Low-cost Sensor Training
Global Best Practices and Toolkits:
The Afri-SET Experience

Presented by:
Dr Allison F. Hughes
&
Mathias A. Borketey
Afri-SET Project, University of Ghana

Various sources of Air pollution in Africa (Ghana)

Afri-SET : The Air Quality Sensor Evaluation and Training Centre for West Africa

Objectives 1

1. To establish a low-cost air sensor evaluation and training hub in Ghana-West Africa

i. Develop Standard Operating Procedures (SOPs) (vetted by AQ-SPEC, AirParif & NILU)

ii. Evaluate 10 sensor types in each year

iii. Build a website to host reports, calibration protocols and other materials in both English and French. (www.afri-set.org)

Afri-SET facility

November 2022

February 2025

February 2026

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Objectives 2

2. To facilitate capacity building of students and air quality practitioners in Africa

Workshop at Carnegie Mellon University (Kigali, Rwanda) March 2023

5-day Workshop at University of Ghana, (Accra, Ghana) January 2024

5-day Workshop at University of Ghana , (Accra, Ghana) January 2025

- All seminar/workshop materials are available for free on our website and YouTube channel

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Objectives 3

3. To promote long-term sustainability and replication of the center

i. Explore funding, partnership, and other opportunities to replicate the center in other regions of Africa

ii. Monetizing training services (in-person and virtual)

iii. Establishing consulting service for LCS (e.g. analyzing other users' data, deployments, etc.)
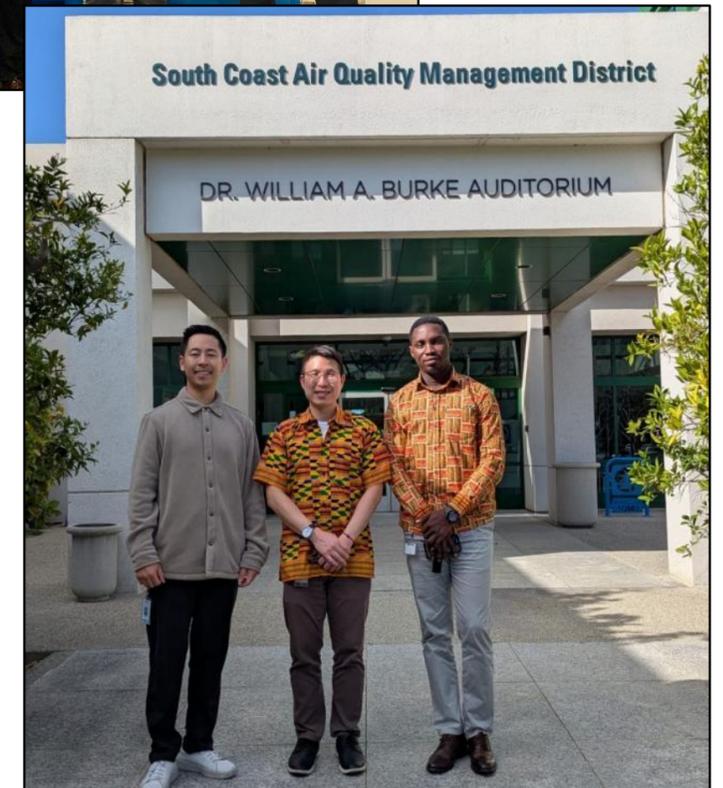
Afri-SET's Researchers visit to NILU,AQSPEC & Airparif

Sensor Evaluation and Calibration at Afri-SET

Reference Monitors
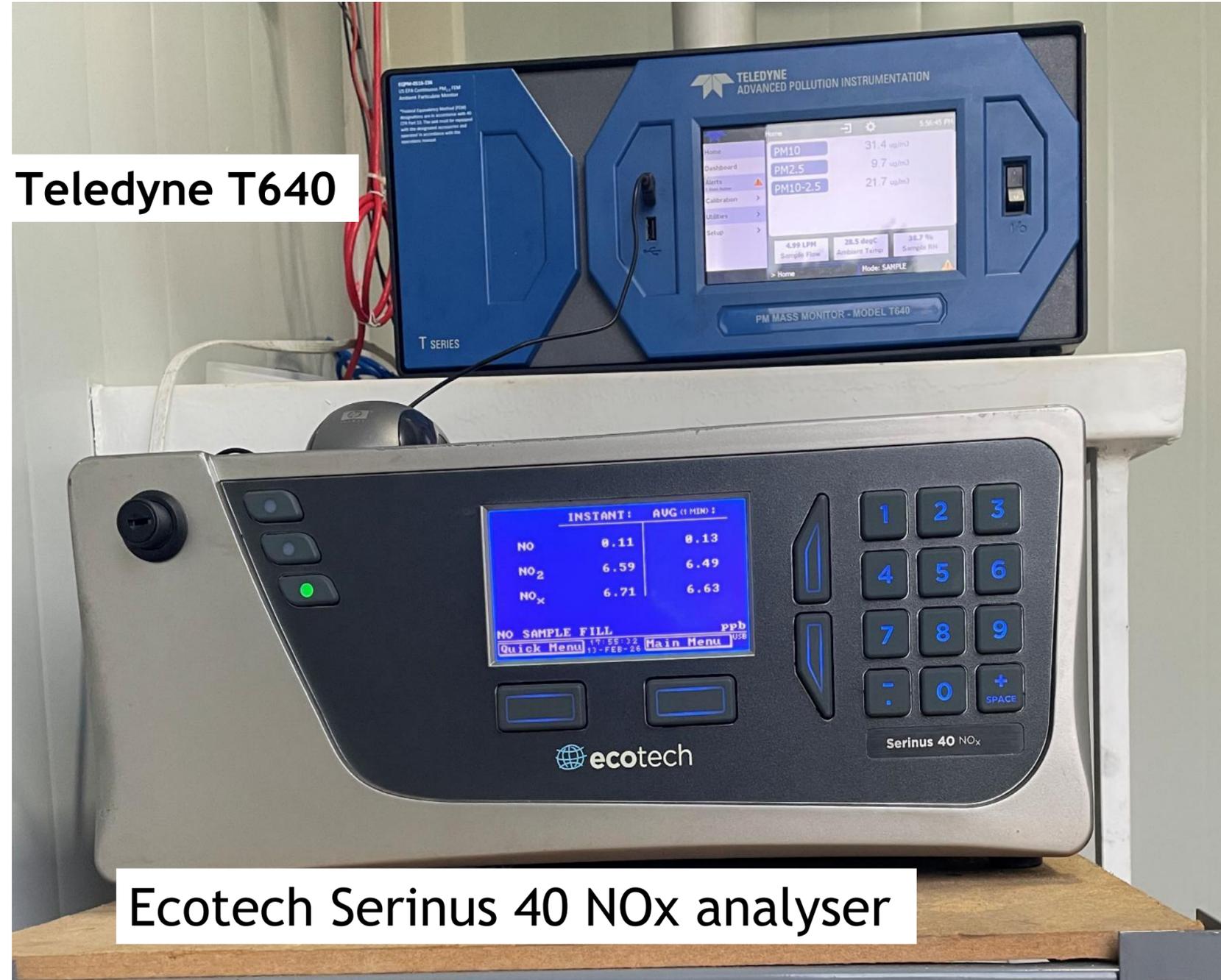
Teledyne T640

Ecotech Serinus 40 NOx analyser

2BTech Ozone monitor

40+ LCS installed at Afri-SET Facility

Airbeam3   atmotube   Airly   Purpleair   Modulair   Airgradient   Kunak   Clarity-NS

Praxis   Atmos   IQAir   AirQo   SensorAfrica   Air Quality EGG   TSI-Bluesky

Standard Operating Procedure(SOP)

❑ Number of sensors (at least 3 identical sensor units)

