfires?utm_source=eos&utm_medium=email&utm_campaign=EosBuzz050319)

### 9.1 text written for the COPD paper - variation of this may be useful

Larsen et al., 2017 [Larsen et al. \(2017\)](#) found that, on average, ground-level PM<sub>2.5</sub> concentrations increased by  $2.9 \mu\text{g}\cdot\text{m}^{-3}$  (2.8, 3.0) when there was a visible wildfire smoke plume overhead (from satellite imagery), as well as a 2.6 ppb (2.5-2.7) increase in O<sub>3</sub>. Satellite data provides a wealth of data and can provide information about air quality where monitors are not present. However, satellite imagery inherently comes with a substantial uncertainty in that satellite data describes the entire atmospheric column and not specifically just air pollution at the ground level, where people are breathing.

## References

- Abatzoglou, J. T. and Williams, A. P. (2016). Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences*, 113(42):11770–11775.
- Adelaine, S. A., Sato, M., Jin, Y., and Godwin, H. (2017). An Assessment of Climate Change Impacts on Los Angeles (California USA) Hospitals, Wildfires Highest Priority. *Prehospital and Disaster Medicine*, 32:556–562.
- Alman, B. L., Pfister, G., Hao, H., Stowell, J., Hu, X., Liu, Y., and Strickland, M. J. (2016). The association of wildfire smoke with respiratory and cardiovascular emergency department visits in Colorado in 2012: a case crossover study. *Environ Health*, 15(1):64.
- Anyenda, E. O., Higashi, T., Kambayashi, Y., Thao, N. T. T., Michigami, Y., Fujimura, M., Hara, J., Tsujiguchi, H., Kitaoka, M., Asakura, H., Hori, D., Yamada, Y., Hayashi, K., Hayakawa, K., and Nakamura, H. (2016). Exposure to daily ambient particulate polycyclic aromatic hydrocarbons and cough occurrence in adult chronic cough patients: A longitudinal study. *Atmospheric Environment*, 140(Supplement C):34 – 41.
- Brokamp, C., Jandarov, R., Rao, M. B., LeMasters, G., and Ryan, P. (2017). Exposure assessment models for elemental components of particulate matter in an urban environment: A comparison of regression and random forest approaches. *Atmospheric Environment*, 151:1–11.
- Crooks, J. L., Cascio, W. E., Percy, M. S., Reyes, J., Neas, L. M., and Hilborn, E. D. (2016). The association between dust storms and daily non-accidental mortality in the united states, 1993–2005. *Environmental Health Perspectives*, 124(11):1735–1743.
- Dennison, P. E., Brewer, S. C., Arnold, J. D., and Moritz, M. A. (2014). Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters*, 41(8):2928–2933. 2014GL059576.
- Giglio, L., Csiszar, I., and Justice, C. O. (2006). Global distribution and seasonality of active fires as observed with the Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. *Journal of Geophysical Research: Biogeosciences*, 111(G2). G02016; <https://modis.gsfc.nasa.gov/data/dataproduct/mod14.php>.
- Hall, D. K. and Riggs, G. A. (2016). MODIS/Aqua Snow Cover Daily L3 Global 500m Grid, Version 6. *NASA National Snow and Ice Data Center Distributed Active Archive Center*. <http://dx.doi.org/10.5067/MODIS/MYD10A1.006>.
- Hawbaker, T. J., Vanderhoof, M. K., Beal, Y.-J., Takacs, J. D., Schmidt, G. L., Falgout, J. T., Williams, B., Fairaux, N. M., Caldwell, M. K., Picotte, J. J., Howard, S. M., Stitt, S., and Dwyer, J. L. (2017). Mapping burned areas using dense time-series of Landsat data. *Remote Sensing of Environment*, 198(Supplement C):504 – 522.
- Homer, C., Dewitz, J., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N., Wickham, J., and Megown, K. (2017). Completion of the 2011 National Land Cover Database for the Conterminous United States – Representing a Decade of Land Cover Change Information.

