Air Quality Sensor Bootcamp

Fundamentals

Air Pollutants & Air Sensors 101

A globally-adopted air quality measurement solution

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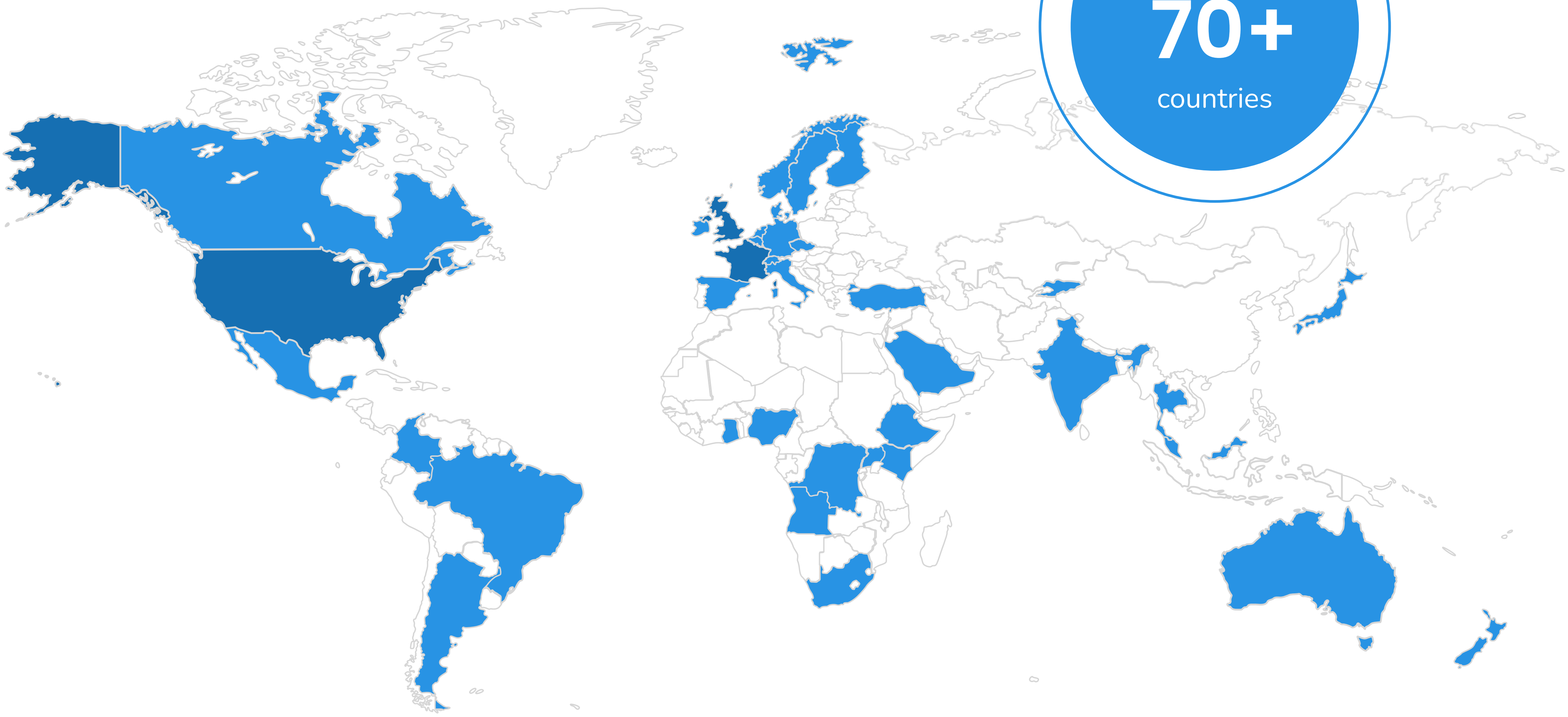

3 sessions throughout June

Fundamentals

June 7, 9am PT/6pm CEST

Jack Kodros

Air Quality Data Scientist

Use Cases

June 14, 9am PT/6pm CEST

Sean Wihera

VP of Business Development & Partnerships

Network Design

June 21, 9am PT/6pm CEST

Dr. Maggie Isied

Business Development Manager

Action items

1. Make sure you're registered for all sessions
2. Join Slack channel (if you haven't already)
3. Complete the homework for all sessions to receive a certificate of completion!







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Air Sensor Bootcamp:
Air Pollutants & Air Sensors 101

Jack Kodros

Air Quality Data Scientist

Agenda

01 Air Pollutants

02 Air Quality Sensor Technology

03 Data Quality and Calibration

04 Q&A

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Clarity Lab

Taking a scientific approach to enhancing sensor performance

Paolo Micalizzi

Co-founder & CTO

Jack Kodros

Air Quality Data Scientist

Levi Stanton

Solutions Engineering Lead

Clarity's in-house team of scientists

- ✓ Explore long-term scientific questions related to air quality sensing
- ✓ Understand how sensors perform in different environments (e.g., climate types, seasons, time of day)
- ✓ Improve sensor performance through calibration, hardware and software innovation

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Why do we care about air pollution?

Mortality Approximately 7 million premature deaths annually are due to the effects of air pollution, about 4 million of which are due to ambient (outdoor) air pollution.

Morbidity Air pollution negatively impacts our day-to-day lives, causing respiratory illness and leading to days of missed work and school — deteriorating quality of life and economy.

Equity The risks of exposure & harm are not equally distributed with disadvantaged communities, children, elderly, immunocompromised facing higher risks.

Climate Air pollution and climate change are two sides of the same coin. They share many of the same causes — and therefore many of the same solutions! Most actions taken to improve air quality will also benefit the climate.

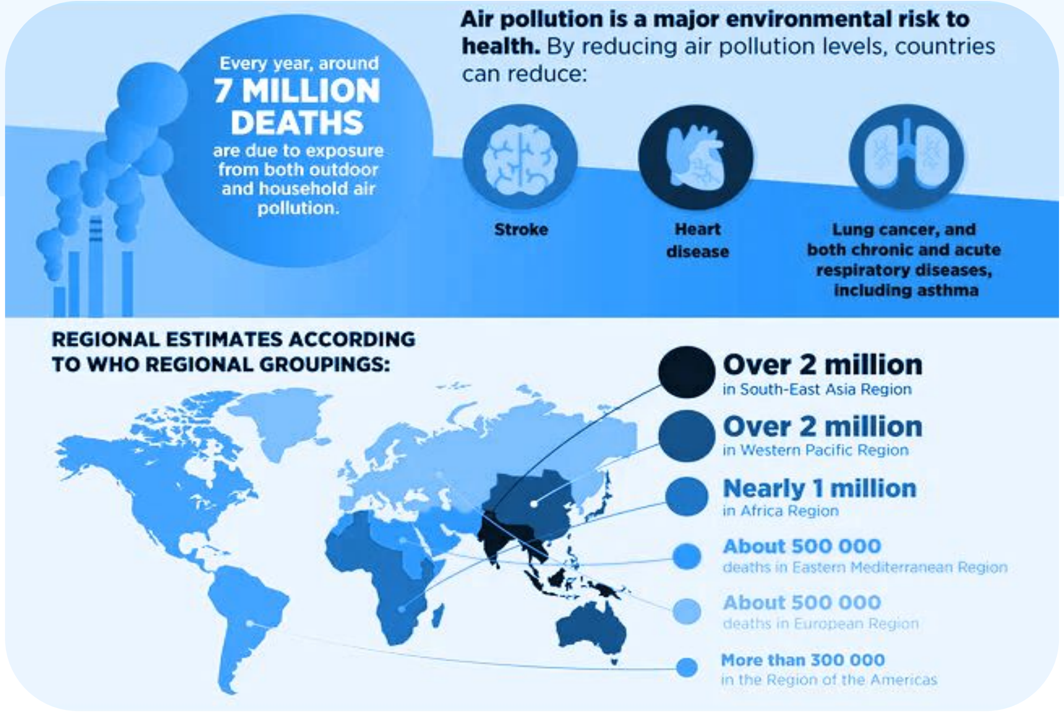

Image provided courtesy of the World Health Organization.

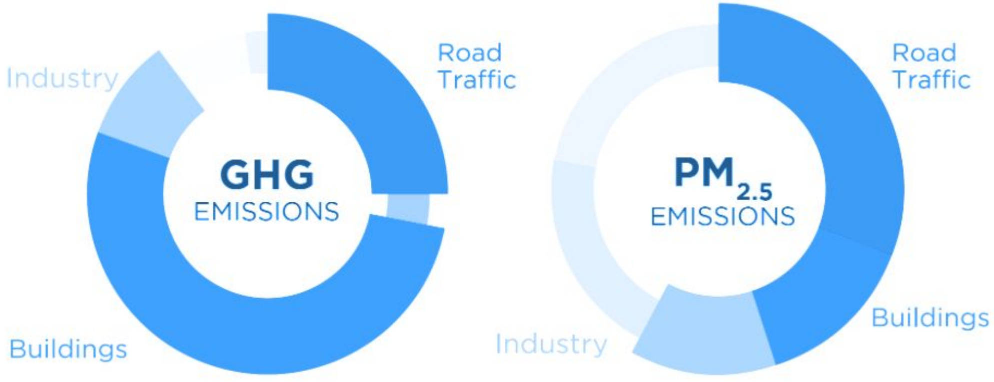

Image provided courtesy of C40 Cities.

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What is air pollution?

