Using Satellite Data to Fill the Gaps in the U.S. Air Pollution Monitoring Network

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Resources for the Future

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Motivation: Clean Air Act and Pollution Monitors

- Nonattainment designation done primarily with ground-based monitors.
- At least 37% of people in U.S. have no $PM_{2.5}$ monitor.
    - 79% of counties
- Finding the optimal monitor location is difficult.

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This paper:

1. Does filling the gaps with satellite data find “attainment” counties that actually exceed the annual $PM_{2.5}$ NAAQS?
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Empirical Strategy

1. Match satellite-measured $PM_{2.5}$ to Census data on population (2010, block-level).
2. Flag counties as misclassified if they contain areas that exceed the NAAQS.
3. Estimate effect of nonattainment designation on $PM_{2.5}$ monitor readings (Auffhammer, Bento, & Lowe 2009).
4. Calculate $PM_{2.5}$-related mortality that could have been avoided if all misclassified areas had been nonattainment.

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Data

Montiors EPA, 1999–2017 (lat/long, days of operation, flag for NAAQS monitor, etc.)

Satellites Composite data from Dalhousie (van Donkelaar et al. 2015; 2016).

- MODIS, MISR, SeaWIFS
- GEOS-Chem
- Calibrated to North America
- Annual average $\mu g/m^3$ $PM_{2.5}$ for $0.01° \times 0.01°$ grid (~ 1 km^2).

Issue with satellites: Actually measure aerosol optical depth (AOD), must be calibrated.

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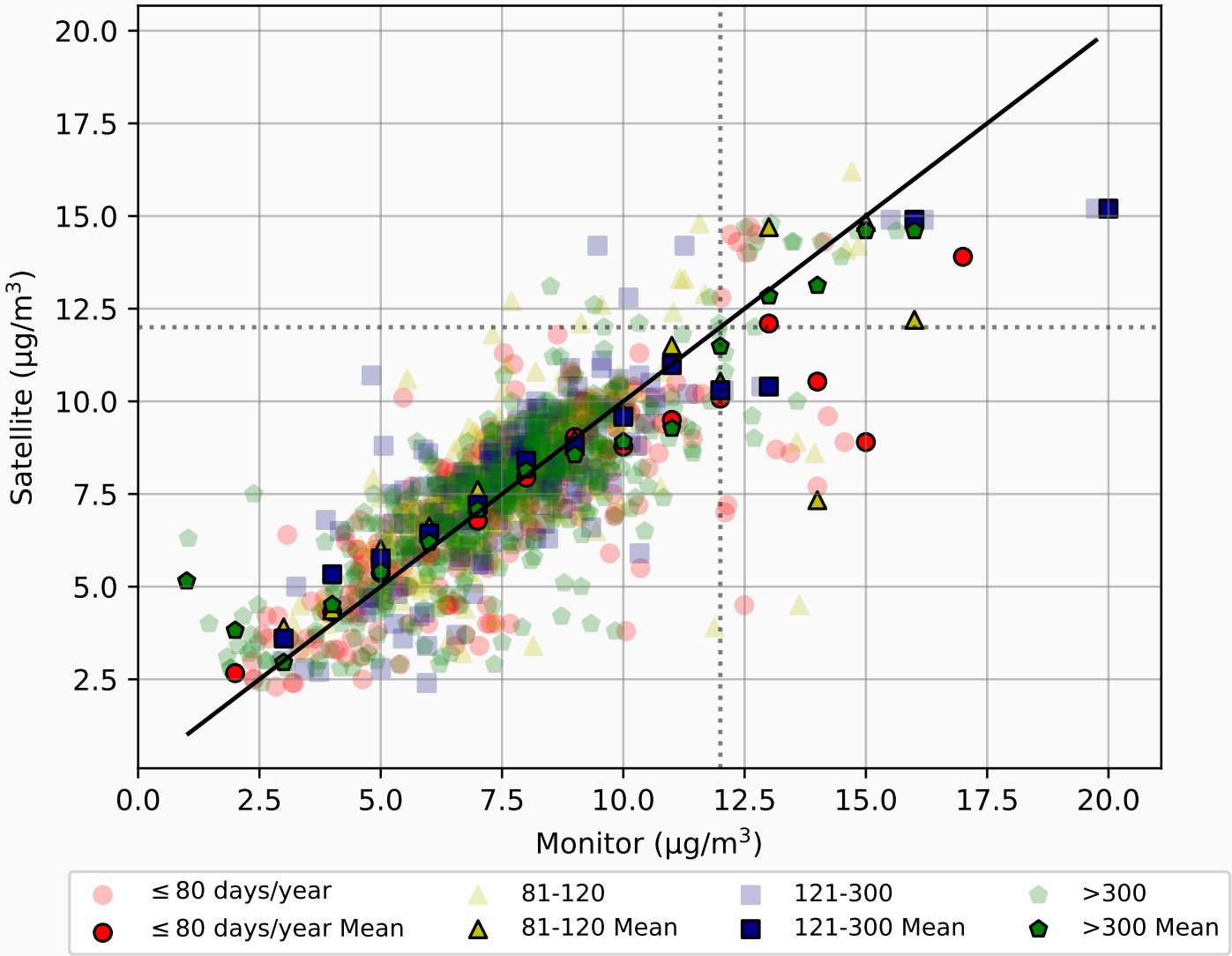
Satellites vs. Monitors



