Filling in the Gaps: Using Consumer Products to Replace Missing Pollution Data

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Motivation

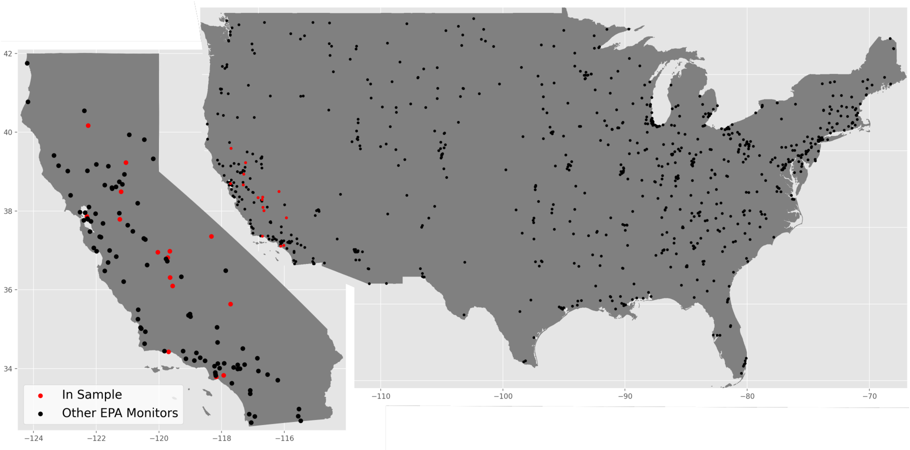
Clean Air

- The Clean Air Act (1970) established National Ambient Air Quality Standards (NAAQS) for US counties
- Either "attainment" or "non-attainment", penalties/forced adoption
- Minimum requirement of 75% of readings, per quarter
- Air quality can change quickly
- Monitor shutoffs are common

Research Questions

- How biased are EPA monitor-based measures of local air quality?
- Does this bias significantly change NAAQS attainment status?

EPA National Ambient Air Quality Standards Monitors



National Ambient Air Quality Standards for PM2.5

Two standards for assessing compliance for ambient PM2.5 concentrations at the location of a monitor:

Daily Design Value (average)

$\Rightarrow$ 3-year rolling average of 1-year average of daily averages

$\Rightarrow$ standard currently set at 15.0 μg/m^3

24-Hour Design Value (98th percentile)

$\Rightarrow$ 3-year rolling average of 1-year 98th percentile of daily averages

$\Rightarrow$ standard currently set at 35 μg/m^3

NAAQS Completeness Criteria for daily monitors

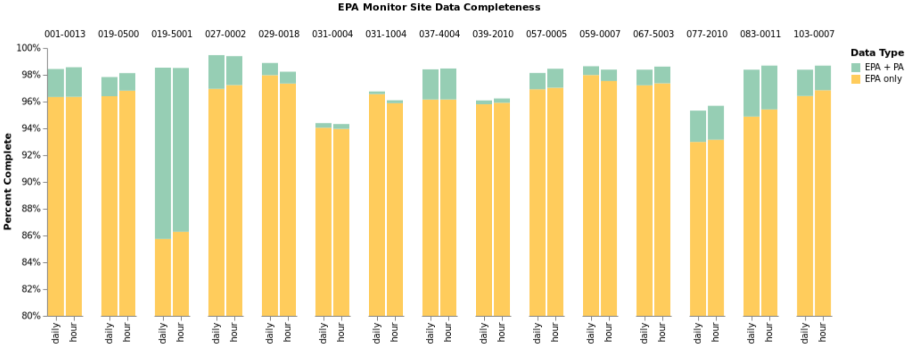
Valid day: minimum of 75% hours reported (18 hours)

Valid quarter: minimum of 75% valid days (22-23 days[1])

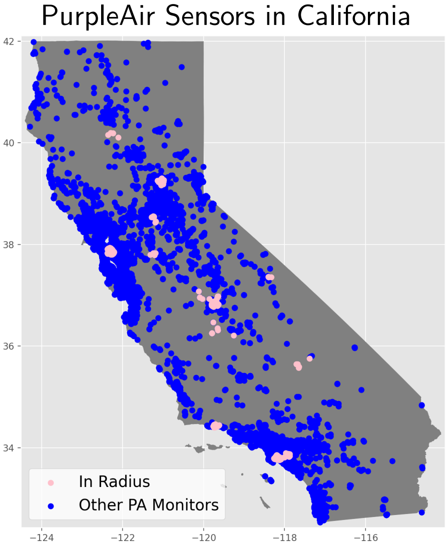
Valid quarterly design value: every in 3-year period (12 quarters)

