Laura Aume, Cheryl Triplett, Robert Lordo, Douglas Turner, Brannon Seay
Battelle Memorial Institute, 505 King Ave. Columbus, OH 43201

Dennis Crumpler
US EPA OAQPS, 109 TW Alexander Dr., Durham, NC 27711

Evaluating Data Quality Objectives within the $PM_{2.5}$ National Ambient Air Monitoring Network

For presentation at the 2022 National Ambient Air Monitoring Conference

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Background / Motivation

- **June 10, 2021:** EPA announced that it will reconsider the particulate matter (PM) National Ambient Air Quality Standards (NAAQS).
  - Annual NAAQS for fine particulate matter ($PM_{2.5}$) were first established in 1997, then revised in 2012.
- **$PM_{2.5}$ ambient air monitoring network:** Provides the data needed to make local attainment decisions relative to the NAAQS.
- **Data Quality Objectives (DQOs):** In 2002, EPA established science-based criteria on **bias and precision** which $PM_{2.5}$ network data need to achieve to ensure sufficient confidence that NAAQS attainment decisions are correct.

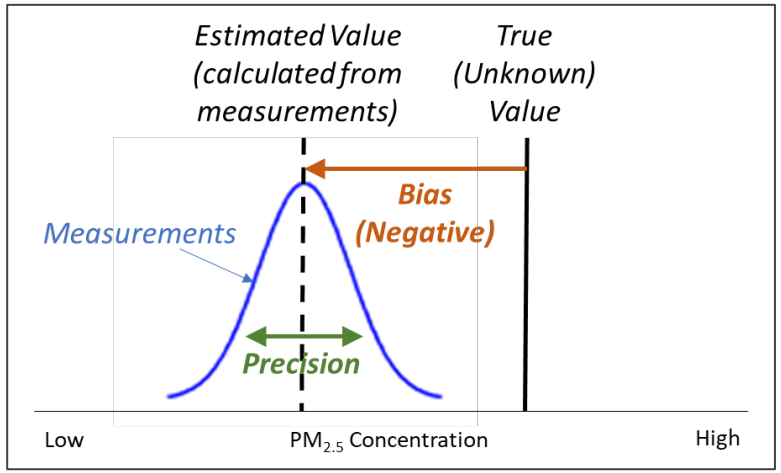
Objective: Given EPA's reconsideration of the NAAQS and recent downward shifts in $PM_{2.5}$ concentrations on average, should EPA update its **bias and precision estimators and DQOs?**

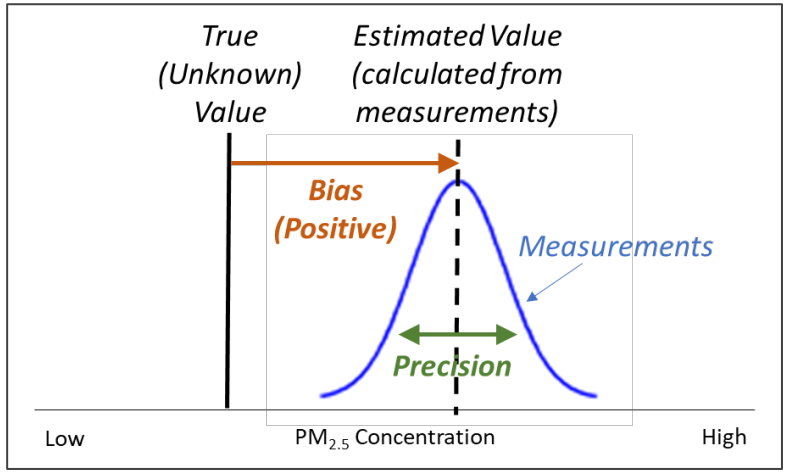
What is bias and precision? Why are they important?

- **Bias:** Systematic or persistent distortion present in a measurement process which causes error in one direction.
  - A constant shift in average measurement from the true concentration, expressed as a ***percentage of the true concentration***.
- **Precision:** Extent of mutual agreement among individual measurements taken under the same conditions.
  - A measure of average scatter of individual data points from their mean concentration, expressed as a ***percentage relative to the mean*** (coefficient of variation, or CV)

Assumptions on the level of bias and precision inherent in the measurement process impact your level of confidence in making correct decisions from your data.

Bias is directional (positive or negative). Precision is non-negative.





EPA's current Data Quality Objectives for the $PM_{2.5}$ national monitoring network

In 2002, EPA established the current network DQOs for bias and precision:

- ***Bias DQO***: Value of bias metric must be **within ±10%** in a given year.
- ***Precision DQO***: Value of precision metric must be **less than 10%.**

Bias metric:	***Precision metric:***
Average percent difference in $PM_{2.5}$ concentrations between collocated samplers	95% upper confidence bound on the CV calculated on percent difference values between collocated samplers

Network DQOs are evaluated annually at the PQAO level.