❑ Sensor Pre-deployment (48hr) in lab before field installation

❑ Evaluation period - 6 weeks in dry season and 6 weeks in wet season

❑ Data analysis and evaluation report

Air Sensor Installation Considerations

1. Out-of-the-Box Components

2. Sensor set-up procedure

3. Sensor Registration & Data Integration

4. Pre-deployment checks

5. Sensor deployments

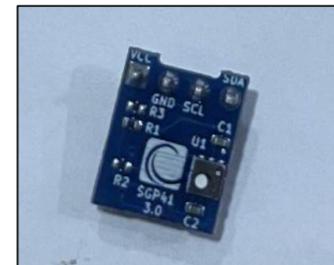6. Post deployment checks

Various Sensors in Air sensors Units

❑Particulate matter (PM) sensor = Plantower (PMS5003T)/Alphasense OPC

❑TVOCs/NOx sensor = Sensirion (metal oxide sensors)/Alphasense

❑CO_2 sensor = SenseAir S8 Non-Dispersive Infrared Radiation (NDIR) CO_2 sensor

❑Temperature/Relative Humidity = ENS210 sensor integrated in the PMS5003T
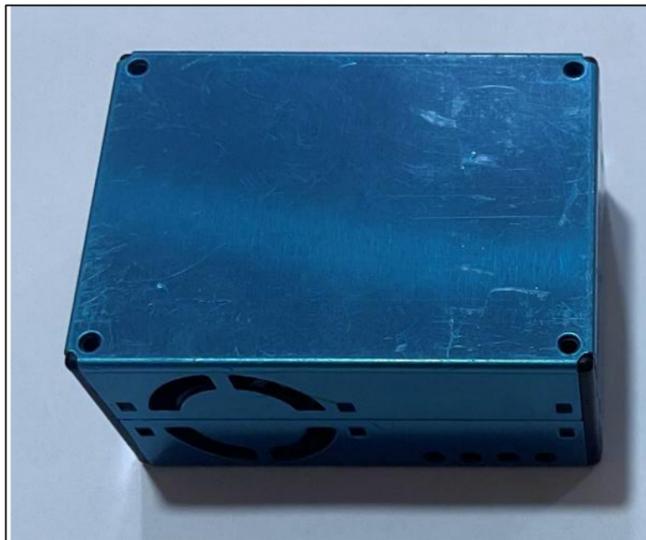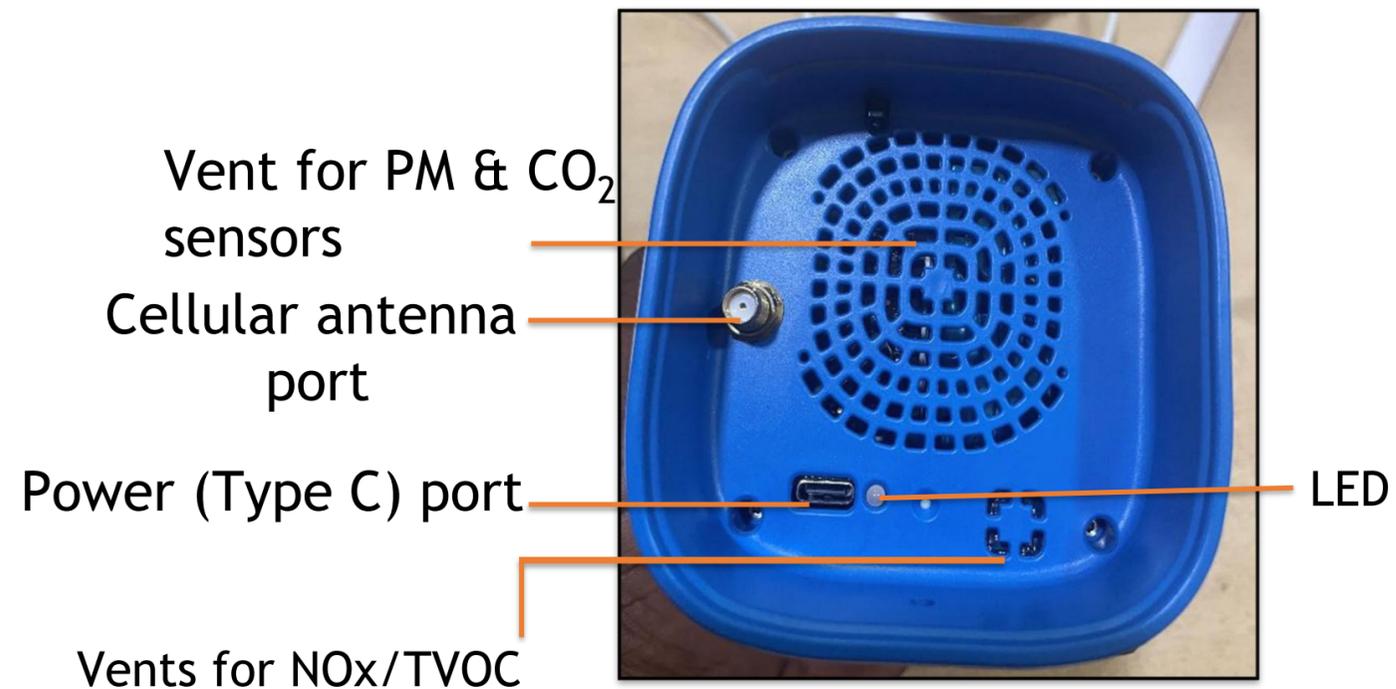
PMS5003T
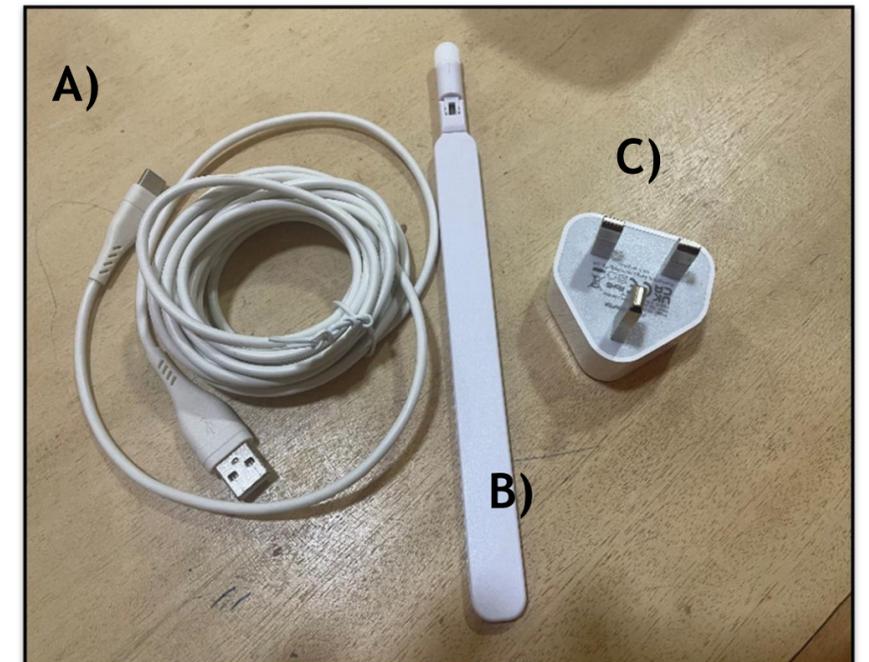
Alphasense OPC

Sensirion (SGP41)

SenseAir S8 NDIR CO_2

1. Hardware Parts List: Out-of-the-Box Components

Open Air Sensor

Vent for PM & CO_2 sensors

Cellular antenna port

Power (Type C) port

Vents for NOx/TVOC

LED

Sensor base

A)

C)

B)

Sensor Accessories
A. 4m USB C to USB A cable
B. Sensor antenna
C. 3-pin plug

2. Pre-Deployment checks

This is usually done in the laboratory 24 hrs to 48 hrs before deployment

a) Ensure sensors are completely assembled

b) Ensure sensors is powered on

c) Check for all LED and Beeps expected from the sensors when powered on or connected to internet.

d) Follow steps to connect sensors to internet and dashboard to check sensors activity

2. Pre-Deployment checks

a) Sensors should be visible on the dashboard

b) Ensure sensors is transmitting data

c) To check the continuity of the data transmission

Sensor active and transmitting data

Name	PM$_{2.5}$ (μg/m³)	PM$_{0.3}$ Count	PM$_1$ (μg/m³)	PM$_{10}$ (μg/m³)	CO$_2$ (ppm)	Temp. (°C)	R. Hum. (%)	TVOC (Ind40)	NO$_x$(Ind41)	Last Update	Admin
84fce606ede0_G4	2.6	380	1.7	4.1	403	27.7	85	—	—	18:53:01	⋮
84fce606f518 Offline	—	—	—	—	—	—	—	—	—	Apr 16, 17:00	⋮
84fce606f568 Offline	—	—	—	—	—	—	—	—	—	Apr 16, 18:10	⋮
84fce606f600_G3	5	444	1.5	5	406	27.5	88	—	—	18:50:11	⋮
84fce6070570 Offline	—	—	—	—	—	—	—	—	—	May 23, 17:23	⋮

Sensor not active and not transmitting data

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3. Sensor deployment

❑Avoid enclosed spaces and ensure adequate airflow (at least 270° circumference)

❑Height Placement (at least 1.5 m)

❑Do not place sensors near structures/objects that can affect air flow to the sensors or block the sensor intake (against a wall, near trees or on the ground blocking inlet)