Air pollution is a mixture of natural and man-made (anthropogenic) substances in the air that can cause **harm.**

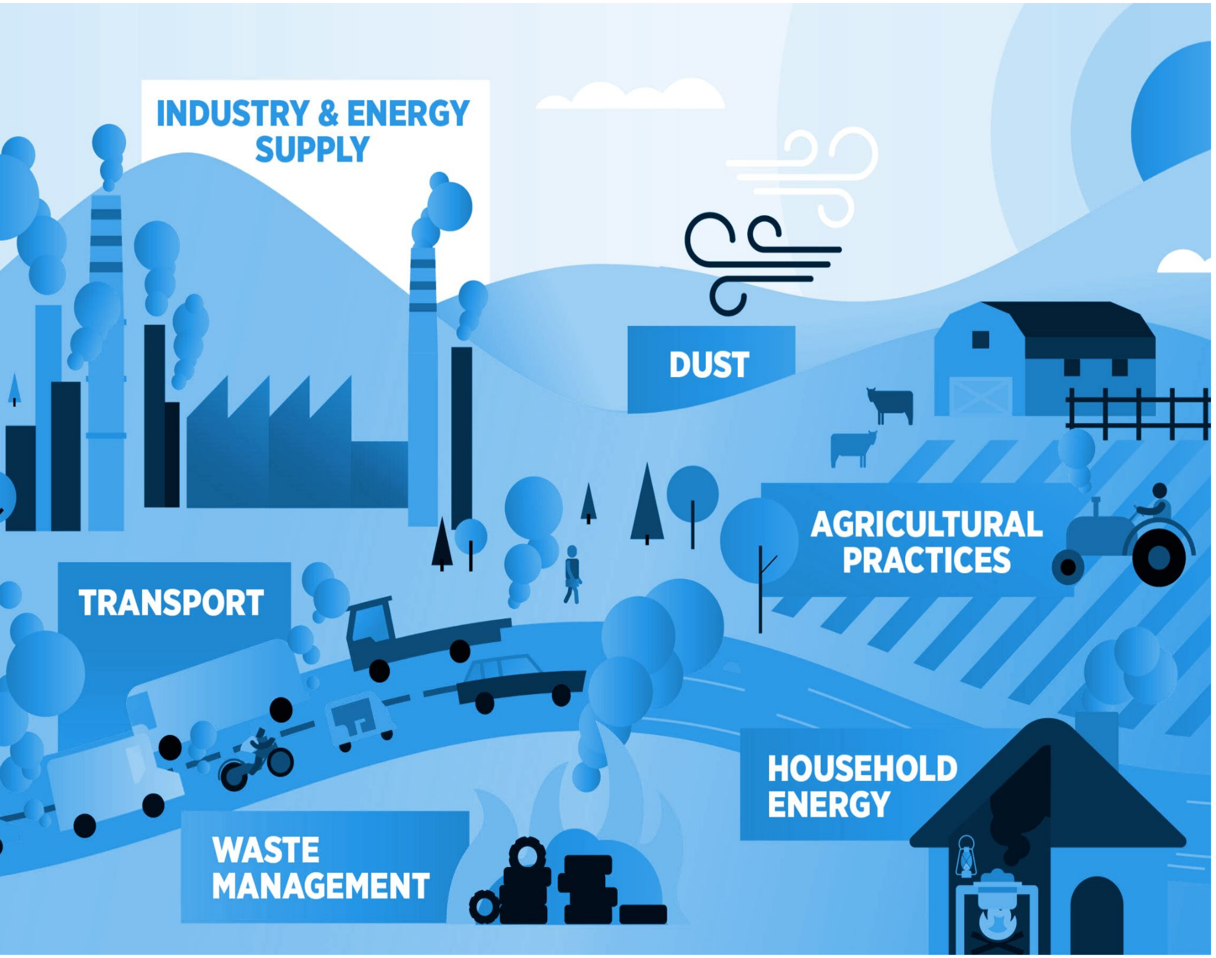

Image provided courtesy of the World Health Organization.

Categories of Air Pollution

By source:

- **Natural:** natural sources like volcanoes, pollen, etc
- **Anthropogenic:** human activities:
    - mobile source (motor vehicles)
    - stationary source (power plants)

By where exposure occurs:

- **Ambient** (outside): background, traffic/roadside, etc.
- **Indoor:** heaters, gas ranges and ovens, etc.

By origin:

- **Primary pollutants:** directly emitted from a source, such as CO
- **Secondary pollutants:** formed in atmosphere from primary pollutants, such as O3

By state of matter:

- **Particulate air pollutants**
- **Gaseous air pollutants**

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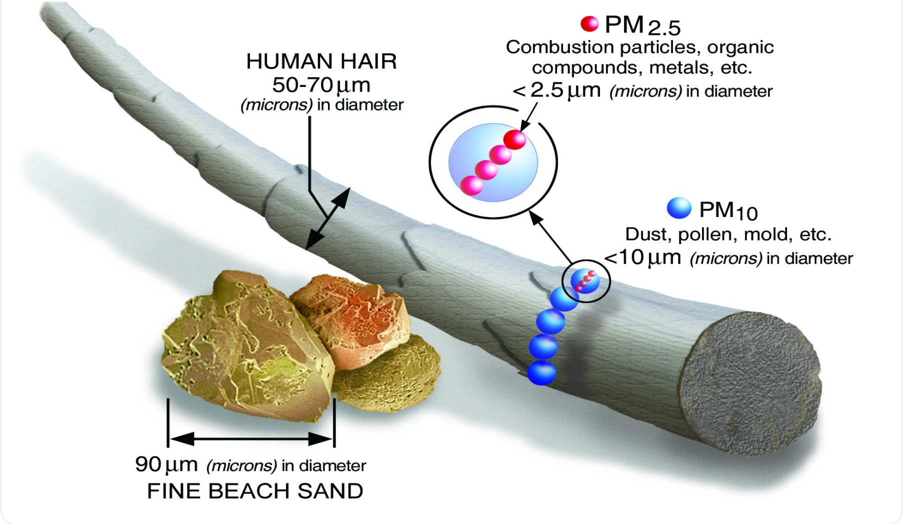
Types of Pollutants

Particulates



Gases

Particulate matter (PM): solid and liquid particles suspended in air — organic and inorganic particles, such as dust, pollen, soot (AKA black carbon), smoke, and liquid droplets. Vary in size, composition, and origin!

PM10 (coarse particles) - particles smaller than 10 µm

- Mechanical processes - road wear, constructions, dust storms

PM2.5 (fine particles) - particles smaller than 2.5 µm

- Combustion sources - vehicles, stoves, power plants

PM1 and PN (ultrafines) - penetrate in our respiratory system

Nitrogen Dioxide (NO_2)

- High temperature combustion (mostly from cars)

Ground level ozone (O_3)

- Forms from sunlight, NOx and VOCs (secondary pollutant)

Carbon Monoxide (CO)

- Cars, trucks and other vehicles or machinery that burn fossil fuels

Sulfur Dioxide (SO_2)

- Primarily from from electric utilities, especially those that burn coal

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"If you can't measure it, you can't fix it."

Air Quality Monitoring Questions

1. How much air pollution is in the air?
2. Where is it going? What does it do?
3. What's the air pollution composition?
4. What are the air pollution sources?
5. Who wants air quality data? And why?
6. Who will be breathing it in? What are the likely health impacts?
7. When does exposure occur, and for how long?
8. What kind of data — and what action — is needed to improve the situation?

How much air pollution is in the air?

Concentration

Pollution results are reported as amount of pollution in a unit volume of air.

Mass concentration (common for PM)

μg/m^3= micrograms per cubic meter, **mg/m^3** = milligrams per cubic meter

Number concentration (common for PM)

#/m^3= number of particles per cubic meter

Common units for gases in the US

ppb = parts per billion, **ppm** =parts per million

In Europe, gases will be reported in μg/m^3

Air Quality Index

Translates concentrations into health impacts for public — color coded (green to maroon)

Air Quality Index (AQI) Values	Levels of Health Concern
When the AQI is in this range:	*..air quality conditions are:*
0 to 50	Good
51 to 100	Moderate
101 to 150	Unhealthy for Sensitive Groups
151 to 200	Unhealthy
201 to 300	Very Unhealthy
301 to 500	Hazardous

Each country/state may have their own AQI

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Types Of Measurement Equipment

Reference

FRM (Federal Reference Method) & FEM (Federal Equivalent Method)

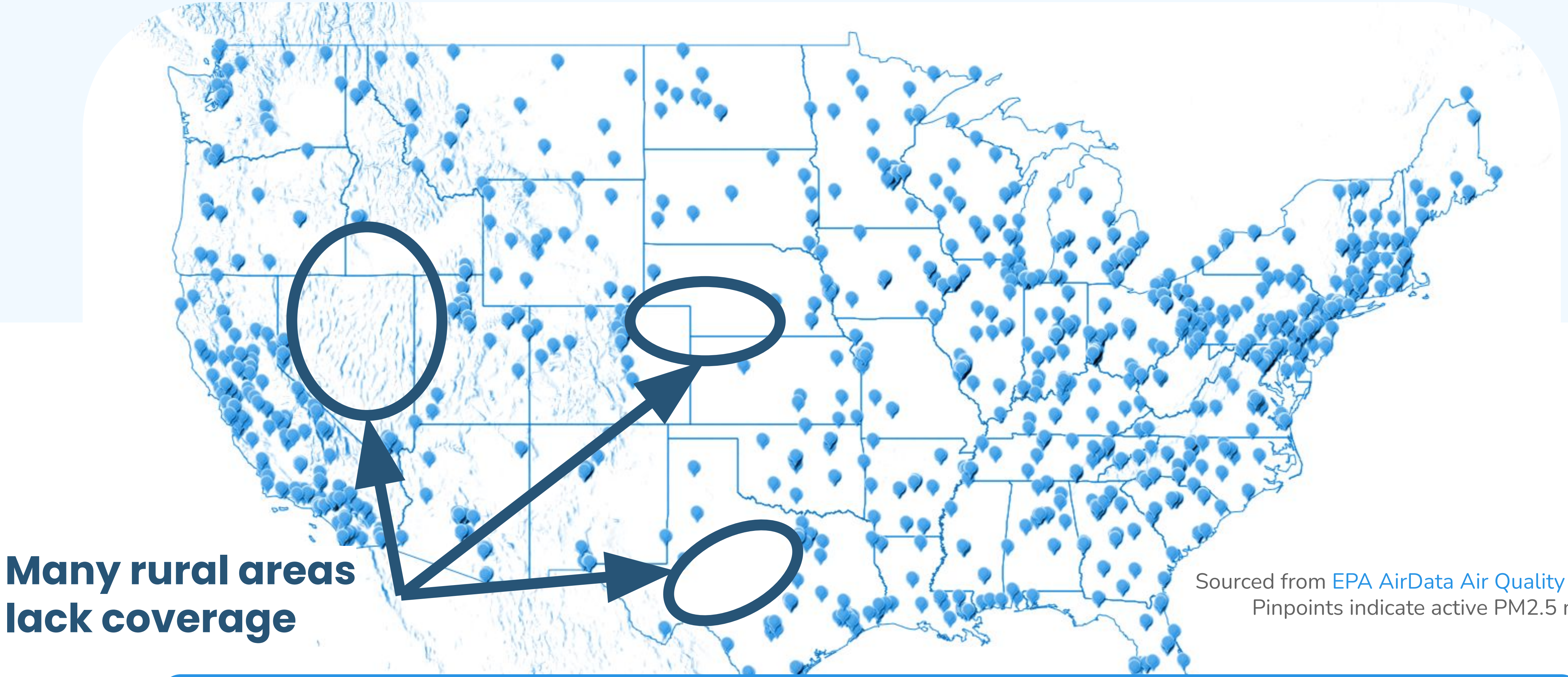
- More expensive (10’s of thousands USD)
- Accurate and reliable
- Used in regulatory monitoring
- Highly sensitive and complex
- Requires trained professionals to operate
- Requires regular maintenance (calibration, cleaning, replacement of parts, etc.)

