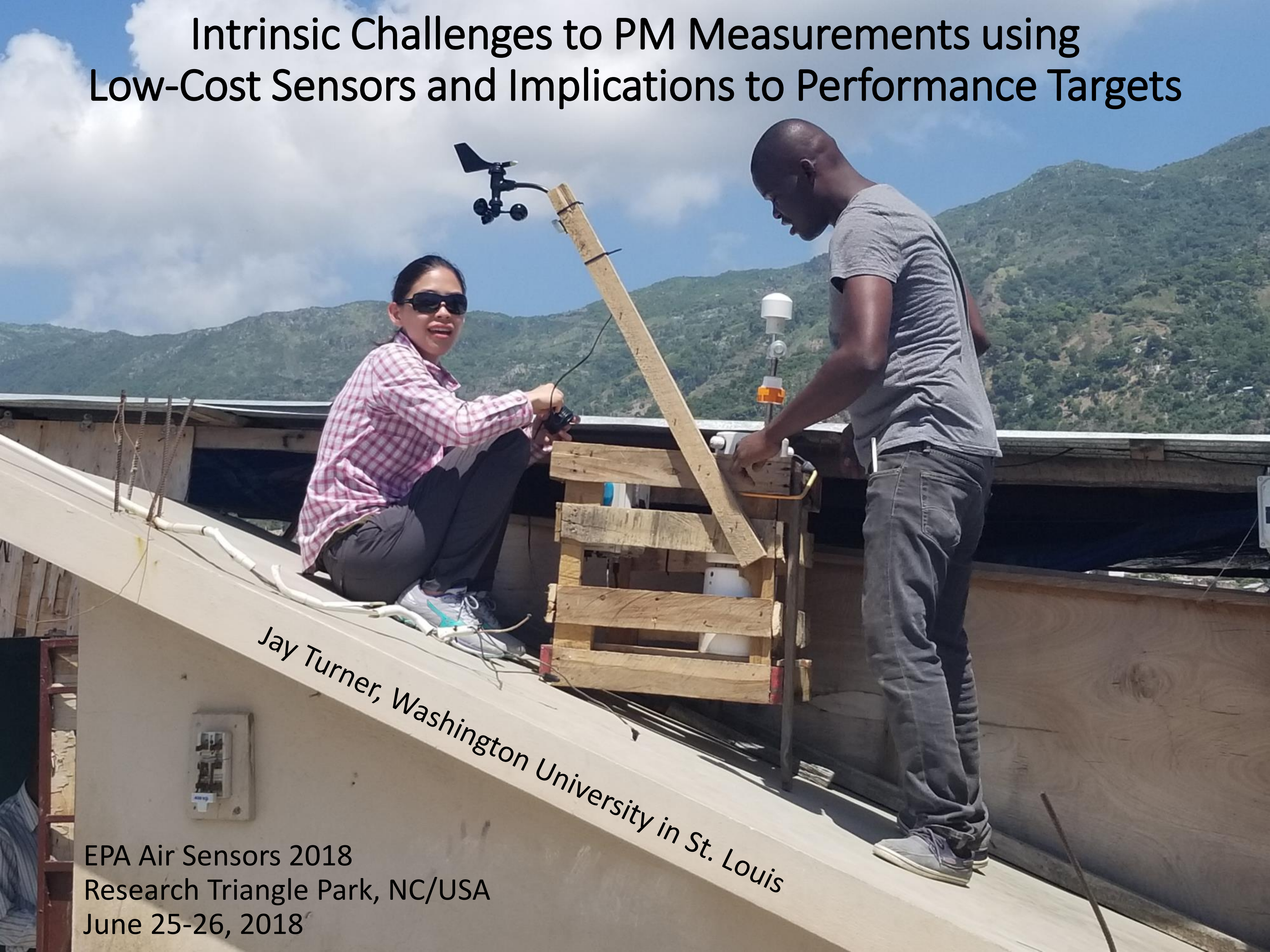
Intrinsic Challenges to PM Measurements using Low-Cost Sensors and Implications to Performance Targets