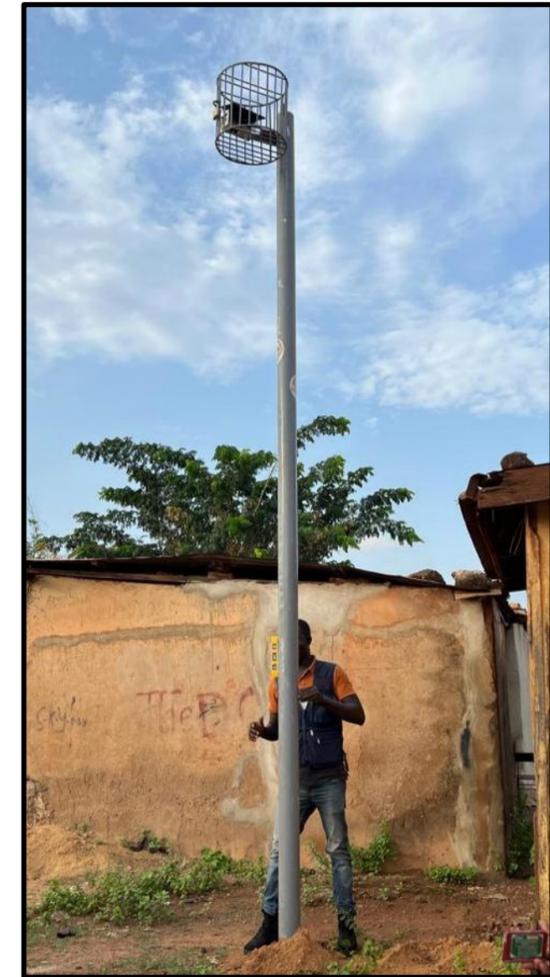❑Do not place sensors near structures that can alter T or RH near the sensor (vents, exhausts, stacks)

3. Sensor deployment

❑ Do not place sensor in locations with risk of vibration, electrical shock or other potential hazards

Additional components

❑Local sim cards (GSM)

❑>1.5 m Mounting Poles + Brackets (metallic/galvanized)

❑Zip ties/fasteners

❑USB Extension Cables

Micro SIM Card

Important Metrics in Sensor Evaluation

❑ **Coefficient of Determination (R^2)**: Metric ranging from 0 to 1. The higher the value, the stronger the relationship and vice versa

❑ **Correlation:** It shows the linear relationship between sensor data and FEM T640 data

❑ **Mean Absolute Error (MAE)**: The absolute difference between the sensors and the reference instruments. The larger MAE values, the higher measurement errors as compared to the reference instruments

❑ **Mean Bias Error (MBE):** The difference between the sensors and the reference instruments. MBE indicates the tendency of the sensors to underestimate (negative MBE values) or overestimate (positive MBE values)

❑ **Outliers** : Data points that significantly differ from other observations

❑ **Root Mean Square Error (RMSE):** A metric to calculate measurement errors and it is considered sensitive to outliers
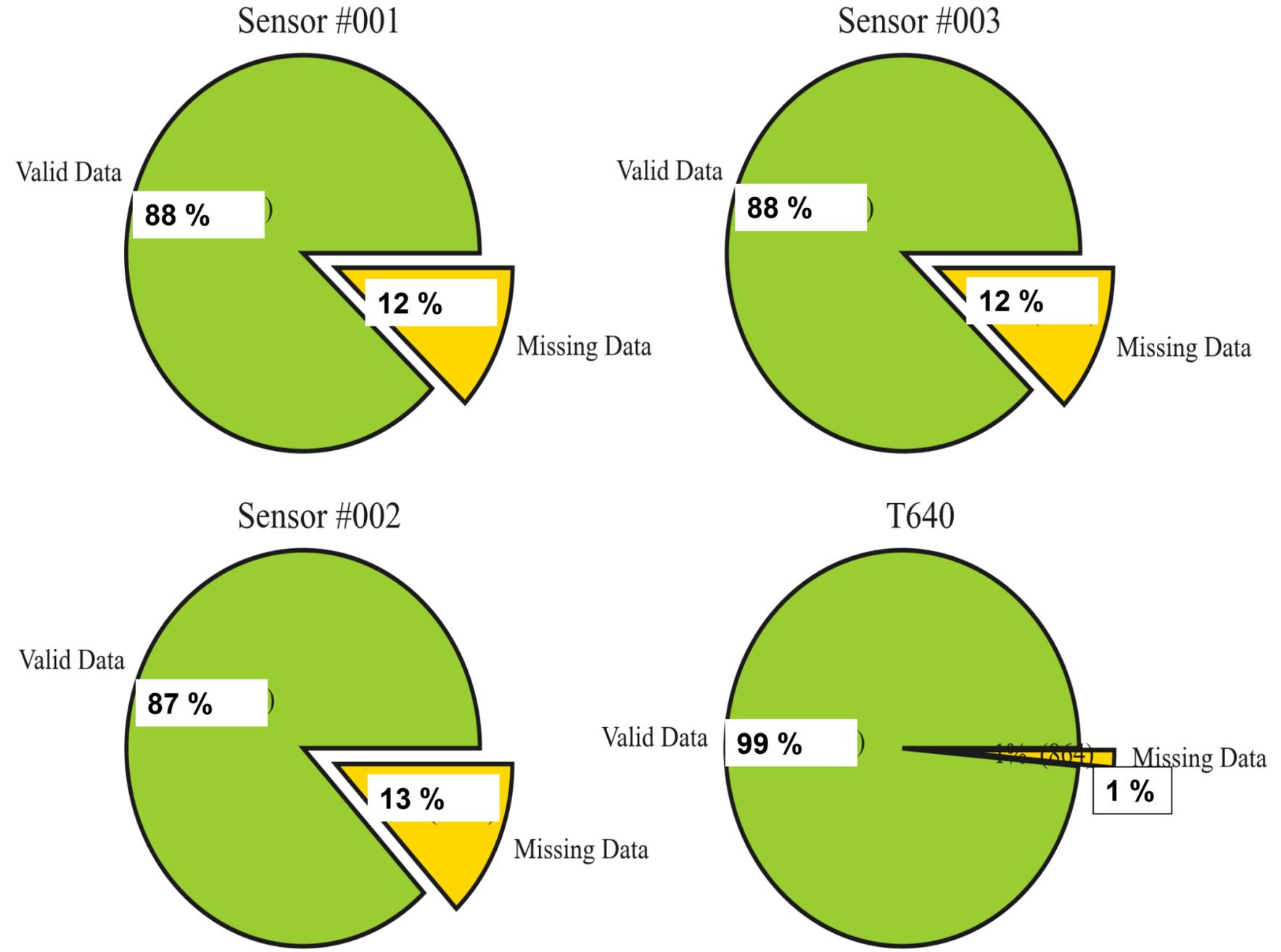
Data recovery

