Public Health Impact of Prescribed Fire ("PHIRE") Study

This project was supported by a grant from the California Department of Forestry and Fire Prevention's (CAL FIRE) Forest Health Research Program (Agreement #8GG19803), as part of California Climate Investments. California Climate Investments is a statewide program that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas (GHG) emissions, strengthening the economy, and improving public health and the environment—particularly in disadvantaged communities.

With increasing wildfires, how does increased use of prescribed burns impact air quality and public health?

The study aims to investigate the community and public health impact of smoke exposure under several emission scenarios to guide decision-making on increasing prescribed burning

Research components

1) Smoke and exposure modeling

2) Health analysis

3) Community engagement

2) Health analysis

2.A. Health effects – hospital and emergency room visits:

- Impact of ambient air pollution, prescribed fire and wildfire smoke

2.B. Attributable health burden, exposure scenarios:

- Historical wildfires and prescribed fire
- Future projected prescribed burning (target)

3) Community Engagement

Communities in Sierra Nevada Wildland-Urban Interface (WUI)

- *What is their experience regarding smoke, symptoms, life impacts?*
- *Knowledge, attitudes and behavior re: RX burns and wildfires?*
- *How can community fire-resilience and preparedness be improved?*

LISTENING SESSIONS

El Dorado and Nevada County
(Report completed)

SURVEY

Mariposa County
Medically vulnerable residents
(Article submitted)

https://www.nevadacitychamber.com/nevada-city-things-to-do/nevada-city-tours/

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Public Health Impact of Prescribed Fire (PHIRE) Study –

Baseline and Projected Prescribed Fire Smoke Exposures in California

By ShihMing Huang, Samantha Kramer, PhD, Melissa Chaveste, Crystal McClure, PhD, Fred Lurmann

Presented at the CAL FIRE Forest Health Research Program Grantee Webinar

November 10, 2022

Sonoma Technology, Petaluma, CA, SonomaTech.com

Acknowledgment

- This study is funded by CAL FIRE Forest Health Research Program, Grant #8GG19803*
- Collaborators:
  - California Dept. of Public Health: Sumi Hoshiko, Principal Investigator
  - Sonoma Technology: ShihMing Huang, Samantha Kramer, Fred Lurmann
  - U.S. EPA: Ana Rappold
  - Sequoia Foundation: Jeff Sanchez
  - Michigan Technological University: Nancy French
  - U.S. Forest Service: Leland Tarnay

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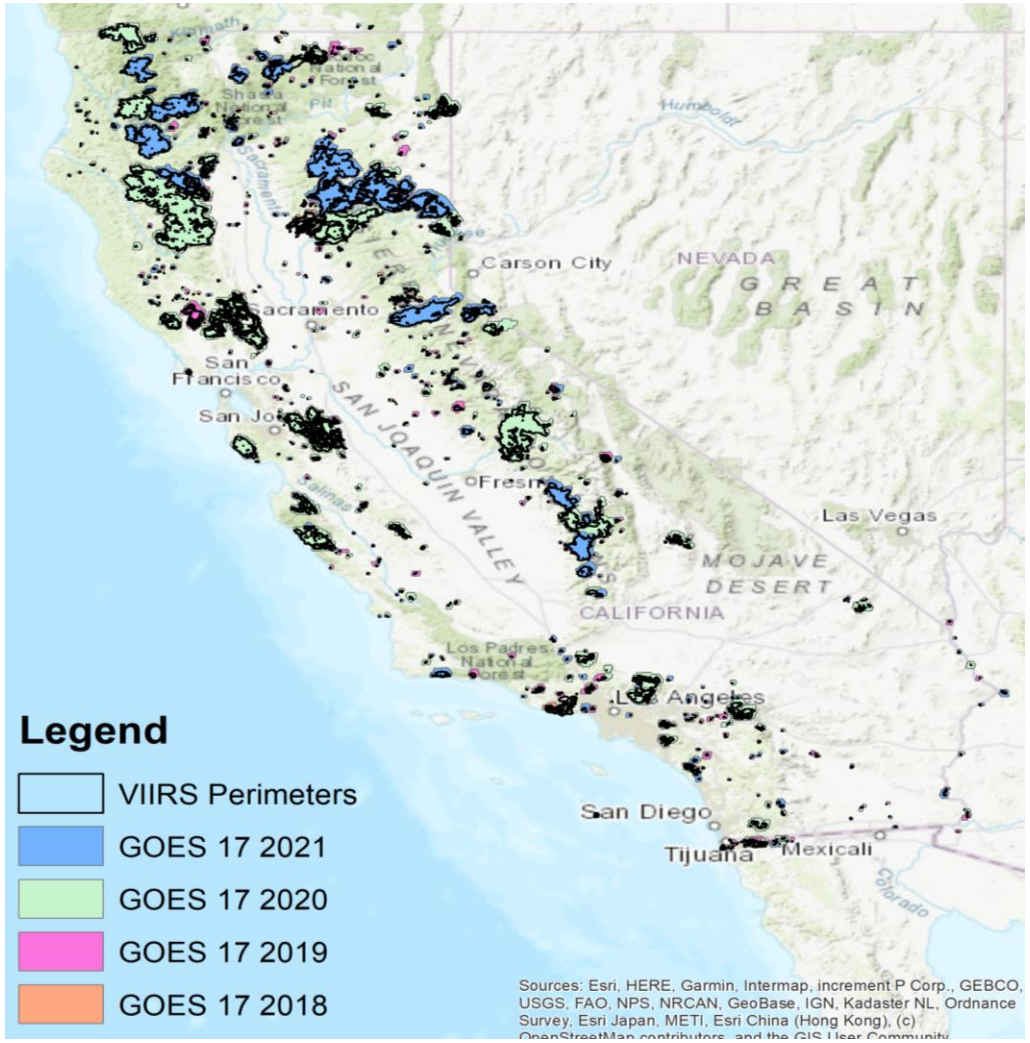
Background and Motivation

Wildfires in California

- Wildfire intensity and the frequency of severe wildfires are increasing in the western U.S., including California.
- 13 of the top 20 most destructive CA wildfires occurred in the last 5 years, costing 148 lives and destroying over 40,000 structures.[a]
- The 8 largest wildfires in CA history all occurred in the last 5 years and each burned from 280K to 1M acres.[a]



[a]Data source: CAL FIRE

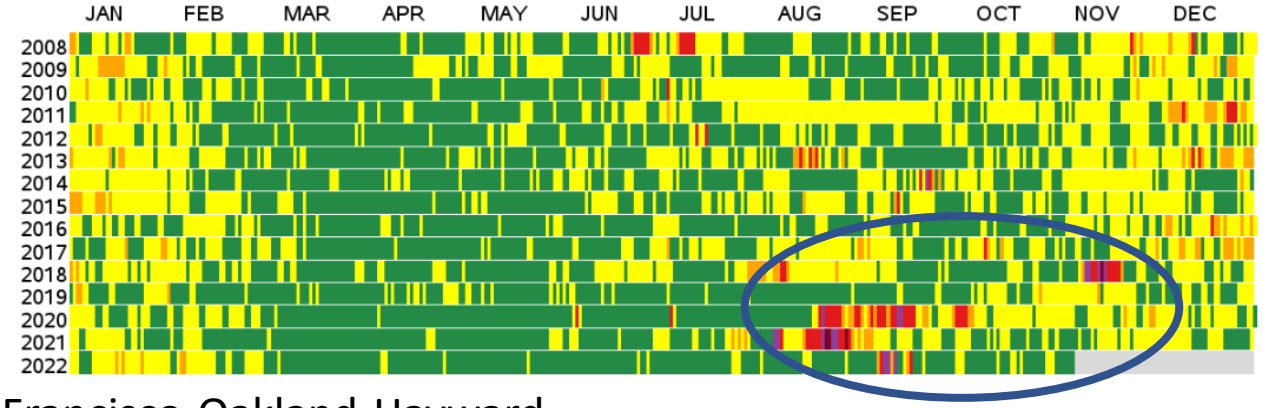
Background and Motivation

Changing wildfire behavior in North America:

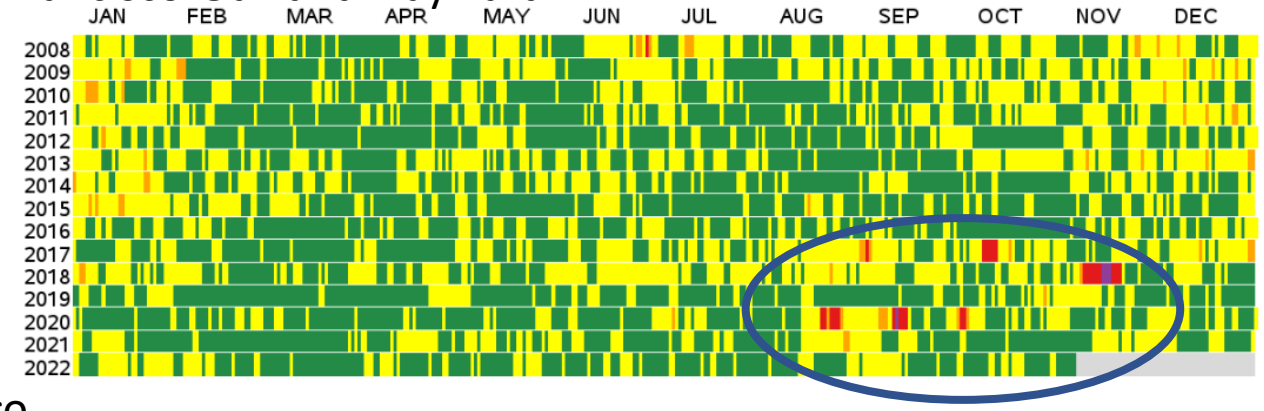
- A trend toward a higher percentage of high severity fires over the last three decades in the southwest and a stronger relationship between high burn severity areas and climate metrics (Muellera et al., 2020)
- Increasing nighttime satellite fire detections and a trend toward larger wildfires in the contiguous U.S. (Freeborn et al., 2020)
- Model simulations and empirical data continue to show drier and longer fire seasons over broader areas and increasing fire potential over areas in North America (Brown et al., 2021; Littell et al., 2018; Wu et al., 2021)

PM2.5 Daily AQI Values, 2008 to 2022

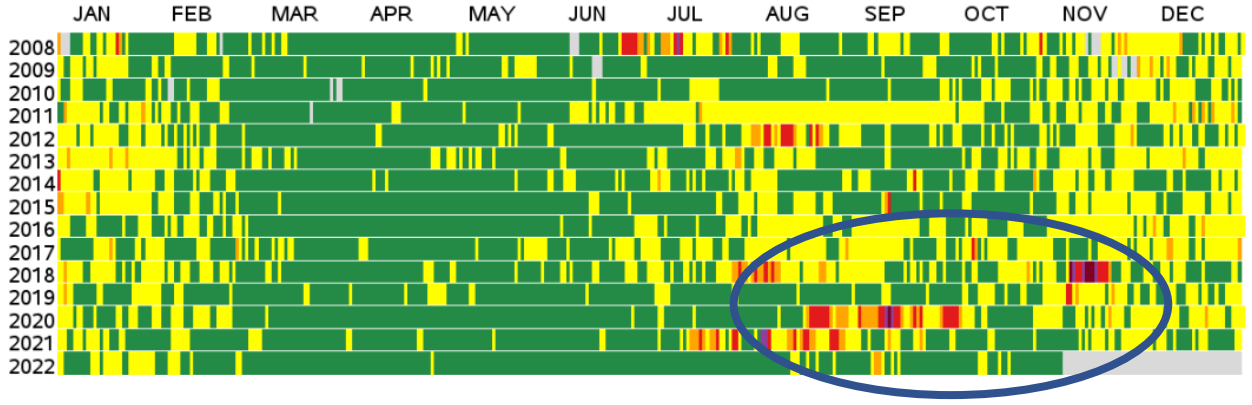
Sacramento—Roseville—Arden-Arcade



San Francisco-Oakland-Hayward



Chico



Record wildfire activities also cause record poor air quality, extending the impacts of these fires to tens of millions of people in California and beyond.