- Photogrammetric Engineering & Remote Sensing*, 81(5):345 – 354. <https://www.mrlc.gov/nlcd2011.php>.
- Hyde, J. C., Yedinak, K. M., Talhelm, A. F., Smith, A. M. S., Bowman, D. M. J. S., Johnston, F. H., Lahm, P., Fitch, M., and Tinkham, W. T. (2017). Air quality policy and fire management responses addressing smoke from wildland fires in the united states and australia. *International Journal of Wildland Fire*, 26:347–363.
- J., F. E., T., A. J., K., B. J., T., F. J., and A., B. B. (2016). Quantifying the human influence on fire ignition across the western usa. *Ecological Applications*, 26(8):2390–2401.
- Jones, B. A. and Berrens, R. P. (2017). Application of an original wildfire smoke health cost benefits transfer protocol to the western us, 2005–2015. *Environmental Management*, 60(5):809–822.
- Kaulfus, A. S., Nair, U., Jaffe, D., Christopher, S. A., and Goodrick, S. (2017). Biomass Burning Smoke Climatology of the United States: Implications for Particulate Matter Air Quality. *Environmental Science & Technology*, 51(20):11731–11741.
- Kollanus, V., Tiittanen, P., Niemi, J. V., and Lanki, T. (2016). Effects of long-range transported air pollution from vegetation fires on daily mortality and hospital admissions in the Helsinki metropolitan area, Finland. *Environ Res*, 151:351–358.
- Kondragunta, S. and Seybold, M. (2009). Revisions to GOES Aerosol and Smoke Product (GASP) Algorithm. <http://www.ssd.noaa.gov/PS/FIRE/GASP/gasp.html>.
- Landis, M. S., Edgerton, E. S., White, E. M., Wentworth, G. R., Sullivan, A. P., and Dillner, A. M. (2018). The impact of the 2016 fort mcmurray horse river wildfire on ambient air pollution levels in the athabasca oil sands region, alberta, canada. *Sci Total Environ*, 618:1665–1676.
- Larsen, A. E., Reich, B. J., Ruminiski, M., and Rappold, A. G. (2017). Impacts of fire smoke plumes on regional air quality, 2006-2013. *Journal of Exposure Science & Environmental Epidemiology*.
- Lassman, W., Ford, B., Gan, R. W., Pfister, G., Magzamen, S., Fischer, E. V., and Pierce, J. R. (2017). Spatial and temporal estimates of population exposure to wildfire smoke during the washington state 2012 wildfire season using blended model, satellite, and in situ data. *Geo-Health*, 1(3):106–121.
- Liu, J. C., Mickley, L. J., Sulprizio, M. P., Dominici, F., Yue, X., Ebisu, K., Anderson, G. B., Khan, R. F. A., Bravo, M. A., and Bell, M. L. (2016a). Particulate air pollution from wildfires in the Western US under climate change. *Climatic Change*, 138(3-4):655–666.
- Liu, J. C., Pereira, G., Uhl, S. A., Bravo, M. A., and Bell, M. L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environ Res*, 136:120–132.
- Liu, J. C., Wilson, A., Mickley, L. J., Dominici, F., Ebisu, K., Wang, Y., Sulprizio, M. P., Peng, R. D., Yue, X., Anderson, G. B., and Bell, M. L. (2016b). Wildfire-specific Fine Particulate Matter and Risk of Hospital Admissions in Urban and Rural Counties. *Epidemiology*, 28:77–85.