- PQAO (primary quality assurance organizations) – State, local, and tribal organizations responsible for ensuring data quality of $PM_{2.5}$ monitors at network sites within their jurisdictions
- EPA also assesses DQOs at the national and regional level.

Precision estimation in the $PM_{2.5}$ national network

- To generate precision data, each PQAO must collocate a $PM_{2.5}$ sampler next to its routine network sampler at 15% of its network sites
  - Collocation types and numbers must also consider the type of routine network sampler (FRM, FEM)
- Standard protocols used to collect samples simultaneously from the collocated samplers and to analyze them for $PM_{2.5}$ concentration
  - Precision sample is collected every 12 days (~30 samples per year at each collocated site)
  - Approximately 7,500 to 8,000 samples for measuring precision were required across the network each year
- PQAOs upload both $PM_{2.5}$ concentrations to AQS
  - Precision and routine sample measurements must be clearly distinguished

Relative percent difference:

$$RPD = \frac{routine - precision}{(routine + precision)/2} \times 100\%$$

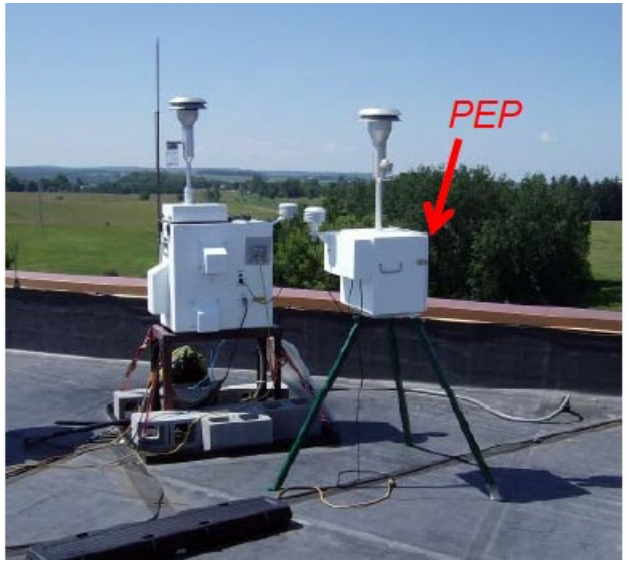
Coefficient of variation:

$$\frac{Std.Dev.\ of\ RPD}{Mean\ of\ RPD} \times 100\%$$

(calculated across sites and time)

EPA's $PM_{2.5}$ Performance Evaluation Program (PEP): Collocating samplers for bias estimation

- A reference standard for characterizing total measurement system bias in the network
  - Bias introduced by field sampling AND laboratory filter weighing
- PEP sampler is collocated with a network sampler, both simultaneously sample for measuring $PM_{2.5}$ conc.
- Routine network sample analyzed under normal protocols
- PEP filter is weighed by EPA's National $PM_{2.5}$-PEP gravimetric lab (Athens, GA) under strict quality system requirements
  - The PEP sample measurement is representative of the "true" $PM_{2.5}$ concentration



Percent difference:

$$\frac{routine - PEP}{PEP} \times 100\%$$

- Annually, 5 or 8 PEP sampling events are to occur per PQAO – approx. 600 events nationally (~86 PQAOs)

Why reassess the DQOs now?

- The average annual NAAQS for $PM_{2.5}$ was higher in 2002 (15 µg/m^3, versus 12 µg/m^3 today).
  - The NAAQS serves as a basis for justifying levels of statistical confidence in decision making
  - At a precision level of 10% and a bias level of 10%, EPA estimated a 5% decision error at 12.2 µg/m^3 (19% below the NAAQS).
  - At a precision level of 10% and a bias level of -10%, EPA estimated a 5% decision error at 18.8 µg/m^3 (25% above the NAAQS).