$$\text{Data recovery (\%)} = \frac{N_{valid\ data}}{N_{test\ period}} * 100$$

Cleansed data

six weeks – wet season

six weeks – dry season

Sensor #001
- Valid Data: 88 %
- Missing Data: 12 %

Sensor #003
- Valid Data: 88 %
- Missing Data: 12 %

Sensor #002
- Valid Data: 87 %
- Missing Data: 13 %

T640
- Valid Data: 99 %
- Missing Data: 1 %

NB: Sensor Data ≥ 75% data recovery is valid for evaluation

Sensor Performance

- Intra-unit measurement variability
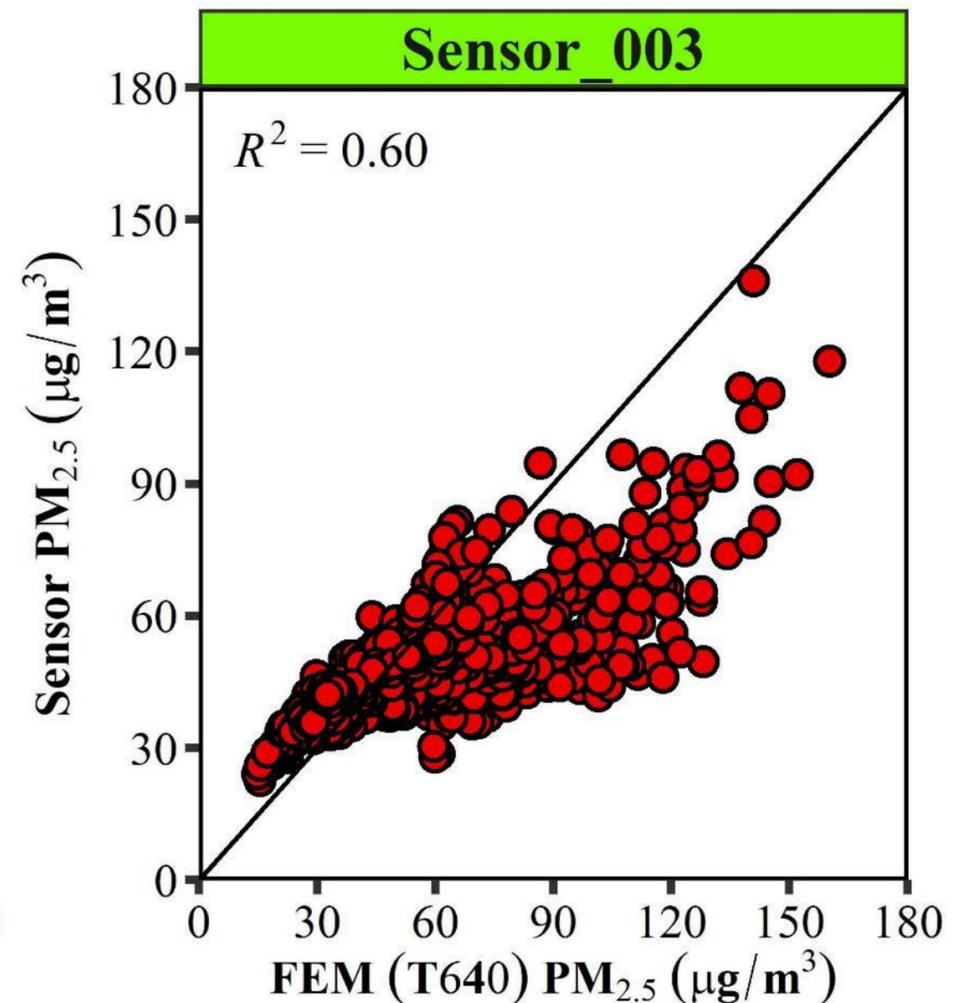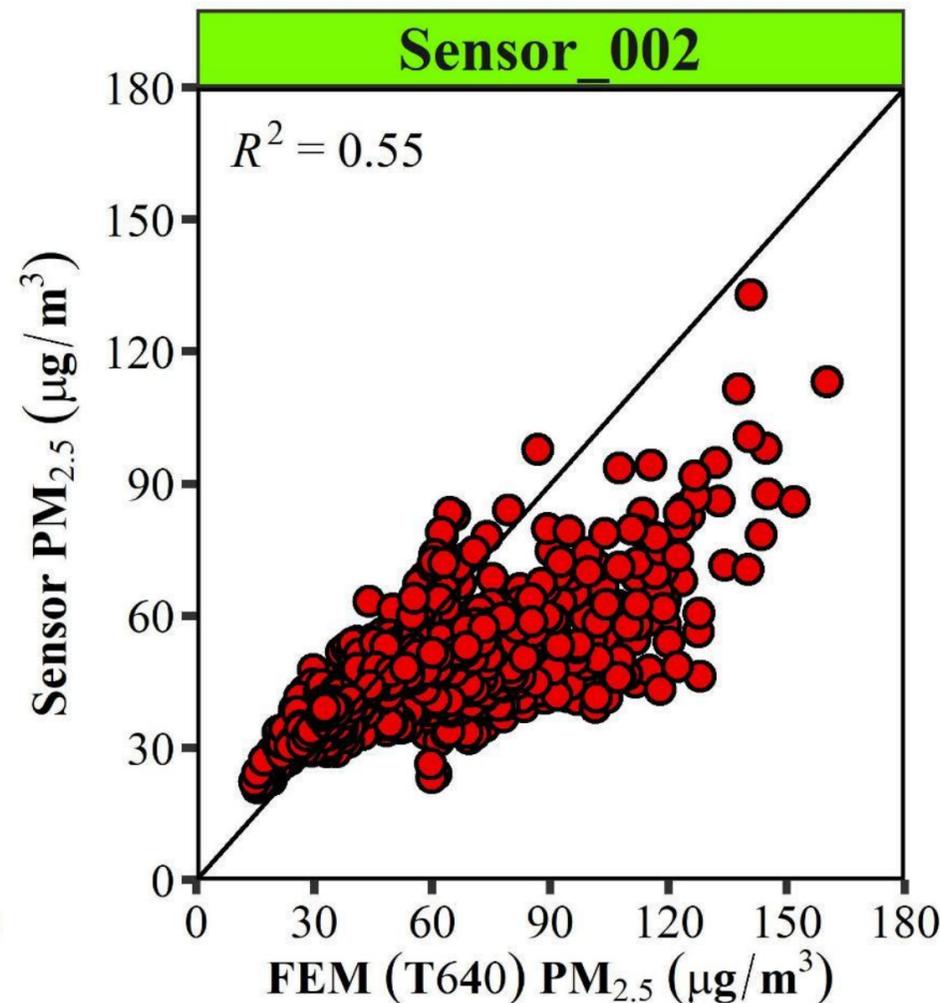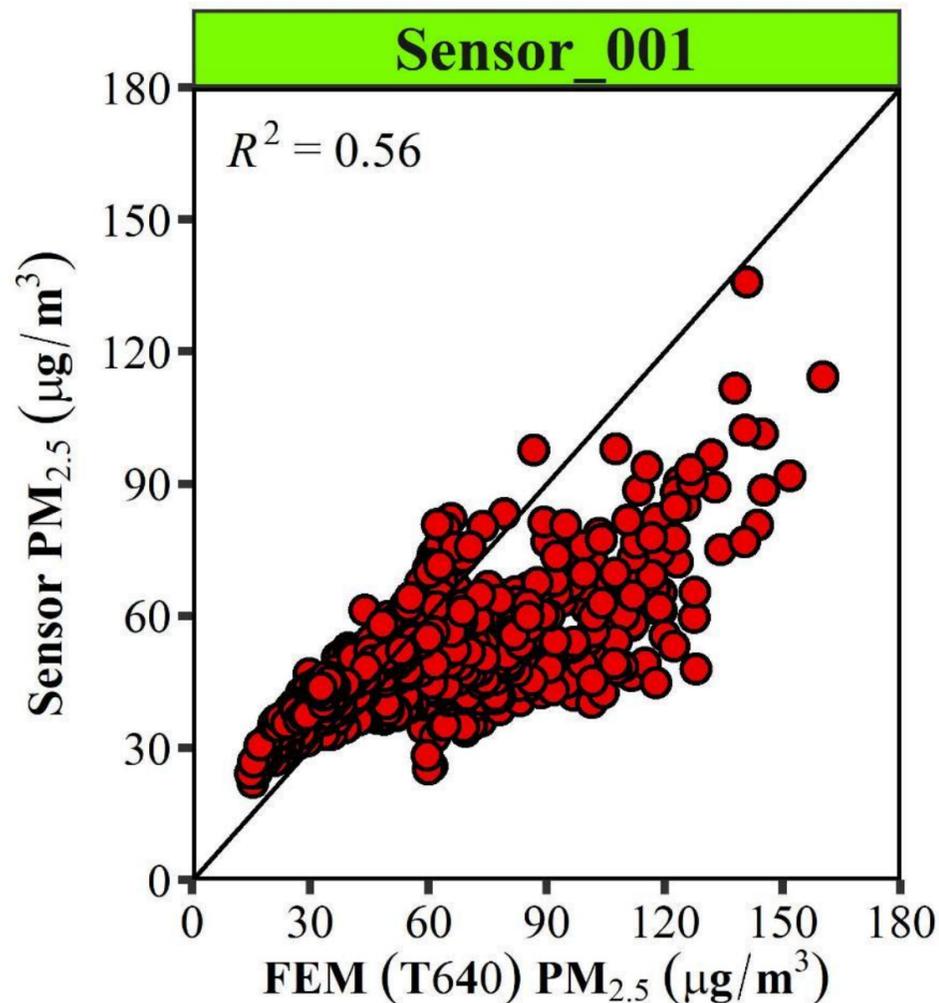- Inter-unit measurement variability in PM levels when compared to the FEM T640
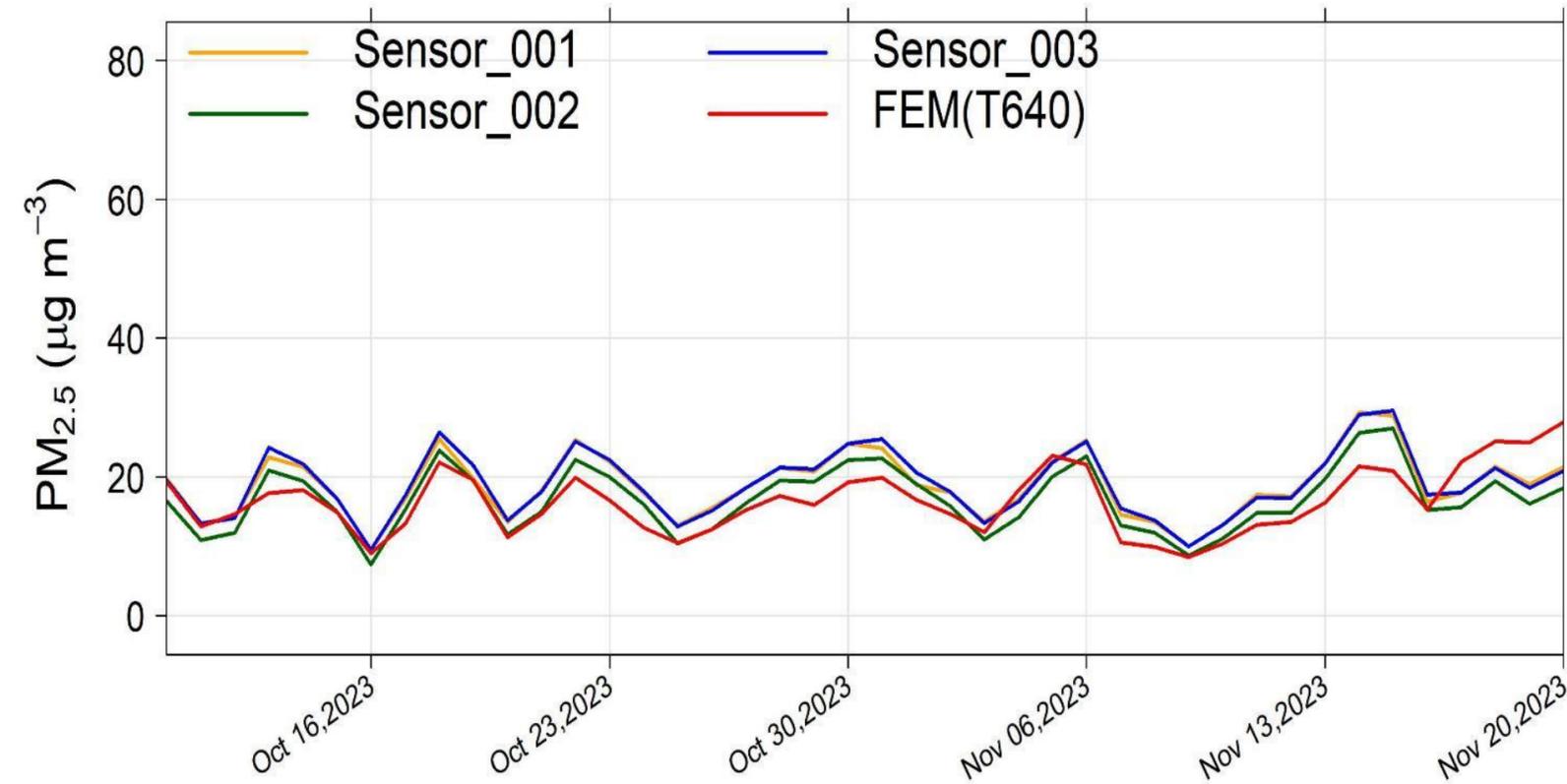

