OVERVIEW OF LOW-COST SENSORS FOR AIR QUALITY MONITORING

Sreekanth Vakacherla

What is air pollution?

Air pollution refers to the release of excessive quantities of harmful substances into the Earth's atmosphere which can reach dangerous levels.

Impacts

- Environment
- Climate
- Health

Source: Borgenproject.org

Criteria pollutants (India)

Pollutants with specified standards

- $PM_{2.5}$
- PM_{10}
- Sulphur dioxide (SO_2)
- Nitrogen dioxide (NO_2)
- Ozone (O_3)
- Lead (Pb)
- Carbon monoxide (CO)
- Benzene (C_6H_6)
- Arsenic (As)
- Ammonia (NH_3)
- Nickel (Ni)
- Benzo(a)pyrene

Need for measurements

- To characterize and report air quality levels
- To identify, prioritize and track trends in pollutants
- To assess and track the effectiveness of programs
- To provide information to researchers and the community
- To assess health impacts of pollutants
- To assess major source impacts

Standard techniques

Pollutants	Measurement Techniques
Particulate Matter	• Gravimetric • Beta Attenuation • Tapered Element Oscillating Microbalances
Ground Level Ozone	• Chemiluminescence • UV Photometry
Carbon Monoxide	• Non Dispersive IR spectroscopy
Nitrogen Oxides	• Jacob and Hochheiser Modified Method • Gas phase Chemiluminescence
Sulphur Dioxide	• Improved West and Gaeke Method • UV Fluorescence
Lead	• ED – XRF

Reference-grade measurements

- **Uses approved reference or equivalent methods**
  - Defined by regulatory bodies
  - Standardized techniques
- **Employs high-precision instruments**
- **Follows strict QA/QC protocols**
  - Regular calibration
  - Routine maintenance
  - Controlled sampling
- **Produces legally defensible data**
  - For regulatory compliance, enforcement, policy decisions
  - Accepted in courts, official reports, national statistics

Reference-grade instruments

Metone BAM1022

Metone BAM1020

Teledyne CO analyzer

Envea NOx analyzer

Ecotech CO analyzer

Micro-weighing balance-Gravimetric

Rack-mounted and sheltered

Trade-offs

- **High capital and operating cost**
  - Limits scalability
- **Infrastructure and maintenance intensive**
  - Continuous power supply
  - Skilled technicians
  - Air conditioned shelters
  - Routine calibrations
- **Limited mobility**
  - Fixed site monitoring

Low-cost sensors (LCS)

- **Affordable and compact air pollution measuring devices**
- **High resolution measurements**
- **Uses simplified sensing technologies**

Aurassure

AirBeam

Atmos

PurpleAir

Key advantages and applications

- **Cost effectiveness**
  - Enables dense monitoring networks
  - Reduced infrastructure requirements
- **Portability and flexibility**
  - Rapid deployment
  - Mobile and personal monitoring
  - Community engagement
- **High-temporal resolution data**
  - Episodic events
  - Traffic peaks
- **Internet of Things (IoT)**

Types of sensors

Particulate matter (PM) sensors

- **Optical (light-scattering) sensors**

Gas sensors

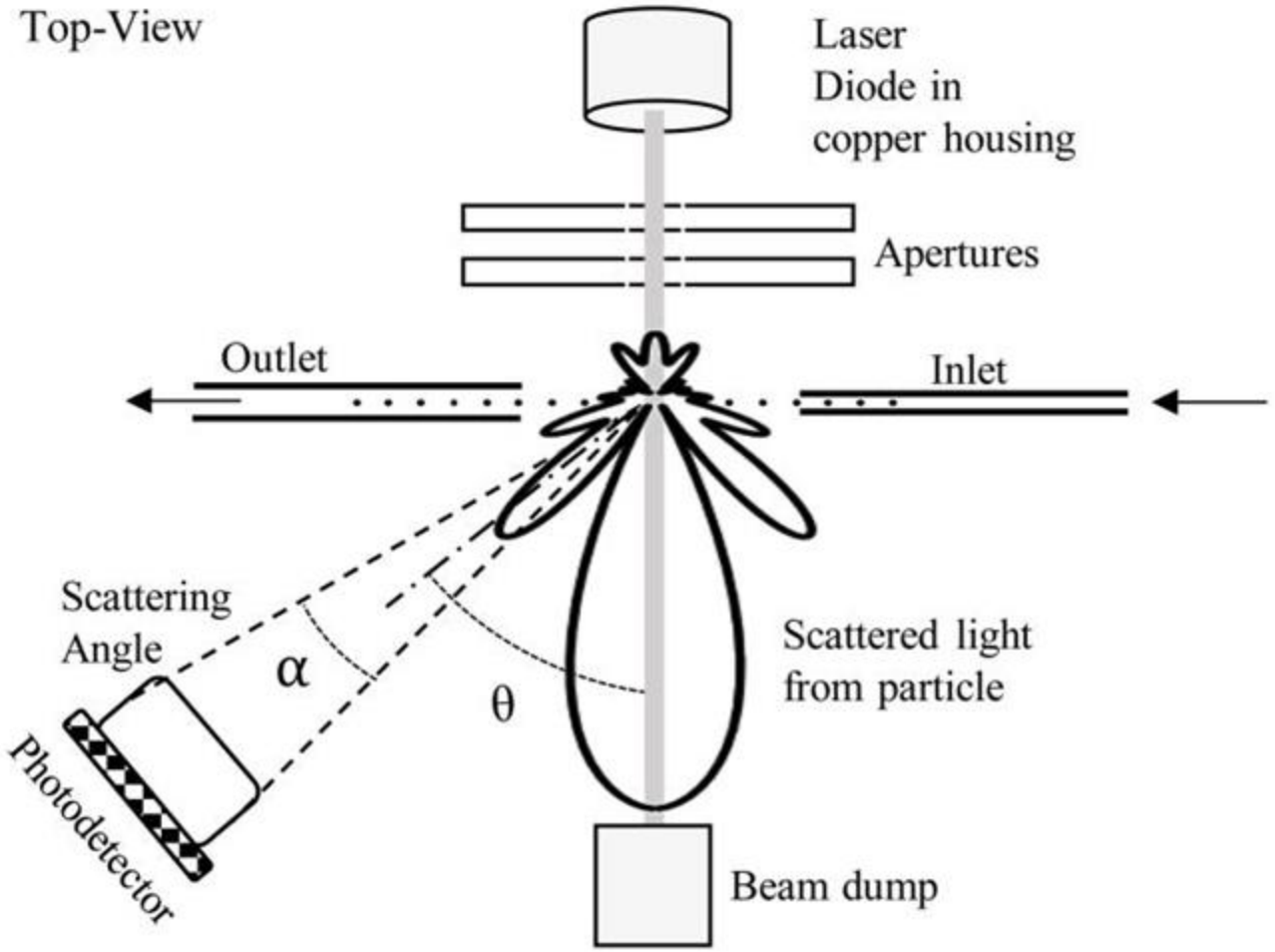
- **Electrochemical sensors** (NO_2, CO, SO_2, O_3, NH_3)
- **Metal-oxide semiconductor (MOS) sensors** (VOCs, CO)
- **NDIR sensors** (mainly CO_2)