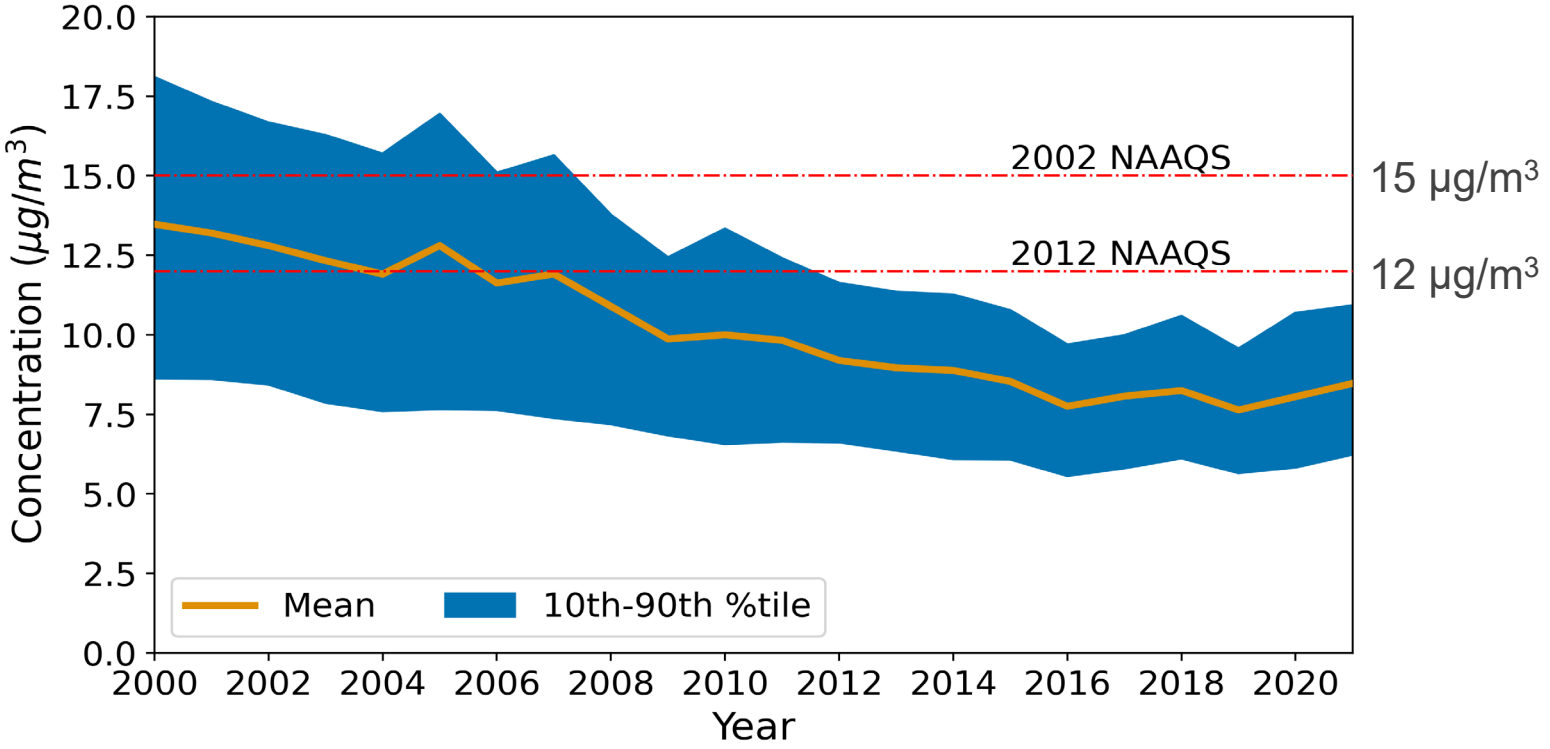
Decision error =

P[Declaring *non-attainment* when true 3-year average <*NAAQS*] +

P[Declaring *attainment* when true 3-year average >*NAAQS*].

- $PM_{2.5}$ concentrations have declined nationally over the past several years.
  - The bias and precision metrics are calculated only using $PM_{2.5}$ measurements exceeding 3 µg/m^3
  - The percentage of sample measurements excluded from DQO assessment (due to low values) continues to increase
  - The shift in the national distribution of $PM_{2.5}$ concentrations toward lower values puts into question whether the DQOs' underlying statistical properties (above) are still valid today

37% decline in nationwide average $PM_{2.5}$ concentration has occurred from 2000 to 2020



Data source: https://www.epa.gov/air-trends/particulate-matter-pm25-trends (data from 375 network sites)

This outcome is one demonstration of how more network samples are shifting to lower concentration values, including values below 3 μg/m³ (excluded from bias/precision)

Region	# Sites with Data	% decline from 2000 to 2020
Ohio Valley	61	45%
Upper Midwest	38	32%
Northeast	76	43%
Northwest*	10	23%
South	30	29%
Southeast	66	45%
Southwest*	20	13%
West	48	28%
Northern Rockies and Plains*	17	16%

* Average $PM_{2.5}$ concentration was below NAAQS in all years.

Should EPA change the bias and precision metrics?