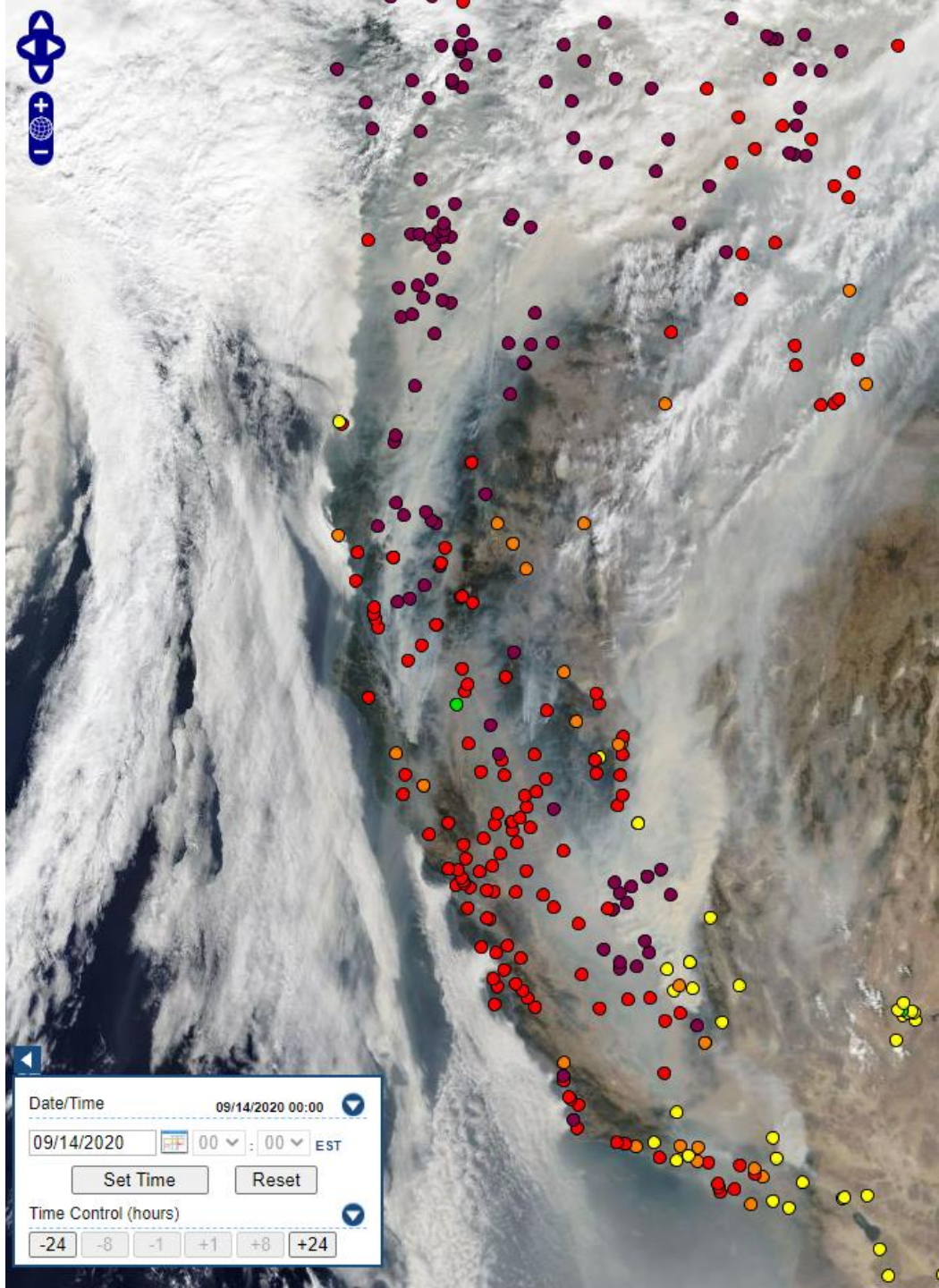
AQI Category

- Good (<=12.0 ug/m3)
- Moderate (12.1-35.4 ug/m3)
- Unhealthy for Sensitive Groups (35.5-55.4 ug/m3)
- Unhealthy (55.5-150.4 ug/m3)
- Very Unhealthy (150.5-250.4 ug/m3)
- Hazardous (>=250.5 ug/m3)

Data Source: US EPA Air Data

September 14, 2020
MODIS Imagery from Terra

- Not just a problem in California
- Most of the population in CA, OR, and WA breathed unhealthy (red), very unhealthy (purple), or hazardous (also purple) air on this day.



Data Source: https://airnowtech.org/

Background and Motivation

It is established that prescribed fire is one of the most effective practices to reduce wildfire hazards.

Outstanding knowledge gaps:

- Additional work is needed to better understand smoke exposures and health impacts from Rx fires (Navarro et al., 2018)
- Limited epidemiologic studies for Rx fire health impacts (EPA 2021)
- Calls for greater attention to Rx fire smoke health impacts in the Southeast (Afrin and Garcia-Menendez 2021)
- Lack of knowledge on Rx fire health costs and benefits; “need to first learn to sustainably coexist with prescribed fire in order to sustainably coexist with wildfire” (Jones et al., 2022)

Research Question

Prescribed (Rx) fires must increase to combat the growing wildfire threat

- The State of California and U.S. Forest Service are scaling up to each treat 500,000 acres/year for a total of 1 million acres/year by 2025.[a]
- This will include up to 500,000 acres/year of beneficial fires, including 300,000 acres of prescribed fires and cultural burning, and up to 200,000 acres of fire managed for resource benefit.[b]
- Significant increase from the average of 200,000 acres/year in 2008-2017 by our estimate.

What are the air quality impacts of Rx fire smoke relative to wildfire smoke?

- WF: high-intensity, unmanaged smoke, broad spatial scale.
- Rx: low-intensity, managed smoke, local spatial scale.

[a]Agreement for Shared Stewardship of California's Forest and Rangelands (2020)
[b]California's Strategic Plan for Expanding the Use of Beneficial Fire (March 2022)

Baseline Scenario – Fire Inventory Data

Wildfire (WF) Data

- Satellite
  - MODIS 2003-2018
- Agency
  - 2003-2017 (USFS FPA FOD)[a]
  - 2018 (GeoMAC, ICS-209, FIRESTAT, CAL FIRE)

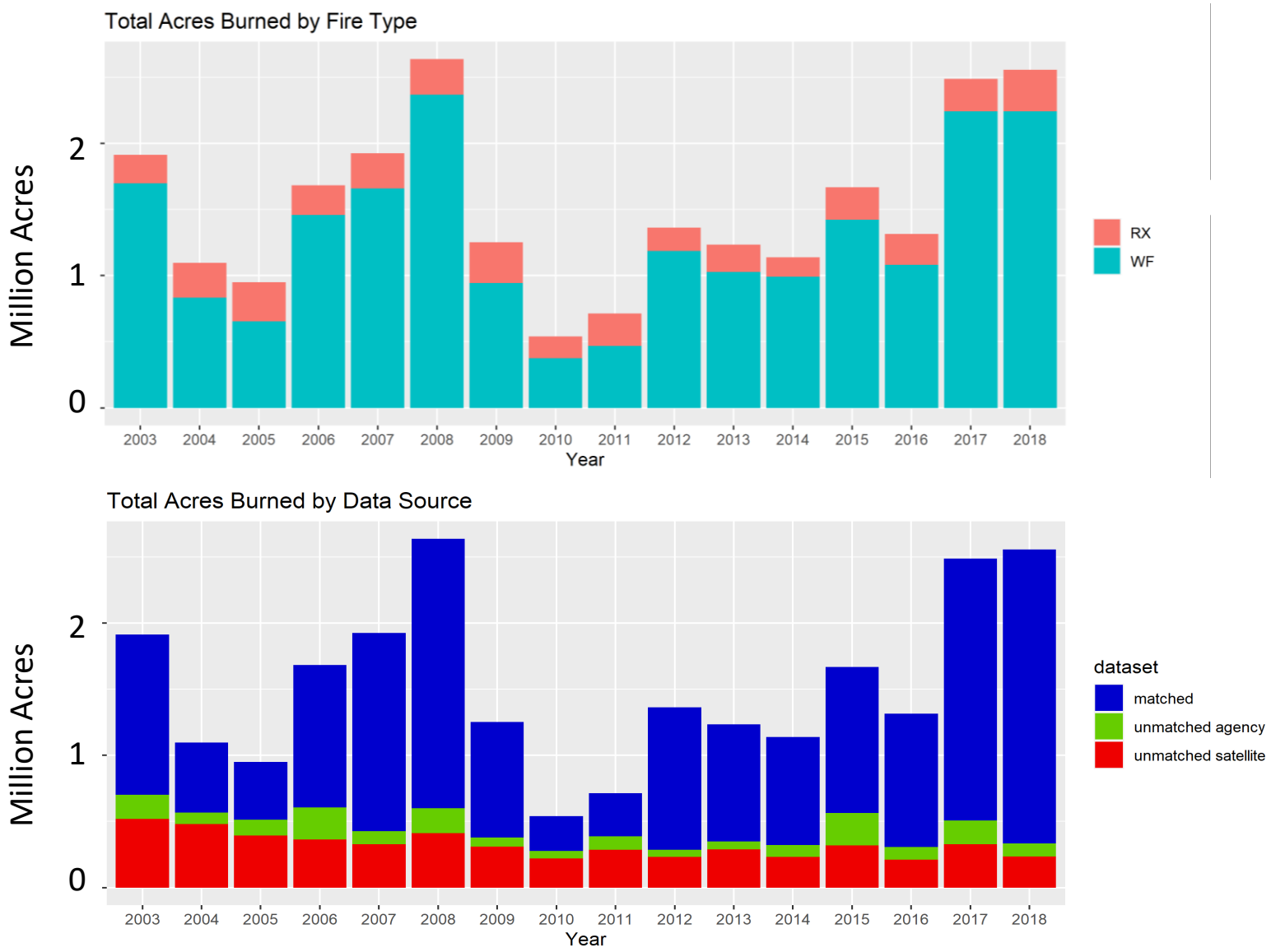
Prescribed Fire (Rx) Data

- Satellite
  - MODIS 2003-2018
- Agency
  - 2003-2018 (CAL FIRE, USFS FACTS, CARB PFIRS)

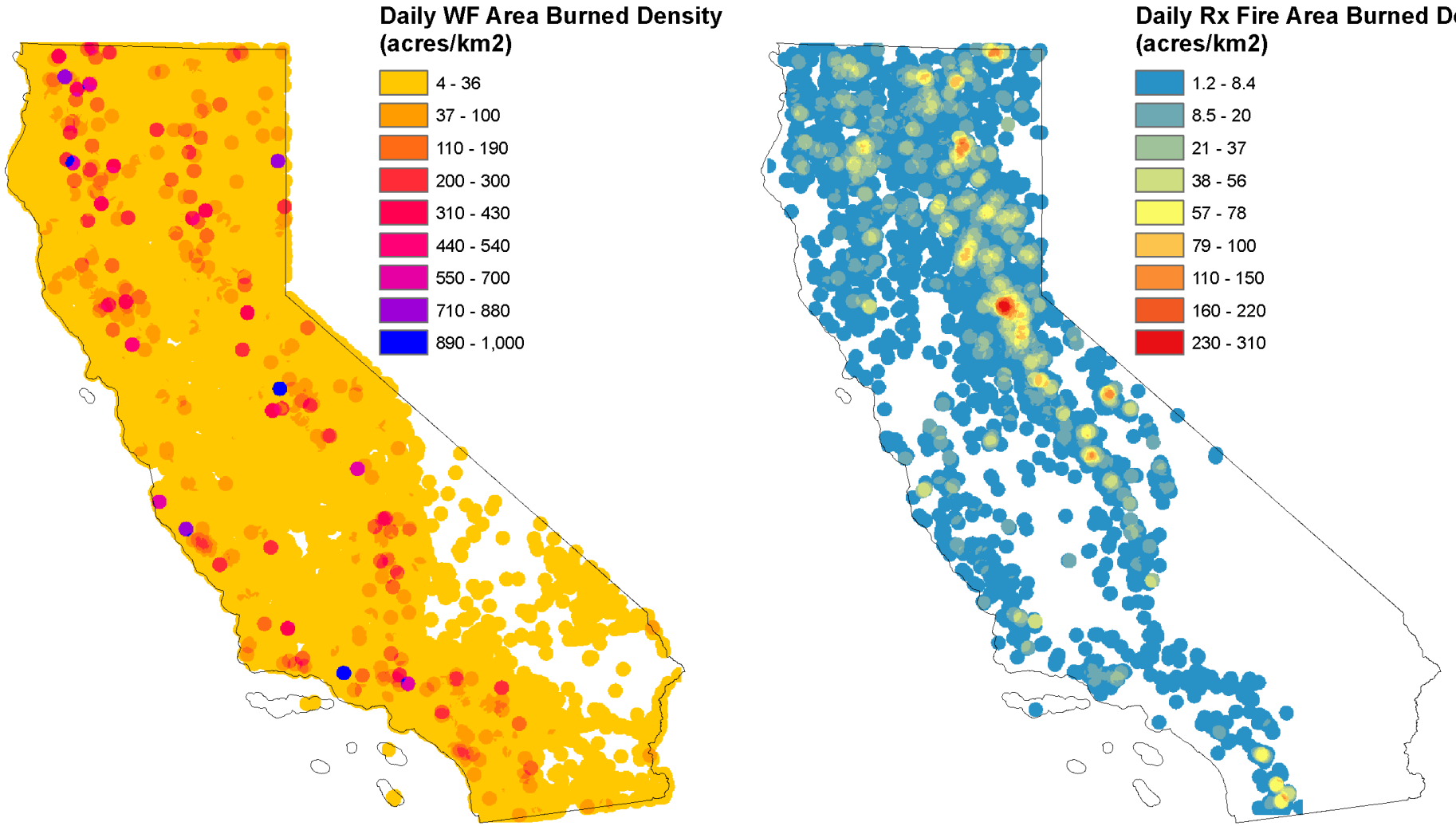
All records were spatiotemporally joined and matched to remove duplicates and reconcile differences in data records from difference sources