- Liu, X., Huey, L. G., Yokelson, R. J., Selimovic, V., Simpson, I. J., Müller, M., Jimenez, J. L., Campuzano-Jost, P., Beyersdorf, A. J., Blake, D. R., Butterfield, Z., Choi, Y., Crounse, J. D., Day, D. A., Diskin, G. S., Dubey, M. K., Fortner, E., Hanisco, T. F., Hu, W., King, L. E., Kleinman, L., Meinardi, S., Mikoviny, T., Onasch, T. B., Palm, B. B., Peischl, J., Pollack, I. B., Ryerson, T. B., Sachse, G. W., Sedlacek, A. J., Shilling, J. E., Springston, S., St. Clair, J. M., Tanner, D. J., Teng, A. P., Wennberg, P. O., Wisthaler, A., and Wolfe, G. M. (2017). Airborne measurements of western U.S. wildfire emissions: Comparison with prescribed burning and air quality implications. *Journal of Geophysical Research: Atmospheres*, 122(11):6108–6129. 2016JD026315.
- Liu, Y., Sarnat, J. A., Kilaru, V., Jacob, D. J., and Koutrakis, P. (2005). Estimating ground-level PM<sub>2.5</sub> in the eastern United States using satellite remote sensing. *Environ Sci Technol*, 39(9):3269–78.
- Long, J. W., Tarnay, L. W., and North, M. P. (2018). Aligning Smoke Management with Ecological and Public Health Goals. *Journal of Forestry*, 116(1):76–86. WOS:000425795800011.
- LP DAAC (2017, accessed November 12, 2017). MCD64A1: MODIS/Terra and Aqua Burned Area Monthly L3 Global 500 m SIN Grid V006. [https://lpdaac.usgs.gov/dataset\\_discovery/modis/modis\\_products\\_table/mcd64a1\\_v006](https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mcd64a1_v006).
- McClure, C. D. and Jaffe, D. A. (2018). Us particulate matter air quality improves except in wildfire-prone areas. *Proc Natl Acad Sci U S A*, pages 1–6.
- NASA LAADS DAAC (2017, accessed November 2, 2017a). MOD04\_L2 - MODIS/Terra Aerosol 5-Min L2 Swath 10km. [https://ladsweb.modaps.eosdis.nasa.gov/api/v1/productPage/product=MOD04\\_L2](https://ladsweb.modaps.eosdis.nasa.gov/api/v1/productPage/product=MOD04_L2).
- NASA LAADS DAAC (2017, accessed November 2, 2017b). MYD04\_L2 - MODIS/Aqua Aerosol 5-Min L2 Swath 10km. [https://ladsweb.modaps.eosdis.nasa.gov/api/v1/productPage/product=MYD04\\_L2](https://ladsweb.modaps.eosdis.nasa.gov/api/v1/productPage/product=MYD04_L2).
- NOAA NCEI (2017, accessed November 2, 2017). *Satellite Data Access by Datasets*. <https://www.ncdc.noaa.gov/data-access/satellite-data/satellite-data-access-datasets>.
- NOAA OSPO (2017, accessed November 3, 2017). *Hazard Mapping System Fire and Smoke Product*. <http://www.ospo.noaa.gov/Products/land/hms.html>.
- O'Dell, K., Ford, B., Fischer, E. V., and Pierce, J. R. (0). The contribution of wildland-fire smoke to us pm<sub>2.5</sub> and its influence on recent trends. *Environmental Science & Technology*, 0(ja):null.
- Radeloff, V. C., Helmers, D. P., Kramer, H. A., Mockrin, M. H., Alexandre, P. M., Bar-Massada, A., Butsic, V., Hawbaker, T. J., Martinuzzi, S., Syphard, A. D., and Stewart, S. I. (2018). Rapid growth of the us wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences*, 115(13):3314–3319.
- Rappold, A. G., Stone, S. L., Cascio, W. E., Neas, L. M., Kilaru, V. J., Carraway, M. S., Szykman, J. J., Ising, A., Cleve, W. E., Meredith, J. T., Vaughan-Batten, H., Deyneka, L., and Devlin, R. B.