Percent difference (*PD*) in collocated concentrations gets extremely large as the site concentration gets small:

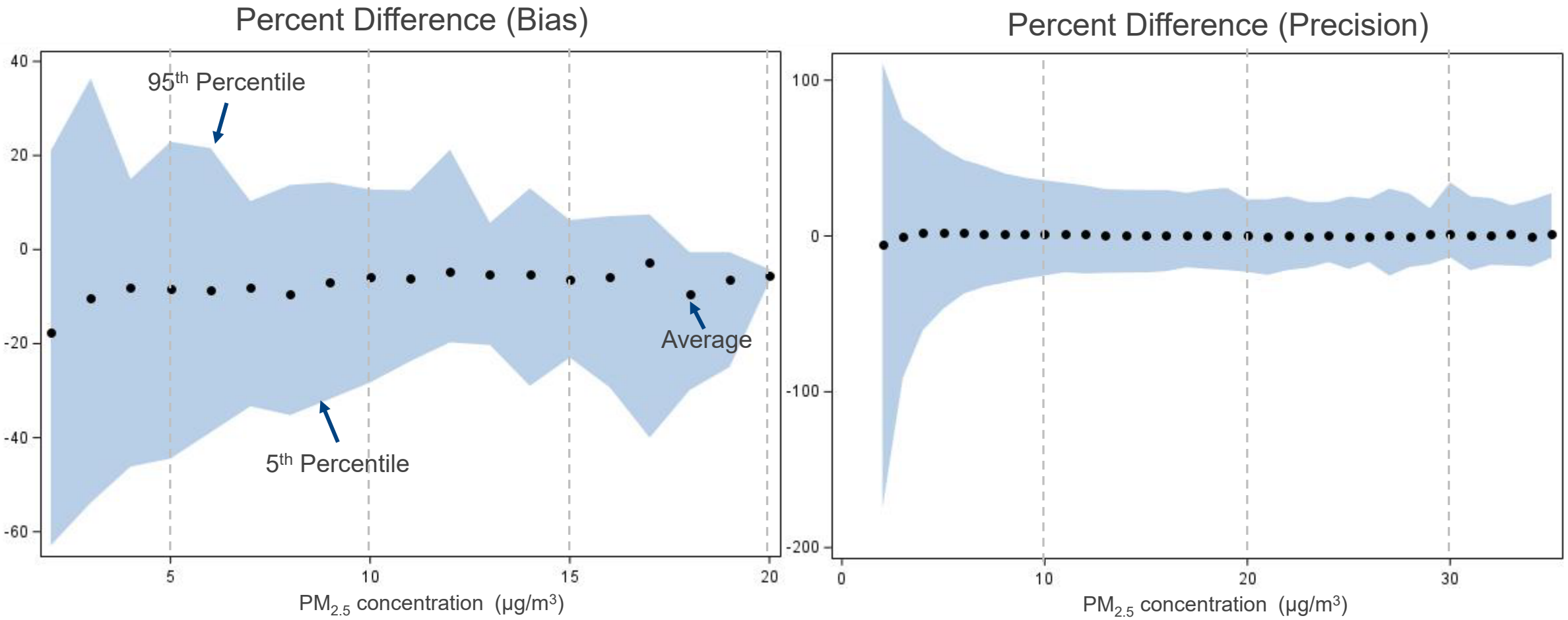
$$PD = \frac{routine - PEP}{PEP} = \frac{routine}{PEP} - 1$$

When both $routine$ and PEP concentrations are very small, even minor (trivial) differences between them can lead to a large value for $\frac{routine}{PEP}$.

Goal: Identify a metric whose distribution (across $PM_{2.5}$ concentration data representing a wide range of site scenarios) is relatively constant across this range, including at concentrations below 3 µg/m^3.

Current bias and precision metrics (percent difference)