[a] Short, 2021

Fire Inventory 2003-2018



Distribution of Daily Fire Activities (2008-2017)



Baseline Scenario – WF and Rx Fire Smoke Modeling for 2008-2017

- BlueSky Smoke Modeling Framework[a]
  - FCCS (fuel loading) > Consume (fuel consumption) > Prichard-O'Neill Emissions[b] (smoke emissions) > FEPS Plumerise (plume rise)
- HYSPLIT Smoke Dispersion
  - 0-500 m height average
  - North American Mesoscale 12-km (NAM12) meteorology
- Dispersion results downscaled to 1-km grid space using bilinear interpolation
- Daily intersection with HMS smoke plume data

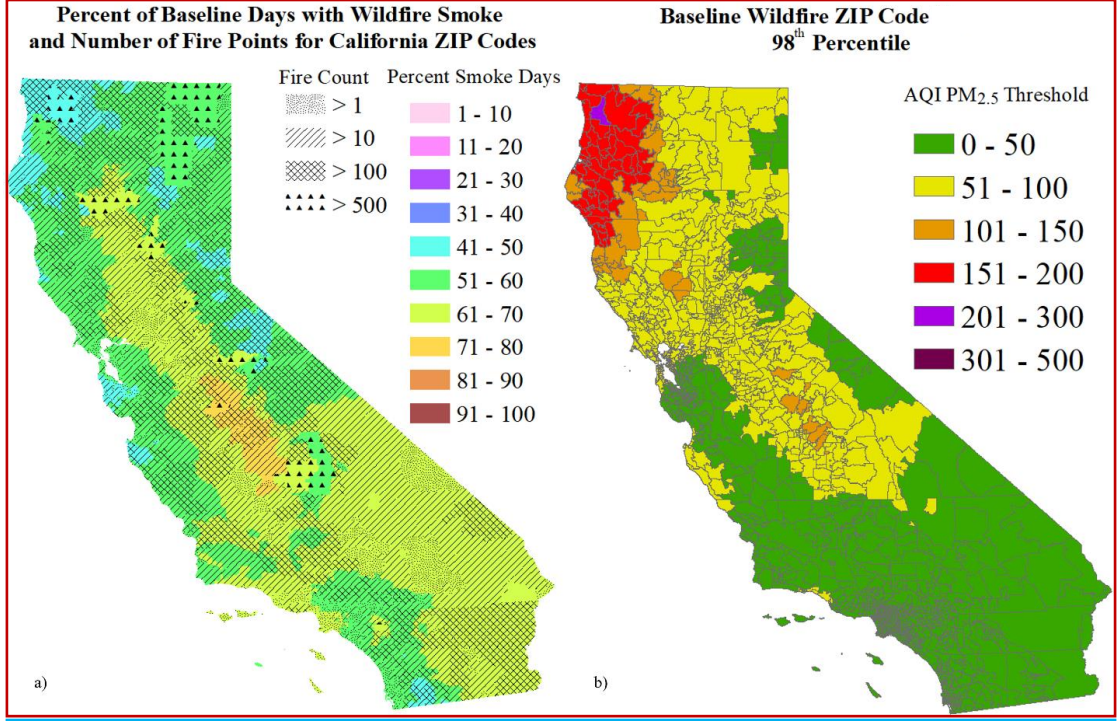
[a]Larkin et al., 2020; [b]Prichard et al., 2020

Baseline Scenario- Smoke Impacts

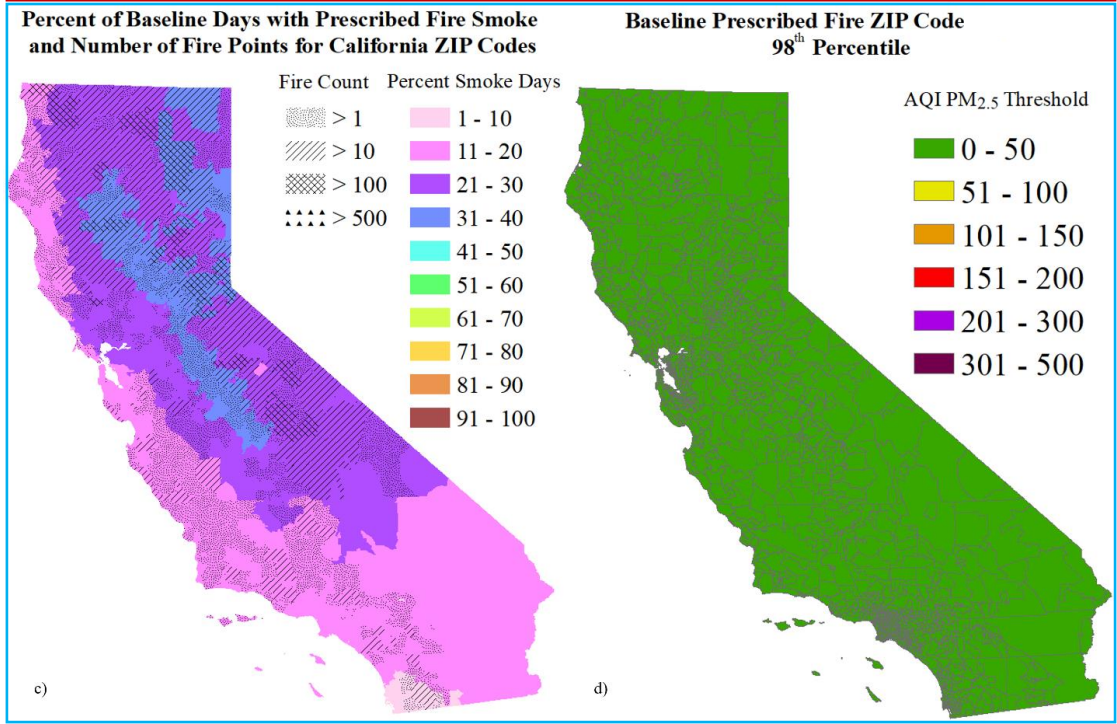
- On a ZIP code level, model results show up to **35% of days with Rx smoke present and 75% of days with WF smoke present**, with the highest frequencies in the Central Valley.
- WF smoke exceeds Rx statewide (frequency and magnitude).
- **All** California ZIP codes experience WF (min = 42%) and Rx smoke days (min = 7%); **not all** ZIP codes have fires.
- At the 98th percentile,* baseline WF smoke alone contributes enough $PM_{2.5}$ to shift the $PM_{2.5}$ AQI into **'Unhealthy'** for many ZIP codes, and **'Unhealthy for Sensitive Groups'** regardless of proximity to high fire density.
- Baseline Rx 98th percentile* smoke concentrations **do not exceed 'Good' AQI category.**

* Not accounting for background ambient concentrations

WF



Rx



Baseline Scenario – Model Evaluation

Modeled Smoke $PM_{2.5}$ Correlation to Measured $PM_{2.5}$				R values (all days | HMS observed smoke days)
Model Scenario	**AQS Sites**	**IMPROVE Sites**		
Smoke PM2.5	**Total PM2.5**	**Total PM2.5**	**TC Derived PM2.5**	**TC Direct PM2.5**
Baseline Wildfire	0.31 | 0.50	0.18 | 0.36	0.19 | 0.37	0.28 | 0.54
Baseline Prescribed Fire	0.37 | 0.58	0.59 | 0.65	0.68 | 0.74	0.64 | 0.45
Baseline Wildfire & Prescribed Fire	0.32 | 0.50	0.2 | 0.36	0.21 | 0.38	0.30 | 0.54

- **Cumulative** smoke $PM_{2.5}$ correlates well with AQS and IMPROVE measurements of Total $PM_{2.5}$.
- Correlation for Rx is greater than WF for both AQS and IMPROVE sites. Stronger correlations, especially at IMPROVE sites, are possibly due to lower background $PM_{2.5}$ concentrations, and therefore relatively higher smoke contributions to measured $PM_{2.5}$.
- When subset for days when HMS smoke is present at the measurement site, the correlation between modeled smoke $PM_{2.5}$ and measured $PM_{2.5}$ improves. By selecting days with observed smoke from an independent data source, we can reduce the bias from ambient $PM_{2.5}$ concentrations.

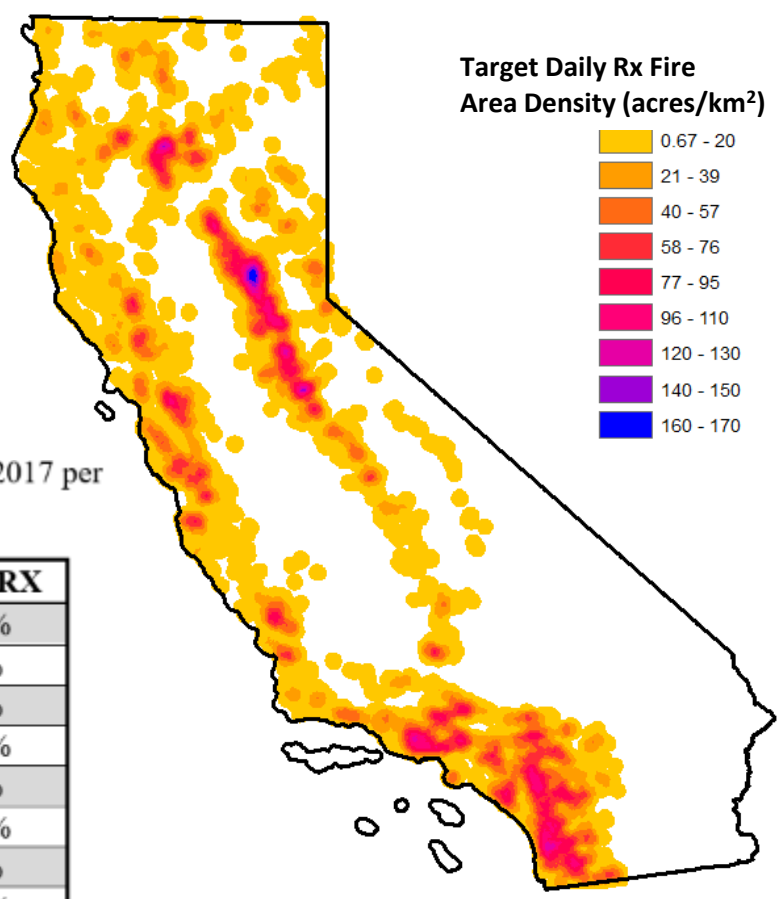
Target Scenario – Prescribed Fire Projection

