Minimizing the Influence of Environmental Conditions on Low-Cost PM Sensors

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Overall Goal:
Reduce Interference of T & RH

The sensor community has identified limitations that must be addressed before low-cost PM sensors can replace, or at least augment, stationary monitors.

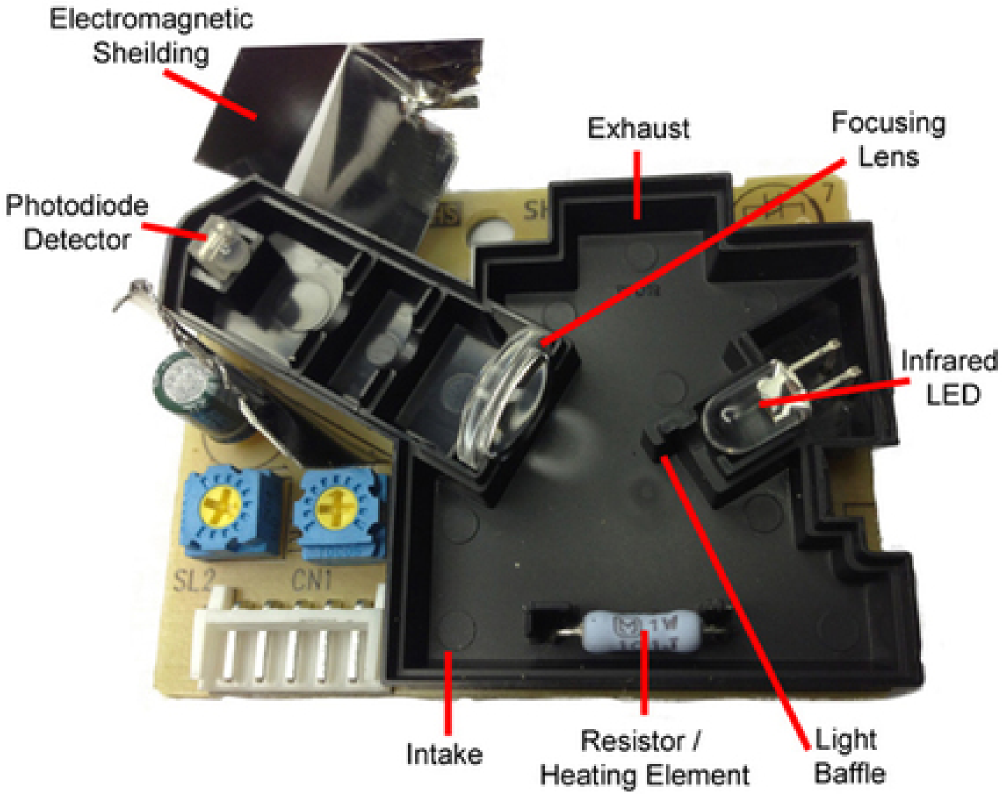
Particularly:

- ***Are they sufficiently sensitive and unbiased in environments with changing humidity and temperature to generate useful data over diurnal cycles, during weather events, as well as over seasons and locations with different environmental conditions than where they were calibrated?***