Low-Cost Sensor

Wide range of commercially available technologies

- Less expensive (hundreds to thousands USD)
- Less accurate and reliable
- Often used in citizen science projects
- Easier to use and maintain
- Smaller and more portable
- May not require as much maintenance, but require calibration checks to ensure accuracy

Reference air quality monitors across the continental U.S.



Sourced from EPA AirData Air Quality Monitors Map.
Pinpoints indicate active PM2.5 monitors.

According to the EPA, two-thirds of counties (2,120 of 3,142) in the United States had no ambient air quality monitoring infrastructure associated with the national monitoring system in 2019.

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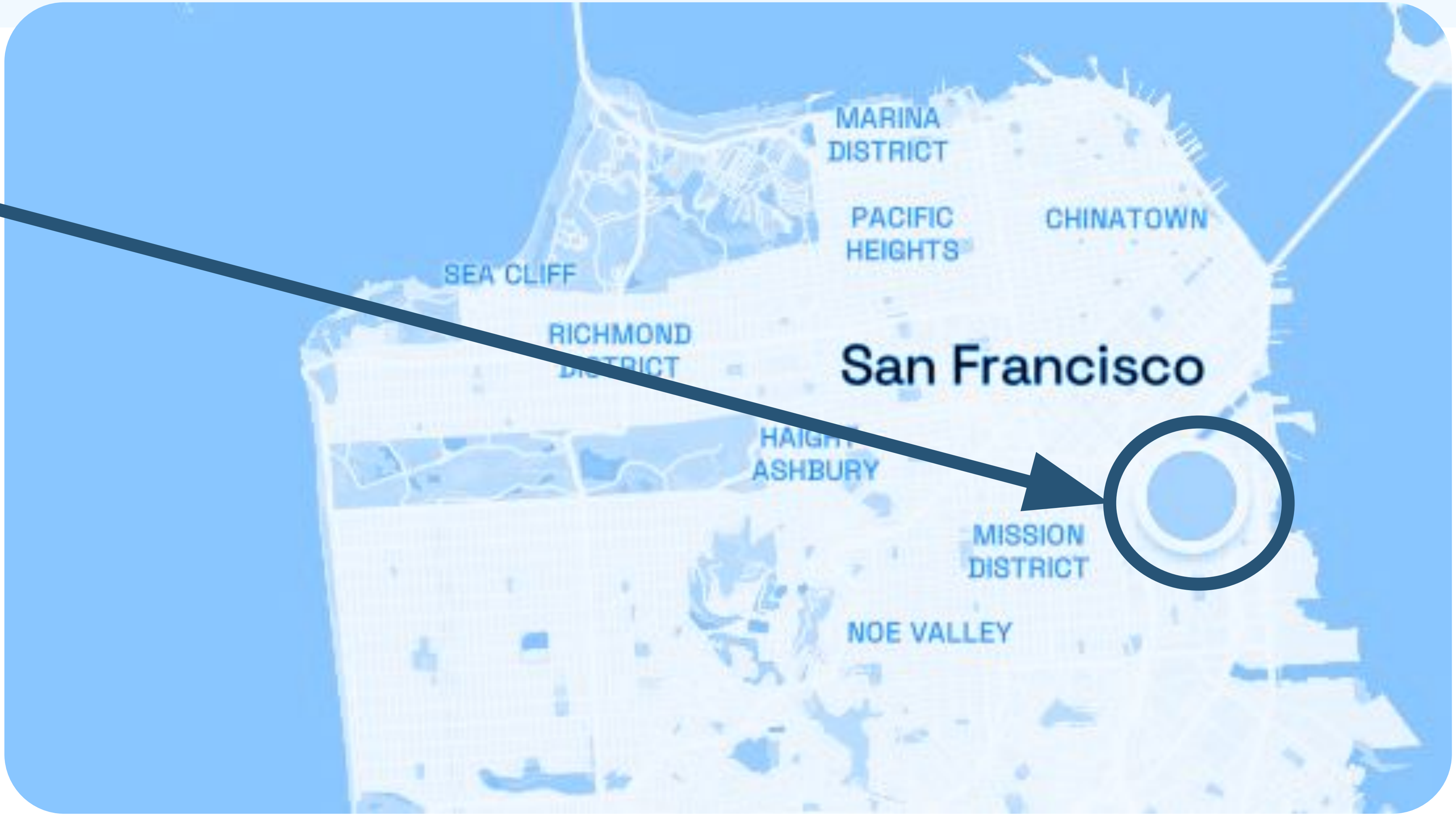
Insufficient coverage in urban areas (e.g. San Francisco)

One monitor for 47 square miles



Air pollutants can vary significantly in urban areas — five to eight times from one end of a block to the other.

Image provided by OpenAQ with data from the US EPA.

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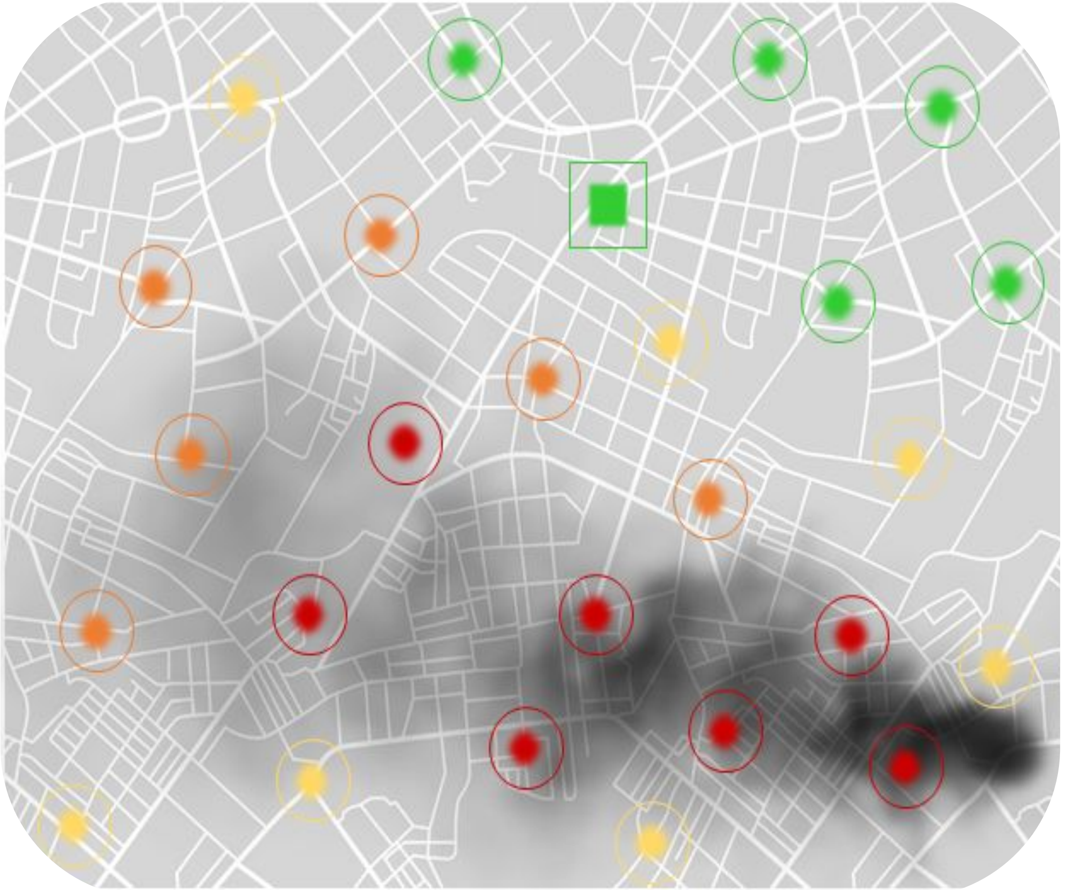
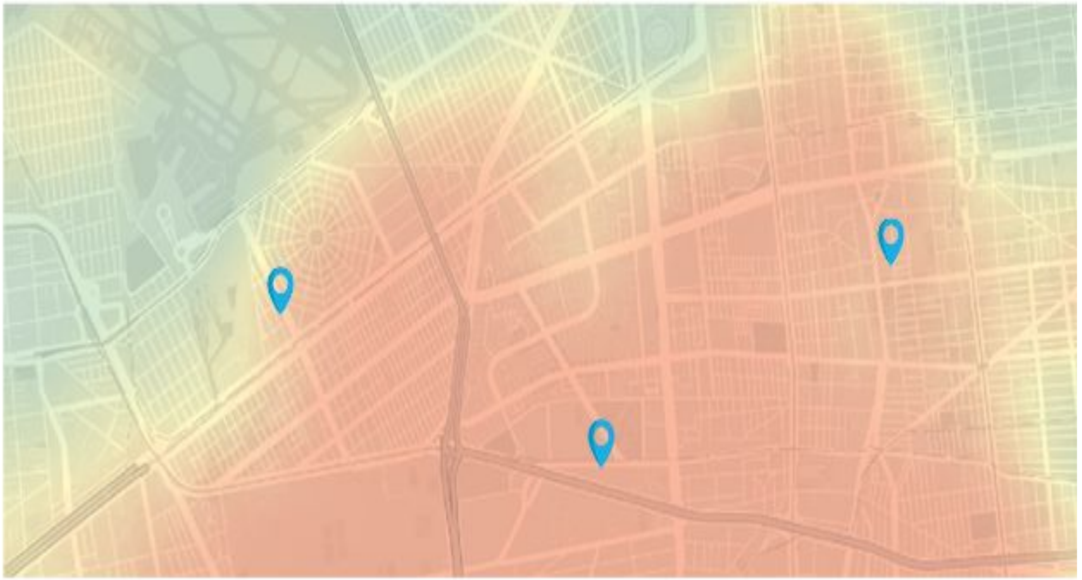
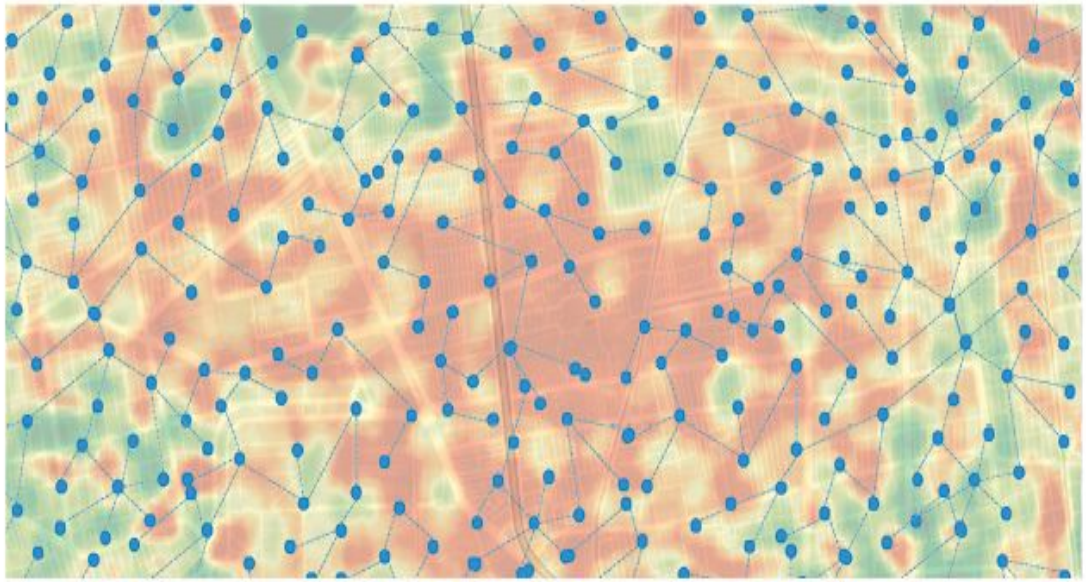
Sparse monitoring networks can miss air pollution events