Jay Turner, Washington University in St. Louis

EPA Air Sensors 2018
Research Triangle Park, NC/USA
June 25-26, 2018

My Lens…

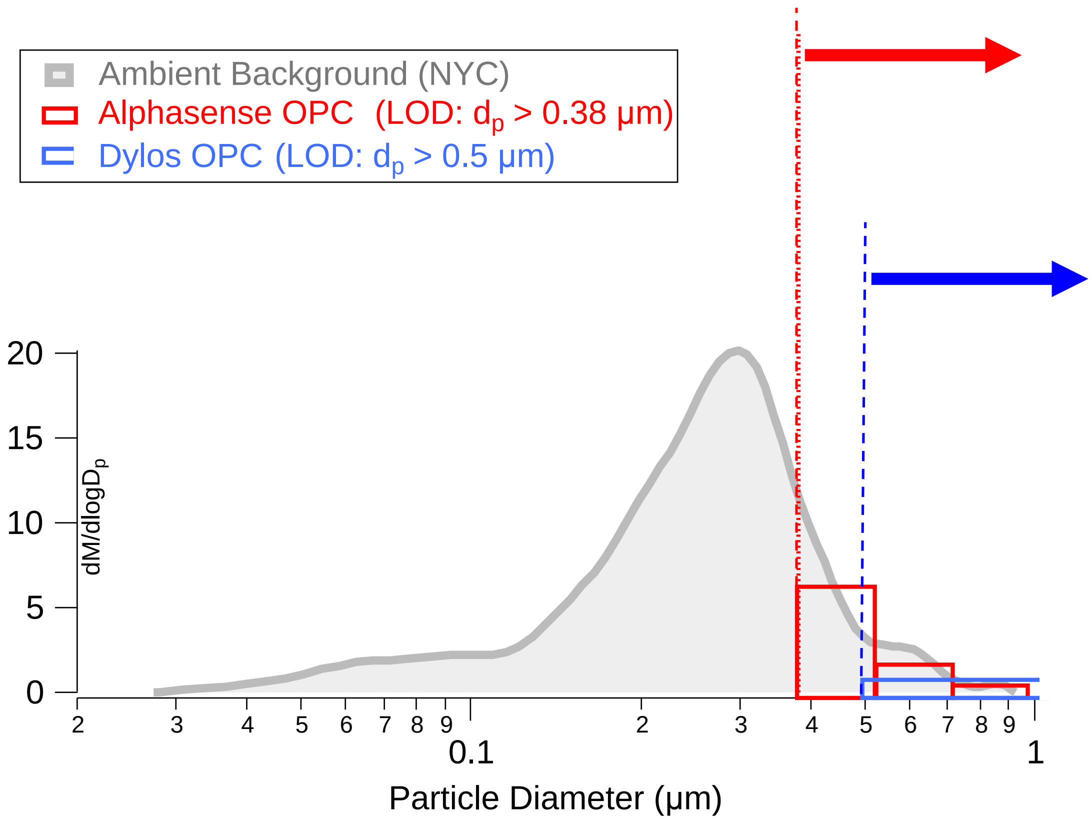
- Sensor node (2) deployment in Haiti starting May 2018
  (led by Brent Williams; Audrey Dang and Lindor Wildor on previous slide)

- Sensor node deployment (4) in Louisville starting July 2018

- Have been pondering data quality objectives for these deployments
  - Disclaimer: primary objective for these studies is gases, but will also measure PM

Acknowledgement: conversations with Eben Cross (Aerodyne)

Optical Particle Counter (OPC)-Based Sensing

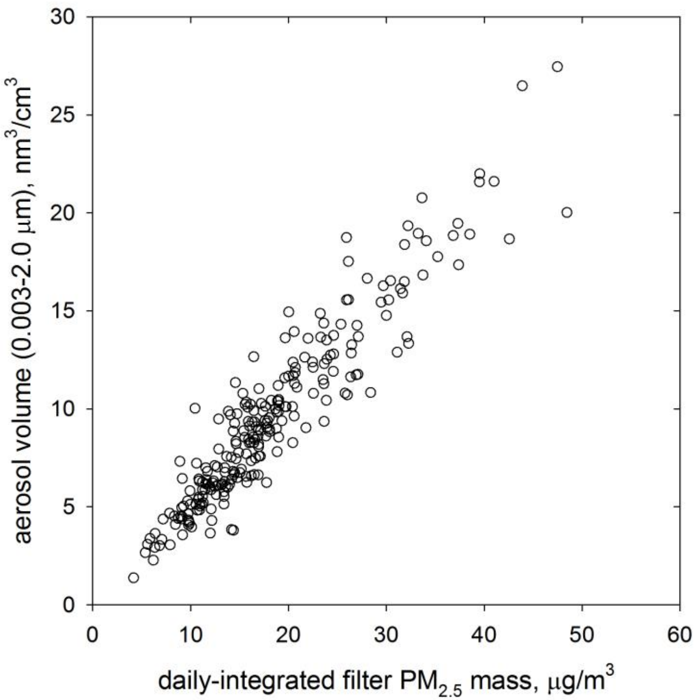


Variability in the size distribution of ambient particulate matter changes the fraction of suspended PM detected by the low-cost OPC