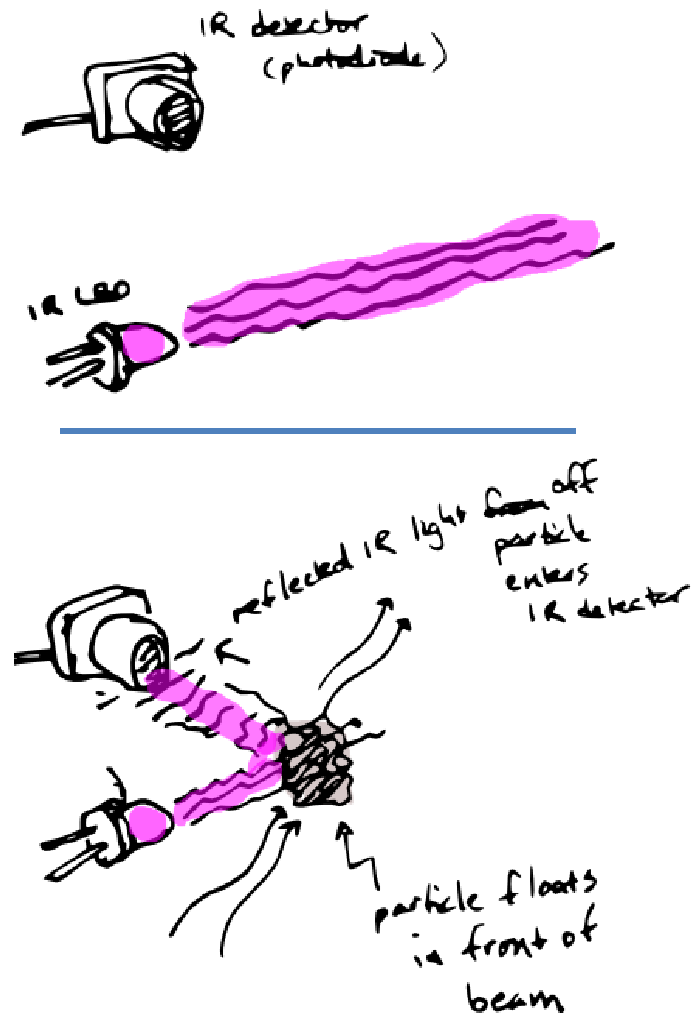
Aims of this presentation

- Describe how variation in humidity and temperature influence sensitivity and bias in low-cost PM sensors,
- Identify ways to account for T and humidity dependence, and
- Estimate how much these approaches could improve sensor performance.

Optical sensors and how they count particles



https://publiclab.org/wiki/optical-pm



https://publiclab.org/profile/DonBlair

Above: Optical (light scattering) sensor (Dustino)

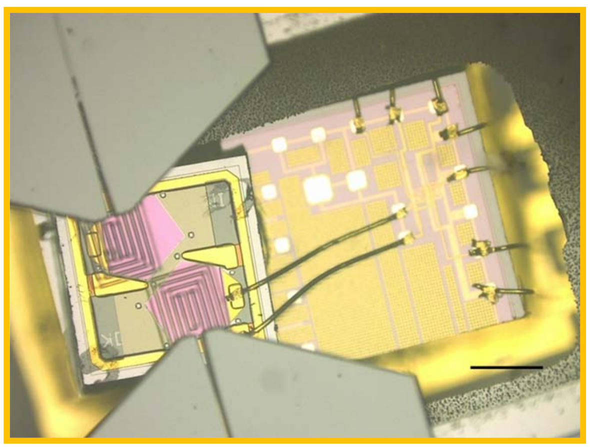
Right: How it works

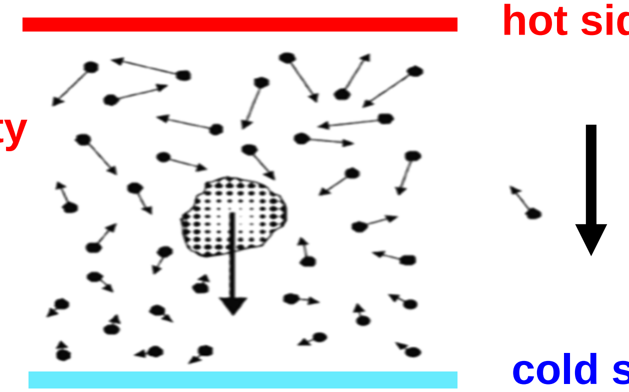
How RH & T influence measurements by optical PM sensors

- Interaction of airborne particles with water vapor depends on their size, composition, as well as the humidity of the surrounding air. Optical properties of the particles are affected.
- Hygroscopic aerosols are affected by changes in RH and can distort sensor output, relative to FEM or FRM instruments over all size ranges.
- The optical elements of the sensors can get foggy and other surfaces such as the circuitry can be affected.
- The humidity typically varies with diurnal cycles, and sensor response to decreasing humidity will lag due to hysteresis.
- Optical PM sensors are not as sensitive to temperature as to humidity.

Resonator-based sensors for PM mass

(resonators in pink)





Paprotny, Doering, Solomon, White, and Gundel (2013).
Doi.org/10.1016/j.sna.2012.12.026

How RH & T affect sensitivity & bias in mass sensors (resonators) for PM

- **Current resonator-based sensors are piezoelectric and have some linear temperature dependence.**
- **The current resonators are based on semiconductor materials that can adsorb water vapor by hydrogen bonding to their surfaces. This can change their electronic properties and sensitivity to particle mass.**
- **Therefore, variability humidity can influence the base frequency of the resonator. This interference can raise the limits of mass detection.**