Alphasense OPC

Plantower PMS

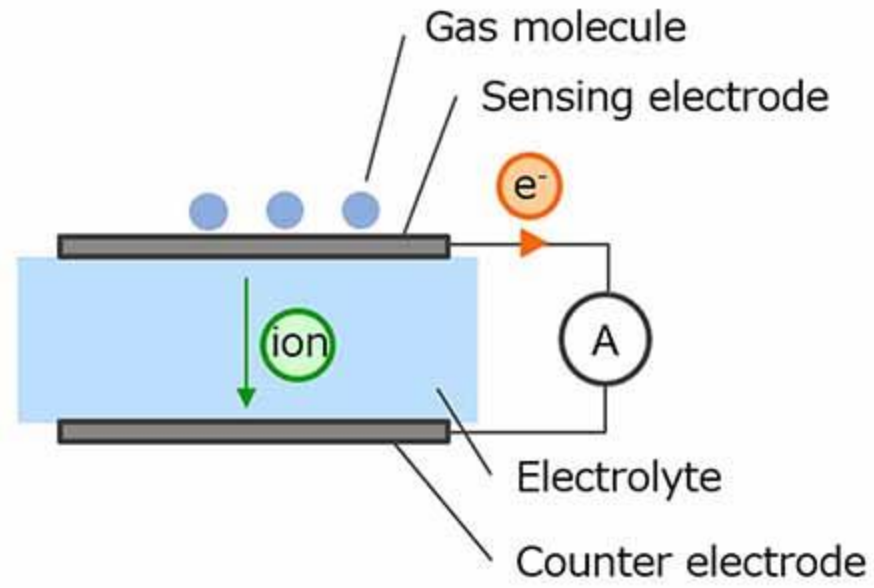
Alphsense gas sensor

Optical scattering technique

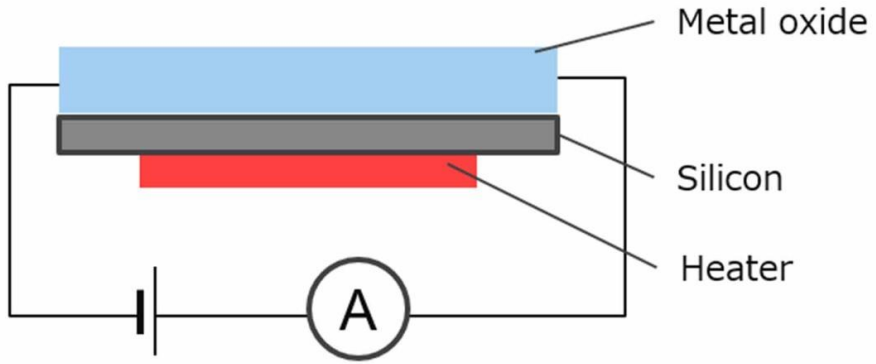


Njalsson & Novsselov, 2018

Electrochemical and MOS



Electrochemical Method

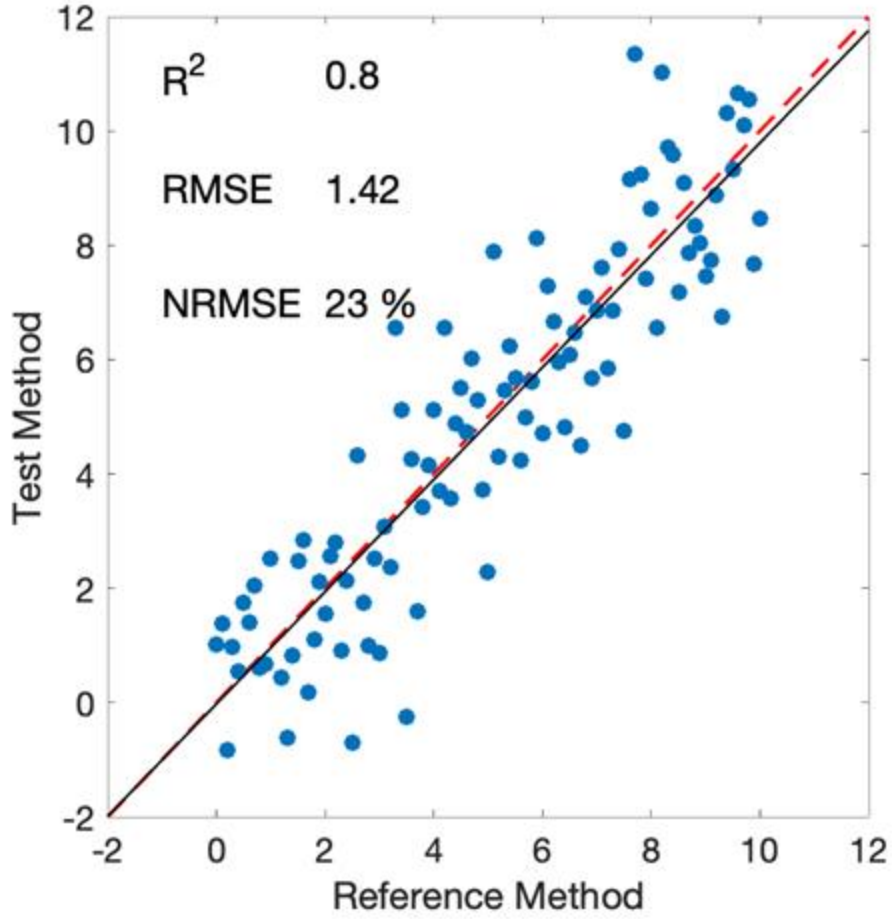


Semiconductor Method

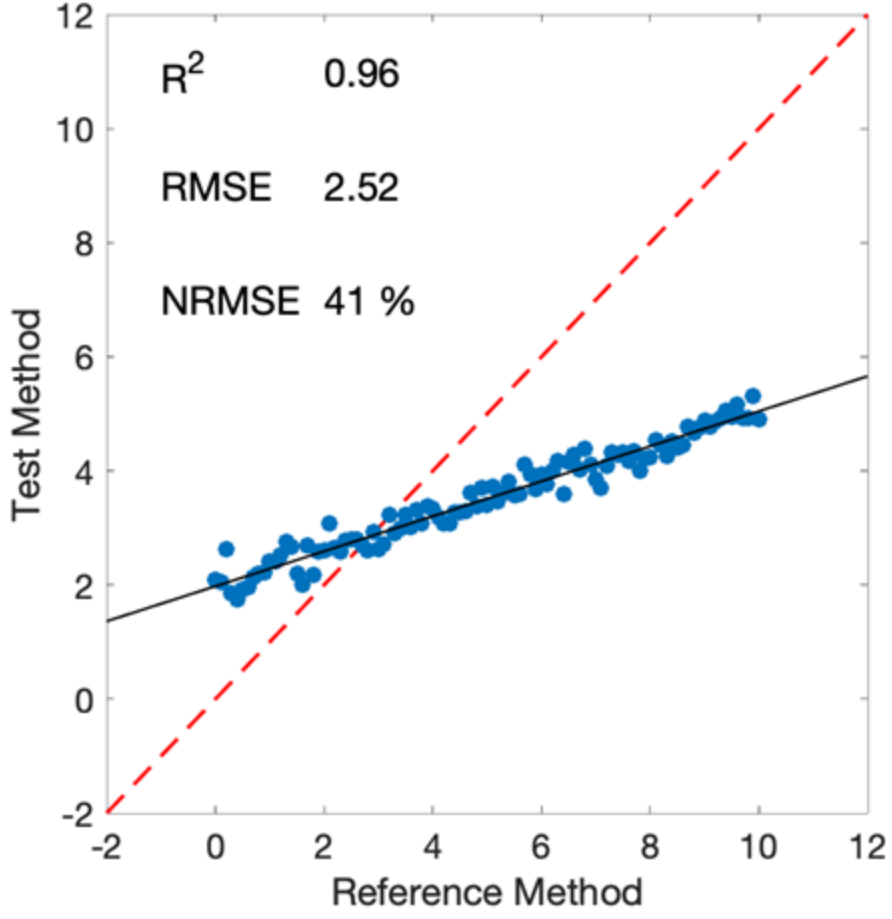
LCS: challenges

- Data inaccuracy (incorrectness)
- Data imprecision (inexactness)
- Possible non-linear response
- Sensitivity to environmental properties (e.g. Humidity)
- Sensitivity to aerosol microphysical properties (size, composition, etc.)
- Spatio-temporal variability in correction factors
- Degradation