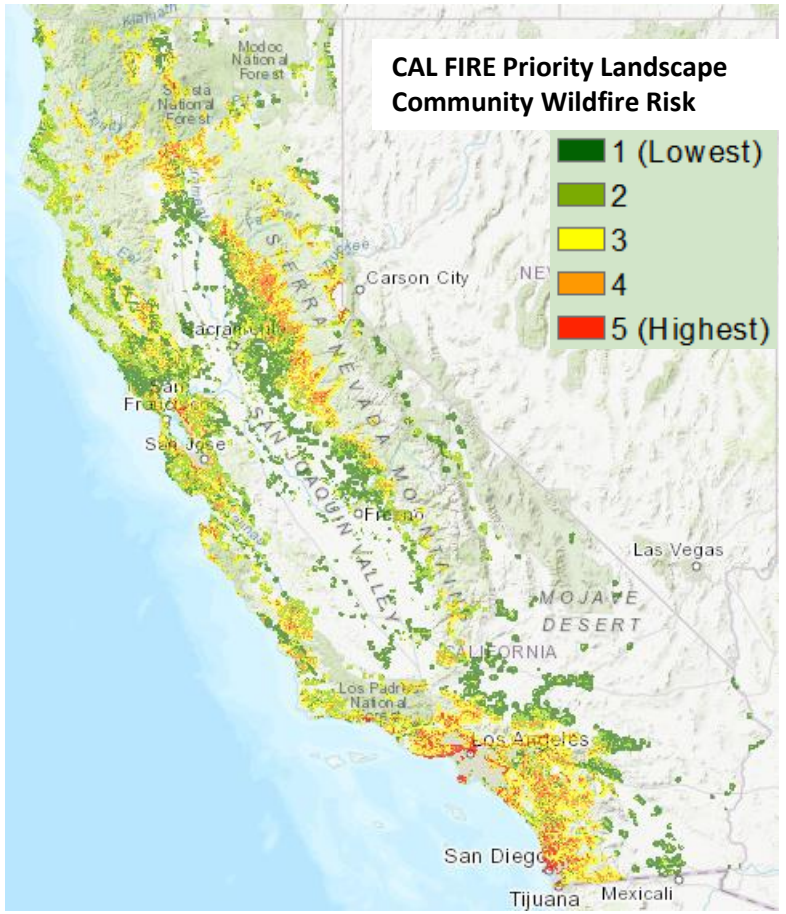
- Rx fire inventory used for classifications (size by vegetation cover type).
- Randomly distributed within CAL FIRE Priority Landscape (risk to communities[a]) Class 4 and 5 (~4 million acres).
- Randomly assigned to eight annual cycles, 500,000 acres per cycle.
- Randomly allocated fire ignitions in each annual cycle to burn days designated by CARB for each California Air Basin (burn days = weather and air quality conditions sufficient for minimal smoke impacts and risk).
- 2014 meteorology data used for smoke modeling of each cycle to keep meteorology constant.
  - Median number of burn days for 2008-2017 records.
  - Wind, soil moisture, and precipitation within two standard deviations compared to baseline period (2008-2017) averages.

[a] https://arcg.is/DvCOe

Target Scenario – Projected Prescribed Fire Area

- Fire locations were randomly selected in piecewise manner to avoid overlap.
- Each annual cycle has ~500,000 acres burned.





Proportion of wildfire and prescribed fire burned in California 2008-2017 per cover type.

Cover Type	Baseline WF	Baseline RX	Target RX
Bare Ground	6.10%	3.5%	14.4%
Evergreen	11.0%	19.0%	4.1%
Grassland	5.8%	2.7%	5.8%
Mixed Forest	31.2%	48.2%	21.5%
Savanna	0.8%	3.2%	0.1%
Shrubland	26.7%	12.6%	31.3%
Wetland	0.1%	0.2%	0.4%
Woodland	18.0%	10.5%	22.6%
Unknown	0.3%	0.1%	0.0%

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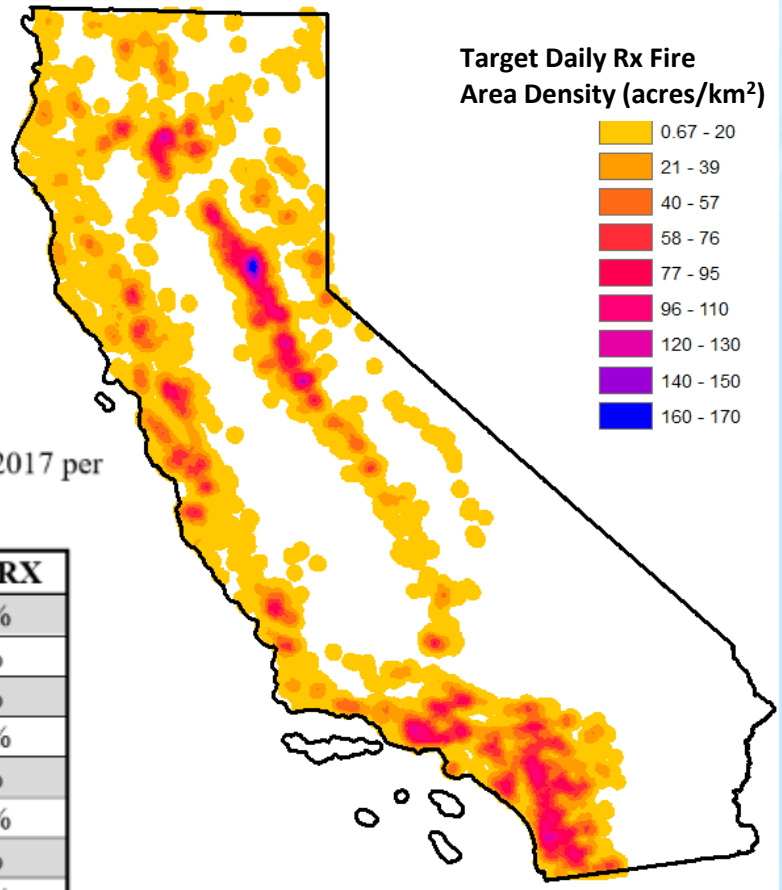

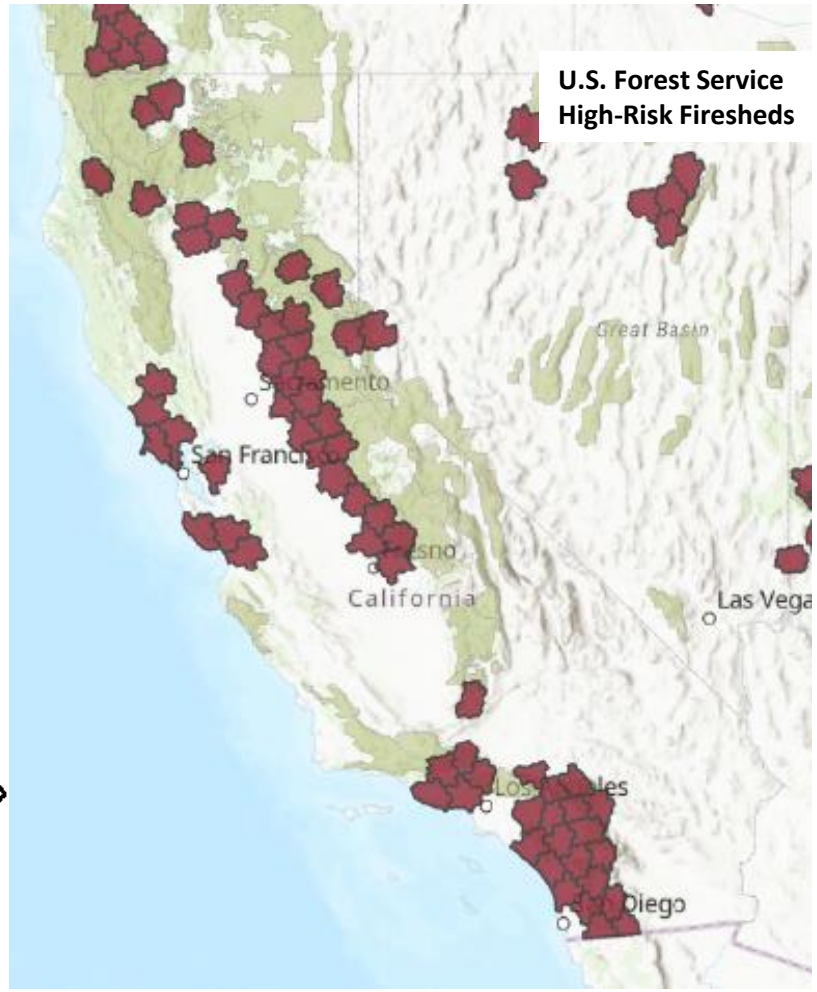

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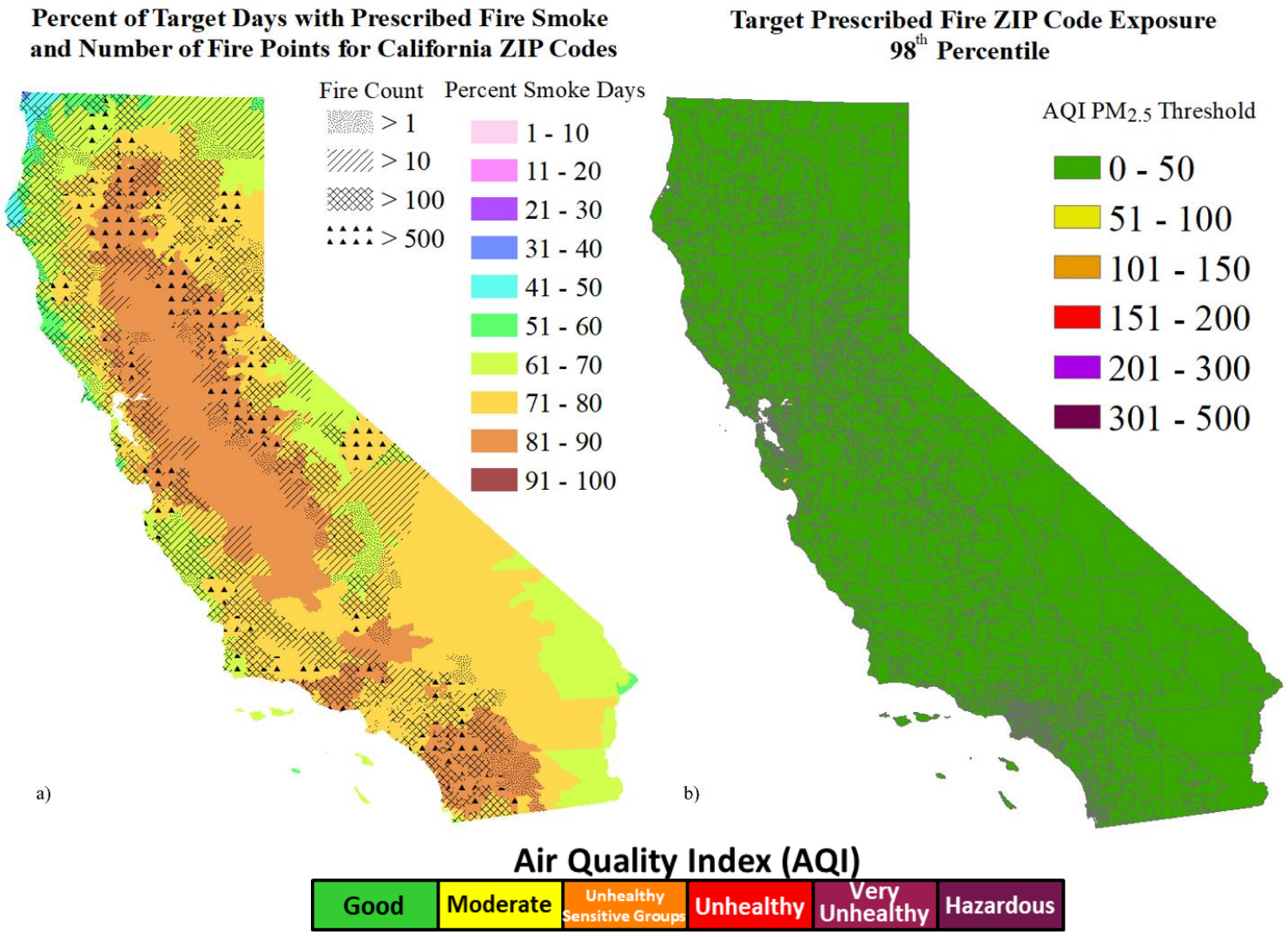
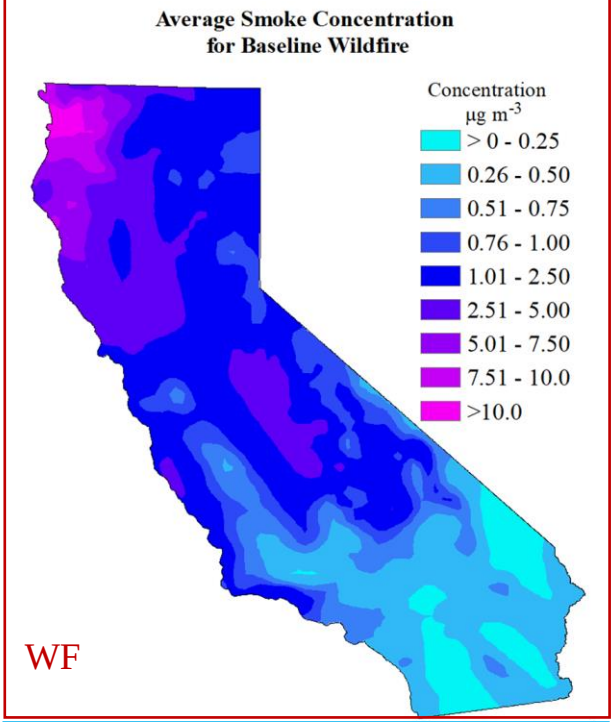
Target Scenario – Projected Prescribed Fire Smoke Impacts