ambient data from Canagaratna *et al.* 2004;
figure courtesy Eben Cross (Aerodyne)

One Year of 24-hr Average Particle Size Distributions (PSD): St. Louis – Midwest Supersite

Total Aerosol Volume



Drivers for scatter (partial list):

- OPC binning assumptions (e.g., refractive index, particle shape)
- $PM_{2.5}$ for filter mass, $PM_{2.0}$ for PSD volume
- Varying particle density
- Daily-average PSD reported for 18-24 valid hours whereas gravimetric mass nearly always 24 hours

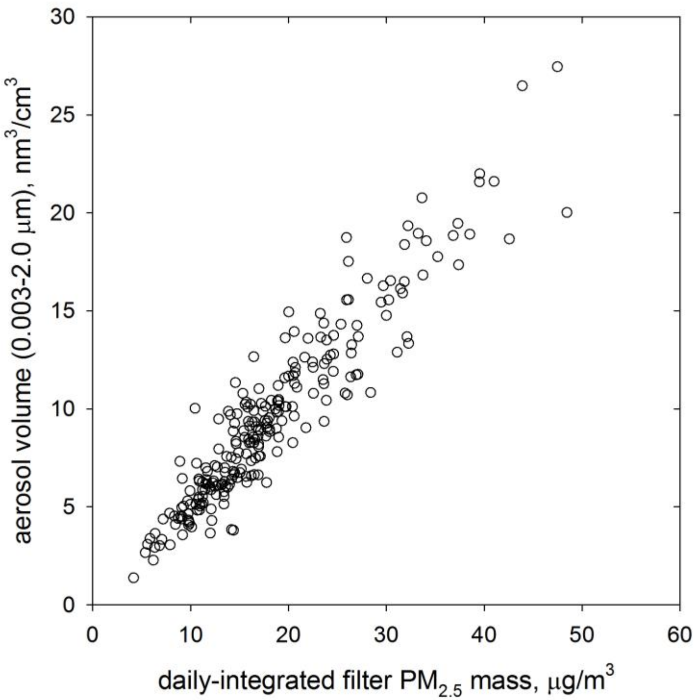
Relative Humidity (RH) Conditions:

- filters equilibrated at 35-40% RH; PSD aerosol controlled to ~40% RH

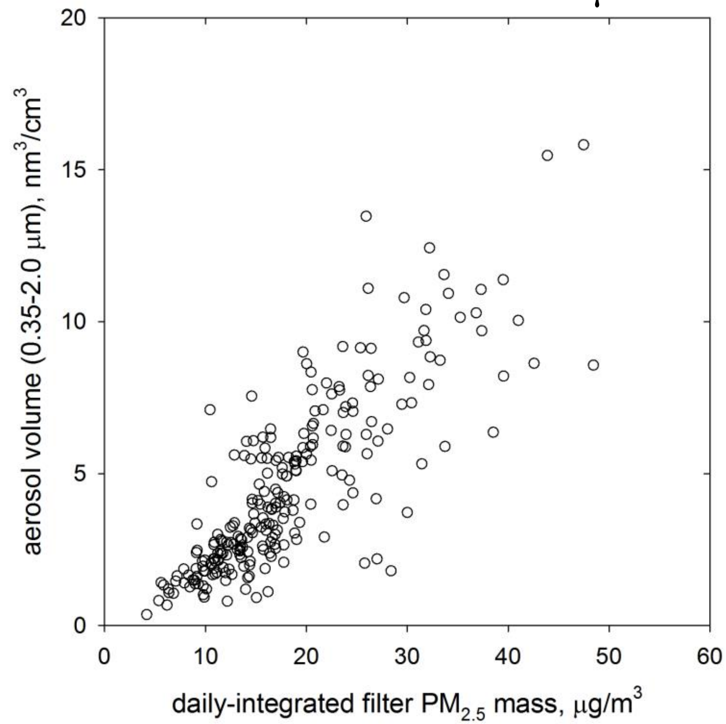
Raw PSD data from Peter McMurry group; gravimetric mass data from Petros Koutrakis group