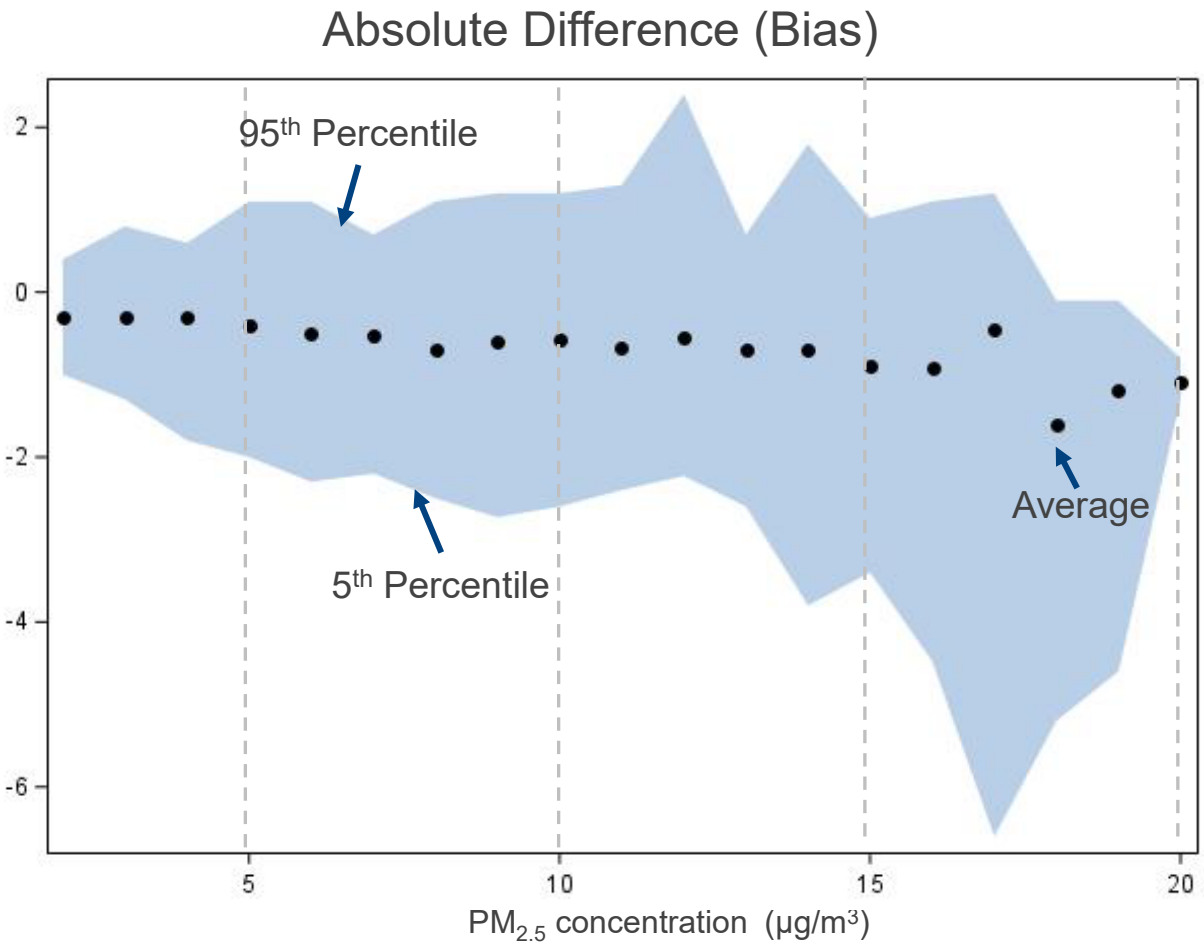
2016-20 network data, FRM samplers only

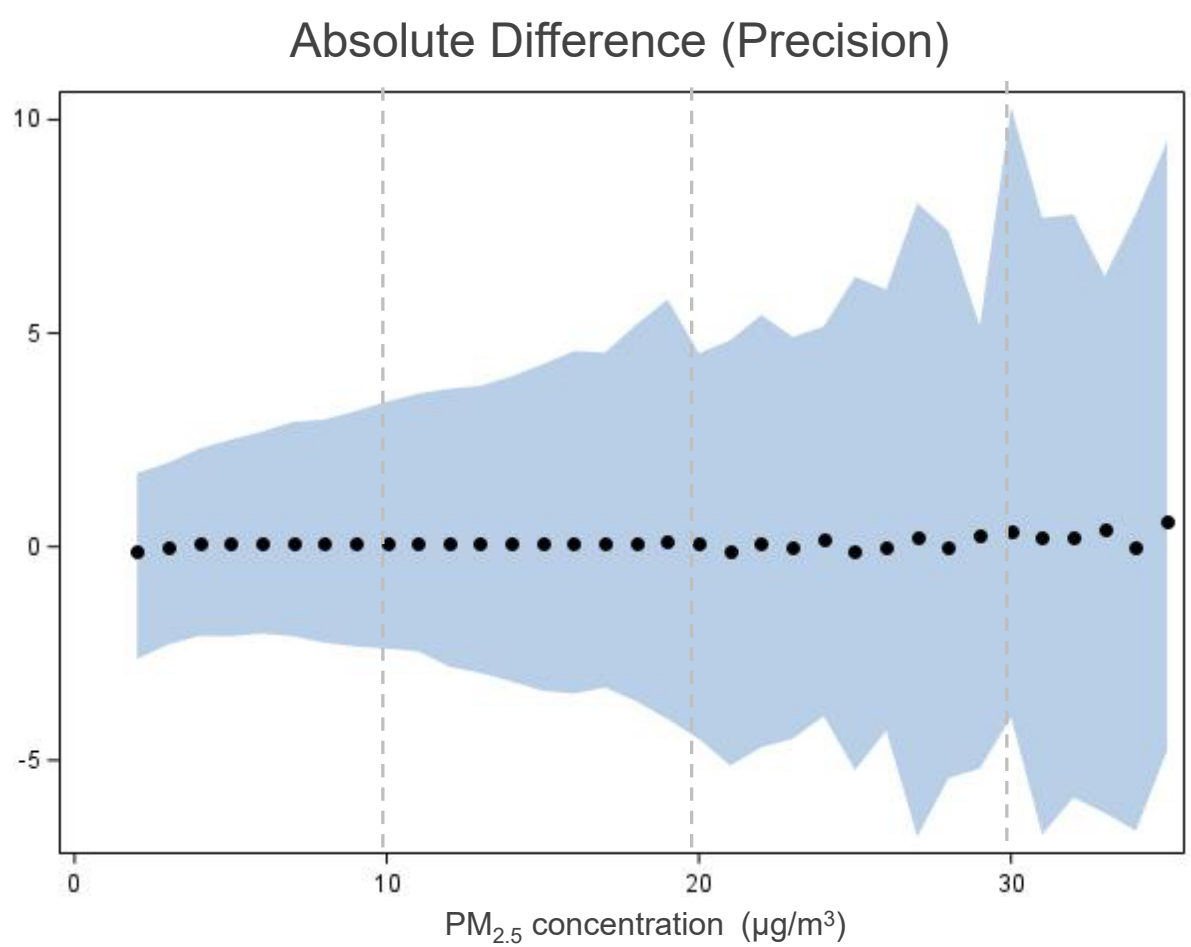


Height of blue region is not constant across concentrations (especially low)!