Wet Period
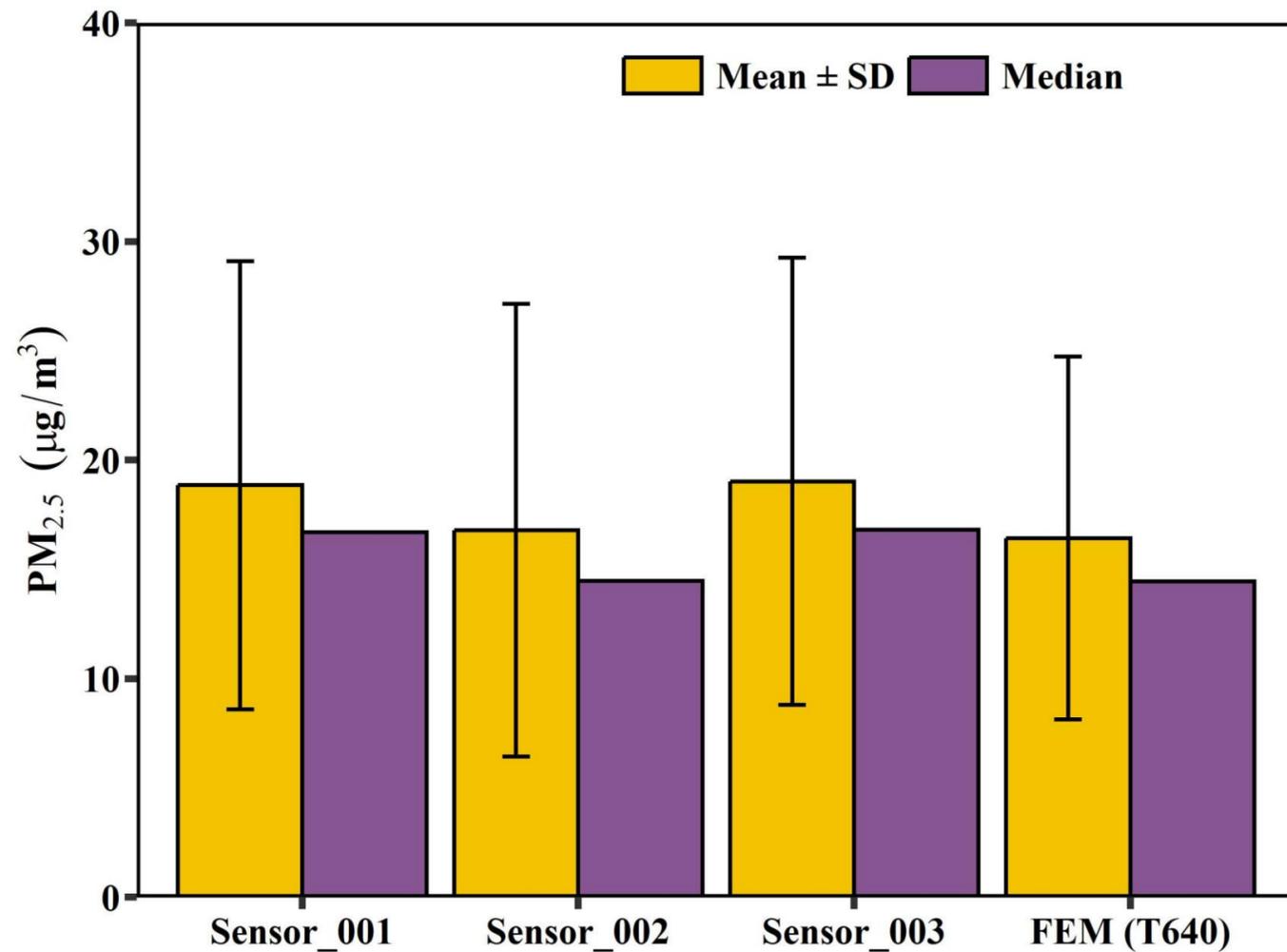
Dry Period
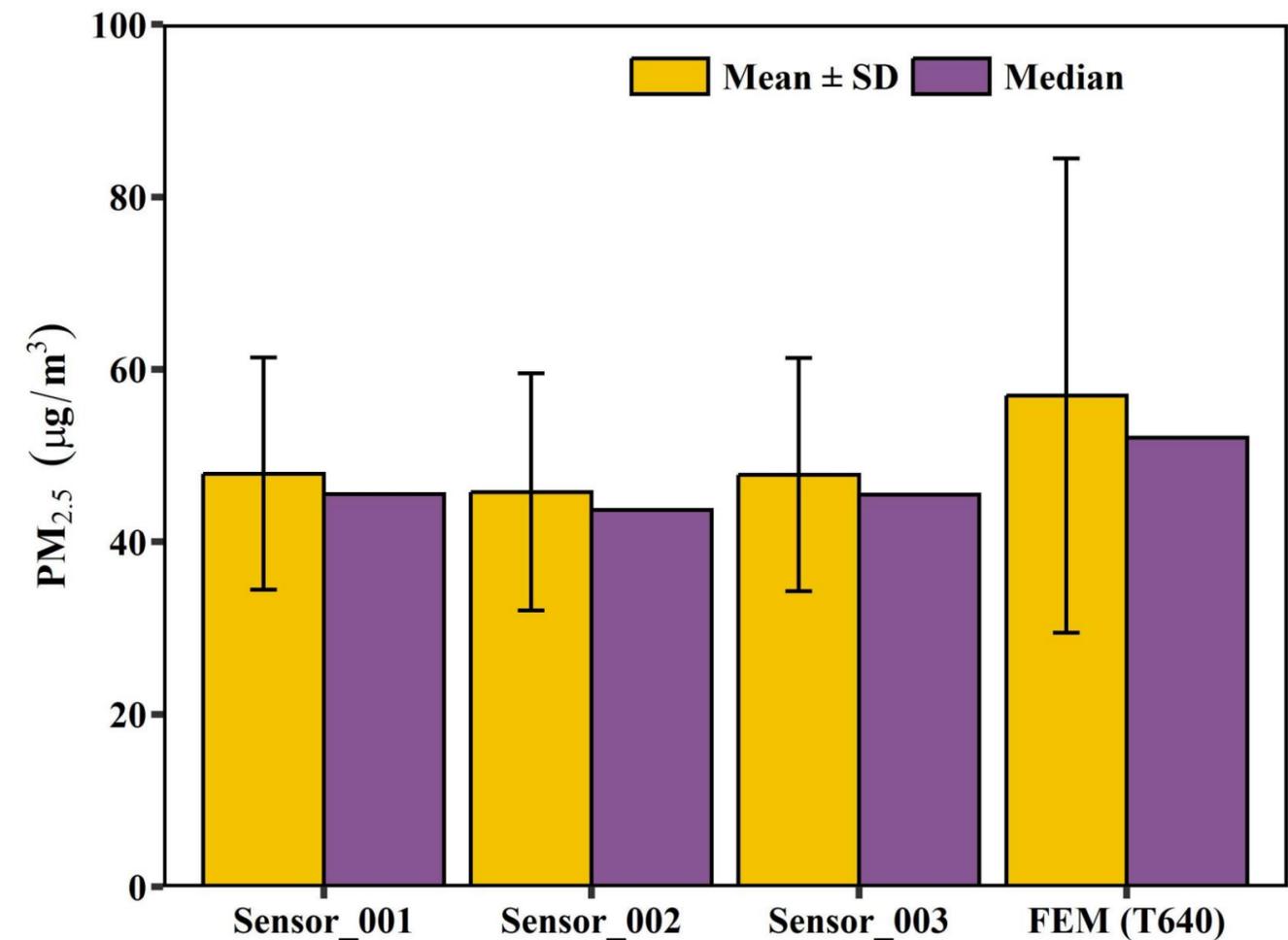
Sensor Performance