Low-cost sensors can help fill in the gaps



Traditional monitoring network



High resolution monitoring network

Hybrid monitoring can provide “the best of both worlds”!

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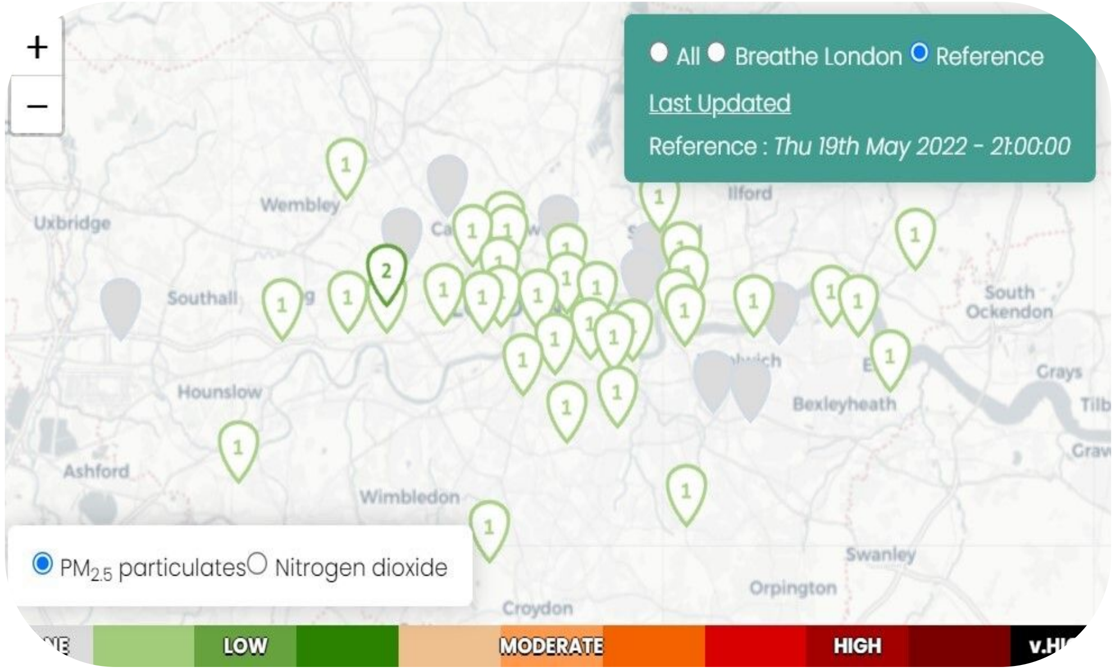
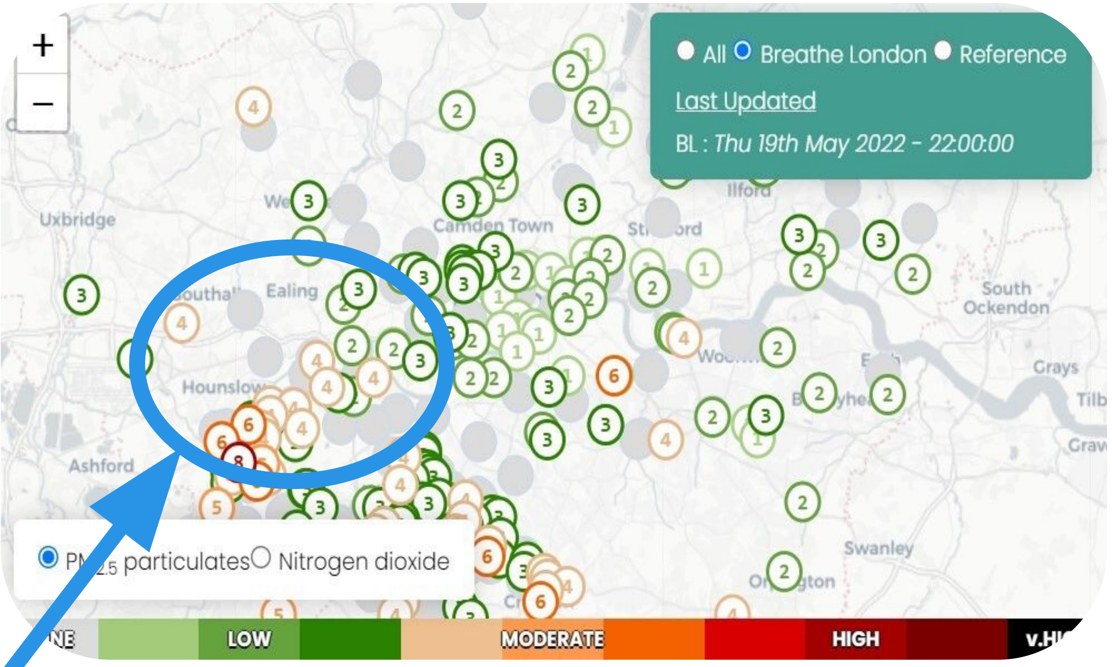
Breathe London — sensors capture air pollution hotspots

London Air Quality Network (reference)



500+ Clarity Nodes across London



Dense network of calibrated air quality sensors captures air pollution events that may be missed by reference network.

What are the appropriate use cases for sensors?

US EPA recommends sensors for:

- Science education and research
- Conducting air monitoring projects
- Supplementing regulatory air quality measurements
- Measuring local air quality to better understand sources of pollution

Air pollution hotspots

Short-term changes in air quality

Air quality data for rural areas

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Sensors help meet the need for local, real-time AQ data

Air pollution hotspots

Hotspots may occur between existing monitoring sites. **Air pollution levels vary significantly from one location to another** — up to 800% between city blocks for PM!

Short-term changes in air quality

Real-time data helps **understand short-term changes in air quality** due to weather patterns or events such as natural disasters and industrial accidents.

Air quality data for rural areas

The distance between monitoring sites tends to be much greater in rural areas, and **some rural areas may not have any monitoring sites at all.**

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Limitations of low-cost air sensor technology

Limited accuracy compared to reference-grade instruments (but calibration can help) — are data trustworthy?

Limited precision — both between brands/manufacturers and unit-to-unit precision for a given sensor

Durability concerns — depending on quality of construction, some LCS may see degrading performance over time

Sensors must be calibrated for different environments and pollutants to produce accurate data and checked for drift

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Why do we calibrate sensor data?