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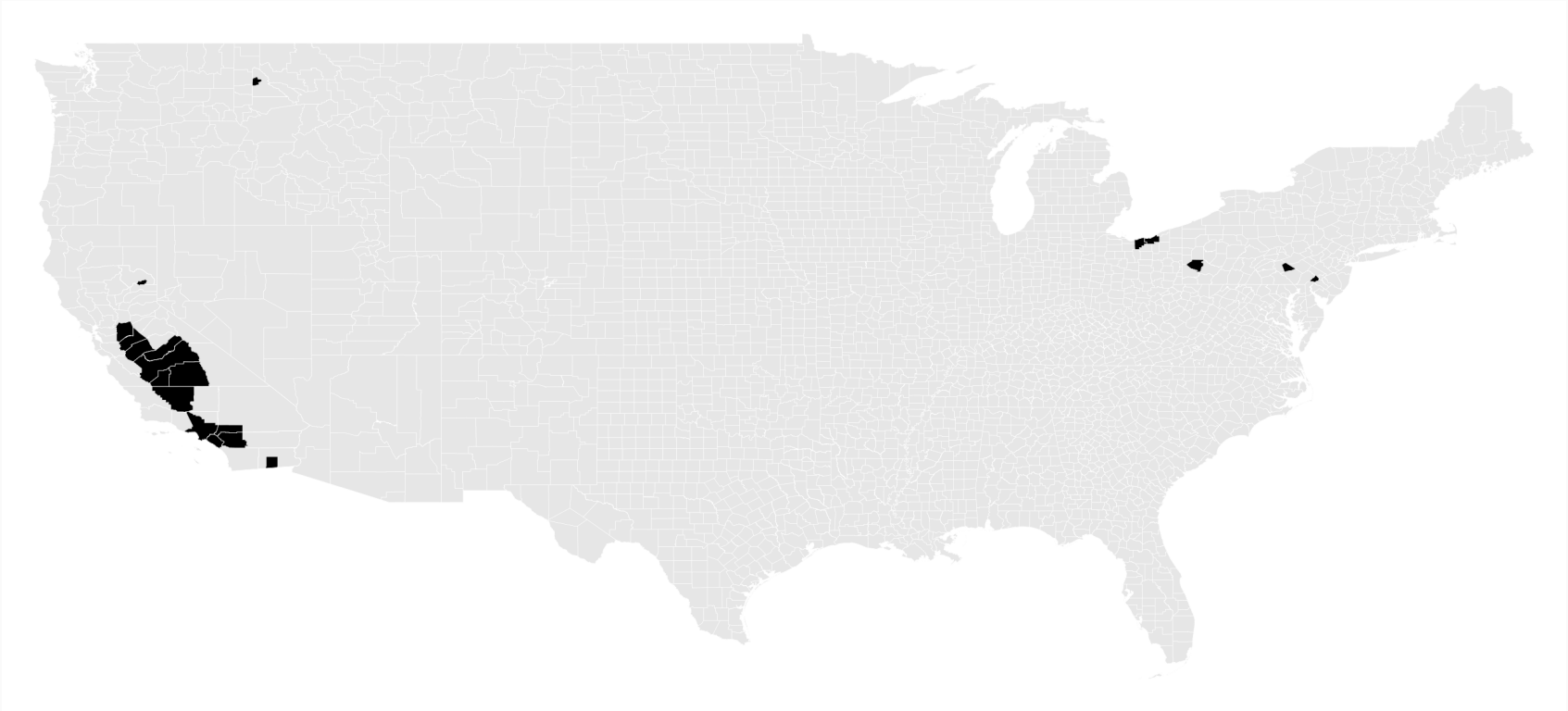
$PM_{2.5}$ Nonattainment, 2012 annual standard