Accuracy versus precision



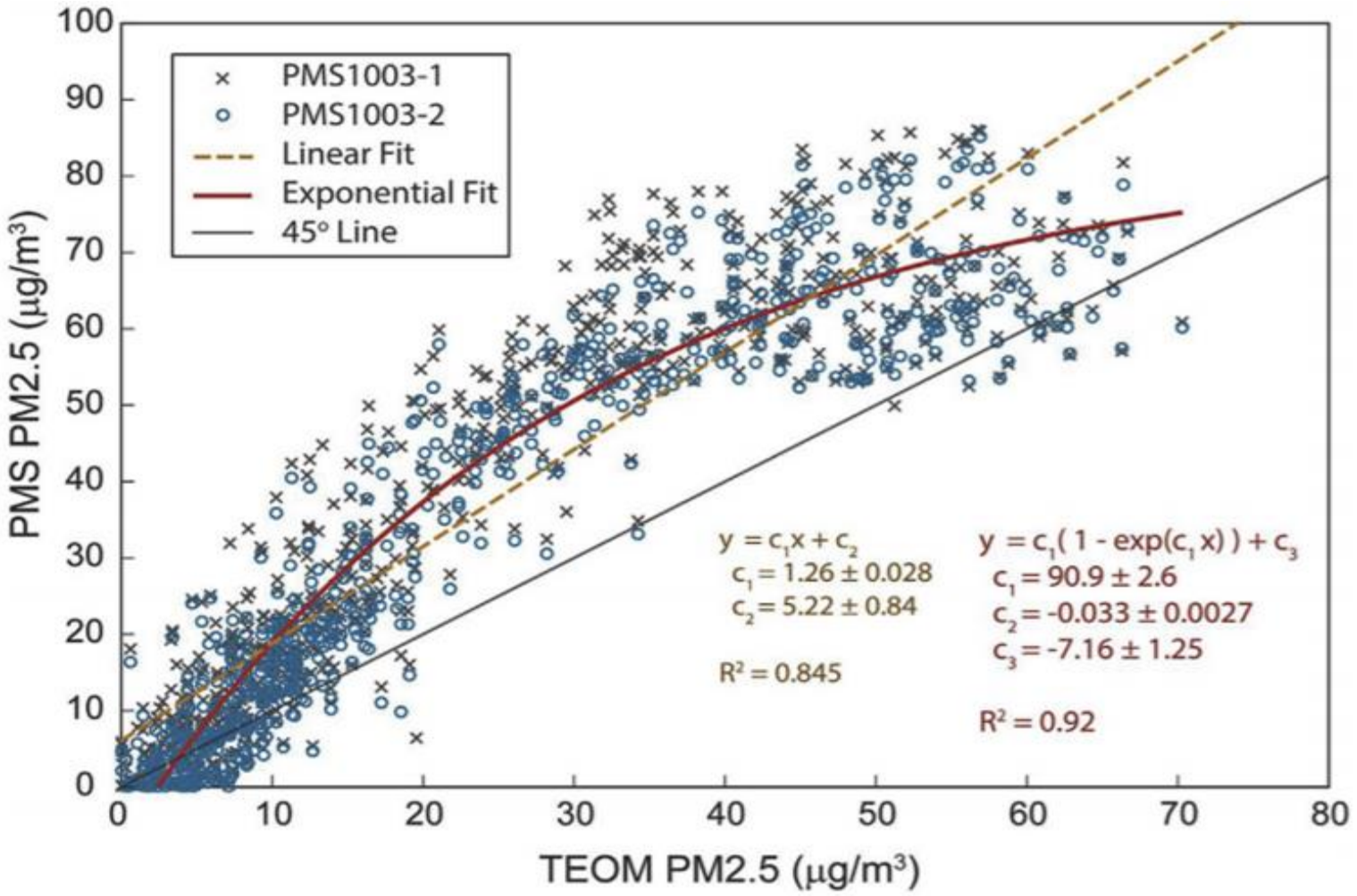
Accuracy: measure of how close a measurement is to the true value