❑ Determine relationship between sensors data and FEM T640 data

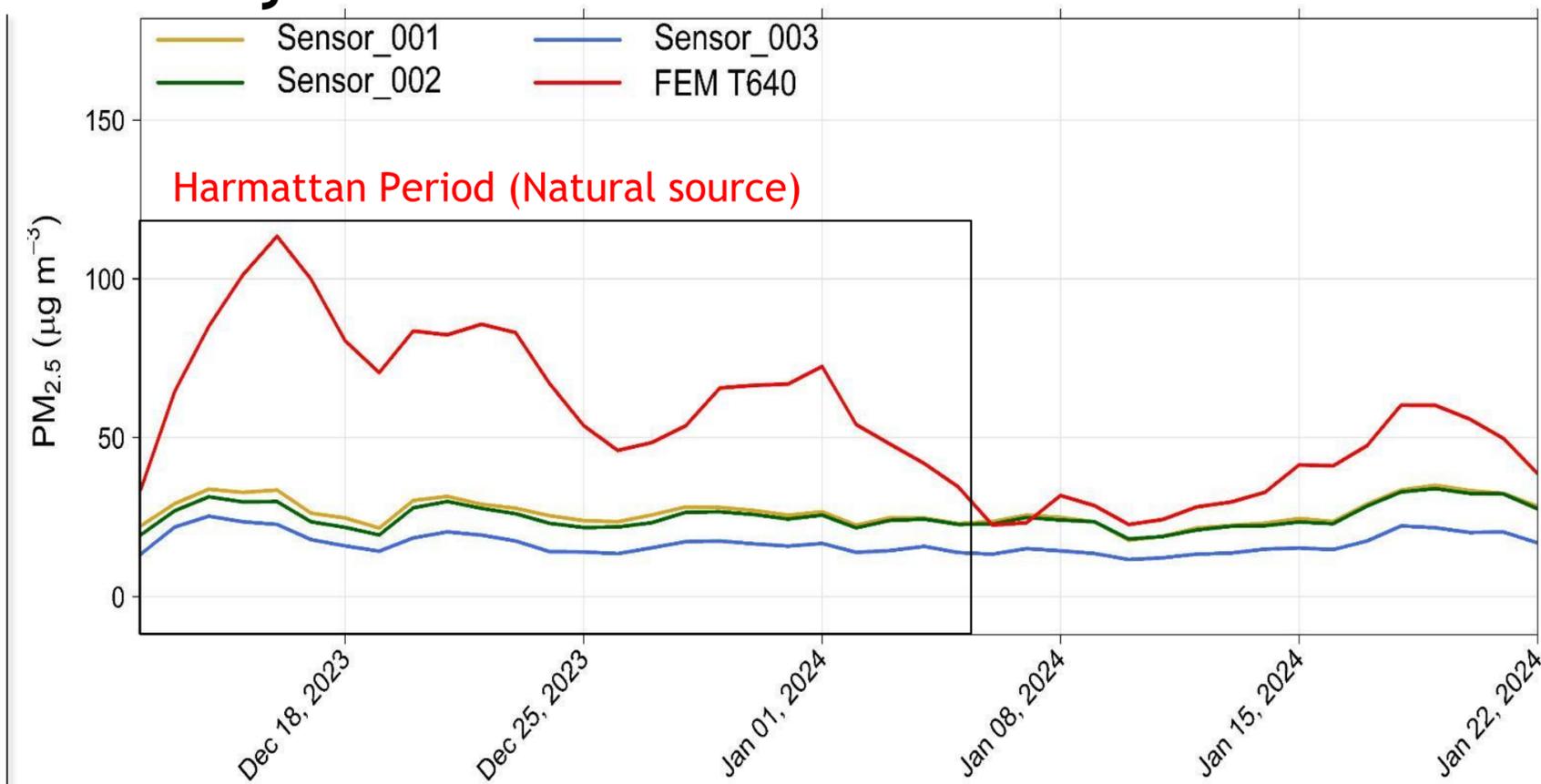❑ Calculate measurement errors from sensors to compare with FEM T640

Diurnal variation

❑ The tendency of the sensors to track the diurnal $PM_{2.5}$ variations of the FEM T640 in both periods

❑ The tendency of the sensors to underestimate or overestimate $PM_{2.5}$ concentration

Wet Period

Dry Period

Sample Summary Statistics

|	WET PERIOD (1-hour mean)				DRY PERIOD (1-hour mean)			
	R^2	MAE	MBE	RMSE	R^2	MAE	MBE	RMSE
Sensor_001	0.74	4.19	2.35	5.47	0.55	15.86	-9.00	21.22
Sensor_002	0.71	3.87	0.21	5.27	0.56	16.27	-11.16	22.24
Sensor_003	0.74	4.28	2.46	5.53	0.60	15.42	-9.16	20.79

Correction / Calibration of LCS under West Africa Meteorological Conditions

❑ Sensor readings are usually distorted by high relative humidity (RH), and seasonal dust events

❑ Without correction, data misrepresents true air quality, leading to unreliable health risk assessments and poor policy guidance.

❑ Develop correction model that incorporates LCS internal relative humidity and temperature data

❑ Statistical and machine learning models (e.g., MLR, Ridge, Random Forest, XGBoost, LGBM etc.)

Seasonal correction

☐ Our study showed notable variability between sensor readings and the FEM (top plots)