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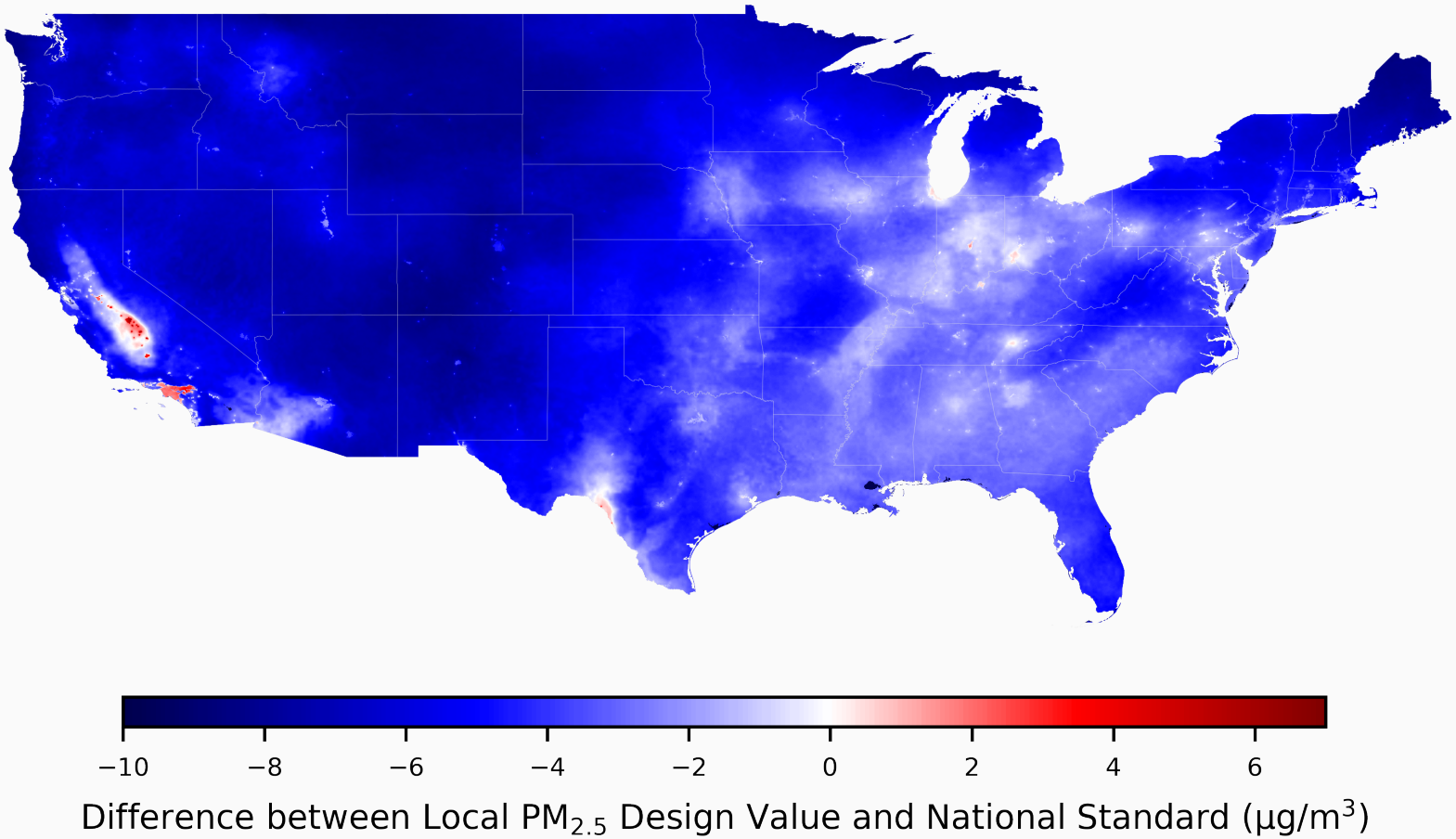
$PM_{2.5}$ design values minus NAAQS (12 $\mu g/m^3$), 2011–2013