Option #1: Replace with absolute difference

2016-20 network data, FRM samplers only

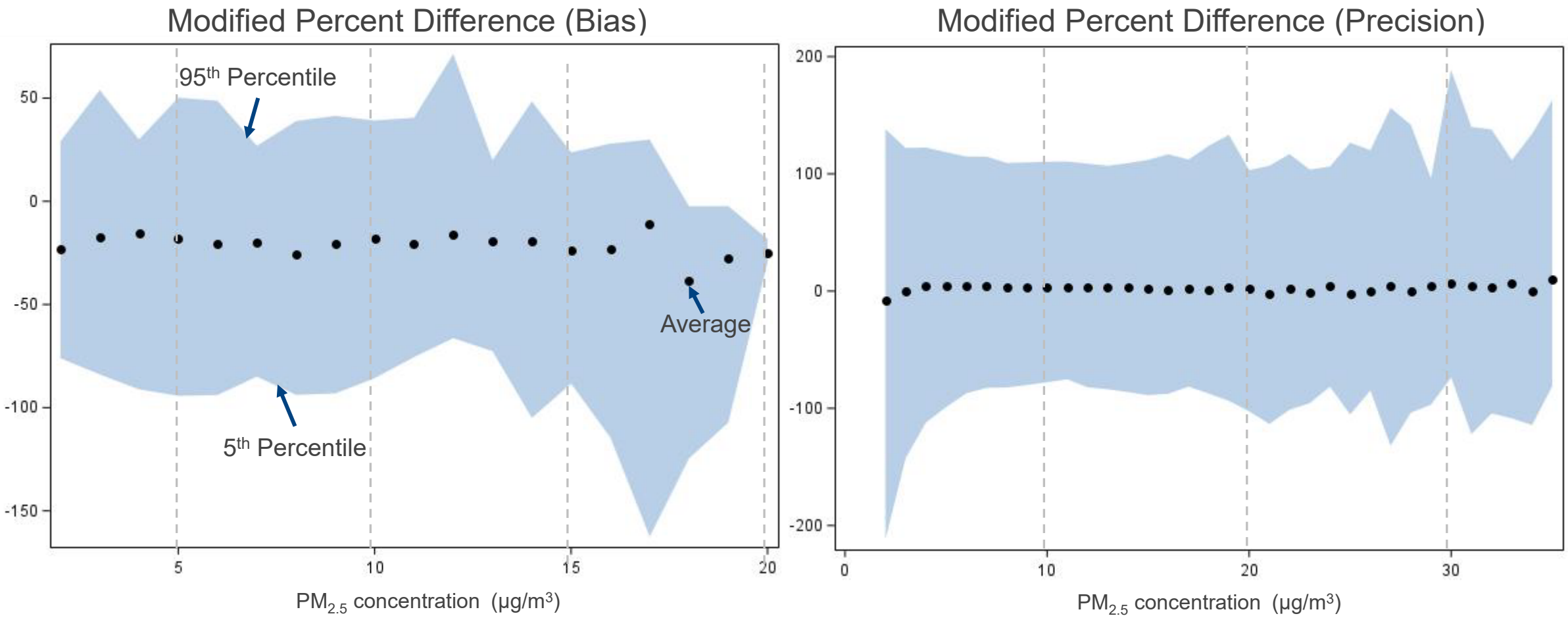




Height of blue region is still not constant across concentrations!