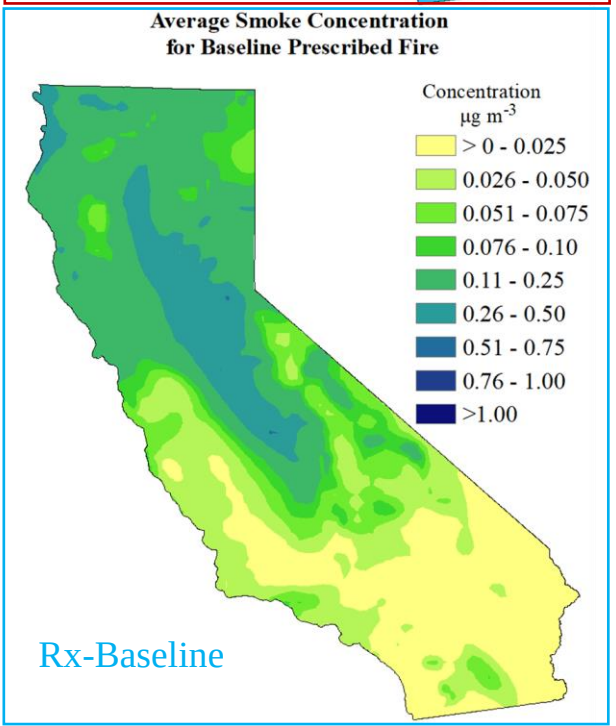
- **Percent of days with smoke present is higher** than baseline Rx at all ZIP codes, and often higher than baseline WF.
- The 98th percentile* of smoke concentration **remains in the 'Good' $PM_{2.5}$ AQI threshold at all but two ZIP codes**; these ZIP codes reach 'Moderate' at a value of 51, which is still considered satisfactory by EPA.
- We allocated fires maintaining the historical size distribution, **skewed toward a higher number of small fires**; however, the distribution of fire sizes may change with increased acreage to treat.

* Not accounting for background ambient concentrations

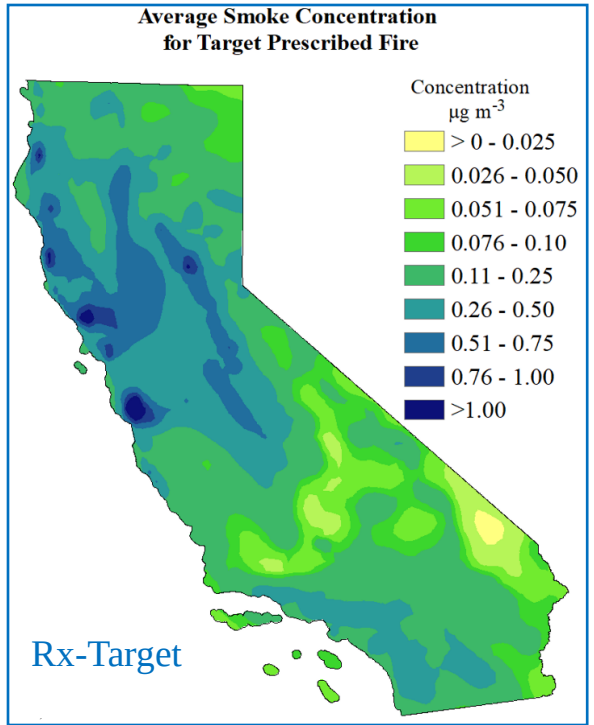
All Scenarios: Average Smoke Concentrations



WF



Rx-Baseline

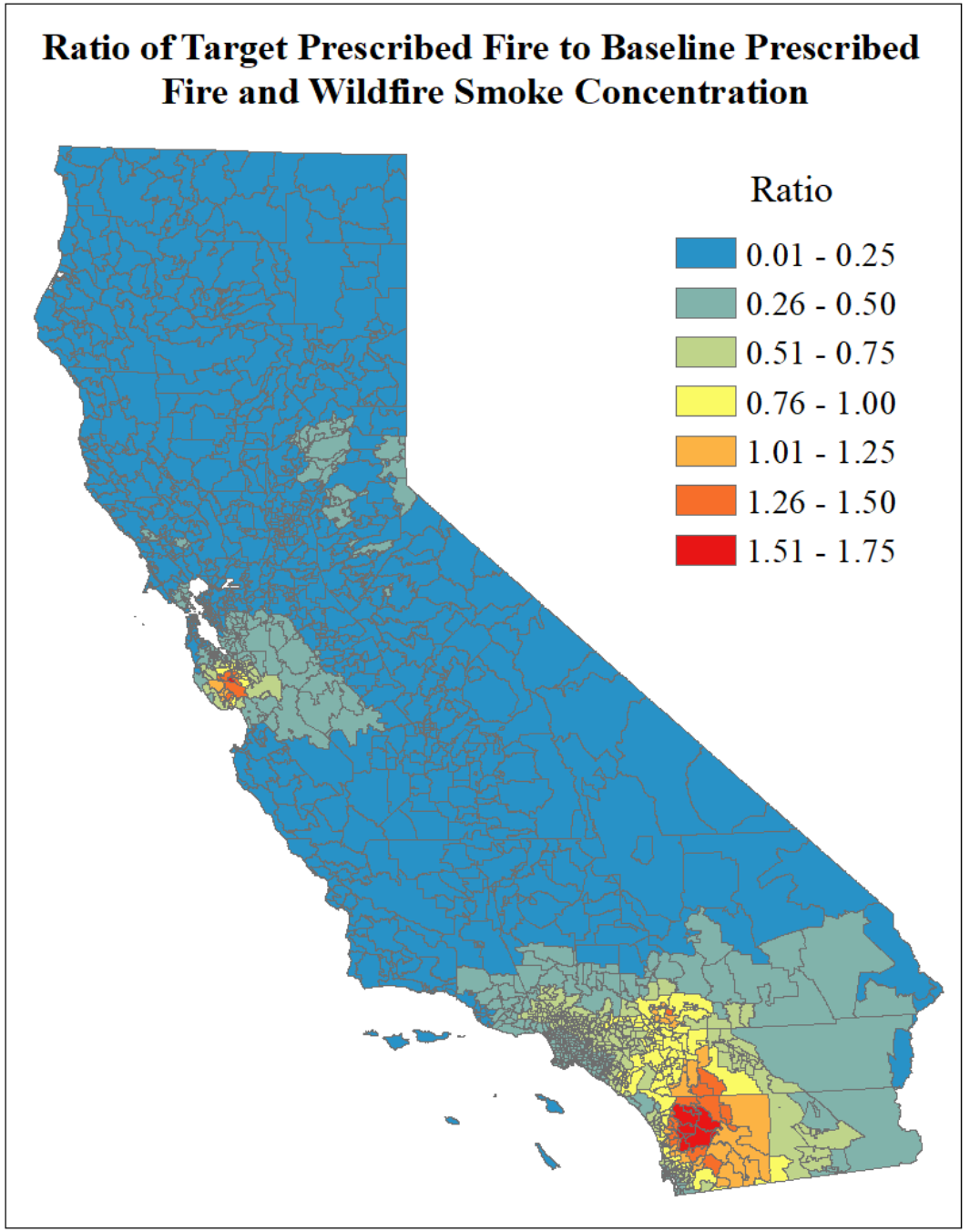


Rx-Target

- Baseline WF smoke concentrations are at least an **order of magnitude larger** than baseline Rx smoke concentrations statewide.
- Target Rx smoke is about **three times** the baseline Rx smoke, on average.
- Baseline WF smoke concentrations **exceed** target RX smoke concentrations in most regions.
- Projected smoke impacts are seen in the Northern Coast Range, San Francisco Bay Area, Sacramento Valley, San Joaquin Valley, and the Sierra Nevada Range.

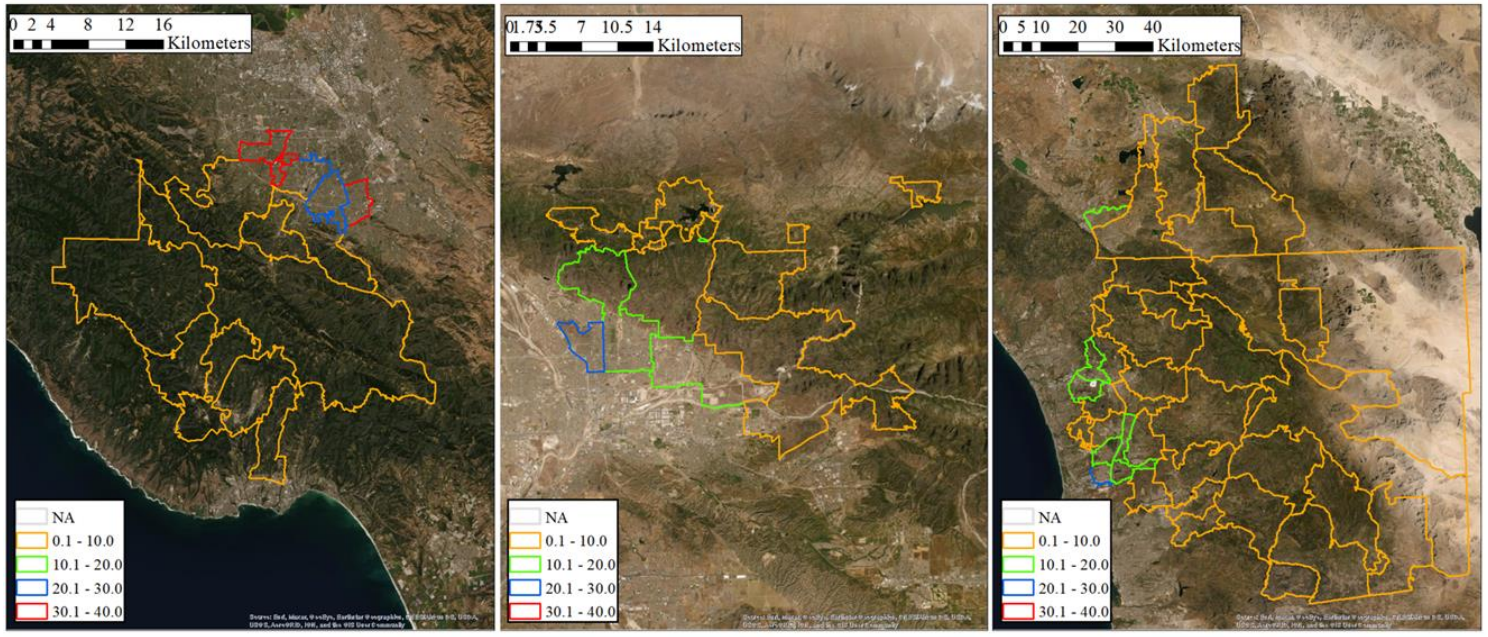
Baseline and Target Scenario – Increased Exposure

- The target prescribed fire scenario, burning 202,343 hectare (500,000 acres) per year in the 1.6 million hectares (4 million acres) of PL4&5, only exceeds the baseline smoke exposure from WF and Rx in **4% of CA ZIP codes**, though this may vary with different meteorology and wind flow.
- **Seventeen percent** of the area within the ZIP codes affected by more smoke than the baseline is **PL4&5**, deemed **high risk** for WF to the surrounding communities.