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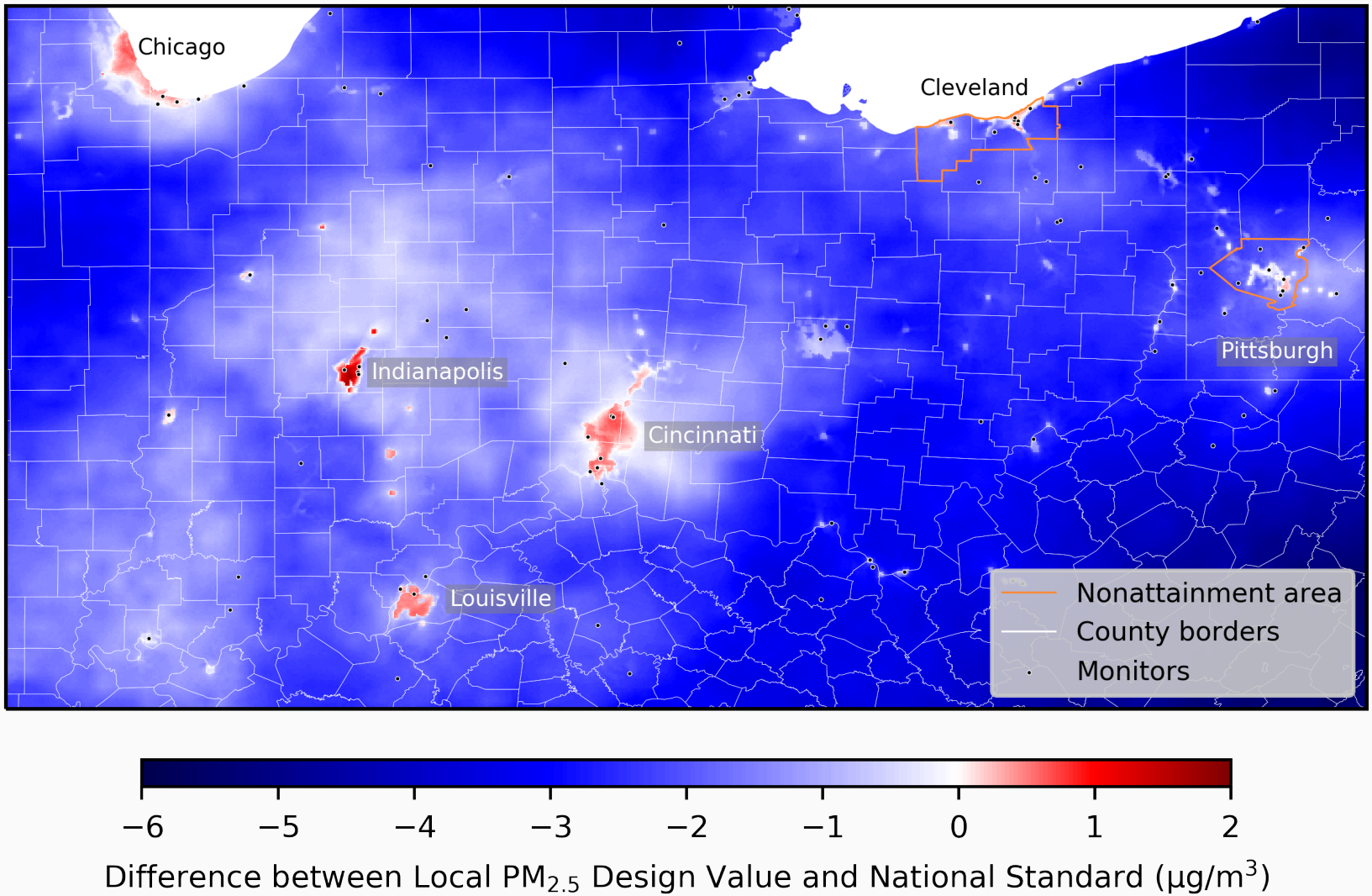
$PM_{2.5}$ Concentration and Attainment Status, 2011–2013