Option #2: Percent difference, but with square root in denominator

2016-20 network data, FRM samplers only



Better achieves a constant range across concentrations, down to 1 µg/m^3.

Key conclusion

A bias (and precision) metric of the form $\frac{(routine - collocated)}{\sqrt{concentration}}$ is more statistically appealing across the range of $PM_{2.5}$ concentrations, even as low as 1 µg/m^3, compared to the current metric of $\frac{routine - collocated}{concentration}$.

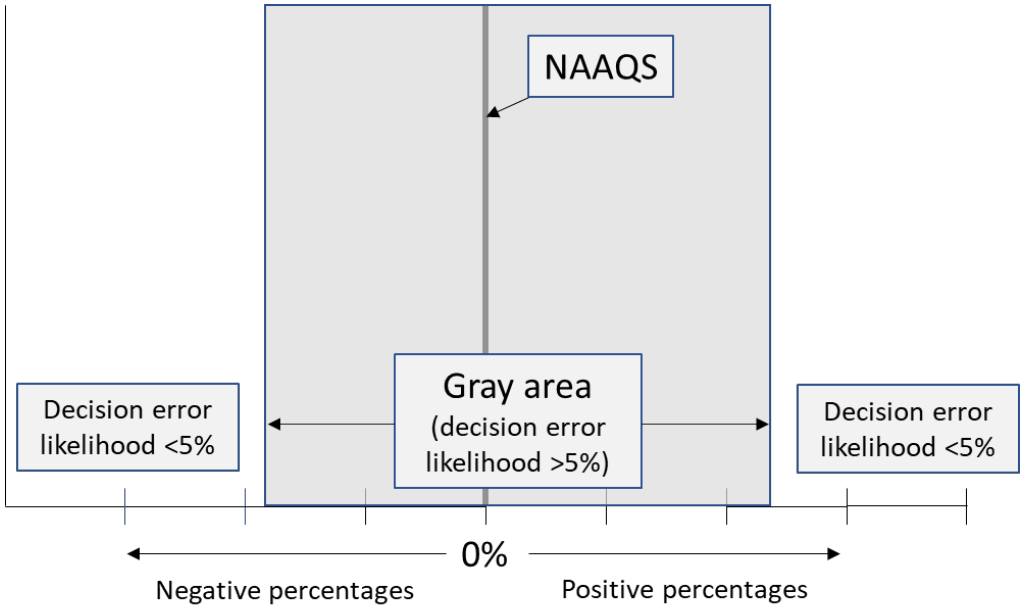
- Here, *concentration* equals *collocated* for the bias metric, and *(routine + collocated)*/2 for the precision metric.
- The units of this metric are non-intuitive, however.
- This metric can be made more intuitive by transforming it to a "percentage at the NAAQS" :

$$\frac{metric\ value}{\sqrt{NAAQS}} \times 100\%$$

- For example, a metric value of $0.3\sqrt{\mu g/m^3}$ can be expressed as 100*0.3/√12 = 8.7% of the NAAQS (12 µg/m^3).

A quick look at NAAQS attainment decision errors at assumed bias and precision levels

- The likelihood of making an error in determining NAAQS attainment (based on network data) gets larger as the (true) $PM_{2.5}$ concentration gets closer to the NAAQS.
- When the true $PM_{2.5}$ concentration is within close proximity of the NAAQS (a "**gray area**"), we are OK with the decision error likelihood being above a specified amount (e.g., 5%).
- When the true $PM_{2.5}$ concentration is outside of the "gray area," we want to limit the decision error likelihood to be no higher than the specified amount.



EPA's DQOs for precision and bias are selected to achieve this statistical property.

Calculated "gray areas" around specified NAAQS values

Gray area based on the current DQOs

NAAQS	Gray Area (% of NAAQS)
12 µg/m³	9.7 - 15.2 µg/m³ (-19% to +27%)
10 µg/m³	8.1 - 12.7 µg/m³ (-19% to +27%)
9 µg/m³	7.3 - 11.4 µg/m³ (-19% to +27%)

- Assumes a bias of 10% and a 90% UCB on CV of 10% at the NAAQS.
- Decision error is controlled to no higher than 5%.
- Assumes bias and precision are constant relative to the square root of the (true) $PM_{2.5}$ concentration.