One Year of 24-hr Average Particle Size Distributions (PSD): St. Louis – Midwest Supersite

Total Aerosol Volume

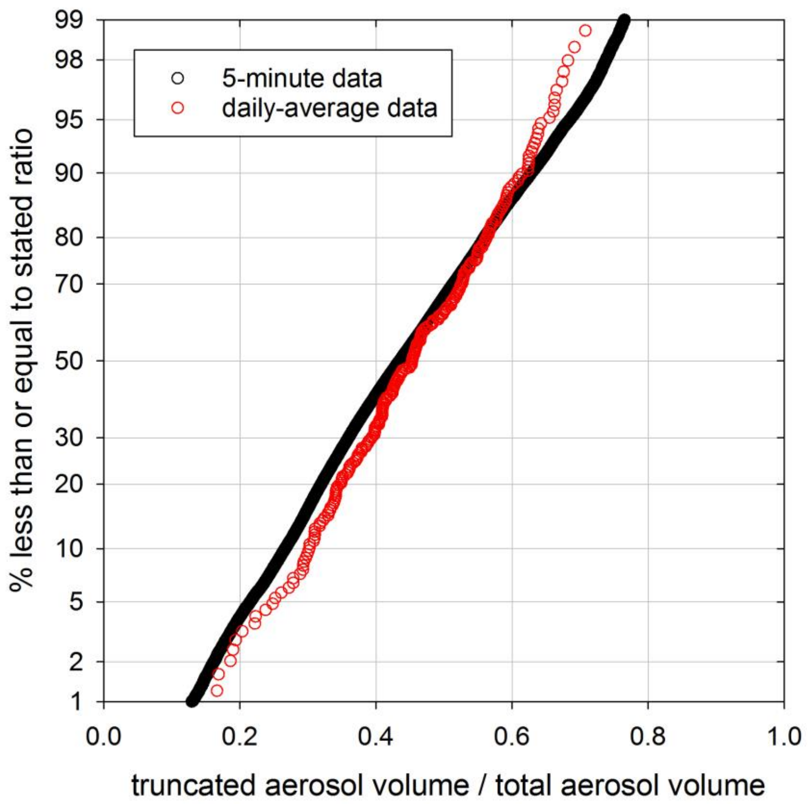


Aerosol Volume > 0.35 μm



Truncating the PSD to measure only particles larger than 0.35 μm leads to much greater variability in the PSD volume – to – gravimetric mass relationship.

One Year of 24-hr Average Particle Size Distributions (PSD): St. Louis – Midwest Supersite