Precision: measure of how close measurements are to each other

Source: internet

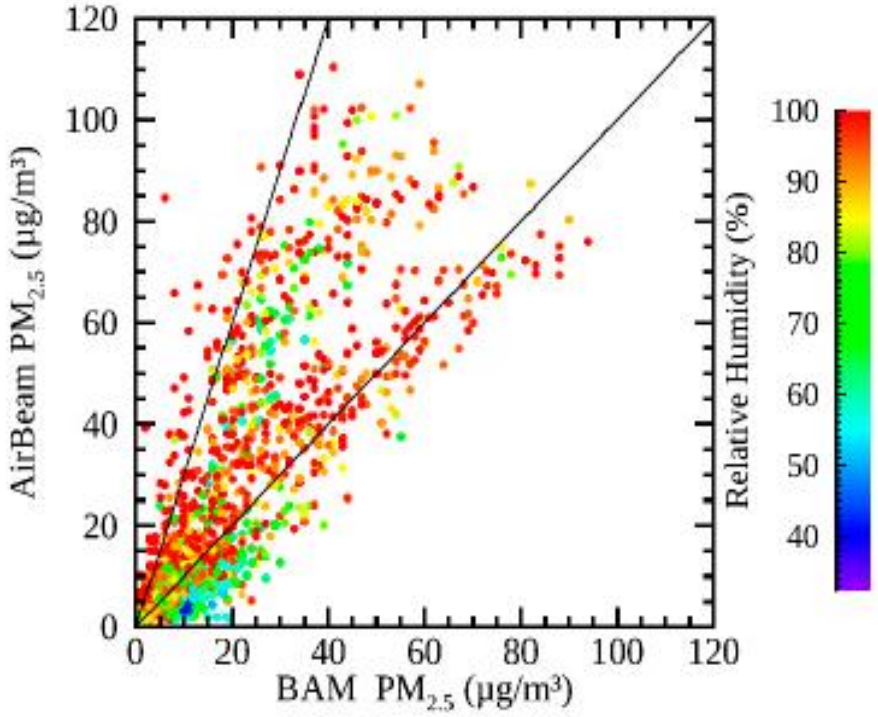
Non-linear response



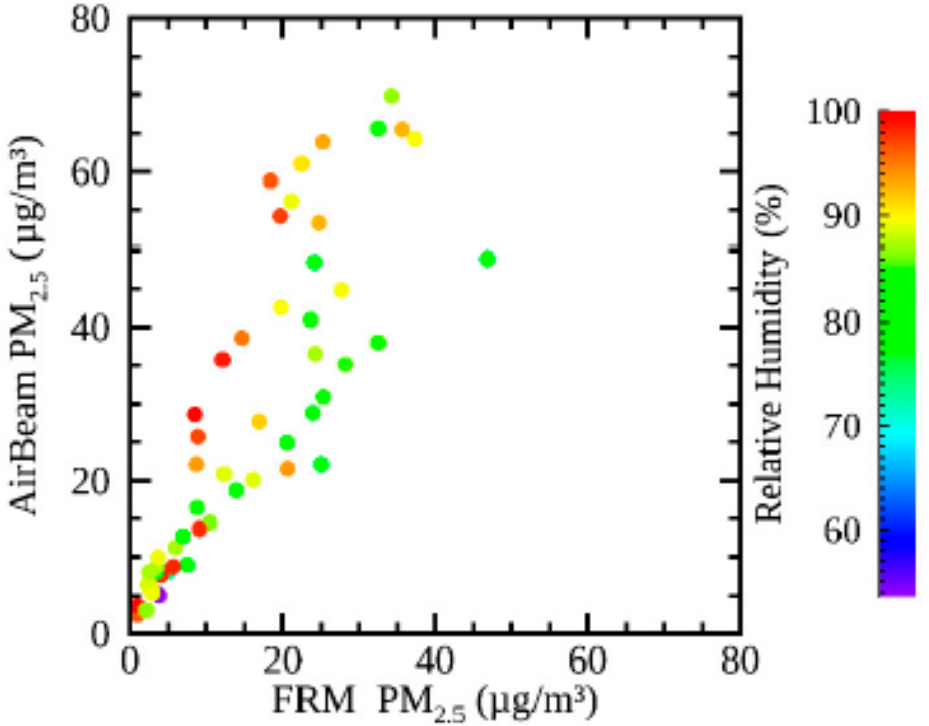
Kelly et al., 2017

Averaging helps

Hourly measurements



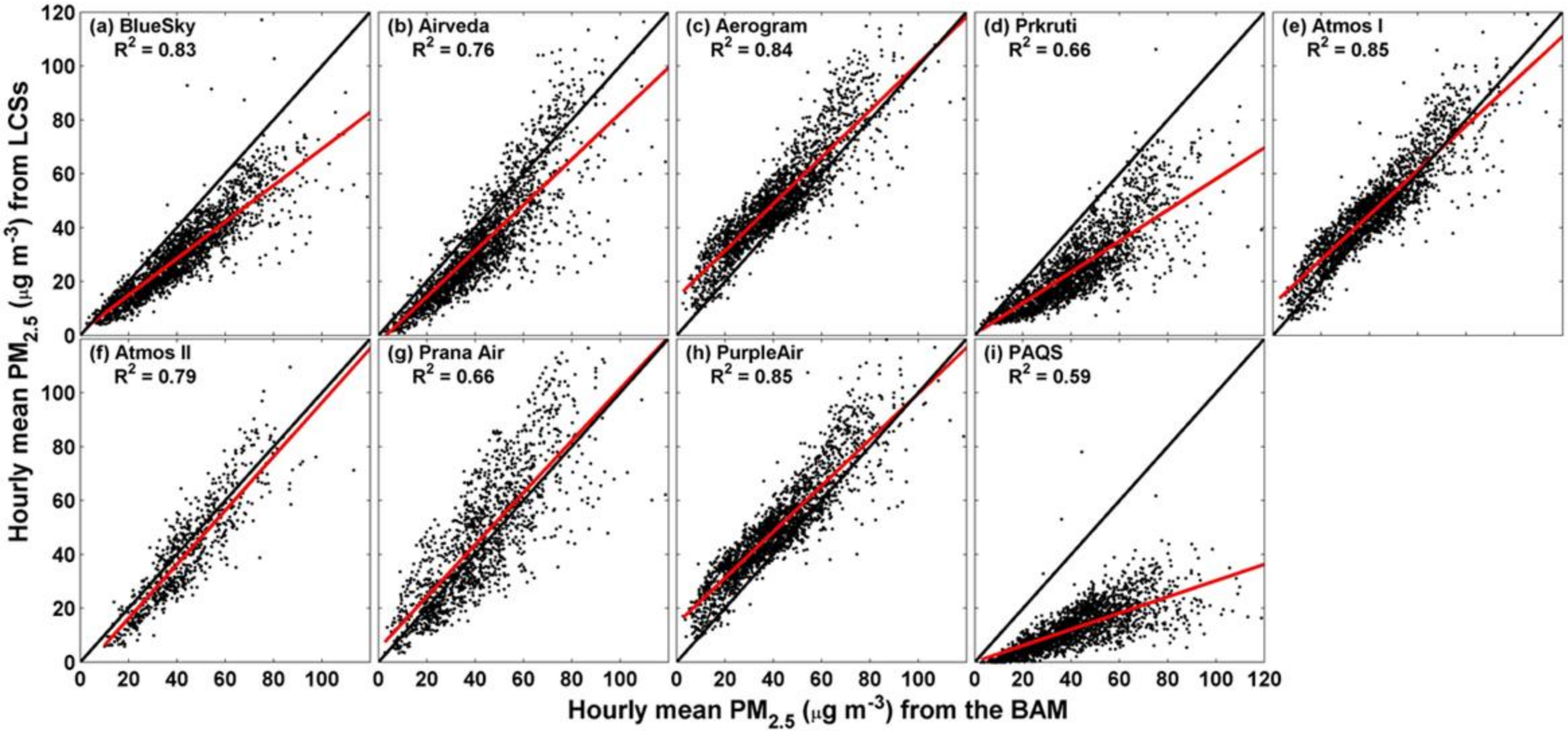
Daily measurements

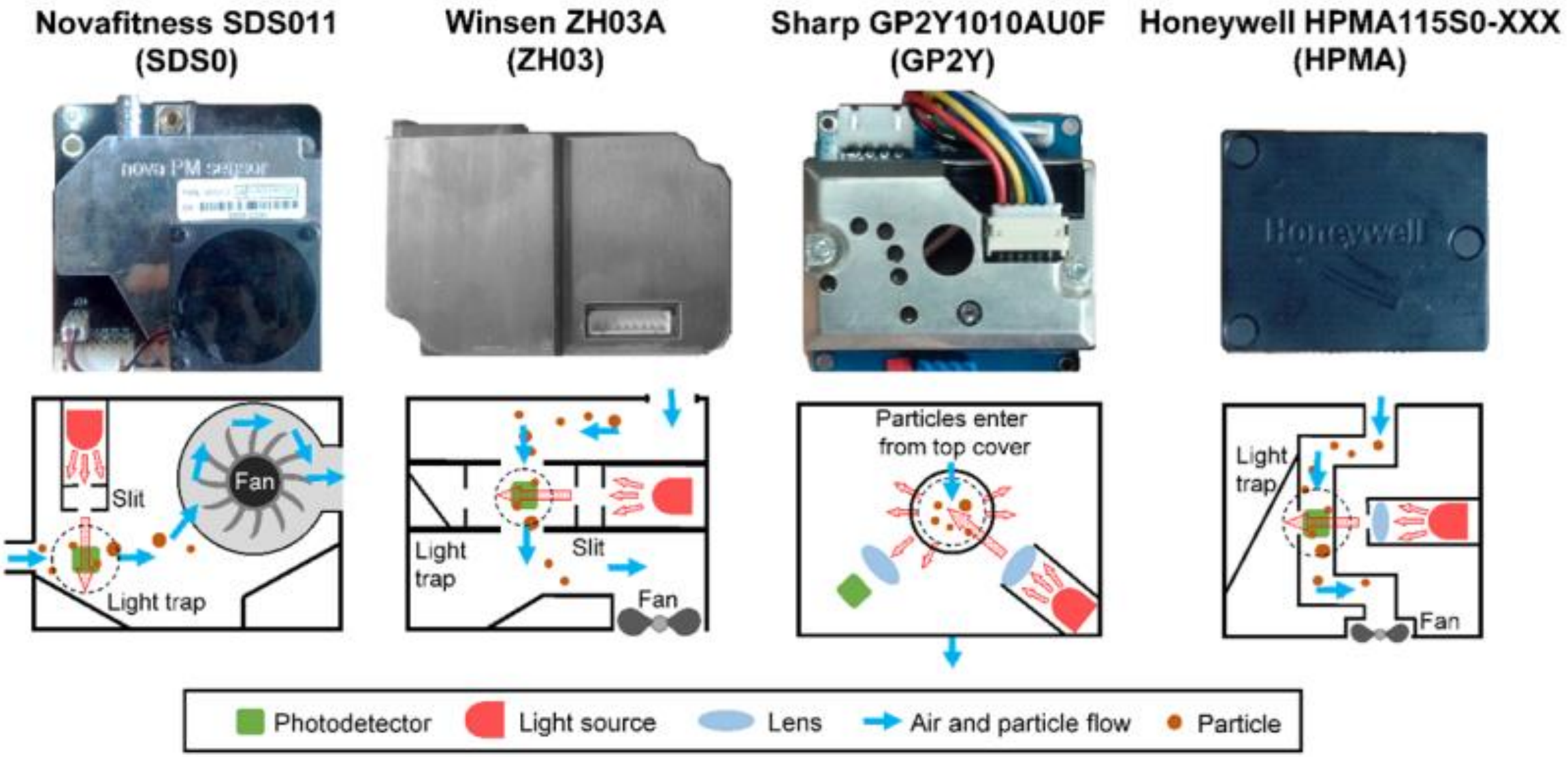


Mukherjee et al., 2017

Collocation experiments

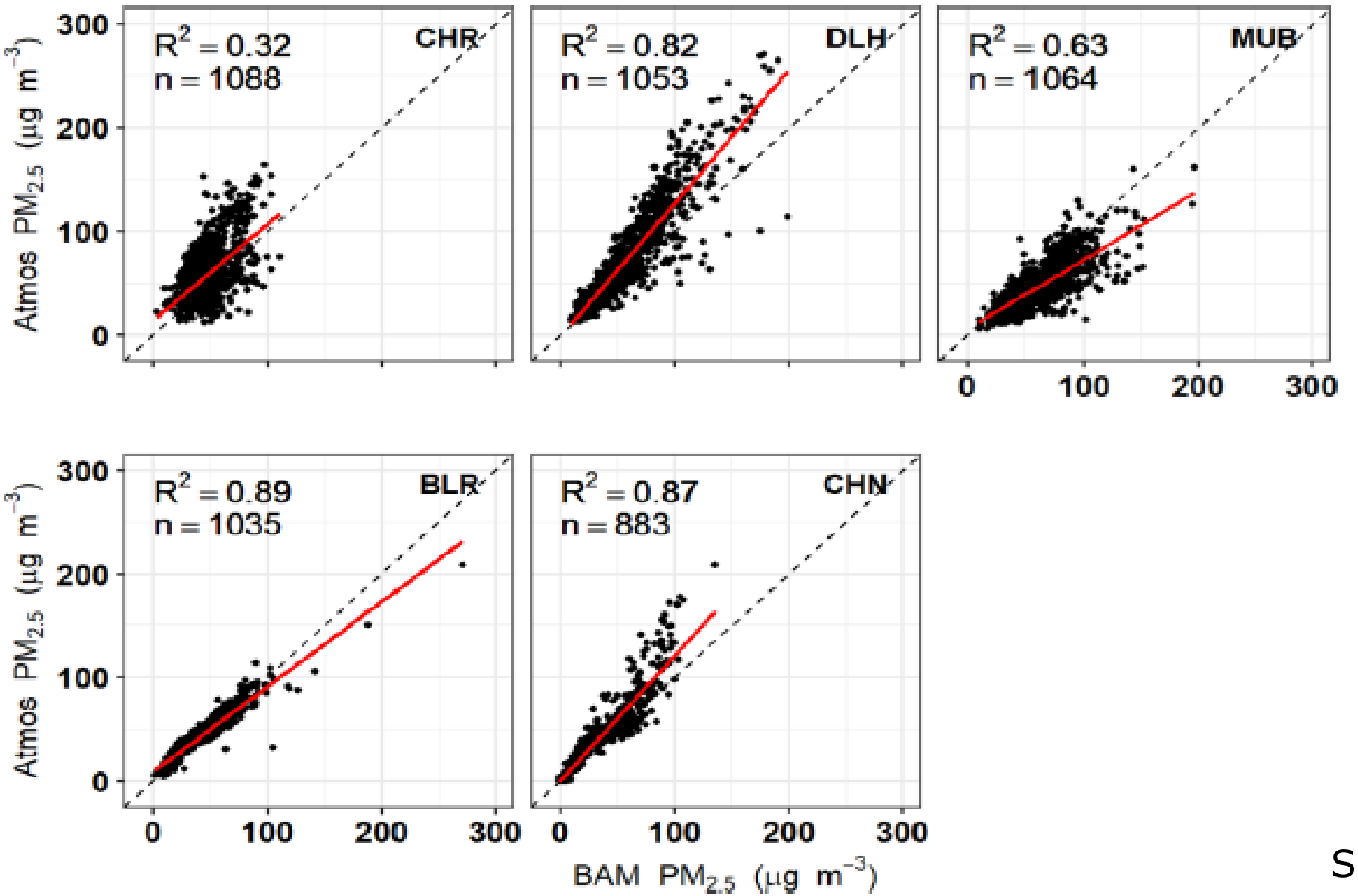
Different PM sensors



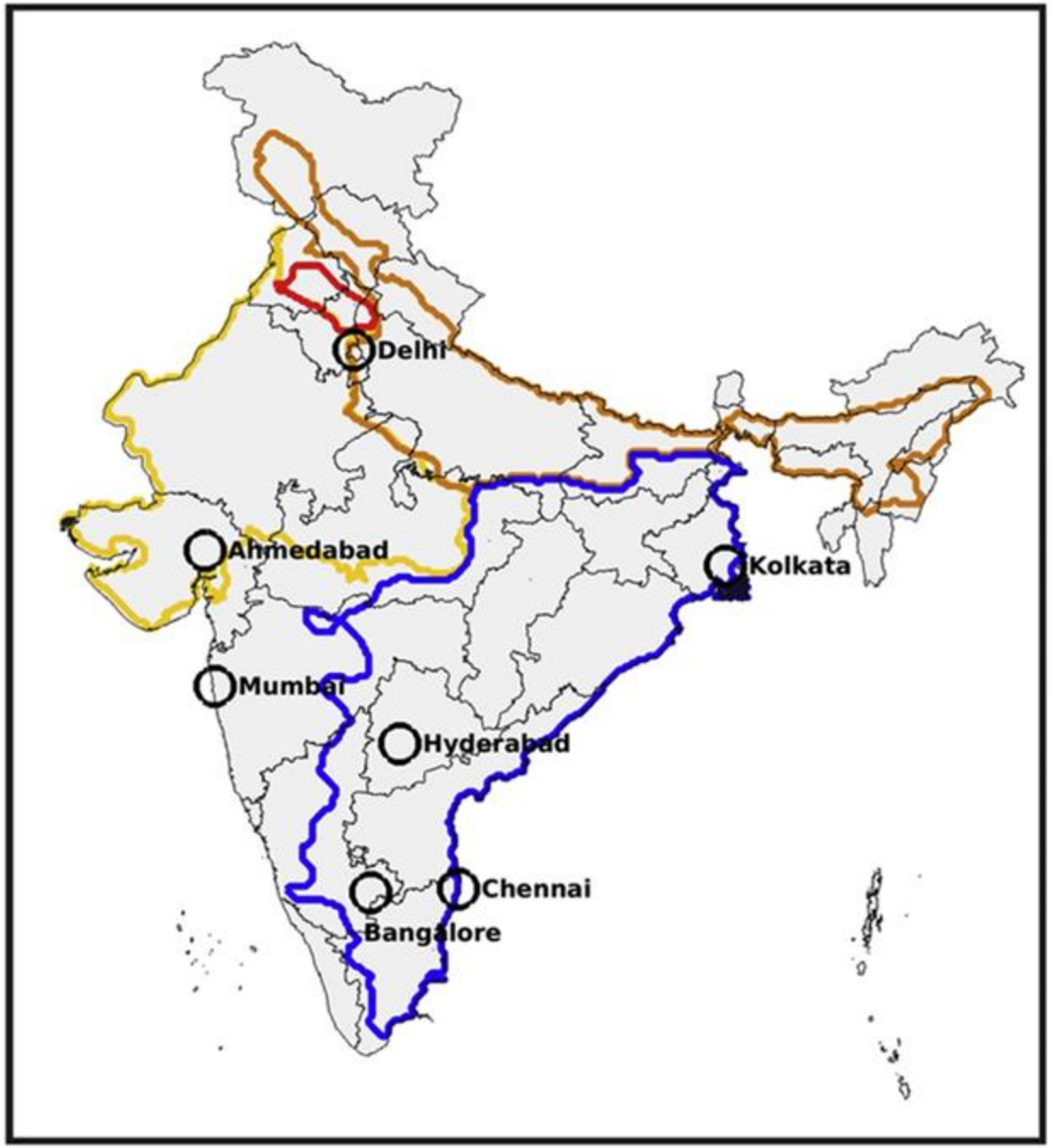