- (2011). Peat bog wildfire smoke exposure in rural north carolina is associated with cardiopulmonary emergency department visits assessed through syndromic surveillance. *Environmental health perspectives*, 119(10):1415–1420.
- Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., and Elliott, C. T. (2016a). Critical Review of Health Impacts of Wildfire Smoke Exposure. *Environ Health Perspect*, 124(9):1334–43.
- Reid, C. E., Jerrett, M., Petersen, M. L., Pfister, G. G., Morefield, P. E., Tager, I. B., Raffuse, S. M., and Balmes, J. R. (2015a). Spatiotemporal prediction of fine particulate matter during the 2008 northern California wildfires using machine learning. *Environ Sci Technol*, 49(6):3887–96.
- Reid, C. E., Jerrett, M., Petersen, M. L., Pfister, G. G., Morefield, P. E., Tager, I. B., Raffuse, S. M., and Balmes, J. R. (2015b). Spatiotemporal prediction of fine particulate matter during the 2008 northern California wildfires using machine learning. *Environ Sci Technol*, 49(6):3887–96.
- Reid, C. E., Jerrett, M., Tager, I. B., Petersen, M. L., Mann, J. K., and Balmes, J. R. (2016b). Differential respiratory health effects from the 2008 northern California wildfires: A spatiotemporal approach. *Environ Res*, 150:227–35.
- Reid, C. E. and Maestas, M. M. (2018). Wildfire smoke exposure under climate change: impact on respiratory health of affected communities. *Current opinion in pulmonary medicine*.
- Requia, W. J., Adams, M. D., Arain, A., Papatheodorou, S., Koutrakis, P., and Mahmoud, M. (2018). Global association of air pollution and cardiorespiratory diseases: A systematic review, meta-analysis, and investigation of modifier variables. *American Journal of Public Health*, 108(S2):S123–S130. PMID: 29072932.
- Ridley, D. A., Heald, C. L., Ridley, K. J., and Kroll, J. H. (2018). Causes and consequences of decreasing atmospheric organic aerosol in the United States. *Proc Natl Acad Sci U S A*, 115(2):290–295. WOS:000419686400043.
- Salimi, F., Henderson, S. B., Morgan, G. G., Jalaludin, B., and Johnston, F. H. (2016). Ambient particulate matter, landscape fire smoke, and emergency ambulance dispatches in Sydney, Australia. *Environ Int*.
- Sampson, P. D., Richards, M., Szpiro, A. A., Bergen, S., Sheppard, L., Larson, T. V., and Kaufman, J. D. (2013). A regionalized national universal kriging model using partial least squares regression for estimating annual pm2.5 concentrations in epidemiology. *Atmospheric Environment*, 75:383 – 392.
- Sapkota, A., Symons, J. M., Kleissl, J., Wang, L., Parlange, M. B., Ondov, J., Breysse, P. N., Diette, G. B., Eggleston, P. A., and Buckley, T. J. (2005). Impact of the 2002 Canadian forest fires on particulate matter air quality in Baltimore city. *Environ Sci Technol*, 39(1):24–32.
- Sayer, A. M., Hsu, N. C., Bettenhausen, C., and Jeong, M.-J. (2013). Validation and uncertainty estimates for MODIS Collection 6 “Deep Blue” aerosol data. *Journal of Geophysical Research: Atmospheres*, 118(14):7864–7872.