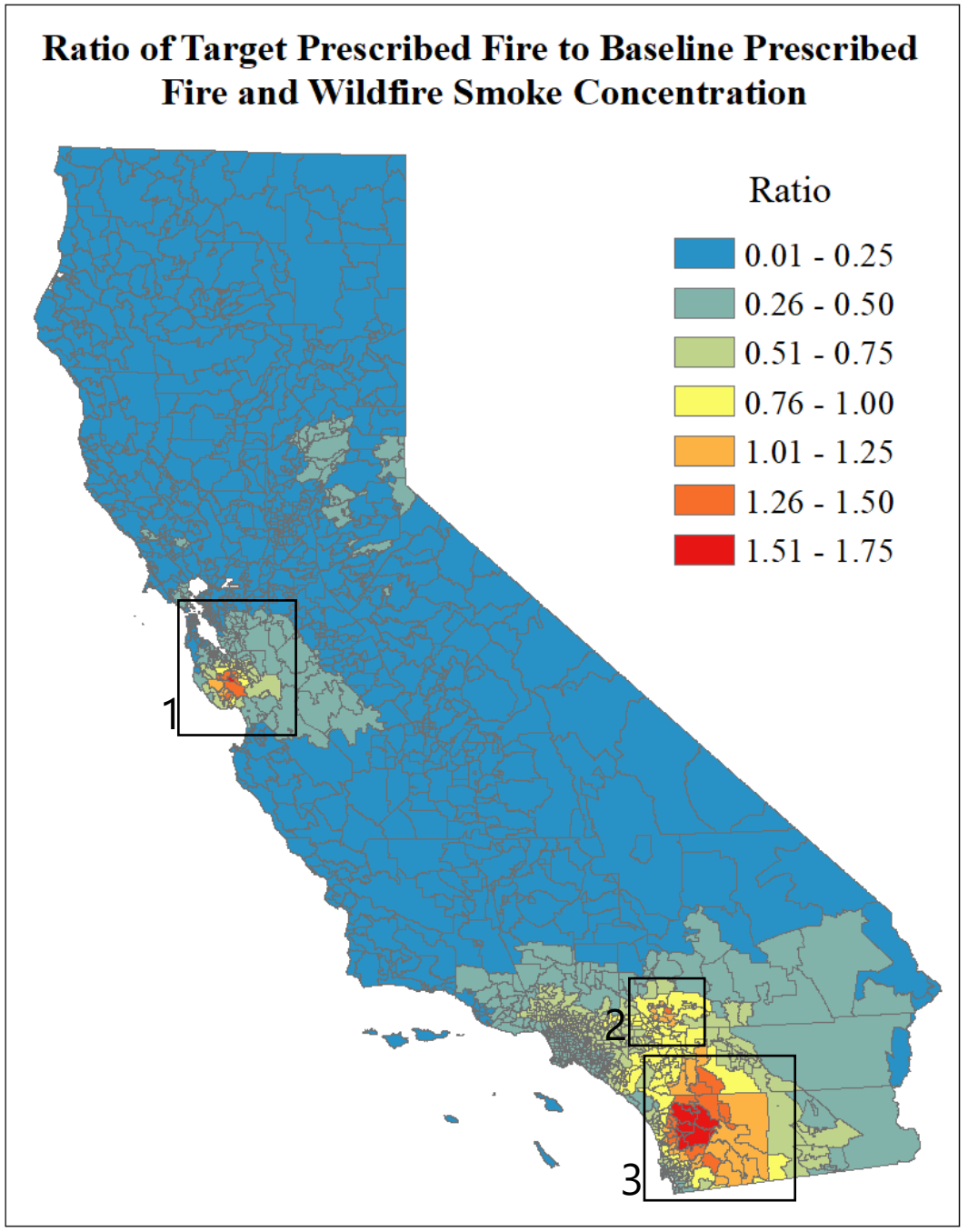


Baseline and Target Scenario – Increased Exposure

- Within the ZIP codes affected by more smoke than the baseline, most have low population density (Pop. / Sq Hectare)



1 2 3



Summary

- Baseline smoke modeling results show moderate agreement with IMPROVE and AQS measurements.
- All California ZIP codes had WF and Rx smoke days present during the baseline period, but not all had fires.
- At the 98th percentile (not accounting for background concentrations) WF smoke alone contributes enough $PM_{2.5}$ to shift the $PM_{2.5}$ AQI into 'Unhealthy', while baseline and target Rx smoke concentrations do not exceed 'Good' (with two exception ZIP codes). Even with a small $PM_{2.5}$ increase due to Rx, the air quality levels of areas with higher background $PM_{2.5}$ concentrations are at higher risk of shift into worse categories.
- The Rx smoke from the target scenario only exceeds baseline smoke exposures in wildland urban interface (WUI) regions at high fire risk.

Key Assumptions, Limitations, and Continued Work

Assumptions and limitations :

- Meteorology was kept constant for target scenarios
- Target scenario is focused on the PL4&5 regions, dominated by WUI areas
- Future prescribed fire characteristics may differ from historical (e.g., larger in size)
- Background ambient $PM_{2.5}$ concentrations are not included in this analysis

This work is ongoing:

- Health effects, attributable health burden, and mortality analysis
- Community engagements, including surveys and listening sessions

To our knowledge, this study is the first to model baseline and hypothetical prescribed fires on a large scale using historical data.

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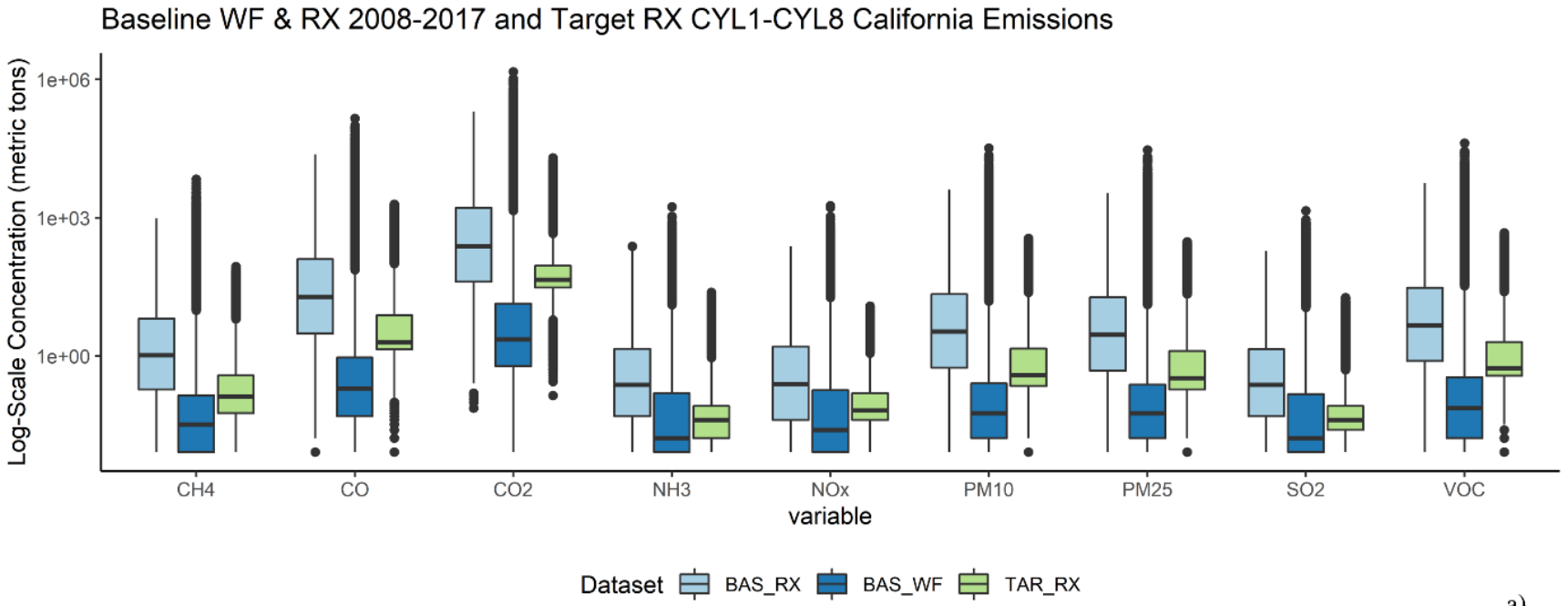
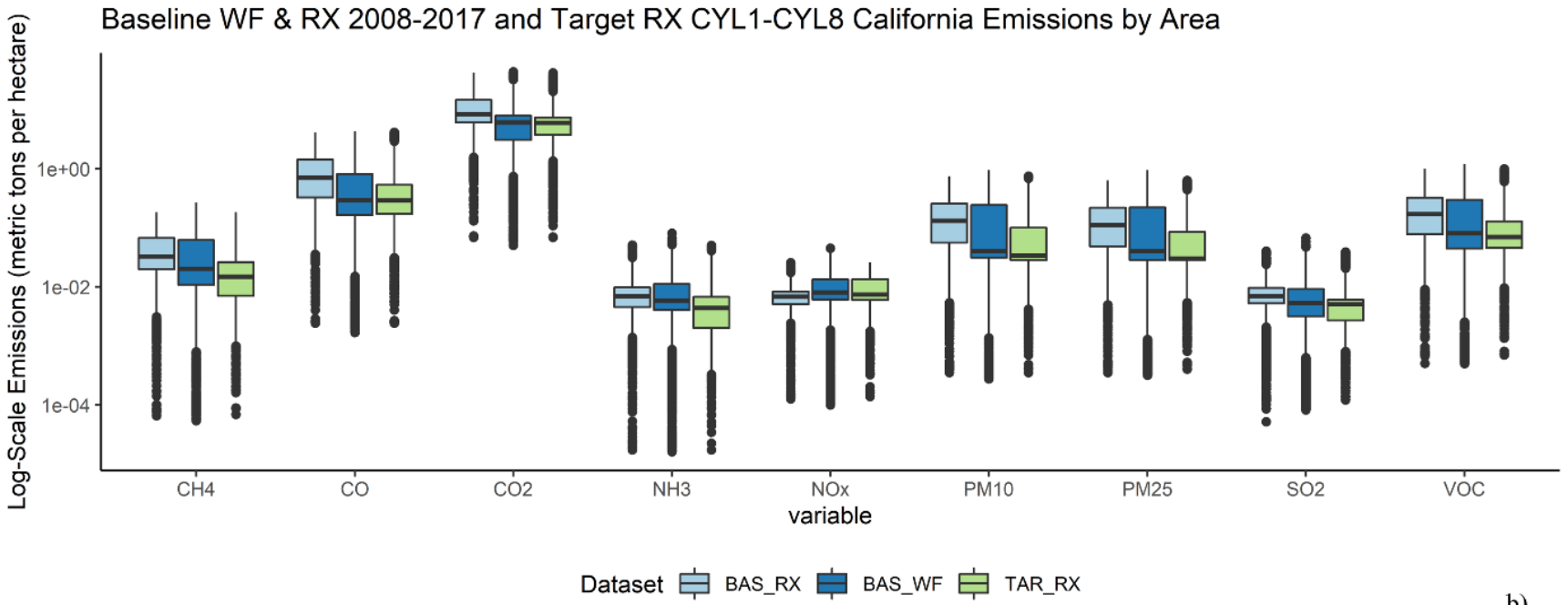
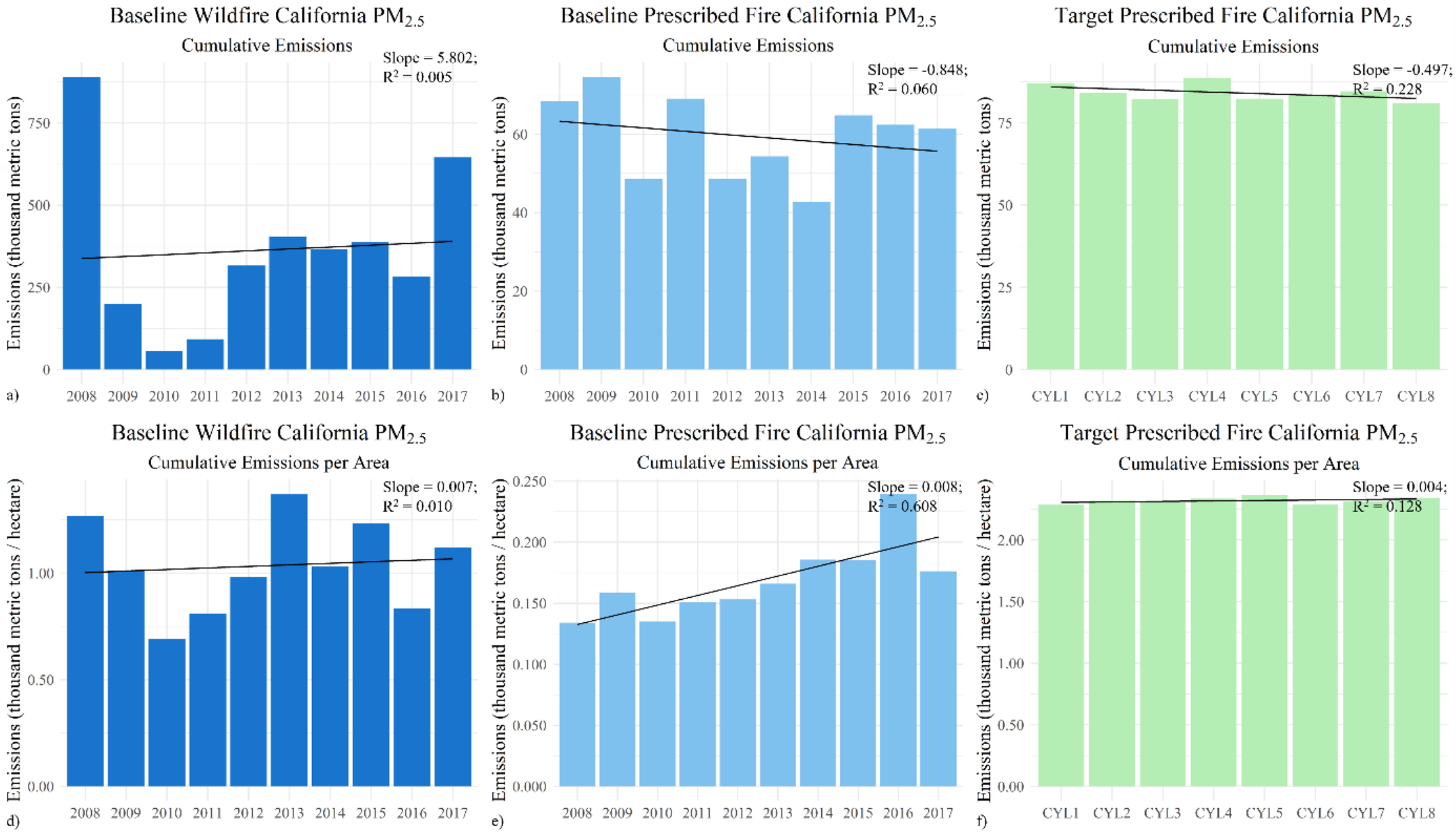
Extra Slides

