Low-Cost and Reference Sensor $PM_{2.5}$ Measurement Intercomparison *and* Regional Trend Assessments from Low-Cost Sensor Networks in Accra, Ghana and Lomé, Togo

Air Sensors International Conference | May 11, 2022

Session 2A: Clean Air Monitoring and Solutions Network Session

Garima Raheja (she/hers) - PhD Student

Lamont-Doherty Earth Observatory of Columbia University

garima.raheja@columbia.edu

@rahejagarima

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

LAMONT-DOHERTY EARTH OBSERVATORY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

Agenda

1. **Project Motivation and Introduction**

2. **Sensor Intercomparison**
   Comparing low-cost (Purple Air, Clarity, Modulair) vs Reference-Grade (Teledyne) instruments

3. **Accra, Ghana**
   Findings from 3 years of data from a network of 18 Clarity nodes in a city of 4.2 million residents

4. **Lomé, Togo**
   Findings from 2 years of data from a network of 5 Purple Air sensors in a city of 1.4 million residents

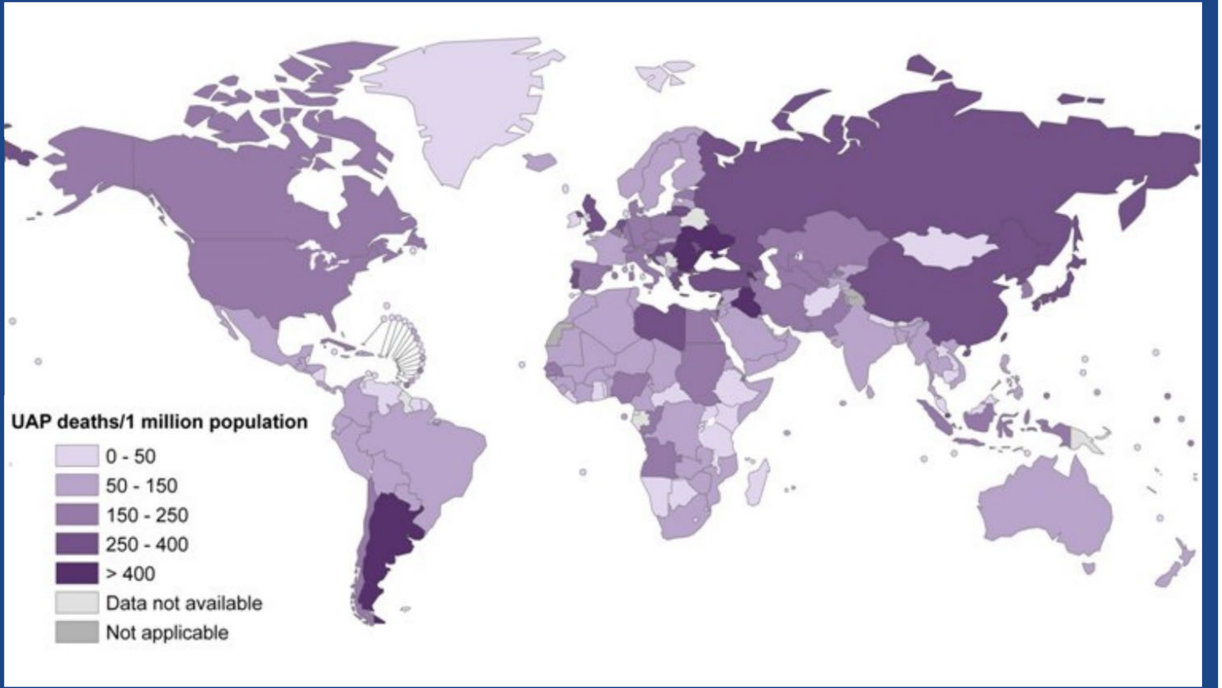
5. **Key Takeaways**

Introduction

Overburdened and Undermonitored

Countries in Africa have high air pollution levels yet remain sparsely monitored

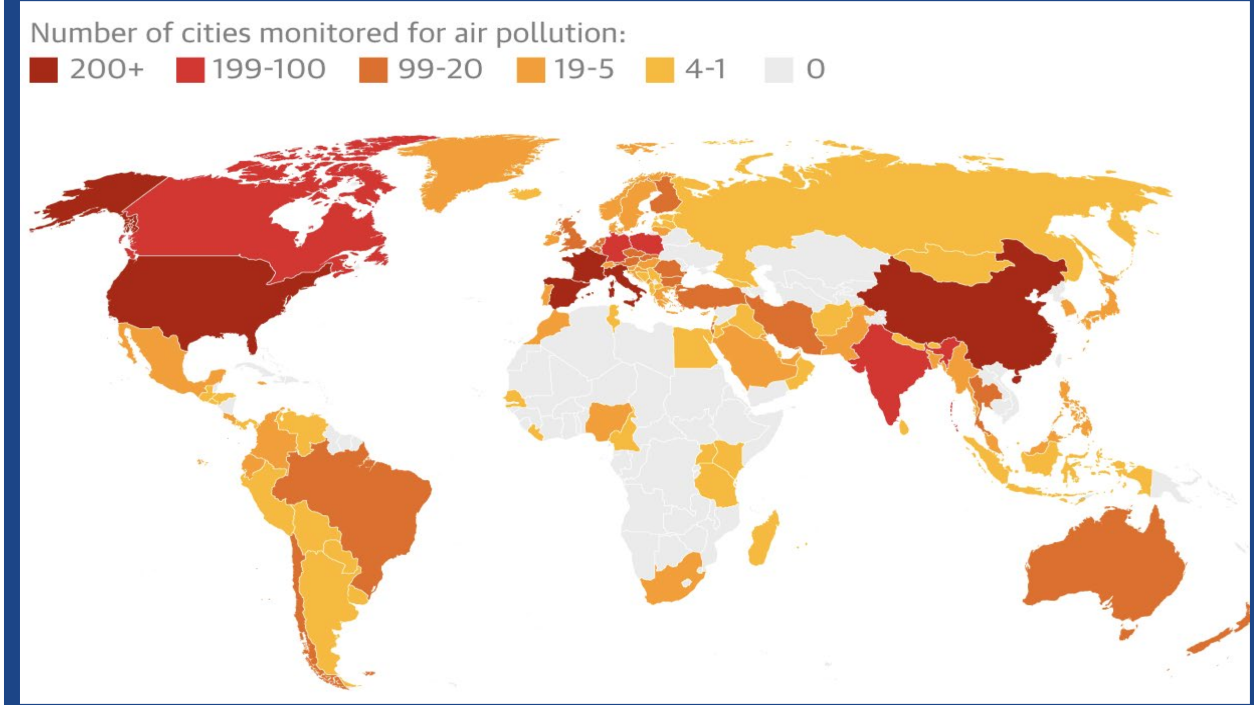
Deaths Attributable to Urban Air Pollution (2004)



Source: WHO

Overburdened and Undermonitored

Countries in Africa have high air pollution levels yet remain sparsely monitored



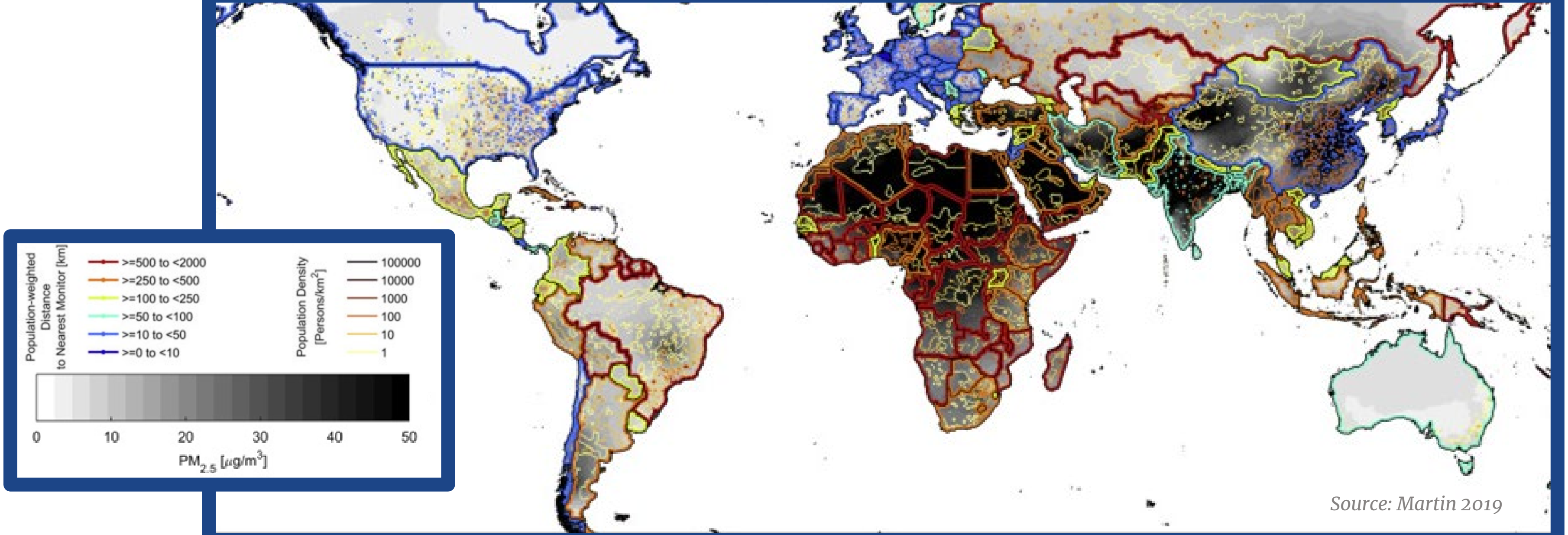
Number of Cities with Air Pollution Monitors (2016)