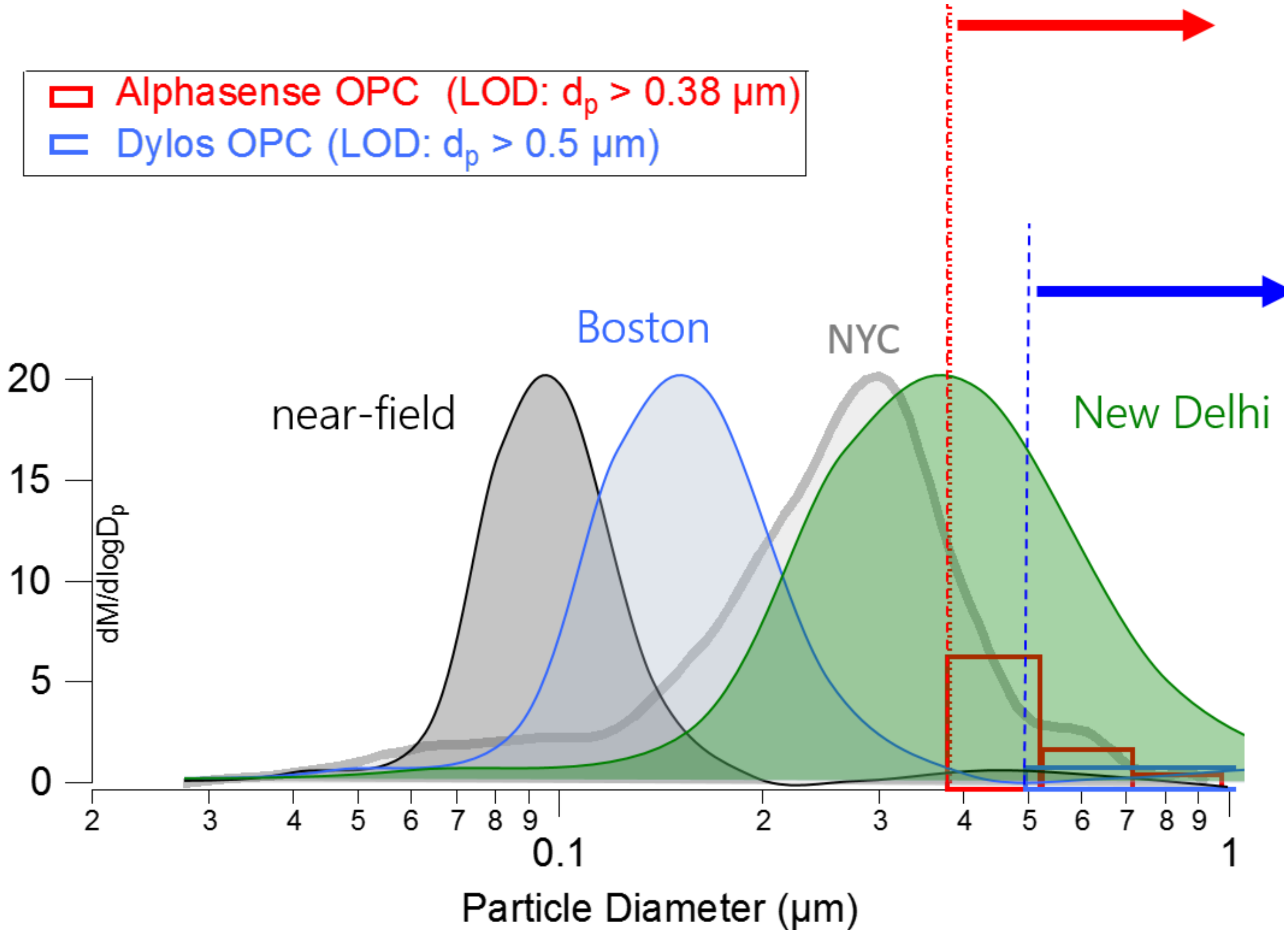


Scaling the truncated (>0.35 μm) aerosol volume to the total aerosol volume

- 24-hour averages
  - Mean (~Median) = 0.45
  - **10th and 90th percentiles differ from the mean by ~50%**
- Arises from shifts in the PSD

This analysis is for a single site over one year. The scaling factor – and its variability – will vary by location and thus is difficult to *a priori* predict. **Need site-specific and in some cases season-specific adjustments, and even then likely noisy.**

Optical Particle Counter (OPC)-Based Sensing



different environments.. different size distributions… different fractions of PM mass detected

Ambient Relative Humidity

- Regulatory and research grade monitors condition the sample stream to control aerosol water content
- Not realistic for low-cost sensor nodes
  - PSD will be influenced by RH according to (size-dependent) hygroscopicity and whether aerosol is a liquid droplet
- Users often try to address through corrections based on low-cost sensor comparisons to reference methods

Implications

- Need consistently reported performance metrics for collocated precision (i.e. across identical low-cost sensors) and comparisons to reference monitors
- Performance evaluations need to document the monitoring location (e.g., background, near-road) and environmental conditions (e.g. RH, T ranges) to place these data in context
- If objective is to use as proxy for “conventional” mass measurements, need study-specific comparisons to reference monitors
  - Might need to compare by season
  - Might need for multiple sites in a network, even on the intraurban scale