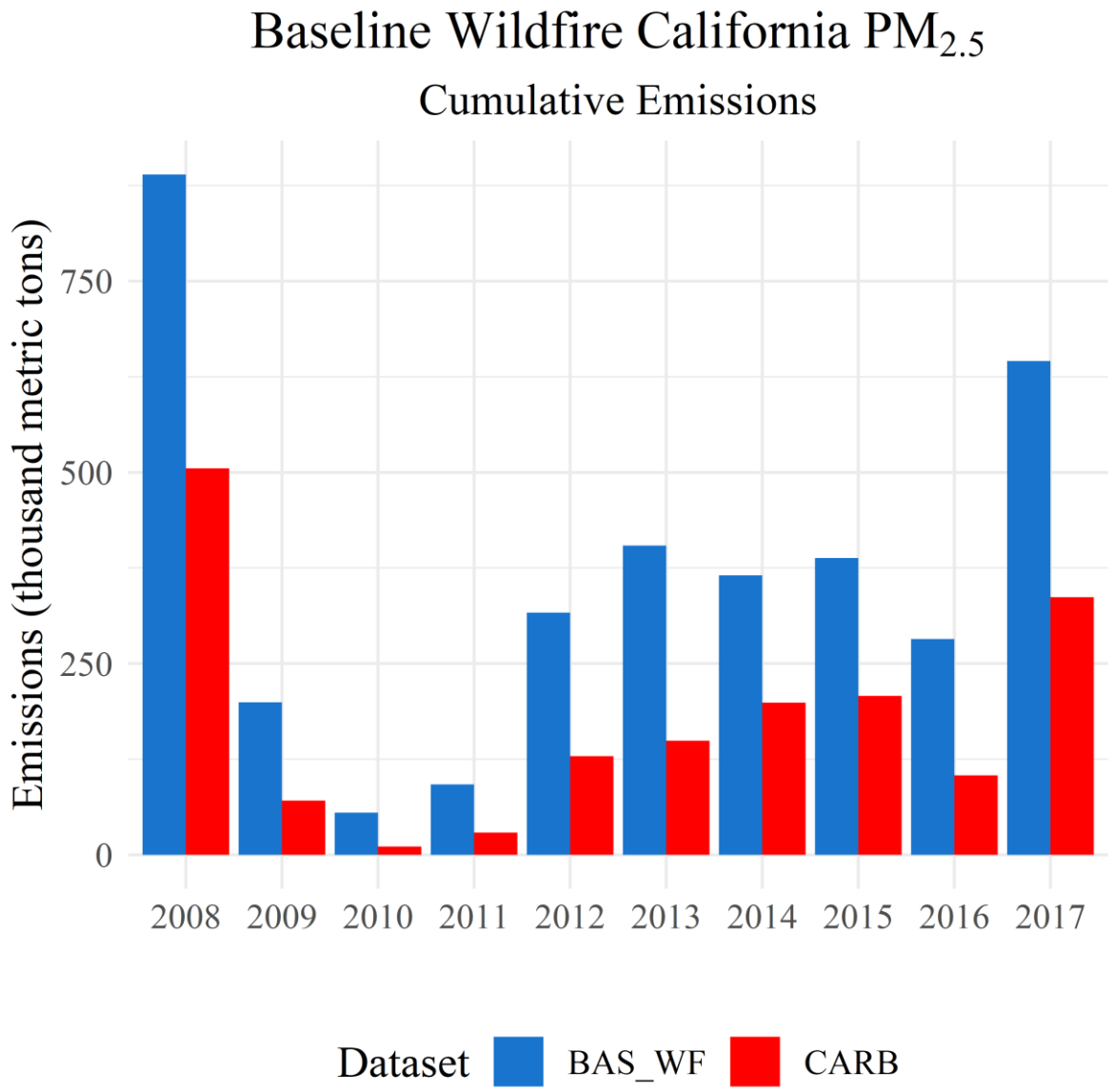

Baseline WF & RX 2008-2017 and Target RX CYL1-CYL8 California Emissions
Log-Scale Concentration (metric tons)
1e+06
1e+03
1e+00
CH4
CO
CO2
NH3
NOx
PM10
PM25
SO2
VOC
variable
Dataset
BAS_RX
BAS_WF
TAR_RX

a)

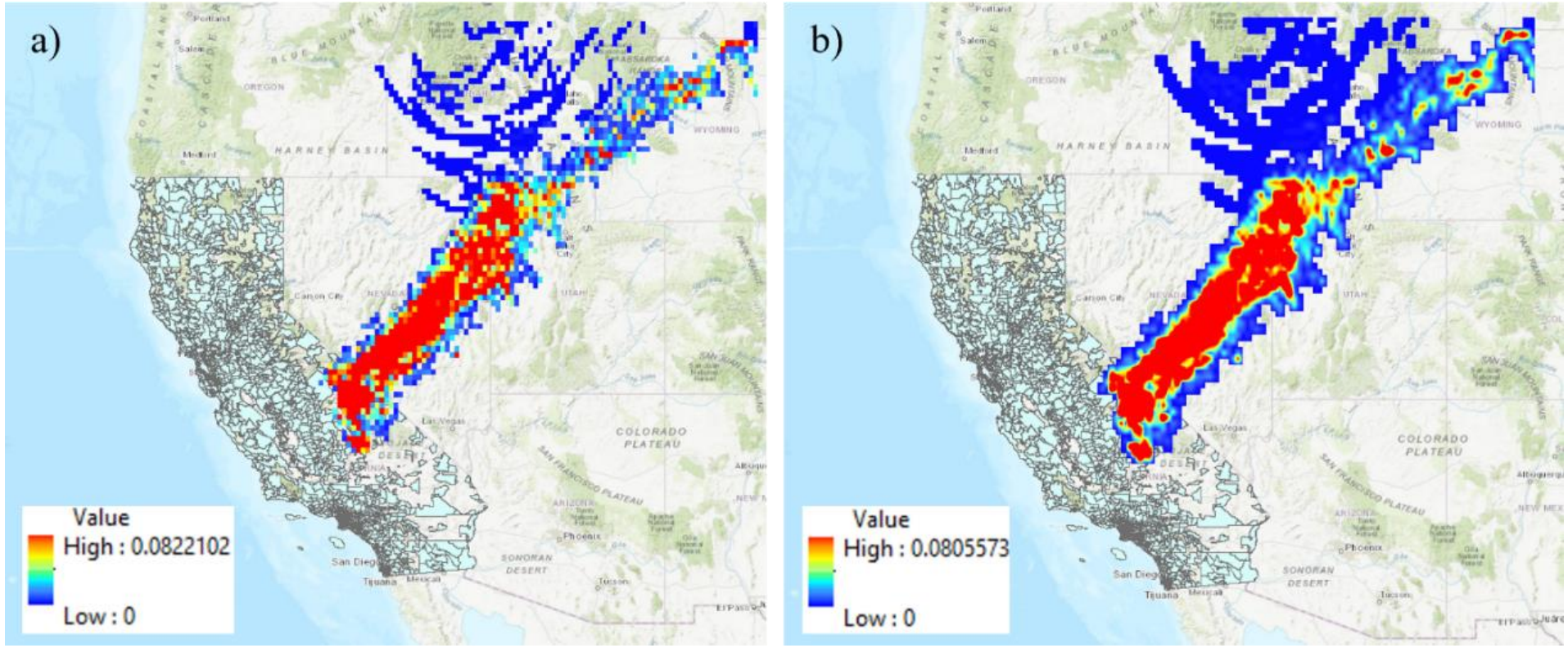

Baseline WF & RX 2008-2017 and Target RX CYL1-CYL8 California Emissions by Area
Log-Scale Emissions (metric tons per hectare)
1e+00
1e-02
1e-04
CH4
CO
CO2
NH3
NOx
PM10
PM25
SO2
VOC
variable
Dataset
BAS_RX
BAS_WF
TAR_RX

b)