Ways to account for T and RH effects

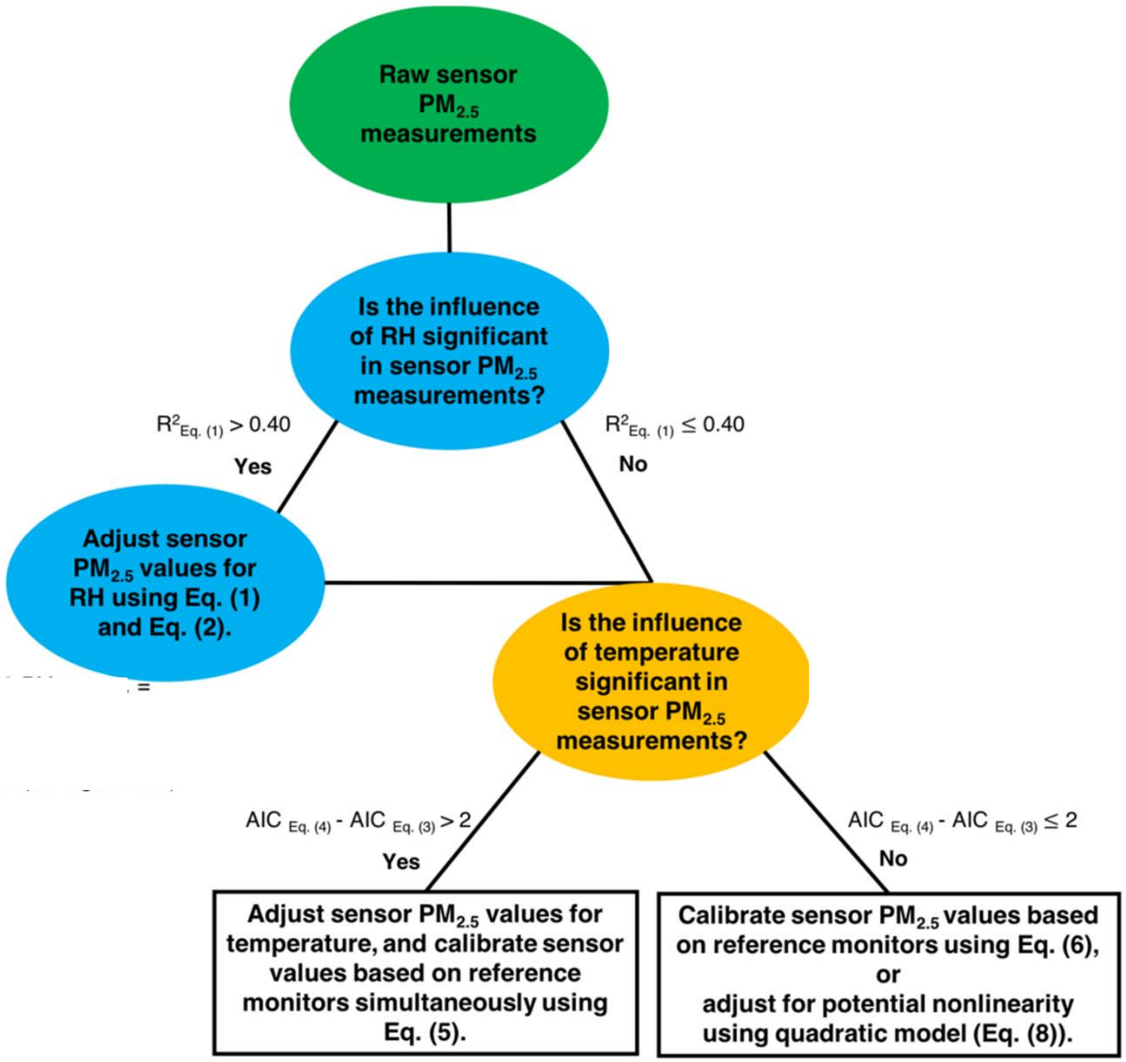
Temperature

- Optical PM sensors are not as sensitive to temperature as to humidity.
- For mass-sensitive resonators, the temperature effects are linear and simple to normalize.

Humidity

- Software: Data analytics, especially machine learning, generate algorithms that adjust the calibration to include the effects of humidity. The next slide shows how.
- Physical solutions are under development for normalizing the humidity effects for both optical and mass sensors.

Derive algorithms with machine learning



Zheng et al. (2018) Field evaluation of low-cost particulate matter sensors, *Atmos. Meas. Tech.* 11, 4823-4846.