- **All air quality measurement instruments** undergo calibration

- **Reference instruments** are typically calibrated periodically and are *assumed to operate well in a variety of environments*

- **Low-cost sensors must be calibrated** for specific environments and pollutants.
  - "Out-of-the-box" sensors perform well in laboratory conditions, but may not perform well in outdoor environments
  - We *specialize* sensors for each individual project

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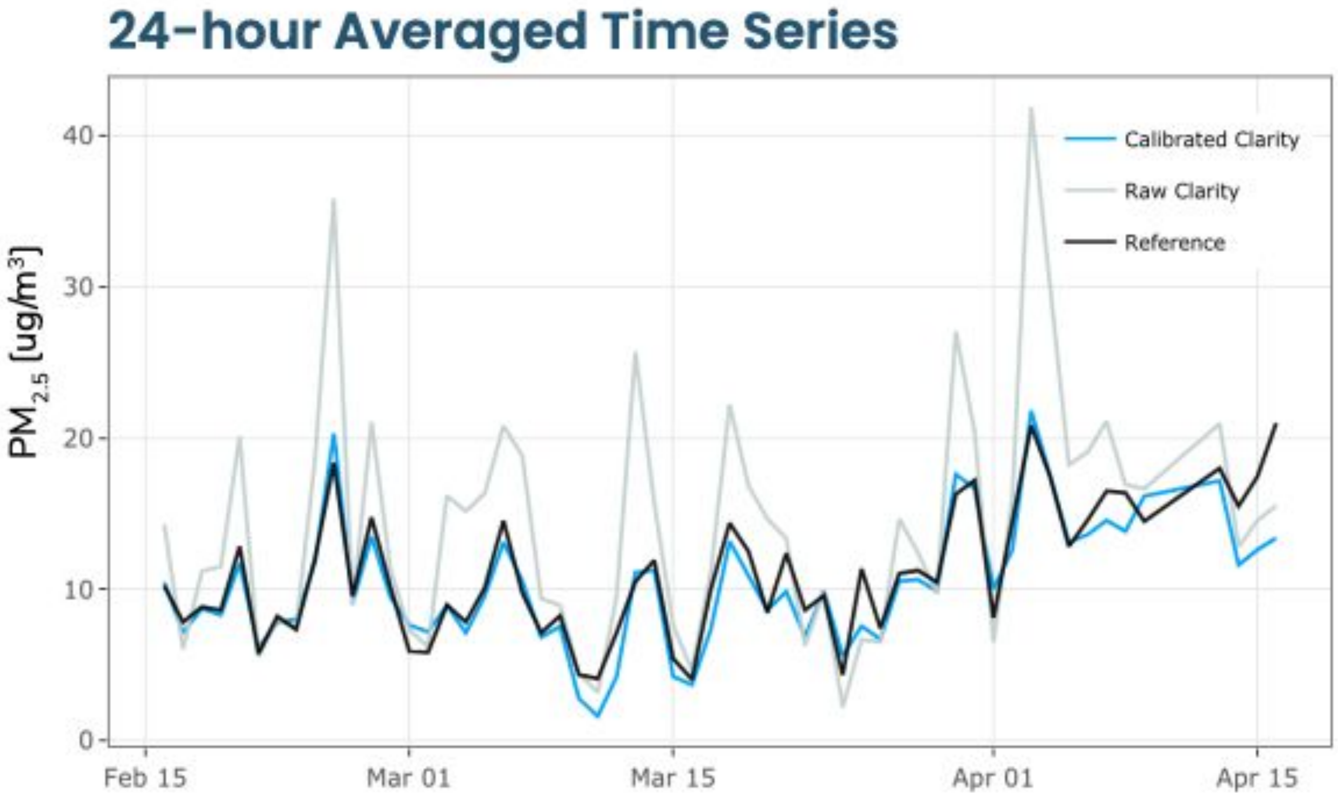
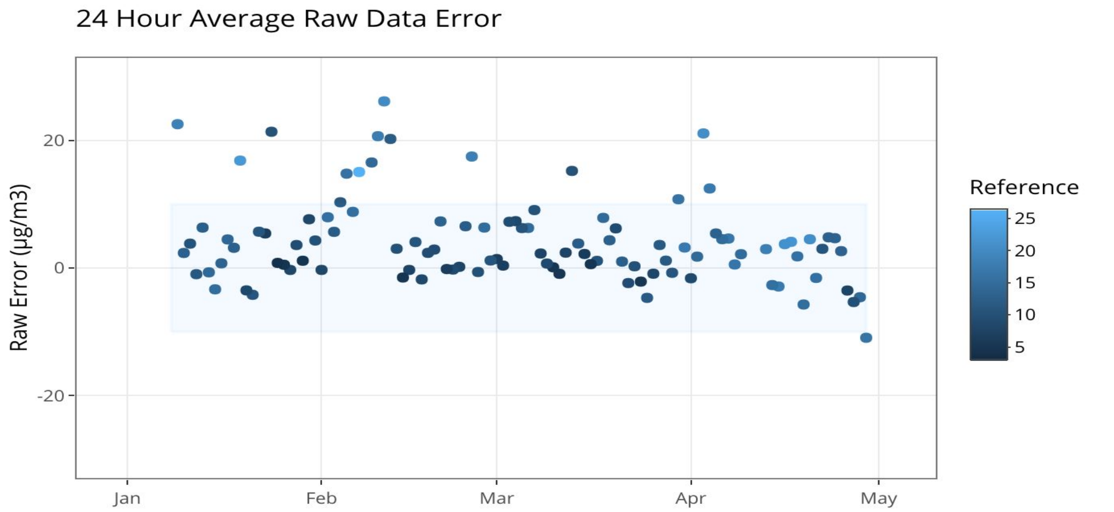
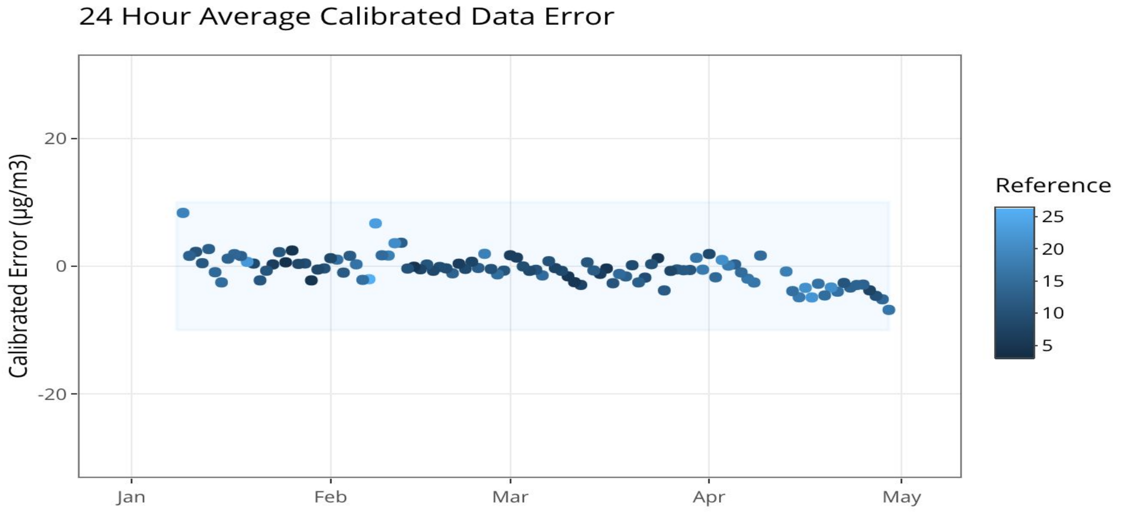
Why do we calibrate sensor data?







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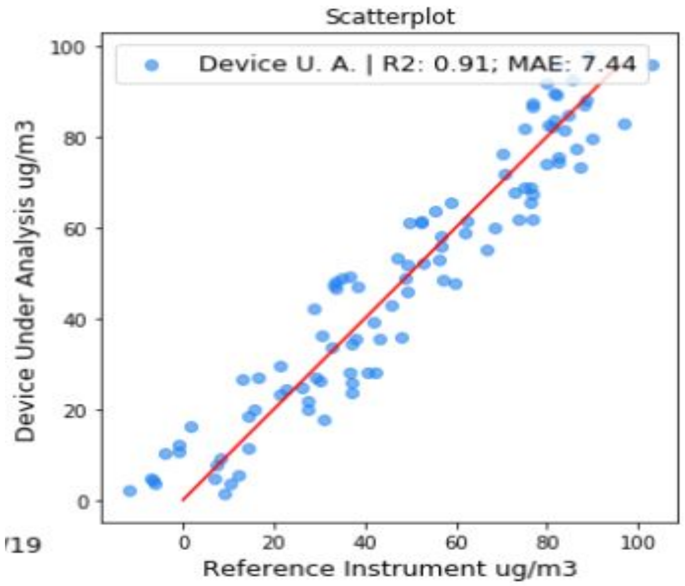
Data quality objectives (DQO) for air sensors

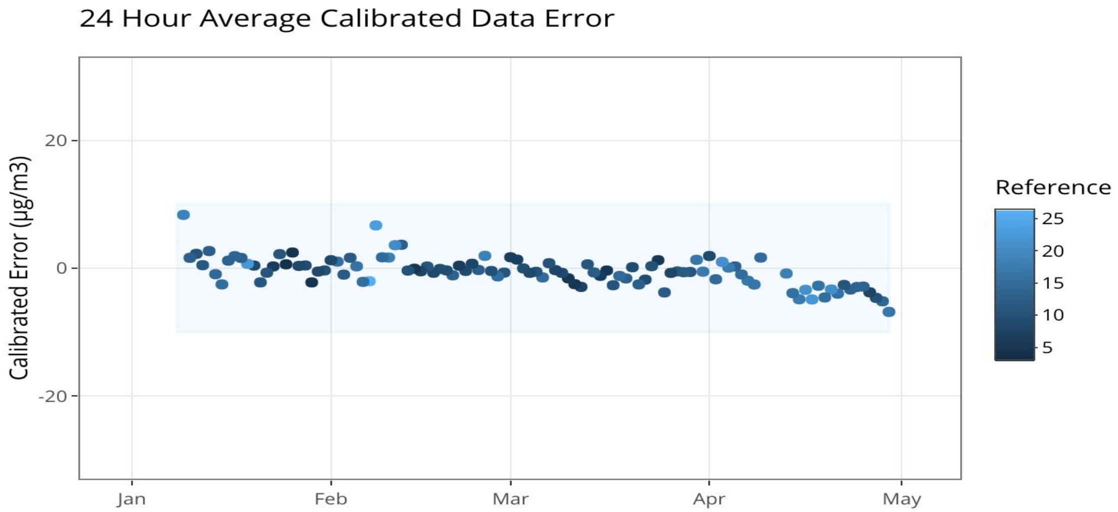
Existing data quality objectives for low-cost PM sensors	USEPA*	EU**	UK MCERTS**
Daily average data completeness	>75%	>90%	>90%
Precision: Standard Deviation (SD)	≤ 5 µg/m³	-	≤ 5 µg/m³
Precision: Coefficient of Variation (CV)	≤ 30%	-	-
Bias***: Slope (m) of y=mx+b	1.0 ± 0.35	-	-
Bias***: Intercept (b) of y=mx+b	-5 ≤ b ≤ 5 µg/m³	-	-
Linearity***: Coefficient of Determination (R^2)	≥ 0.70	-	-
Error: Root Mean Square Error (RMSE)	≤ 7 µg/m³	-	-
Error: Normalized Root Mean Square Error (NRMSE)****	≤ 30%	-	-
Uncertainty*****	-	≤ 50%	≤ 50%

Key metrics for assessing quality of sensor data

R^2 Squared Pearson correlation coefficient

- Range from 0 to 1 (no units)
- The closer to 1, the better!