☐ Different measurement accuracy and consistency across different types of LCS (bottom plots)
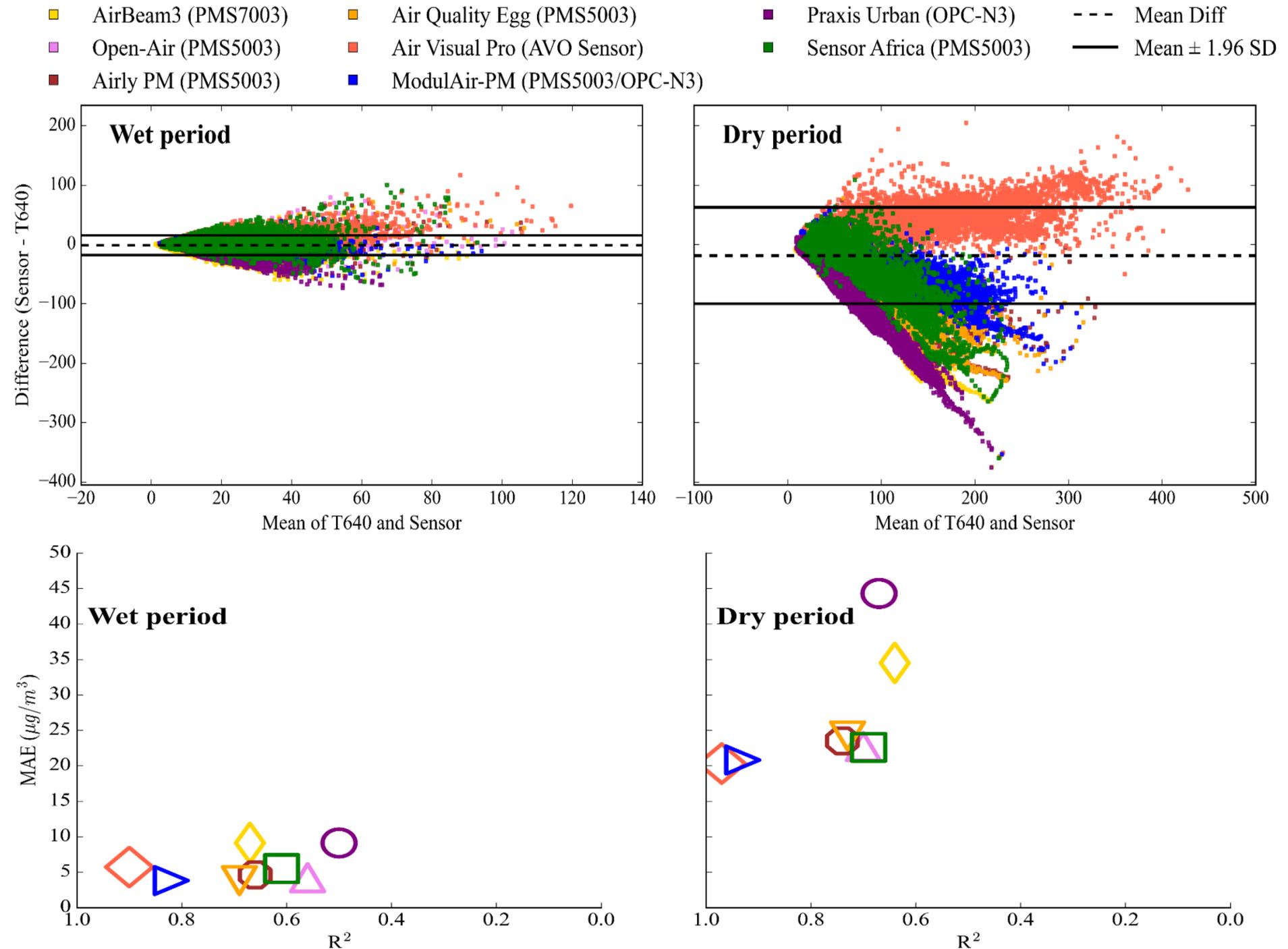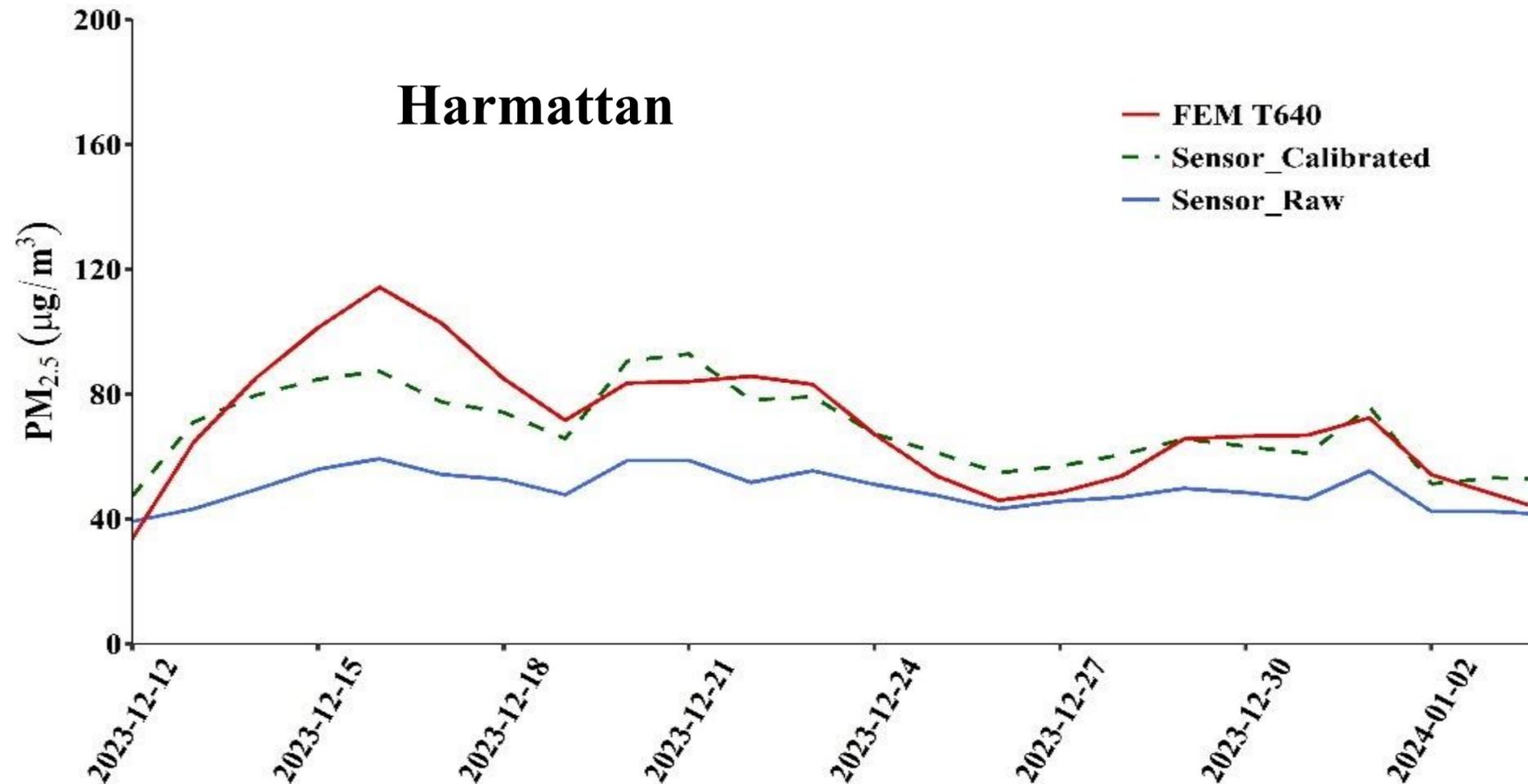

Nimo et al., (2025)

Seasonal correction

❑Three correction models

- Wet season: model data collected during the wet season
- Dry (non-Harmattan) season: Based on data collected during the dry season
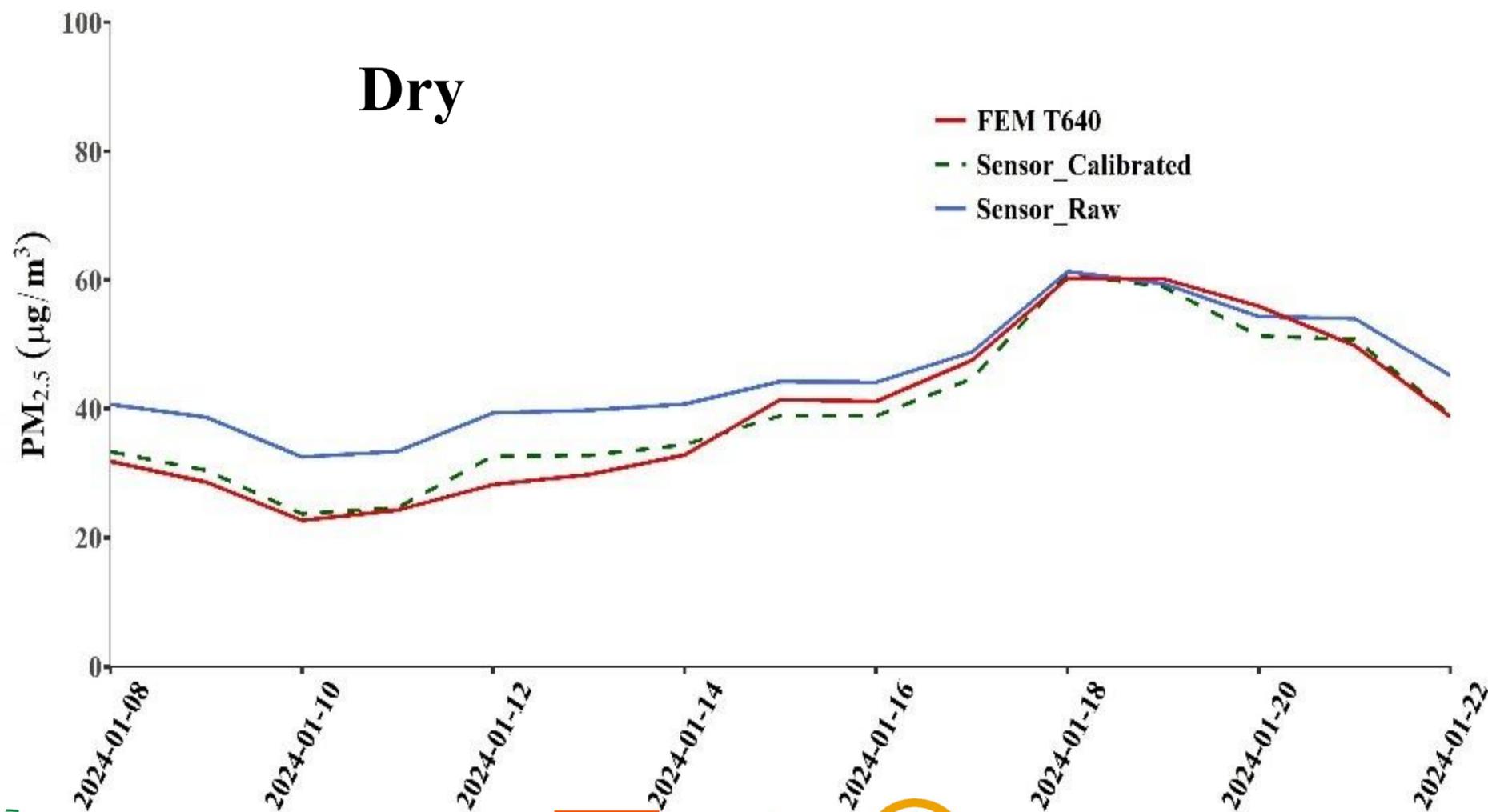- Dry (Harmattan) season: Based on data collected during the Harmattan season

	Raw	Cal
$R^2 =$	0.71	0.74
RMSE=	5.08	4.14
MAE=	3.72	2.89
nRMSE	30%	25%
MBE =	0.54	0.02