Source: WHO

Overburdened and Undermonitored

Countries in Africa have high air pollution levels yet remain sparsely monitored

Population-Weighted Distance to Nearest Monitor



Source: Martin 2019

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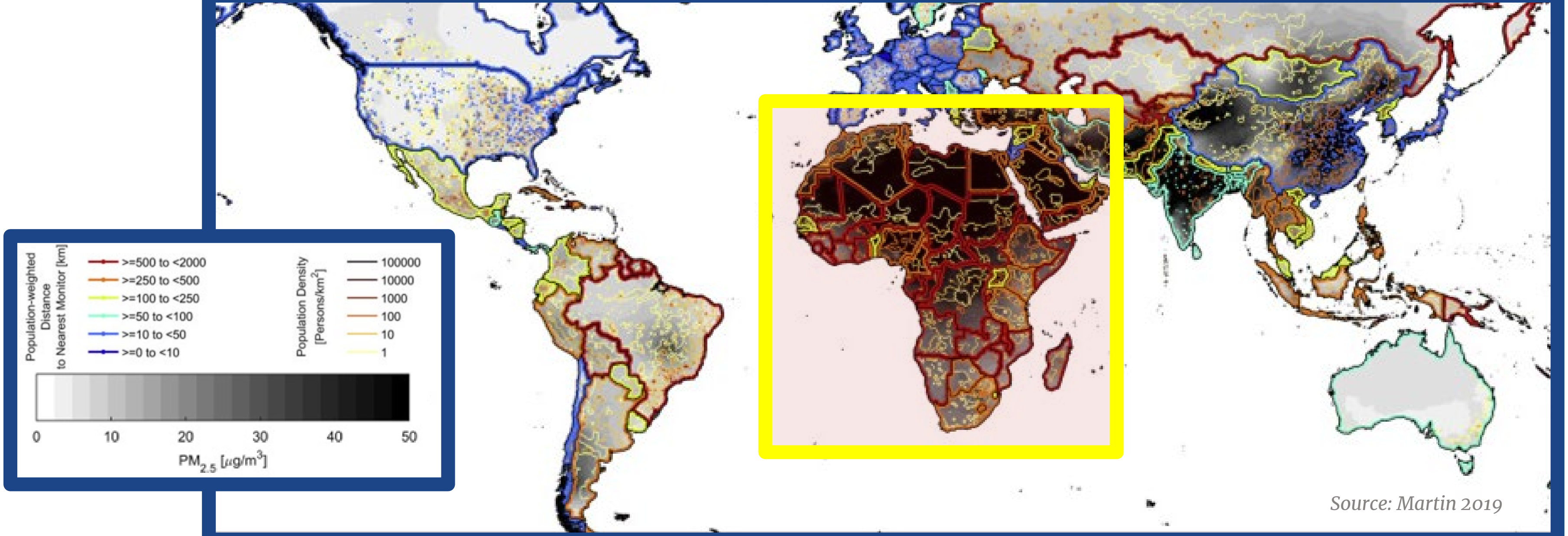
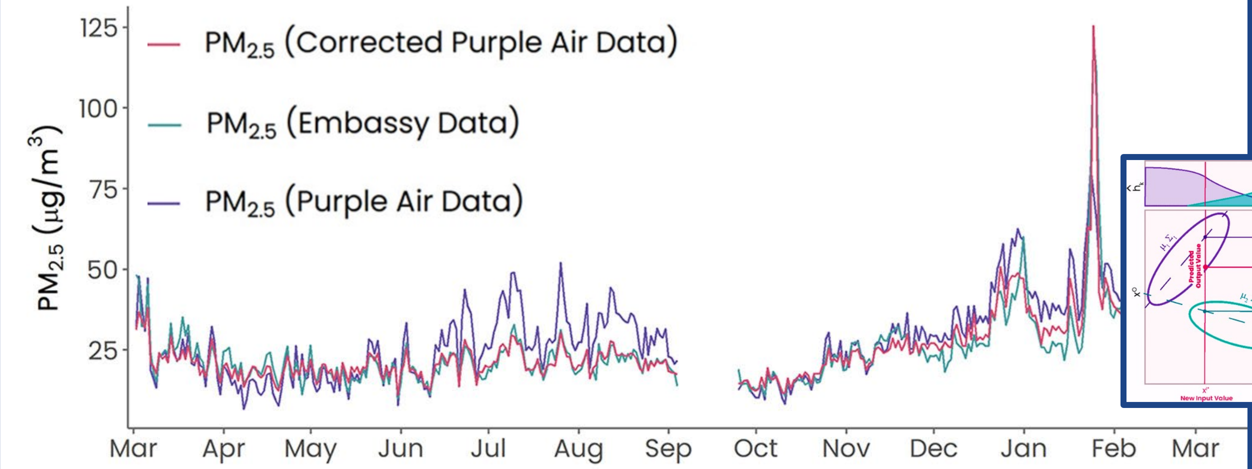