Mean Absolute Error (MAE) & RMSE (root mean squared error)

- Both provide the average difference between non-FEM/FRM device and reference monitor
- The lower the better

Key metrics for assessing quality of sensor data

R^2	MAE	Recommendation
High	Low	The sensor performs well and can collect useful data
High	High	The sensor needs calibration
Low	Low	It is not possible to evaluate the sensor, repeat the test with a wider concentration range
Low	High	The sensor is inaccurate and cannot collect useful data

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Assessing data quality — accuracy vs. precision

Accuracy: Compare non-FEM/FRM device against FEM/FRM in collocation study

Precision: Compare non-FEM/FRM devices with each other (between device variability)

Accurate Precise

Not Accurate Precise

Accurate Not Precise

Not Accurate Not Precise

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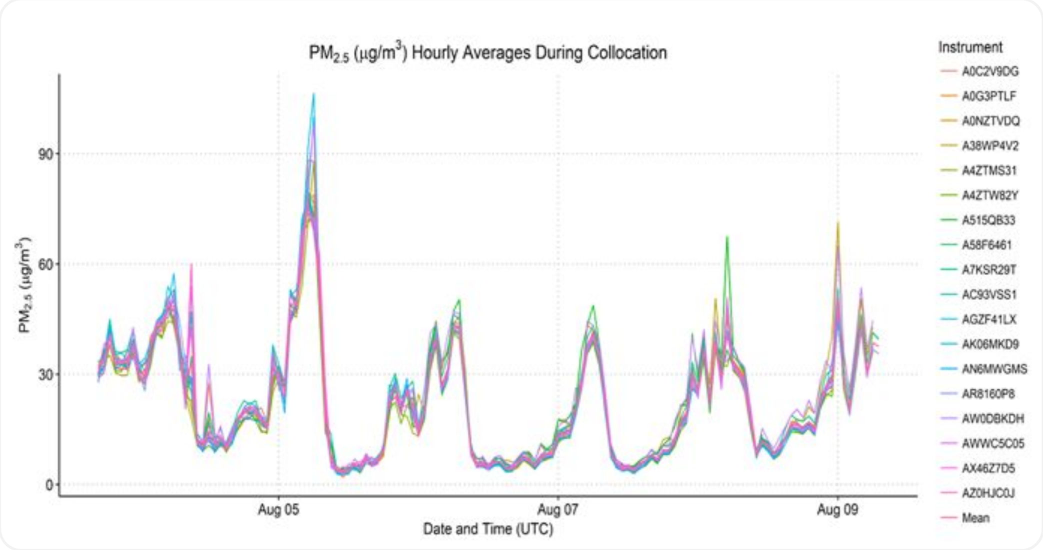
Collocation — a key step for accuracy

Collocation Study: Place monitors in same location to measure the same air:

- Reference + Clarity (accuracy)
- Multiple Clarity devices (precision)



18 Clarity devices collocated with in Accra, Ghana - very high precision!

Collocations of Clarity sensors in London (top) and Quezon City (bottom)

Important — we recommend leaving one low-cost sensor collocated with reference equipment following deployment for ongoing calibration.

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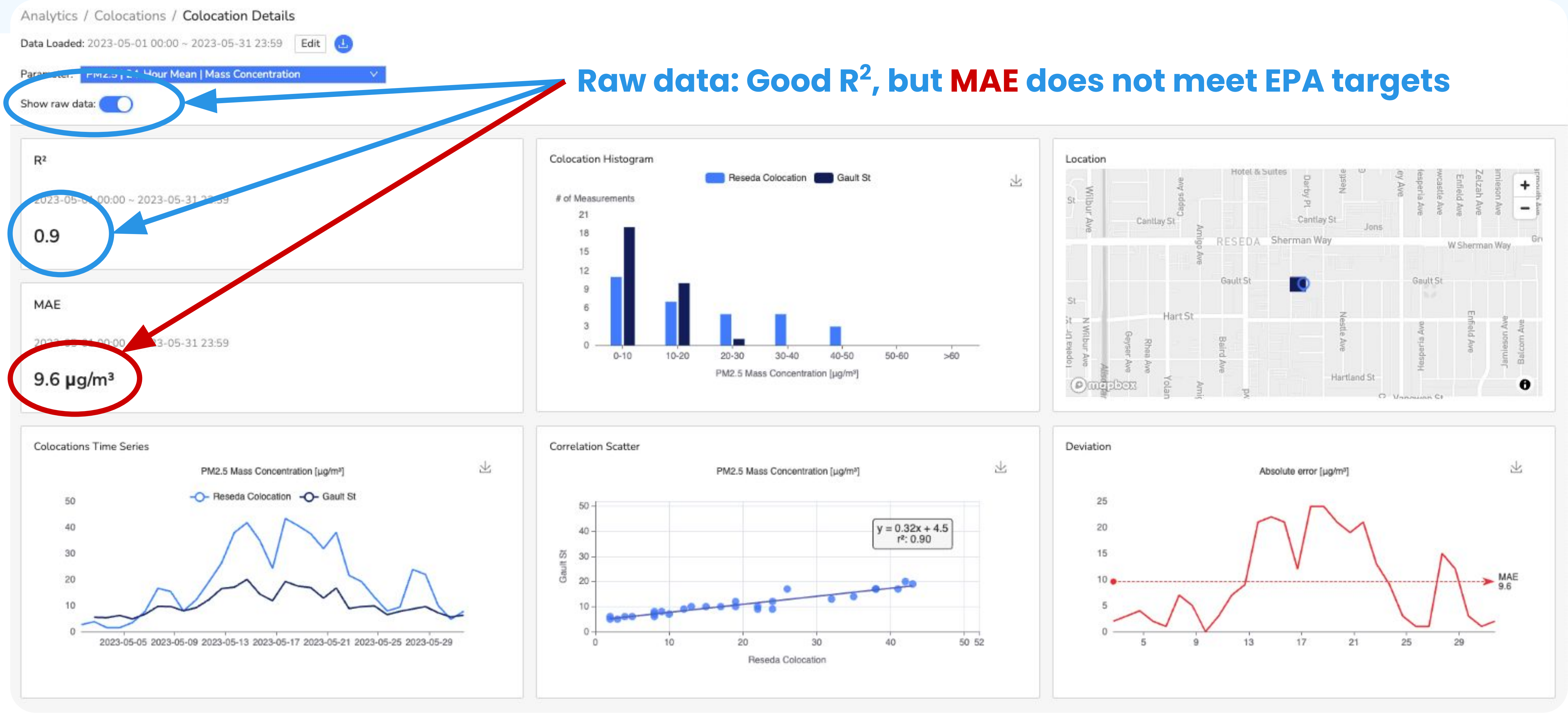
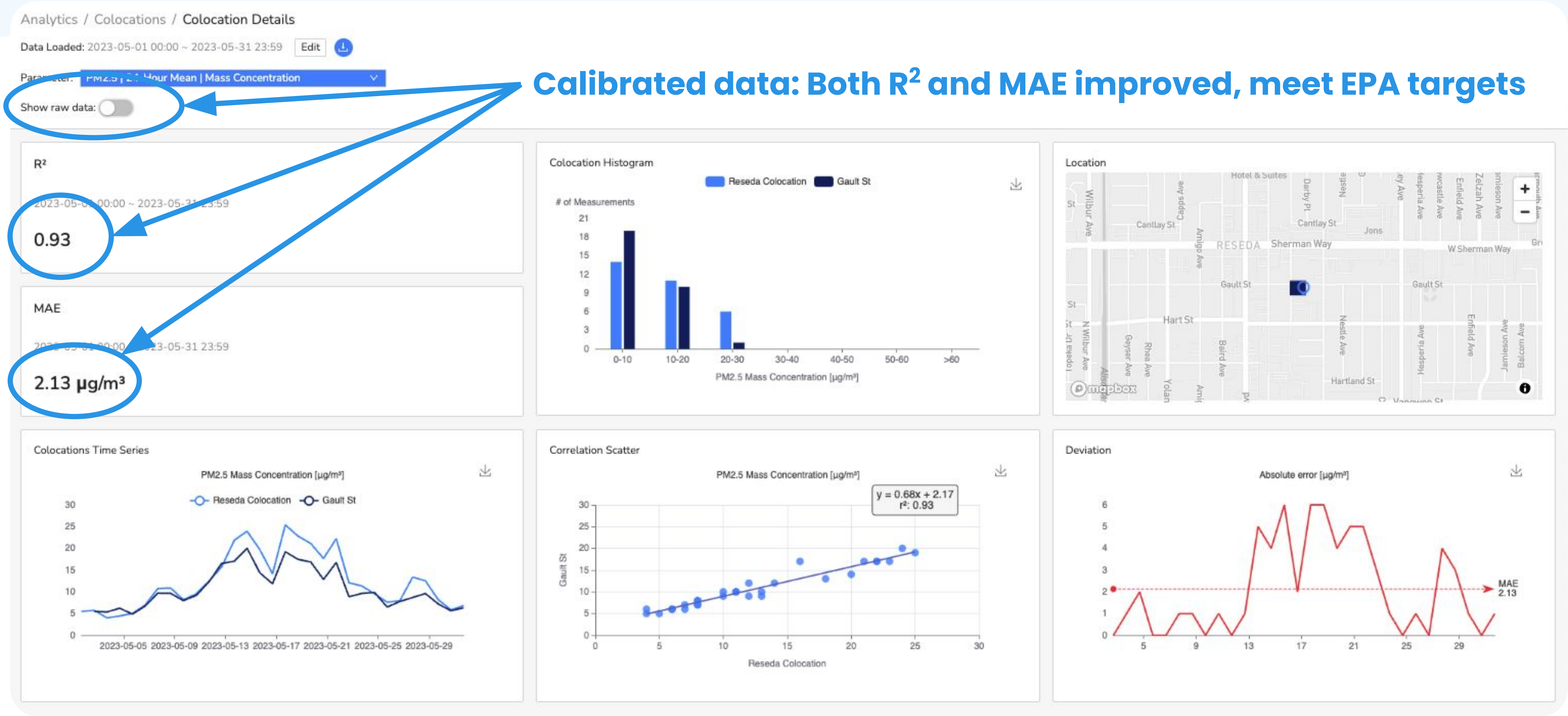
Los Angeles collocation — before calibration