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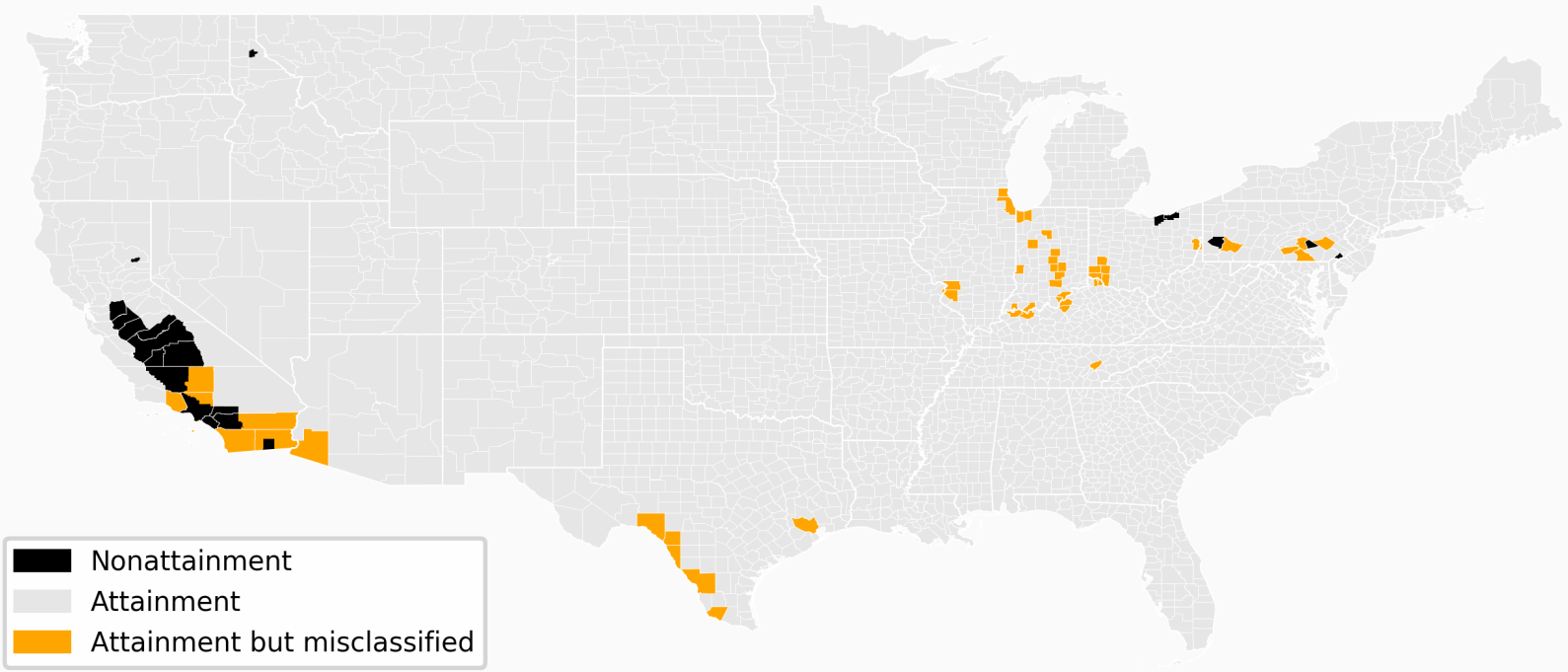
Counties misclassified under $PM_{2.5}$ 2012 annual standard



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Misclassified population is both monitored and un-monitored