Gray area based on observed metric values

- Observed bias metric is $-0.10412/\sqrt{concentration}$.
- Observed precision metric is $0.422418/\sqrt{concentration}$.

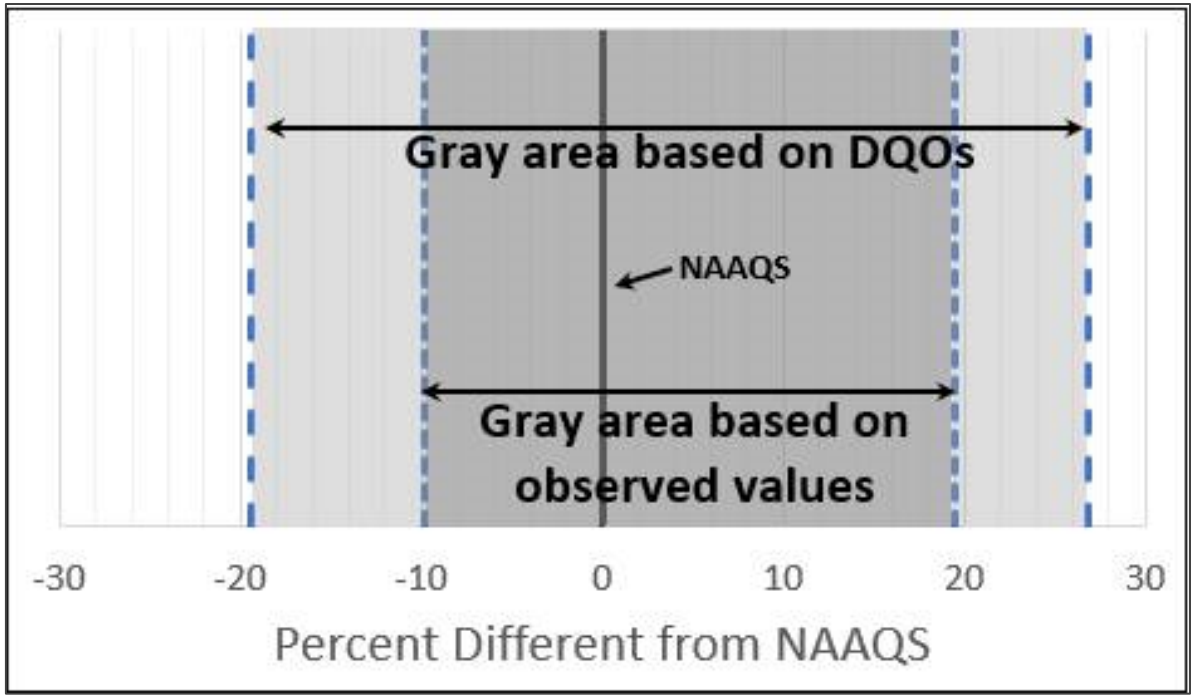
They translate to the following:

True Concentration	Bias (% of Conc.)	Precision (% of Conc.)
12 µg/m³	0.4 µg/m³ (3.0%)	1.5 µg/m³ (12.2%)
10 µg/m³	0.3 µg/m³ (3.3%)	1.3 µg/m³ (13.4%)
9 µg/m³	0.3 µg/m³ (3.5%)	1.3 µg/m³ (14.1%)

- Bias and precision are as observed in the data
- Decision error is controlled to no higher than 5%
- Assumes bias and precision are constant relative to the square root of the (true) $PM_{2.5}$ concentration

NAAQS	Gray Area (% of NAAQS)
12 µg/m³	10.8 - 14.3 µg/m³ (-10% to +19%)
10 µg/m³	9.0 - 12.0 µg/m³ (-10% to +20%)
9 µg/m³	8.1 - 10.8 µg/m³ (-10% to +20%)

Calculated “gray areas” around specified NAAQS values



Gray area based on the current DQOs	(-19% to +27%)
Gray area based on observed metric values	(-10% to +19%)

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It can be done

Laura Aume: AumeL@Battelle.org
Bob Lordo: Lordo@Battelle.org

Dennis Crumpler (EPA $PM_{2.5}$ National QA Lead): Crumpler.Dennis@epa.gov

This work was funded by the U.S. EPA under Task Order 68HERH21F0263 on Blanket Purchase Agreement No. 68HERD21A0001.