Source: Martin 2019

Low-Cost Sensors Can Bridge the Monitoring Gap

High-density networks of calibrated low-cost sensors can offer a detailed look in cities

Corrected Low-Cost Sensor *vs* Reference Monitor



Source: McFarlane 2021

ACS EARTH AND SPACE CHEMISTRY

Application of Gaussian Mixture Regression for the Correction of Low Cost $PM_{2.5}$ Monitoring Data in Accra, Ghana

Celeste McFarlane, Garima Raheja, Carl Malings, Emmanuel K. E. Appoh, Allison Felix Hughes , and Daniel M. Westervelt*

Cite this: *ACS Earth Space Chem.* 2021, 5, 9, 2268–2279

Publication Date: August 25, 2021

https://doi.org/10.1021/acsearthspacechem.1c00217

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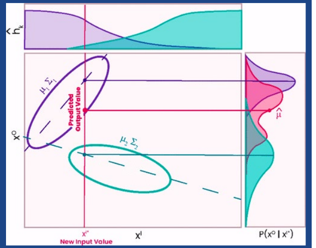
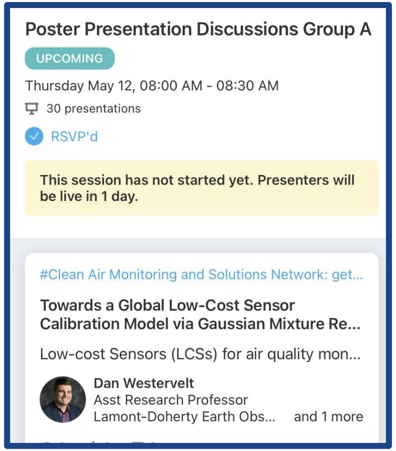




Sensor Intercomparison

Comparing 23 Devices for 2 Months

3 types of low-cost sensors were co-located with a reference monitor at the Univ of Ghana