	Counties with No monitor	Counties with $\geq$ 1 monitor	Total
West Virginia	0	24,069	24,069
Tennessee	0	54,181	54,181
Arizona	0	195,751	195,751
Missouri	0	319,294	319,294
Kentucky	975,135	233,242	1,208,377
Pennsylvania	633,269	1,081,820	1,715,089
Ohio	945,497	1,240,213	2,185,710
Indiana	616,795	2,229,834	2,846,629
Texas	418,007	4,092,459	4,510,466
California	844,427	4,059,633	4,904,060
Illinois	6,437,475	0	6,437,475
Total	10,870,605	13,530,496	24,401,101

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Distribution of Demographic Groups by Attainment Status

	(1)	(2)	(3)	(4)	(5)
	Percentage of Group Classified as			Nonattain. by Satellites (2) + (3)	Monitors' False Negative Rate (2) / (4)
	Attainment	Misclassified	Nonattainment		
Population	84.5	8.0	7.6	15.5	51.2
Rural	96.4	2.4	1.1	3.6	68.6
Urban	81.6	9.3	9.1	18.4	50.4
Race/Ethnicity					
White	88.7	6.7	4.6	11.3	59.6
Black	85.4	9.5	5.1	14.6	65.1
Hispanic	70.0	11.6	18.4	30.0	38.5
Asian	73.7	8.6	17.7	26.3	32.8
Other	72.4	10.1	17.5	27.6	36.5
Education					
No H.S. Diploma	81.0	8.6	10.5	19.0	45.0
H.S. Diploma	86.7	7.3	6.1	13.3	54.5
Some College	85.1	7.6	7.2	14.9	51.4
College Degree or More	84.7	8.1	7.1	15.3	53.3
Household Income					
<$35,000	86.0	7.6	6.3	14.0	54.6
$35,000–75,000	85.8	7.7	6.5	14.2	54.2
>$75,000	84.4	8.1	7.5	15.6	52.1

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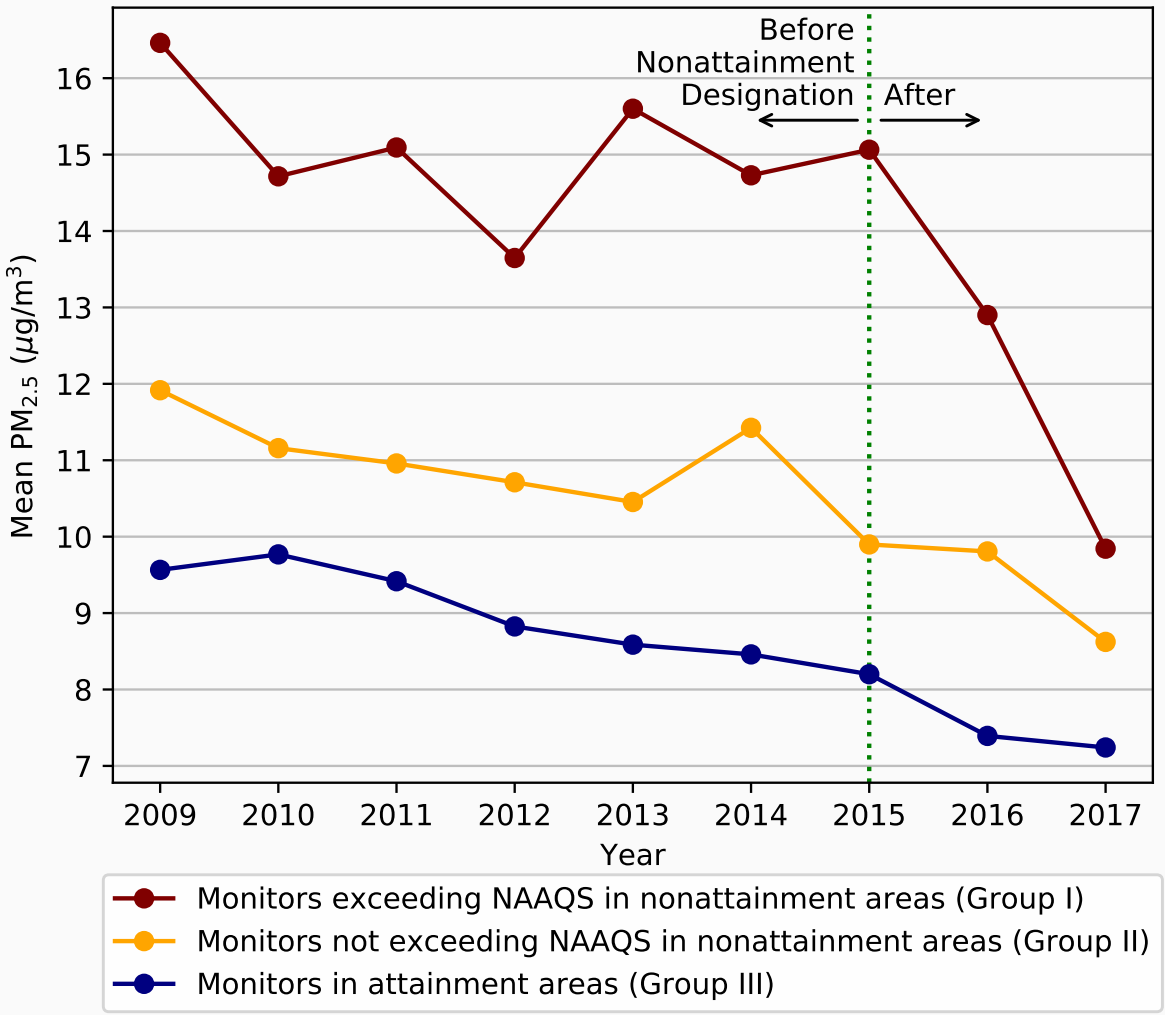
Average monitor readings by attainment and NAAQS status