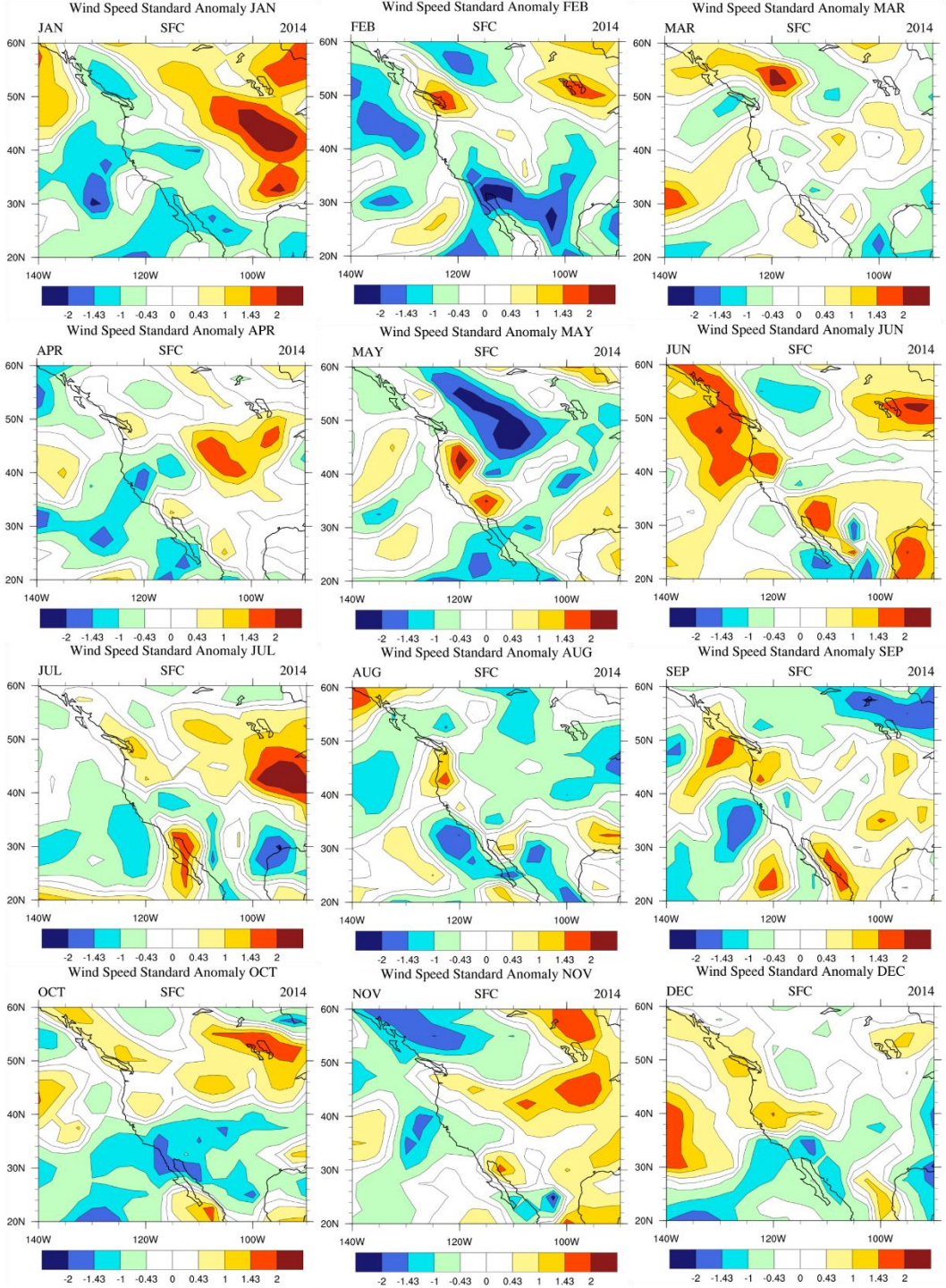

Baseline Wildfire California PM2.5
Cumulative Emissions
Slope = 5.802;
R2 = 0.005
Emissions (thousand metric tons)
0
250
500
750
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
a)
Baseline Prescribed Fire California PM2.5
Cumulative Emissions
Slope = -0.848;
R2 = 0.060
Emissions (thousand metric tons)
0
20
40
60
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
b)
Target Prescribed Fire California PM2.5
Cumulative Emissions
Slope = -0.497;
R2 = 0.228
Emissions (thousand metric tons)
0
25
50
75
CYL1 CYL2 CYL3 CYL4 CYL5 CYL6 CYL7 CYL8
c)
Baseline Wildfire California PM2.5
Cumulative Emissions per Area
Slope = 0.007;
R2 = 0.010
Emissions (thousand metric tons / hectare)
0.00
0.50
1.00
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
d)
Baseline Prescribed Fire California PM2.5
Cumulative Emissions per Area
Slope = 0.008;
R2 = 0.608
Emissions (thousand metric tons / hectare)
0.000
0.050
0.100
0.150
0.200
0.250
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
e)
Target Prescribed Fire California PM2.5
Cumulative Emissions per Area
Slope = 0.004;
R2 = 0.128
Emissions (thousand metric tons / hectare)
0.00
0.50
1.00
1.50
2.00
CYL1 CYL2 CYL3 CYL4 CYL5 CYL6 CYL7 CYL8
f)


Baseline Wildfire California $PM_{2.5}$
Cumulative Emissions
Emissions (thousand metric tons)
750
500
250
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Dataset
BAS_WF
CARB

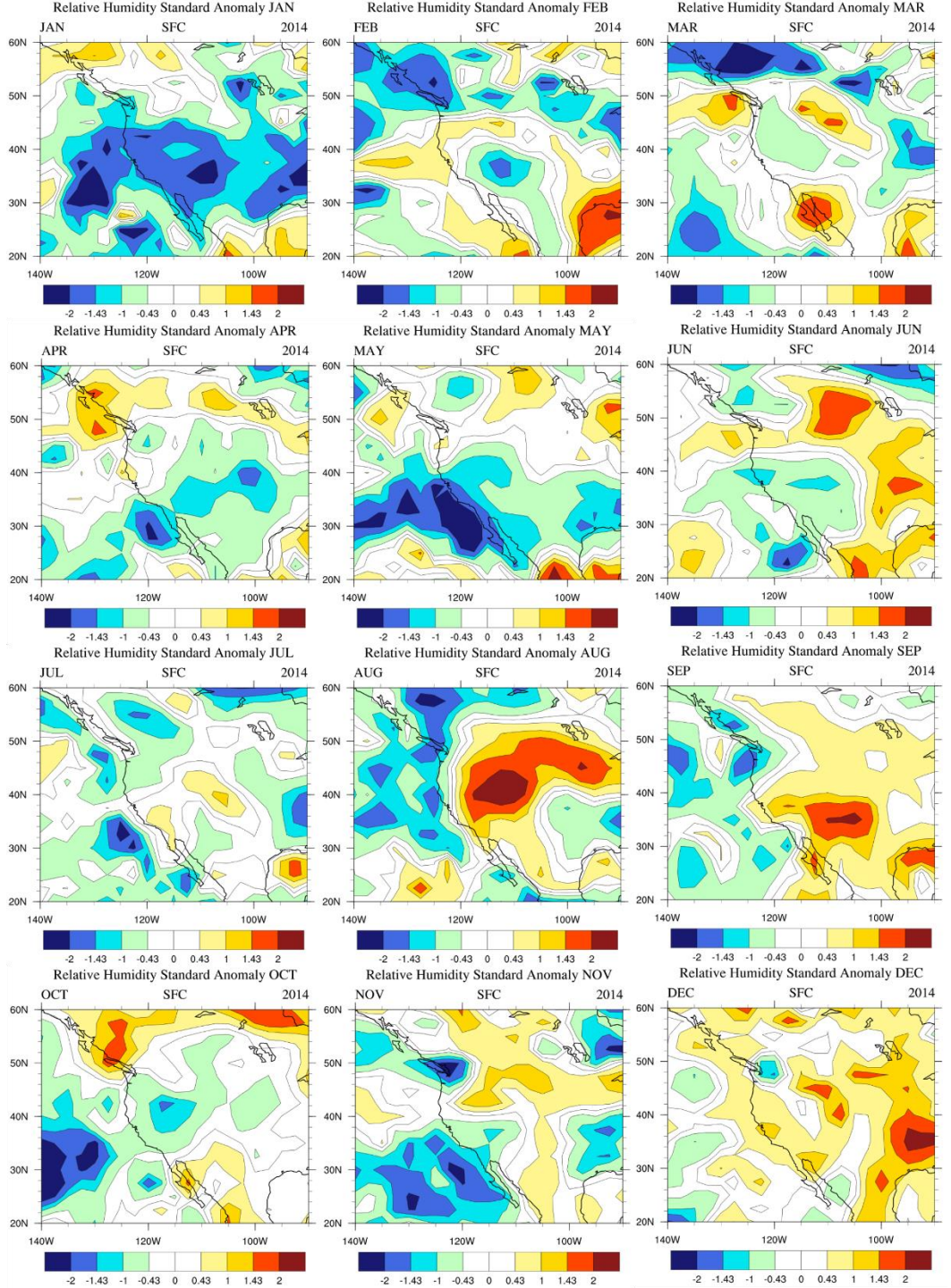
Example of downscaled model output from 12 km to 1 km



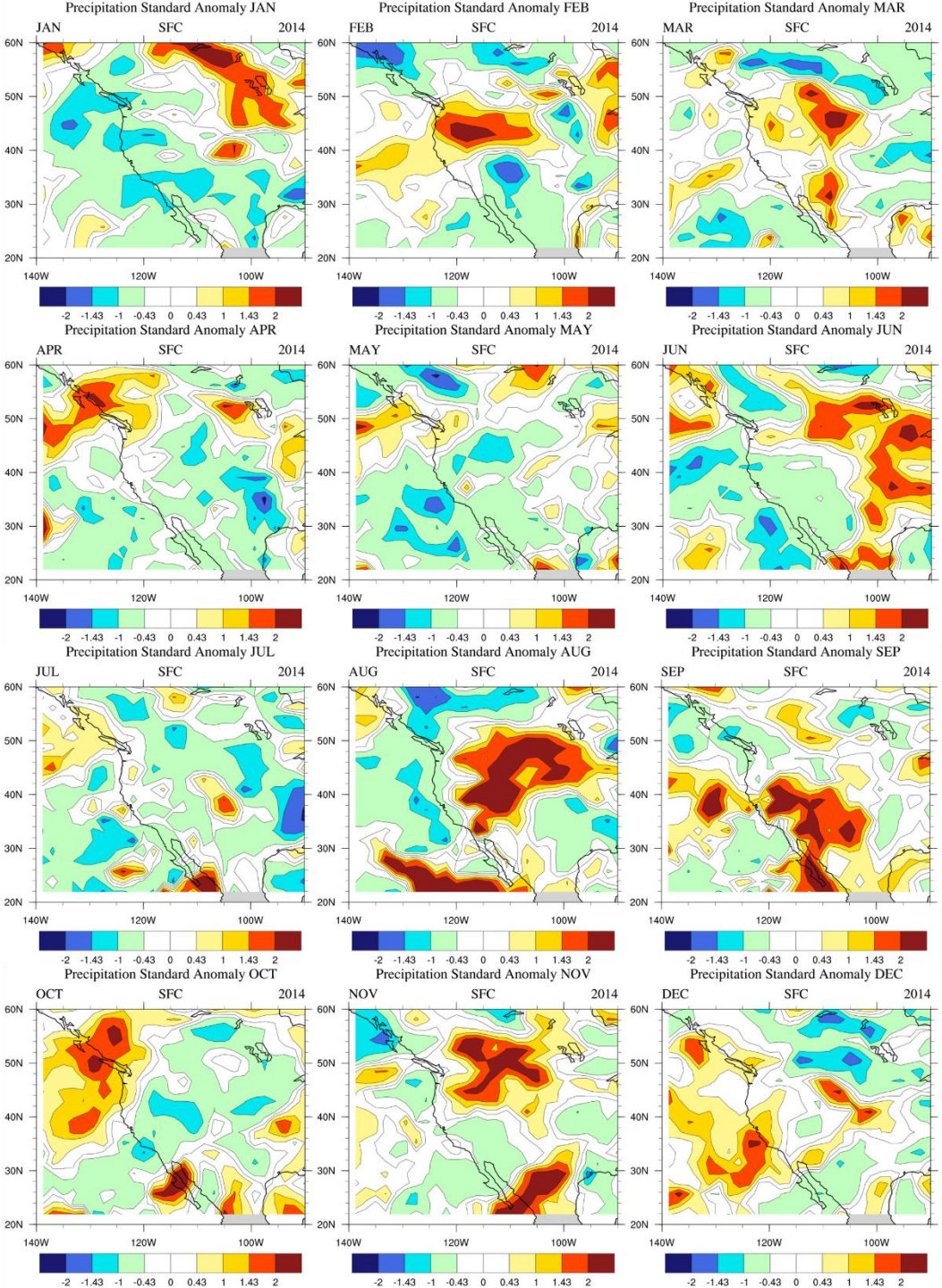
2014 Surface Wind Speed Standard Anomaly



2014 Surface Relative Humidity Standard Anomaly



2014 Surface Precipitation Standard Anomaly



2014 Surface Soil Moisture Standard Anomaly