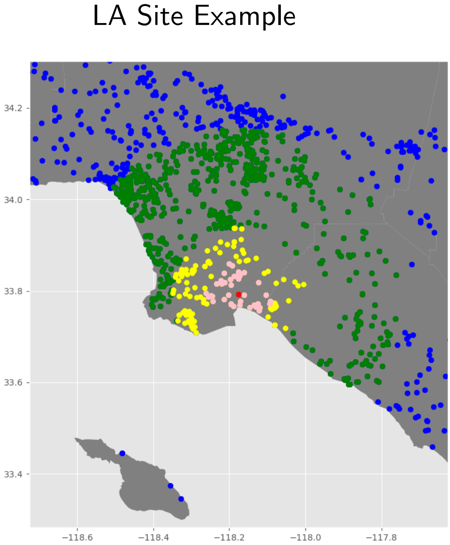
[1] fewer for monitors that report less frequent observations

Observed Completeness of NAAQS Monitors in sample

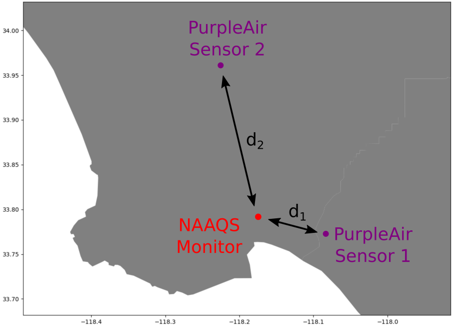


PurpleAir Outdoor Monitors





Alternate measure of ambient PM2.5 Concentration



Inverse-distance Weighted Average Ambient PM2.5

$$PA_t^{IDW} = \sum_{j=1}^{J_t} \frac{\frac{1}{d_j} \cdot PA_{j,t}}{\sum_{j}^{J_t} \frac{1}{d_j}} = \sum_{j=1}^{J^t} w_{j,t} \cdot PA_{j,t}$$

- J_t = active PurpleAir sensors around the NAAQS monitor at time t

Predicting Missing EPA Data

$$EPA_t = \beta_0 + \beta_1 PA_t^{IDW} + \varepsilon_t$$

Table: Reported NAAQS Monitor PM2.5 (site 037-4004)

	(1)	(2)
intercept		6.924^{***}
		(0.076)
PurpleAir IDW Average	0.741^{***}	0.444^{***}
	(0.003)	(0.004)
Observations	36,813	36,813
R^2	0.658	0.240
F Statistic	70924.412^{***}	11642.169^{***}

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Calculating Design Values for an EPA Site

Pseudo Design Values

$\mathrm{DV}_p = p$ design value for quarter, calculated using **reported** PM2.5 data from EPA monitor, $\forall p \in \{\text{Daily, 24-Hour}\}$

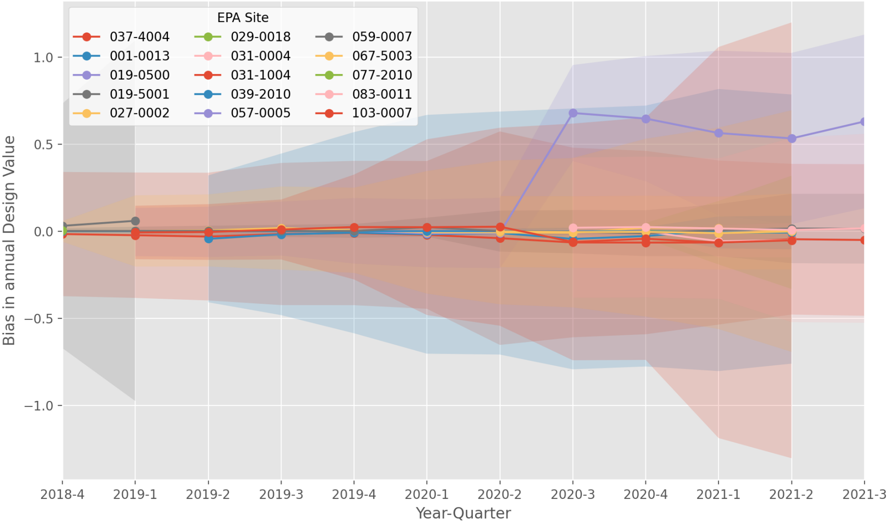
Imputed Design Values

$\widetilde{\mathrm{DV}}_p = p$ design value for quarter, calculated using **imputed** PM2.5 data from EPA monitor and PA sensors