Los Angeles collocation — after calibration

Calibrated data: Both R^2 and MAE improved, meet EPA targets



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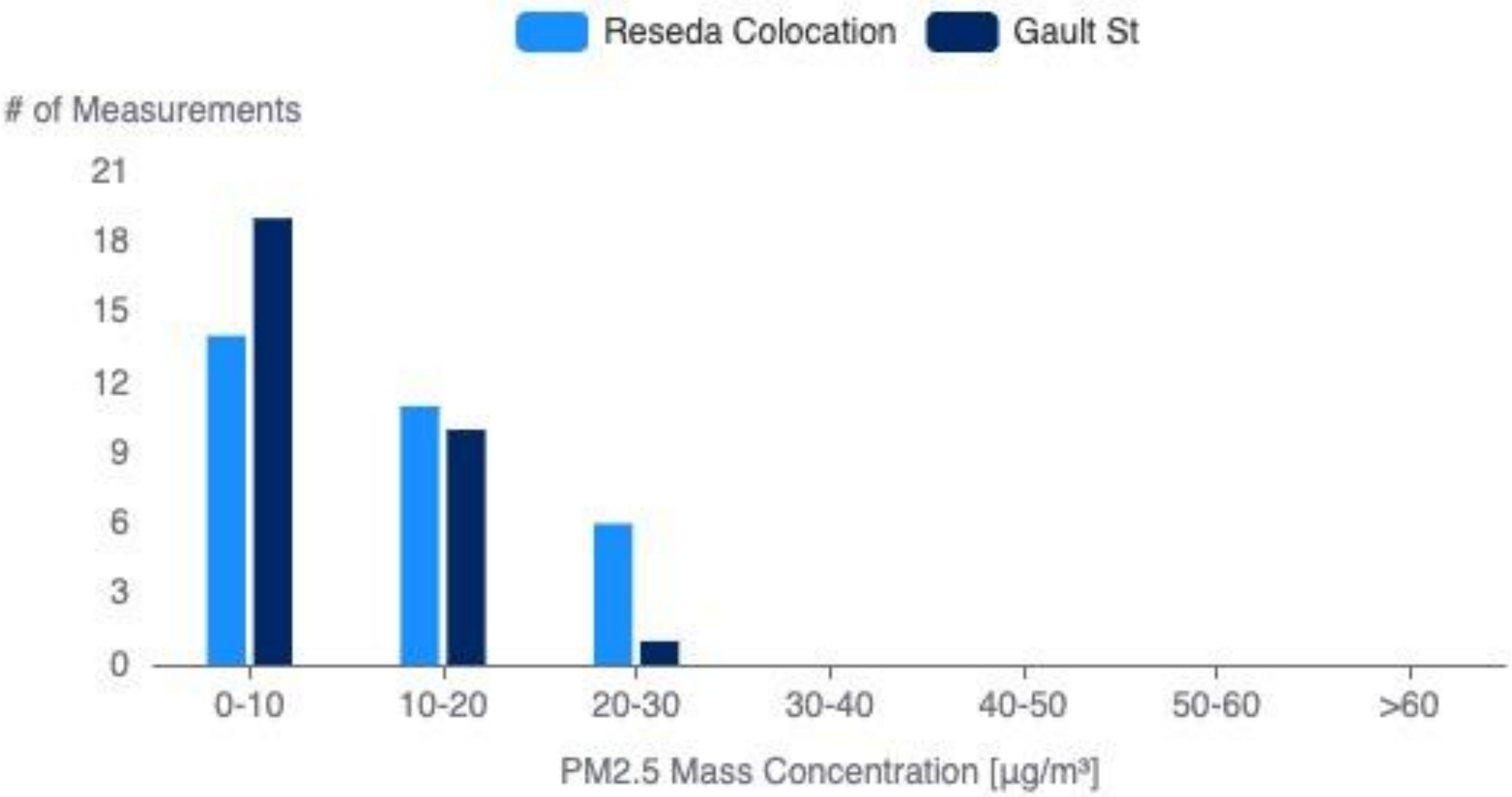
Understanding the data — Collocation Histogram (Los Angeles)



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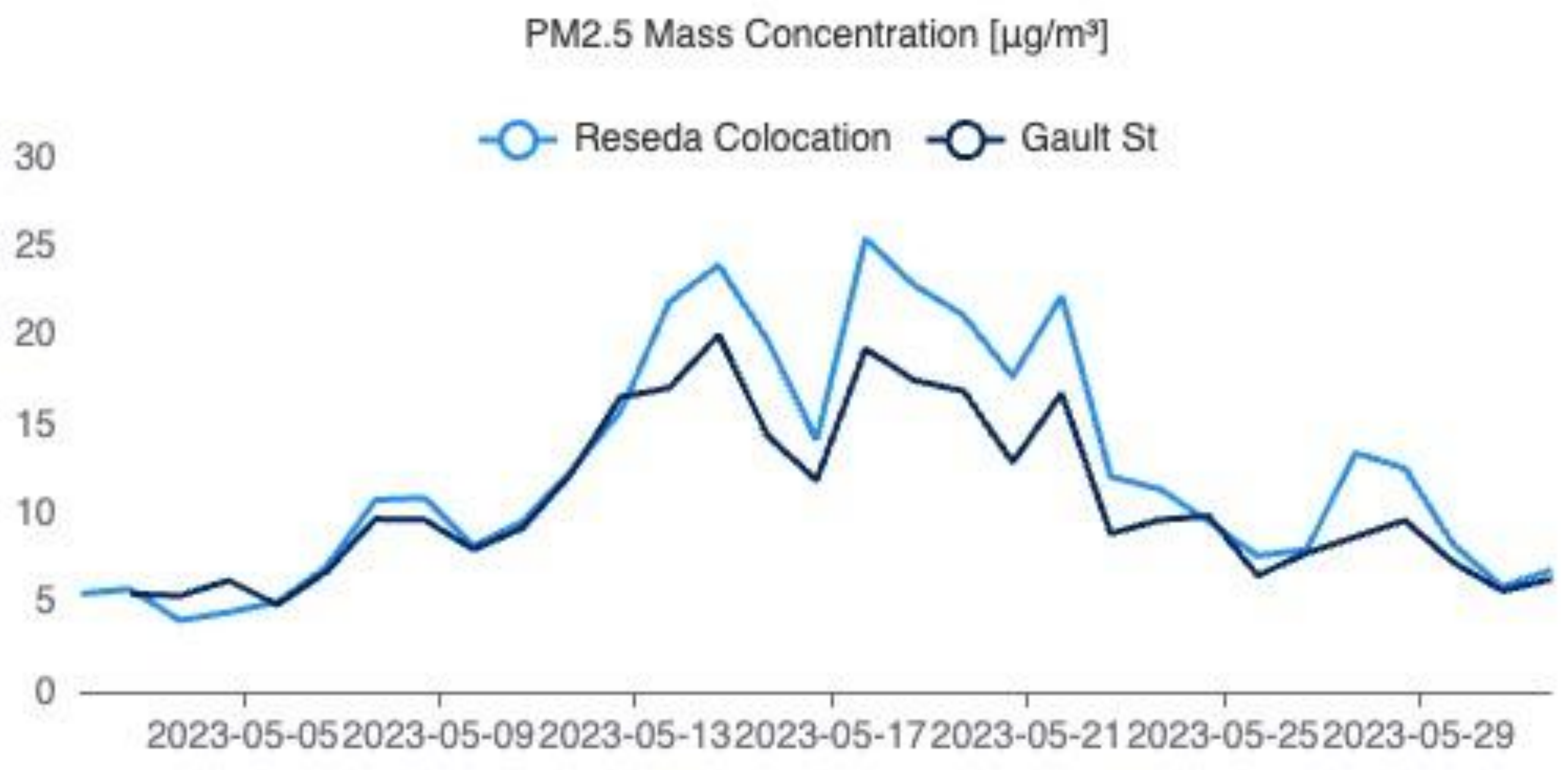
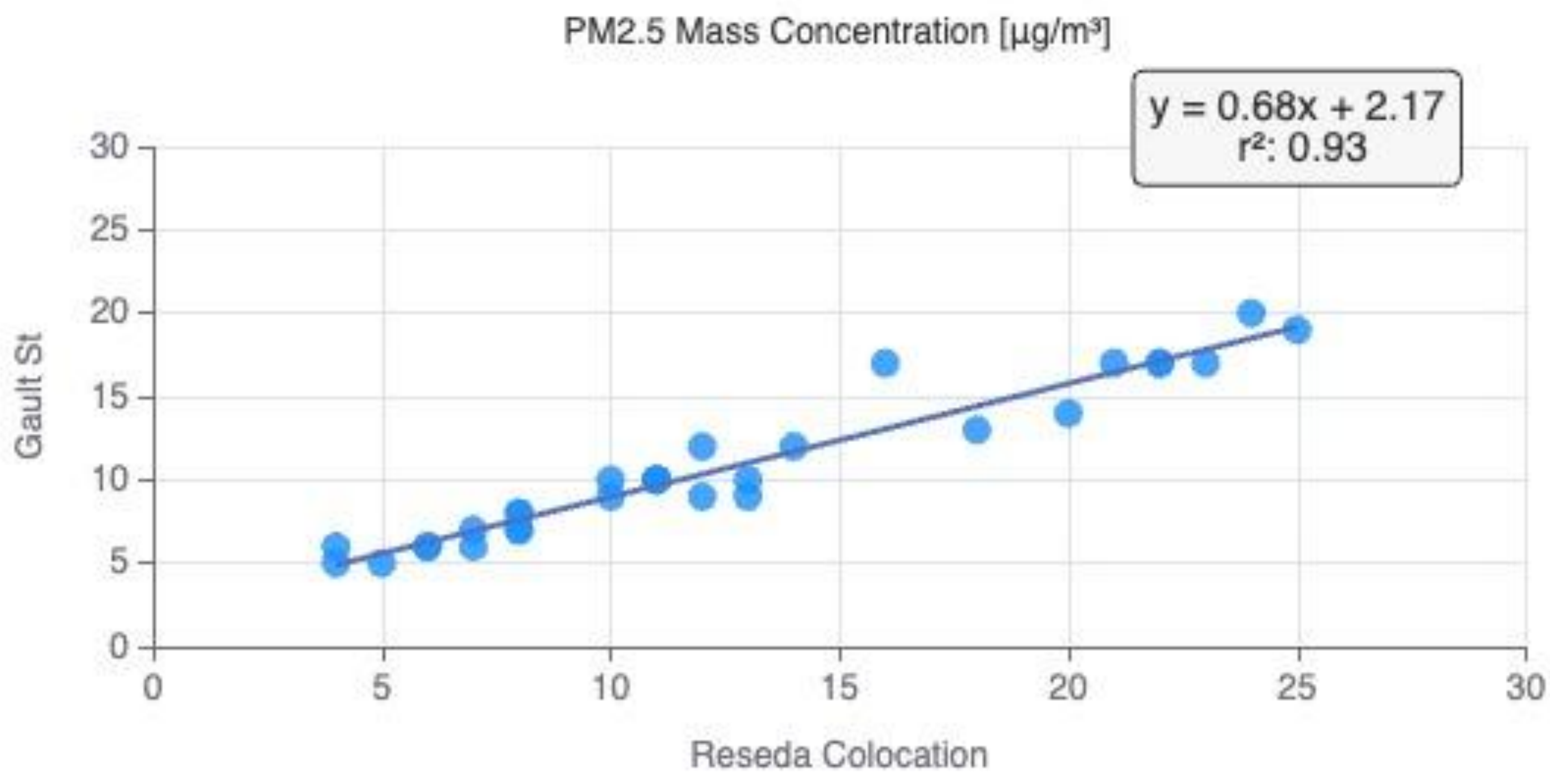
Understanding the data — Collocation Time Series (Los Angeles)