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How does nonattainment designation change $PM_{2.5}$ levels?

$$
\begin{aligned}
P_{mt} = &\beta_1 \left(\text{Nonattainment}_m \times \text{post}_t \times \text{OverNAAQS}_m\right) + \\
&\beta_2 \left(\text{Nonattainment}_m \times \text{post}_t\right) + \\
&\delta_t + \delta_m + \varepsilon_{mt}
\end{aligned}
$$

- P_{mt} is pollution reading for monitor m, year t; Post is $t > 2015$
- Nonattainment and "Over NAAQS" determined in 2015.
- δ_m, δ_t are monitor and year effects; ε is residual.
- **Relative to attain. monitors, the effect of nonattainment on**
  - nonattainment monitor under NAAQS $= \beta_2$
  - nonattainment monitor over NAAQS $= \beta_1 + \beta_2$

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Estimate of nonattainment effect on monitor readings

	(1)	(2)
Non-attainment × post × Over NAAQS		-2.3019***
		(0.5326)
Non-attainment × post	-1.1416***	-0.4729**
	(0.2435)	(0.2055)
R^2	0.822	0.825

N=4,712. Outcome is annual average monitor reading ($\mu g/m^3$ $PM_{2.5}$). Regression includes monitor and year fixed effects. Standard errors clustered by monitor: *** $p < .01$, ** $p < .05$.

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How can we calculate excess mortality?

$$\text{Lower PM in new regime} \times \frac{\text{Mortality Increase}}{\text{PM Exposure}} \times \text{Baseline mortality rate} = \text{Excess mortality}$$

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$$\underbrace{\text{Lower PM in new regime}}_{\text{Estimated}} \times \underbrace{\frac{\text{Mortality Increase}}{\text{PM Exposure}}}_{\text{Lepeule et al. (2012)}} \times \underbrace{\text{Baseline mortality rate}}_{\text{From CDC}} = \text{Excess mortality}$$

↓ -2.77 or -0.47

↓ 1.4% per $\mu g/m^3$

↓ Varies by county

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Calculating avoidable deaths due to misclassification

- If misclassified areas had been correctly classified…
- **5,452 deaths** would have been avoided in 2016–2017
- VSL implied social cost: **$49 billion**.
    - Standard VSL, $9 million.

Conclusion

- 24.4 million people live in “misclassified” counties.
- Correct classification would have saved 5,452 lives.
    - $49 billion in VSL
- Implies that satellite data can cost-effectively
    - help find NAAQS exceedences.
    - help with monitor placement.

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