Hapidin et al., 2019

Different cities



Sreekanth et al., 2022

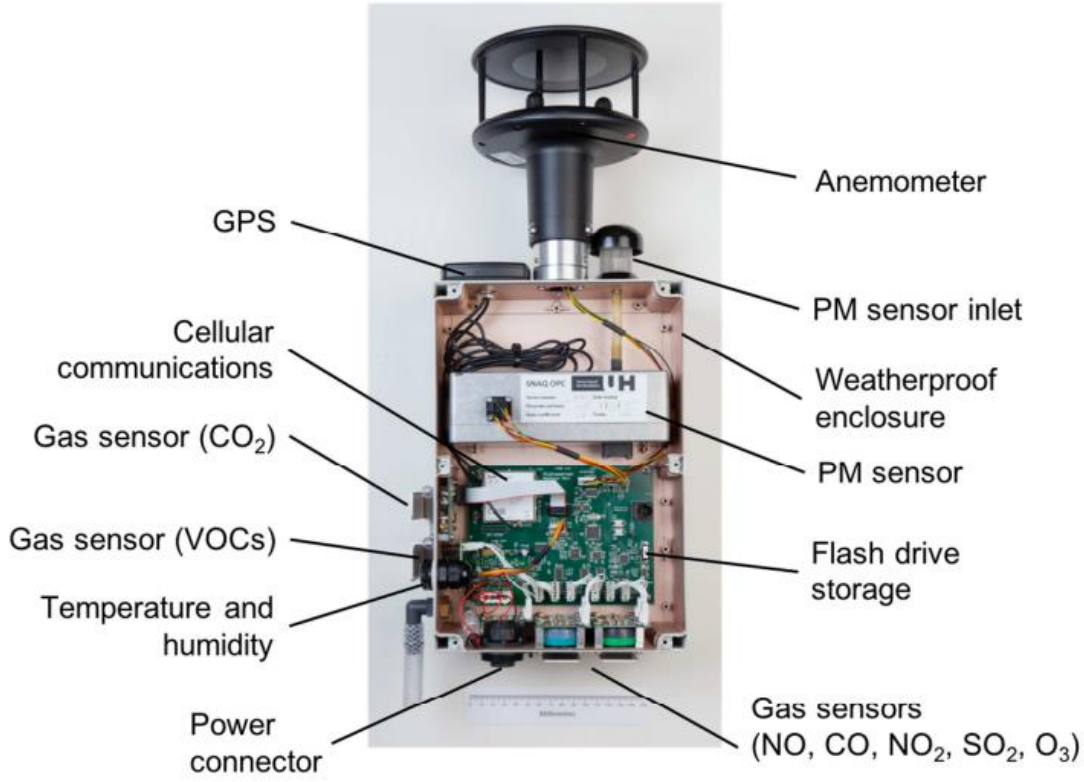


Dust
Coal
Residential Biomass
Open Fires

www.iitk.ac.in/atman/airshed.php

Components of an LCS module

- Sensing elements
- Environmental sensors
- Signal conditioning
- Microcontroller / processor
- Power supply system
- Data storage
- Communication module
- Enclosure and housing
- Firmware and software
- Backend and visualization (system-level)



source: ccacoalition.org

Selecting the right sensor

- **Objective of the study**
  - Which pollutant?
  - Purpose of the data
- **Pollutant-specific sensor suitability**
- **Performance characteristics**
  - Accuracy
  - Limit of detection
  - Response rate
  - Linearity
- **Environmental robustness**
  - Sensitivity to temperature and RH
  - Performance during high pollution
  - Dust and heat resistance
- **Calibration and correction needs**
- **Deployment context**
  - Static vs mobile vs personal vs citizen science
- **Communication and data handling**
  - IoT module
  - Data hosting
  - Data formats
- **Cost beyond capital**
  - Calibration costs
  - Sensor replacement frequency
- **Aftersales support**

Low-cost is really ‘low-cost’?

- Less capital cost – high workforce cost
- Large data sets – storage requirements
- Need soft-skilled people
- Short shelf life of the sensors

Method	Cost	Robustness	Logistics and data processing (1 = easier)	Main strength
Reference-grade stationary	$$$	High	1	Temporal
Low-cost stationary	$	?	3	Temporal and spatial

Questions?