Seasonal correction

☐ Three correction models

- Wet season: model data collected during the wet season
- Dry (non-Harmattan) season: Based on data collected during the dry season
- Dry (Harmattan) season: Based on data collected during the Harmattan season

	Raw	Cal
R^2	0.80	0.92
RMSE=	8.3	4.68
MAE=	7.1	3.56
nRMSE=	20%	11%
MBE=	3.43	-0.52

Seasonal correction

❑Three correction models
- Wet season: model data collected during the wet season
- Dry (non-Harmattan) season: Based on data collected during the dry season
- Dry (Harmattan) season: Based on data collected during the Harmattan season
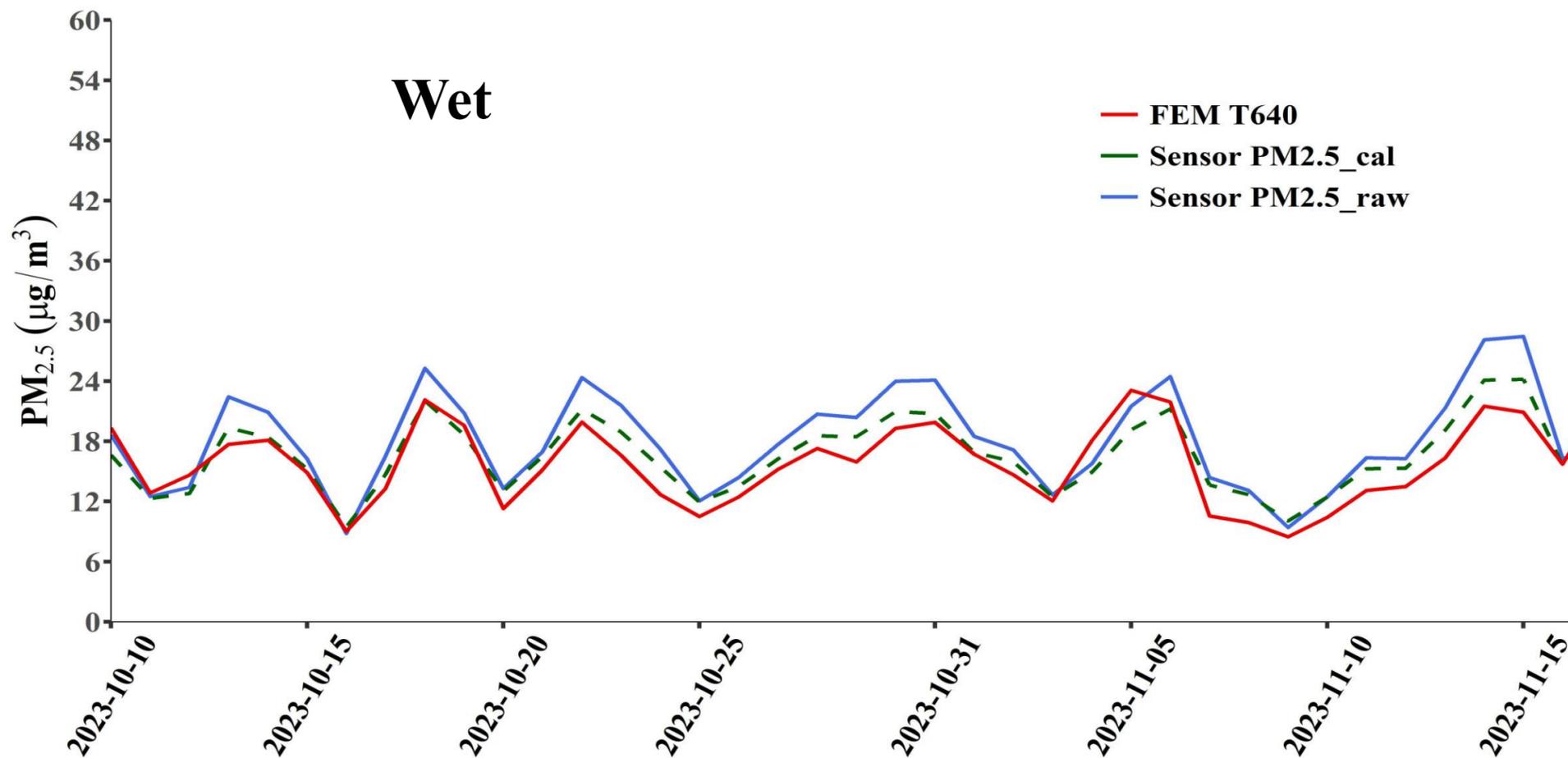
	Raw	Cal
R^2 =	0.63	0.74
RMSE=	27.5	13.7
MAE =	22.0	10.3
nRMSE=	40%	21%
MBE =	-20.7	-0.02

The Afri-SET Approach

❏ To provide correction factors for individual LCS brand evaluated at Afri-SET

❏ All models created to calibrate low-cost sensors are available for download

❏ Reports are generated after each period (wet and dry)

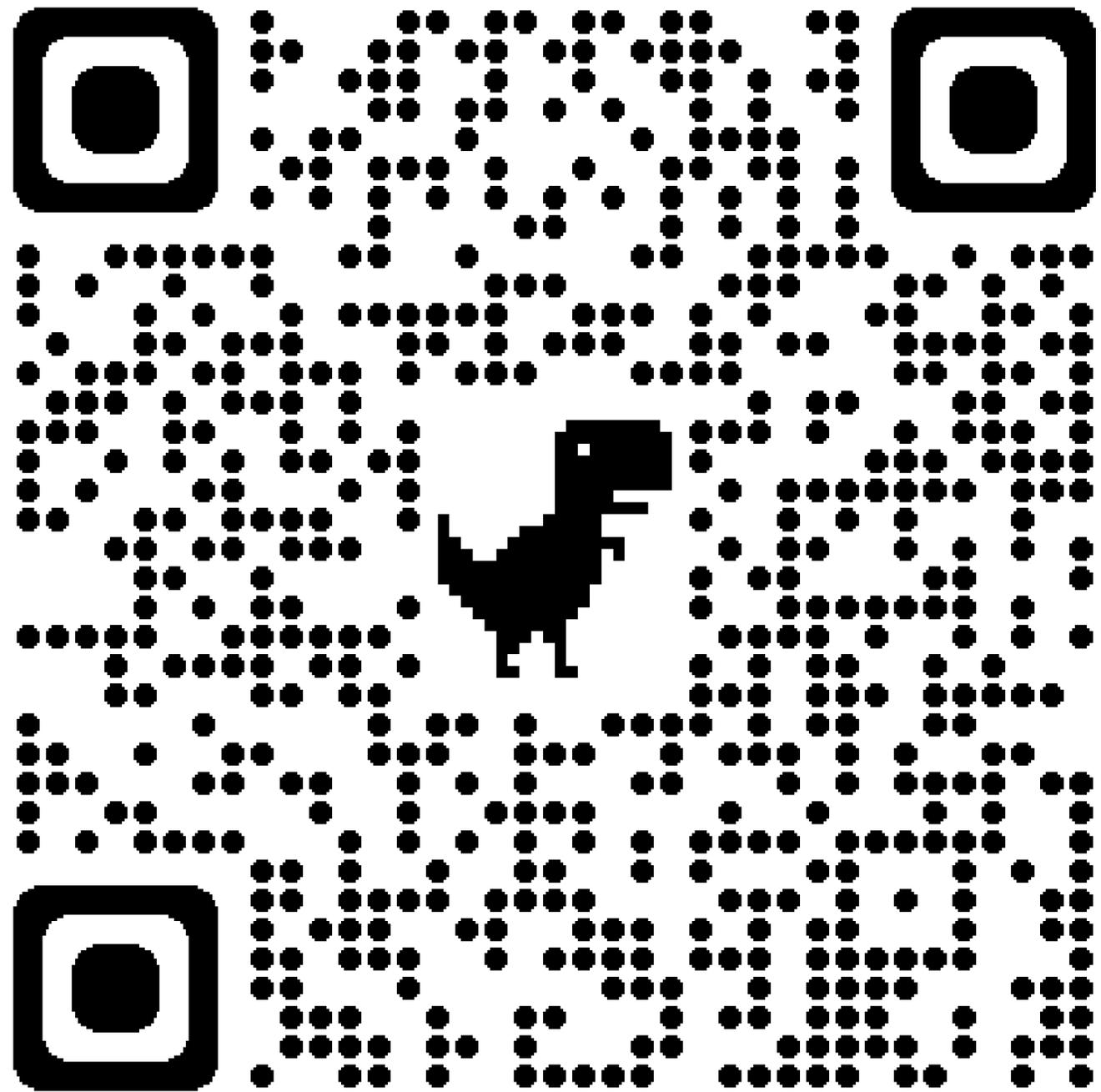❏ All reports, articles, publications and data are available at the Afri-SET website - www.afriset.org

Acknowledgement

Thank you

ahughes@ug.edu.gh

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