Bias in Design Values

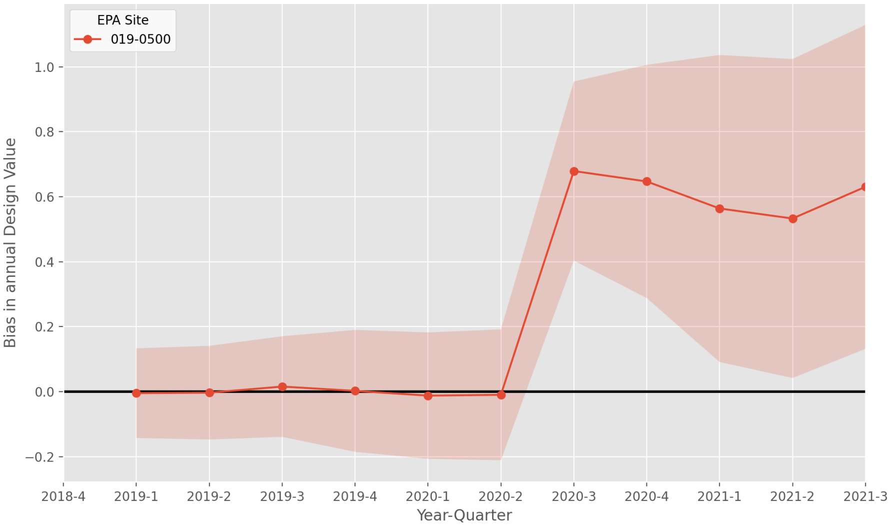
$$\text{bias from missing data in } \mathrm{DV}_p \approx \widetilde{\mathrm{DV}}_p - \mathrm{DV}_p$$

Results for Daily Design Value: Sample EPA Sites



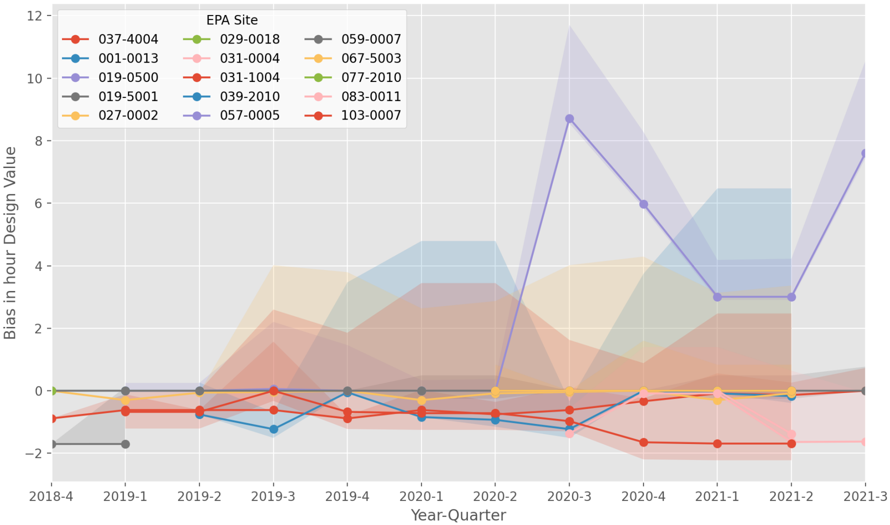
Shaded regions are 95% confidence intervals from interpolating the data.

Results for Daily Design Value: Fresno



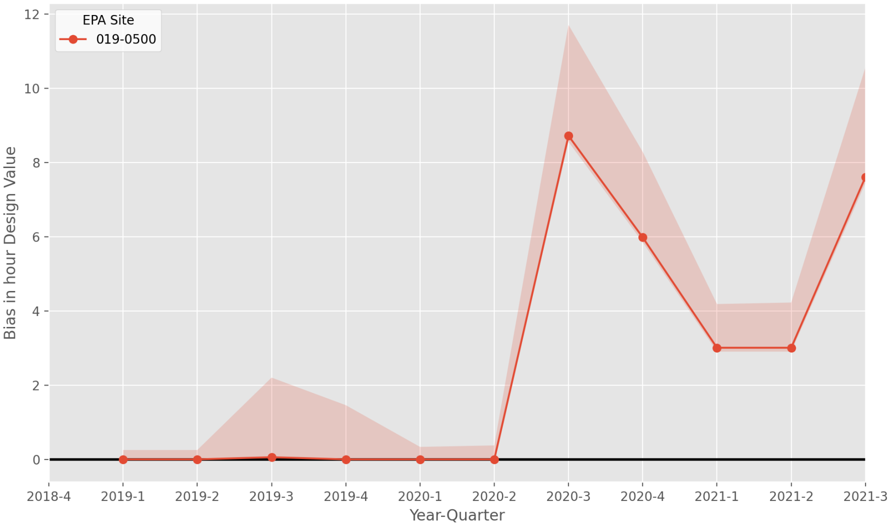
Shaded regions are 95% confidence intervals from interpolating the data.