- Schoennagel, T., Balch, J. K., Brenkert-Smith, H., Dennison, P. E., Harvey, B. J., Krawchuk, M. A., Mietkiewicz, N., Morgan, P., Moritz, M. A., Rasker, R., Turner, M. G., and Whitlock, C. (2017). Adapt to more wildfire in western North American forests as climate changes. *Proc Natl Acad Sci U S A*, 114(18):4582–4590.
- Schroeder, W., Oliva, P., Giglio, L., and Csiszar, I. A. (2014). The New VIIRS 375m active fire detection data product: Algorithm description and initial assessment. *Remote Sensing of Environment*, 143(Supplement C):85 – 96.
- Schweizer, D., Cisneros, R., Traina, S., Ghezzehei, T. A., and Shaw, G. (2017). Using National Ambient Air Quality Standards for fine particulate matter to assess regional wildland fire smoke and air quality management. *Journal of Environmental Management*, 201:345–356.
- Silcox, G. D., Kelly, K. E., Crosman, E. T., Whiteman, C. D., and Allen, B. L. (2012). Wintertime pm2.5 concentrations during persistent, multi-day cold-air pools in a mountain valley. *Atmospheric Environment*, 46:17 – 24.
- Steel, Z. L., Safford, H. D., and Viers, J. H. (2015). The fire frequency-severity relationship and the legacy of fire suppression in California forests. *Ecosphere*, 6(1):1–23. art8.
- Thelen, B., French, N. H., Koziol, B. W., Billmire, M., Owen, R. C., Johnson, J., Ginsberg, M., Loboda, T., and Wu, S. (2013). Modeling acute respiratory illness during the 2007 San Diego wildland fires using a coupled emissions-transport system and generalized additive modeling. *Environmental Health*, 12(1):94.
- Tinling, M. A., West, J. J., Cascio, W. E., Kilaru, V., and Rappold, A. G. (2016). Repeating cardiopulmonary health effects in rural North Carolina population during a second large peat wildfire. *Environ Health*, 15(1):12.
- Torvela, T., Tissari, J., Sippula, O., Kaivosoja, T., Leskinen, J., Virén, A., Lähde, A., and Jokiniemi, J. (2014). Effect of wood combustion conditions on the morphology of freshly emitted fine particles. *Atmospheric Environment*, 87(Supplement C):65 – 76.
- US EPA (2017, accessed November 2, 2017a). *AQS Memos - Technical Note on Reporting PM2.5 Continuous Monitoring and Speciation Data to the Air Quality System (AQS)*. <https://www.epa.gov/aqs/aqs-memos-technical-note-reporting-pm25-continuous-monitoring-and-speciation-data-air-quality>.
- US EPA (2017, accessed November 2, 2017b). *Parameters*. <https://aqs.epa.gov/aqsweb/documents/codetables/parameters.html>.
- US EPA (2017, accessed November 2, 2017c). *PM 2.5 - Visibility (IMPROVE)*. <https://www3.epa.gov/ttnamti1/visdata.html>.
- US EPA (2017, accessed November 2, 2017d). *Sampling Methods for All Parameters*. [https://aqs.epa.gov/aqsweb/documents/codetables/methods\\_all.html](https://aqs.epa.gov/aqsweb/documents/codetables/methods_all.html).
- US National Weather Service (2016, accessed November 2, 2017a). *National Weather Service Instruction 10-1605*. <https://www.ncdc.noaa.gov/stormevents/pd01016005curr.pdf>.

- US National Weather Service (2017, accessed November 2, 2017b). *Storm Events Database*. <https://www.ncdc.noaa.gov/stormevents/>.
- US National Weather Service (2017, accessed November 2, 2017c). *Storm Events Database: Database Details*. <https://www.ncdc.noaa.gov/stormevents/details.jsp>.
- USGS (2017, accessed November 6, 2017). *About 3DEP Products and Services*. [https://nationalmap.gov/3DEP/3dep\\_prodserv.html](https://nationalmap.gov/3DEP/3dep_prodserv.html).
- Vaidyanathan, A., Yip, F., and Garbe, P. (2018). Developing an online tool for identifying at-risk populations to wildfire smoke hazards. *Sci Total Environ*, 619:376–383. WOS:000424144200040.
- Westerling, A. L. (2016a). Correction to ‘increasing western us forest wildfire activity: sensitivity to changes in the timing of spring’. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 371(1707).
- Westerling, A. L. (2016b). Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. *Philos Trans R Soc Lond B Biol Sci*, 371(1696). bibtex: westerling\_increasing\_2016.
- Whiteman, C. D., Hoch, S. W., Horel, J. D., and Charland, A. (2014). Relationship between particulate air pollution and meteorological variables in Utah’s Salt Lake Valley. *Atmospheric Environment*, 94(Supplement C):742 – 753.
- Williamson, G. J., Bowman, D. M. J. S., Price, O. F., Henderson, S. B., and Johnston, F. H. (2016). A transdisciplinary approach to understanding the health effects of wildfire and prescribed fire smoke regimes. *Environmental Research Letters*, 11(12):125009. WOS:000390332300001.