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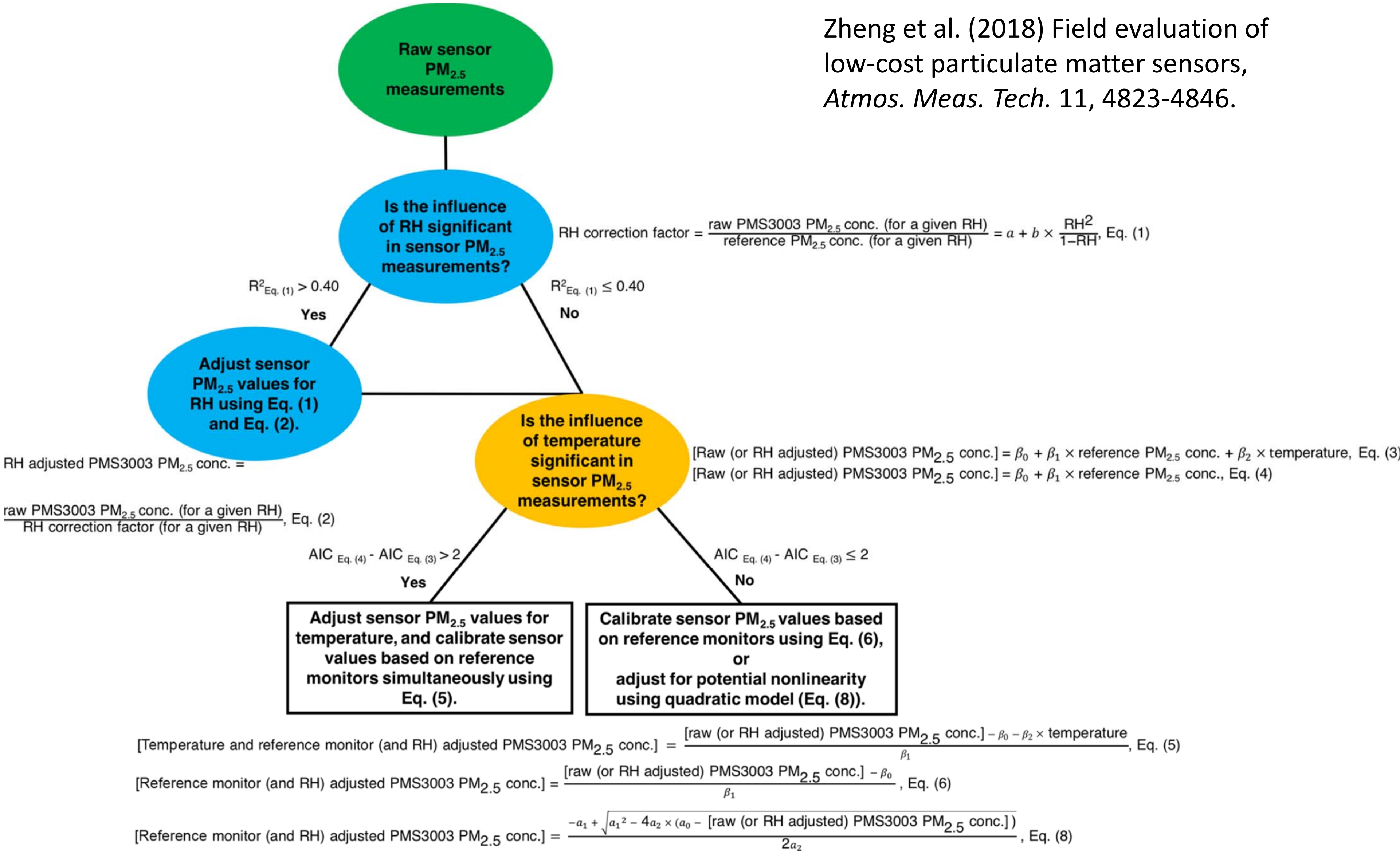

An example of a physical solution

Differential sampling for a resonator-based sensor

- Requires two identical sensing elements, e.g., FBARs
- Using a common inlet, a filter removes particles from one stream, and particles are collected in the other.
- Particle-free sensor only measures environmental effects.
- Particle-laden side measures environmental effects and particle mass.
- Difference in the change in frequency between the two sides should provide particle mass independent of T and RH.
- Can be applied to optical and gas sensors.

How much could these approaches improve sensor performance?

The growing literature on use of low-cost sensors in monitoring ambient air shows that accounting for the influence of environmental conditions on the sensors significantly improves the correlation of their data with FEM instruments that operate at controlled T and RH.

In general, calibration algorithms derived from machine learning indicate that humidity is among the biggest contributors to error in the raw data from optical sensors. The algorithms are less useful for high humidity, as well as when PM levels are below about 10 $\mu g/m^3$.

Continuing the Discussion: P Solomon's Big Questions

Q: What is the big deal about RH affecting particles in the air?
Are these approaches and algorithms needed for the best results?

A: Varying humidity changes particle size (up or down), and hydrogen bonding can affect some sensor materials.

For continuing discussion by sensor users, developers and regulators:

This issue could be considered a problem only because the reference is held constant.

Are sensors operating in ambient RH and T making better measurements of what is in the air than reference monitors that condition the air and particles?

A constant baseline for measurements under all RH and T conditions or is it that water was believed not to have health effects, or both?

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