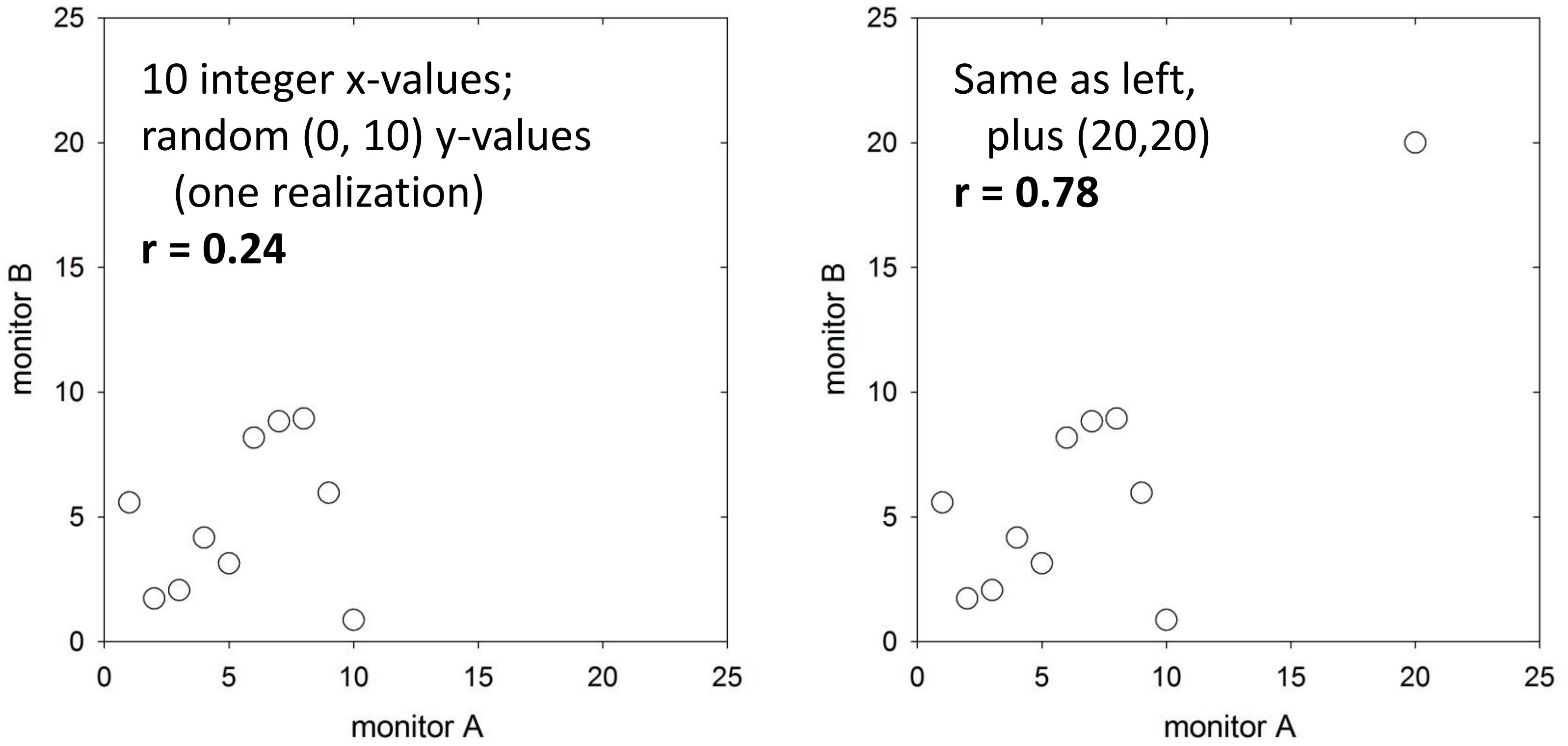
Implications (continued)

Key points:

- If interested in gross features (e.g. hot spots), low-cost sensors may have high value with little effort
    - Still need to consider the sensor intrinsic characteristics
- If interested in spatial and/or temporal variability fine features, low-cost sensors require significant effort
    - Extensive collocation (identical sensors, reference monitors)
    - Perhaps empirical data manipulations ("corrections") to improve data quality

Performance Measures

Need to move beyond correlation when comparing monitors! Many low-cost sensor evaluation papers/reports misuse or overinterpret this statistic



Performance Measures

- EPA Federal Equivalency Method (FEM) test reporting requirements perhaps a good framework for defining performance measures
  - Precision, additive and multiplicative bias, correlation, coefficient of divergence
    - Include bias-corrected precision for collocated identical sensors
  - Report results for different averaging times (e.g. measurement base, 1-hour, 24-hour)
  - Report results before and after any empirical corrections
- Consistent performance reporting with associated metadata allows potential users to make informed decisions
- *Immediate Need:* standardized performance reporting conventions