Results for 24-hour Design Value: Sample EPA Sites



Shaded regions are 95% confidence intervals from interpolating the data.

Results for 24-hour Design Value: Fresno



Shaded regions are 95% confidence intervals from interpolating the data.

Conclusions & Discussion

1. Most tested sites show little evidence of bias from missing data, but one has large, meaningful bias

2. Even one site can affect millions of people due to the sparsity of monitoring sites

3. As high-pollution locations continue to reduce pollution, this bias may play an important role in determining NAAQS compliance

4. Underlines importance of expanding the monitor network or exploring alternative measures of ambient air quality

Future Work

- Optimal regulation of ambient pollution under monitor expense-accuracy tradeoff
- Expand test to rest of US monitors
- Explore spatial distribution of air quality in unmonitored locations

Appendix: Correction of PurpleAir Readings

$$\widetilde{PA}_{j,t} = \begin{cases} 0.52 * PA_{j,t} - 0.086 * H_{j,t} + 5.75, & \text{if } PA_{j,t} \leq 343\mu\text{g/m}^3 \\ 0.46 * PA_{j,t} + 0.(3.93e - 4)PA_{j,t}^2 + 2.97, & \text{otherwise} \end{cases}$$

- $PA_{j,t}$ = ambient PM2.5 measured by PurpleAir sensor j at time t
- $H_{j,t} \in [0, 1]$ is the relative humidity

Appendix: Better Prediction of EPA PM2.5

$$\widetilde{PA}_{j,t} = \begin{cases} 0.52 * PA_{j,t} - 0.086 * H_{j,t} + 5.75, & \text{if } PA_{j,t} \leq 343\mu\text{g}/\text{m}^3 \\ 0.46 * PA_{j,t} + 0.(3.93e - 4)PA_{j,t}^2 + 2.97, & \text{otherwise} \end{cases}$$

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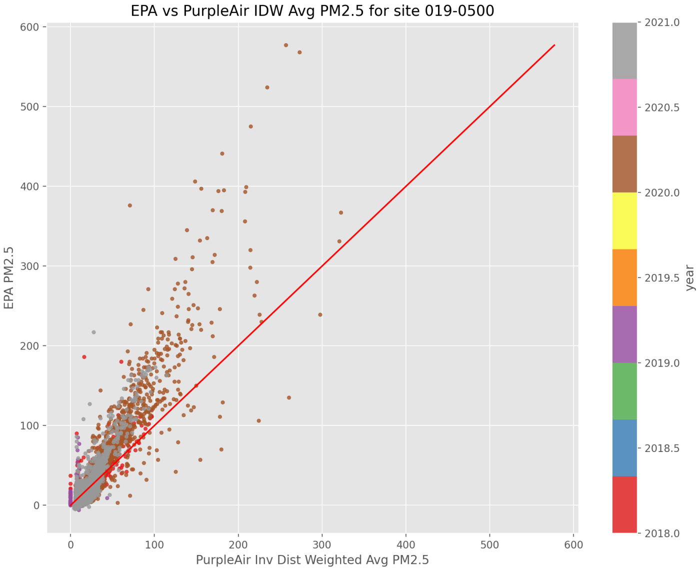
Appendix: Fresno Site Data



Appendix: Fresno, California DV Bias Table

Table: Design Value Comparison for Fresno, CA. (95% CI Bounds)

Year-Quarter	Annual DV Difference	Upper Bound	Lower Bound	Hour DV Difference	Upper Bound	Lower Bound
2018-4	Invalid DV			Invalid DV		
2019-1	-0.005	0.133	-0.143	0.000	0.252	0.000
2019-2	-0.003	0.141	-0.147	0.000	0.252	0.000
2019-3	0.015	0.170	-0.139	0.058	2.202	0.000
2019-4	0.002	0.190	-0.185	0.000	1.460	-0.024
2020-1	-0.012	0.182	-0.207	0.000	0.335	0.000
2020-2	-0.010	0.191	-0.211	0.000	0.376	0.000
2020-3	0.679	0.954	0.403	8.718	11.704	8.556
2020-4	0.647	1.006	0.288	5.979	8.281	5.851
2021-1	0.564	1.036	0.091	3.007	4.184	2.903
2021-2	0.533	1.024	0.042	3.007	4.225	2.903
2021-3	0.630	1.129	0.132	7.607	10.557	7.444