Understanding the data — Correlation Scatter (Los Angeles)



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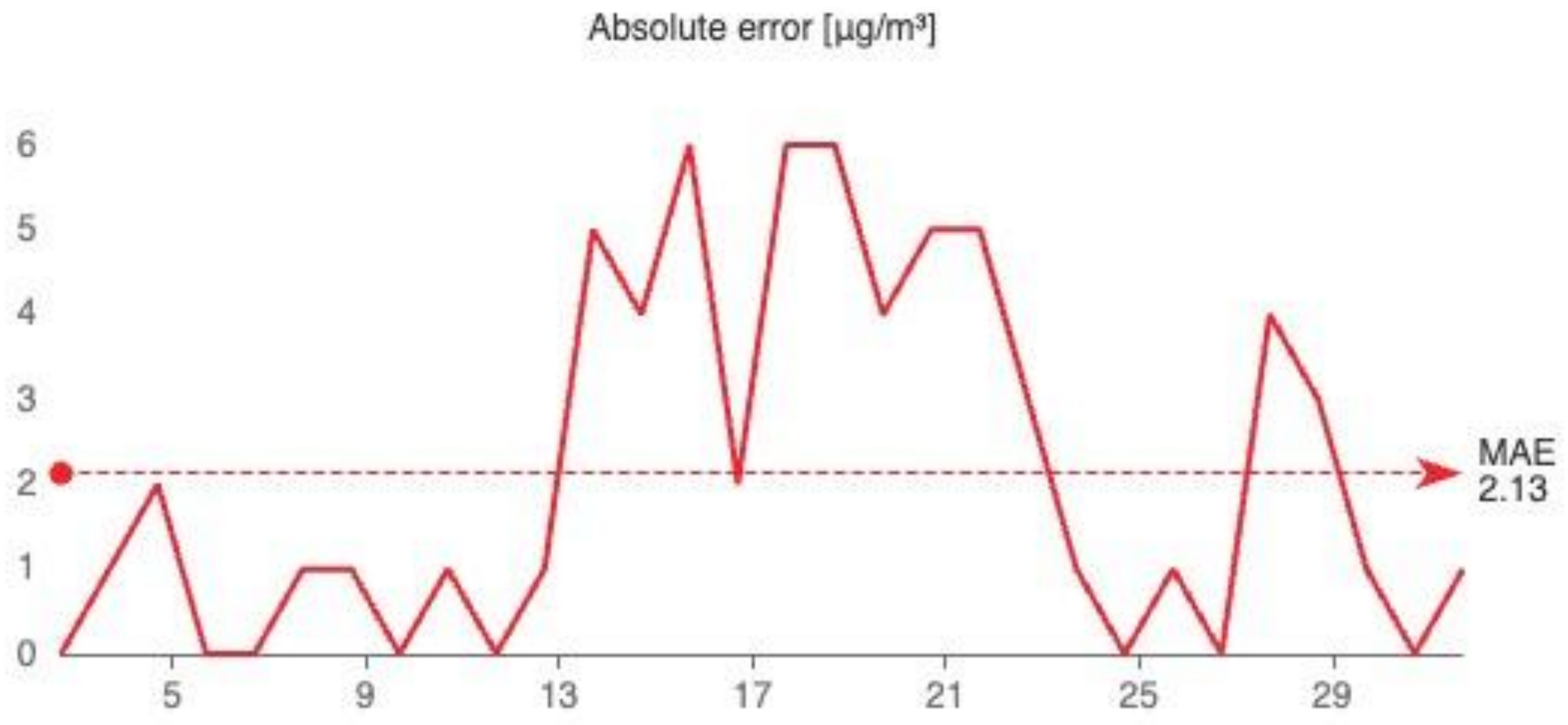
Understanding the data — Deviation (Los Angeles)



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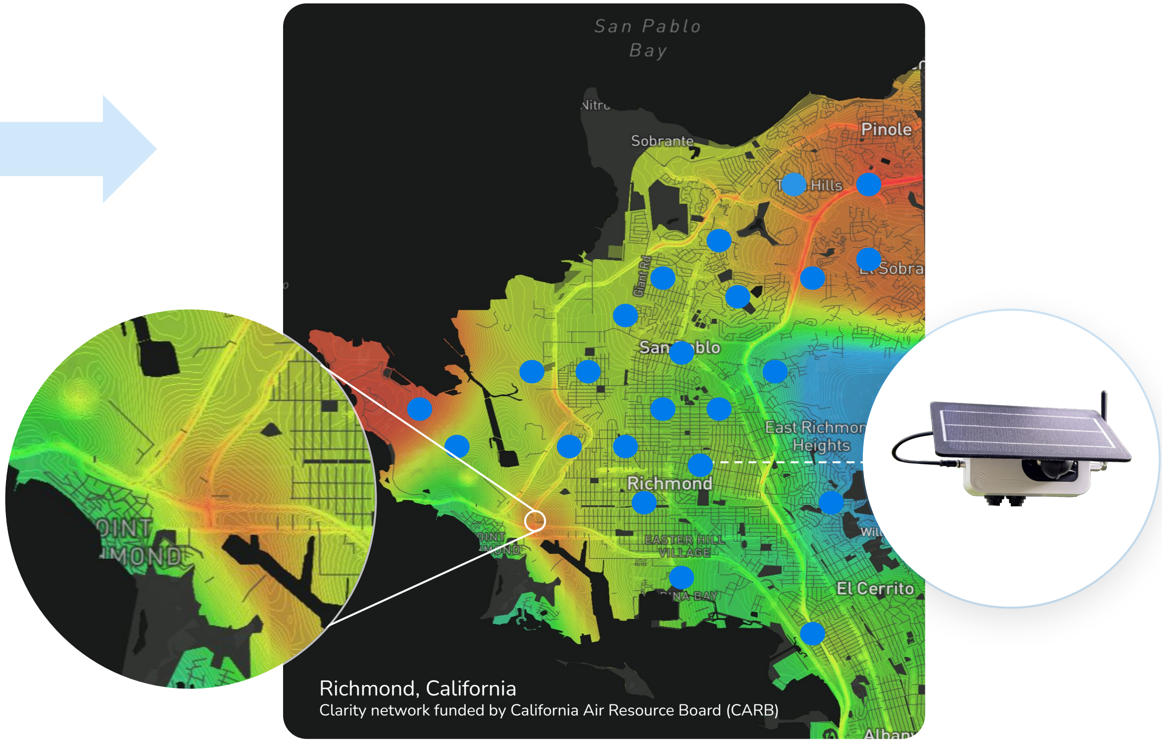
Hybrid Networks: Filling the gaps with low-cost sensors

Regulatory Air Monitoring

Sparse, under-representative air quality information

Hybrid Monitoring



Localized, real-time & accurate air quality data

Register for the next webinar on June 14th!

Use Cases — Lessons Learned from Air Monitoring Projects in 70+ Countries

June 14, 9am PT/6pm CEST

Sean Wihera

VP of Business Development & Partnerships

Q & A

Any questions?

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Homework:
Moving from data to action

- Use Clarity Dashboard to evaluate air quality and sensor performance
- Instructions will be shared via Slack and email
- Data provided by Los Angeles Unified School District