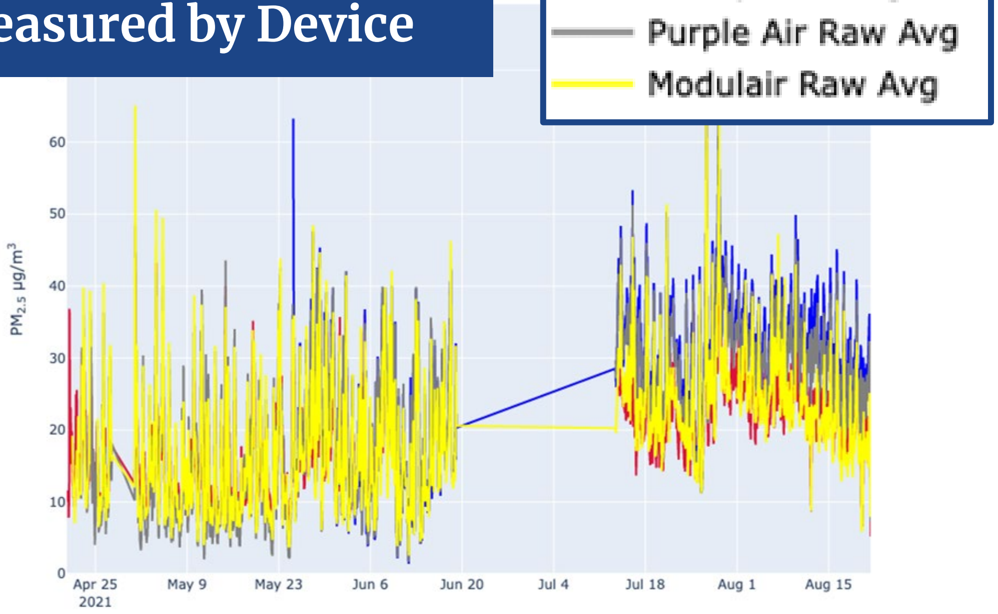
1 Teledyne

17 Clarity

2 Purple Air

2 Quant AQ Modulair

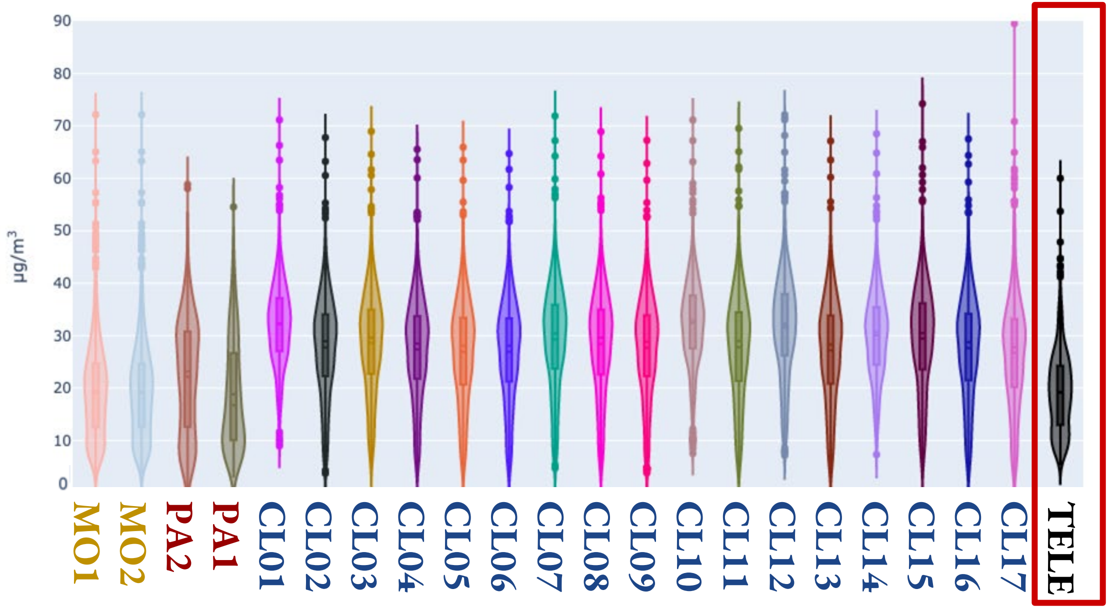
Average Raw $PM_{2.5}$ Measured by Device



Low-Cost Sensors Show Striking Accuracy

Modulair sensors show lowest mean absolute error; correlation dependent on humidity

Raw $PM_{2.5}$ - Intercomparison Period

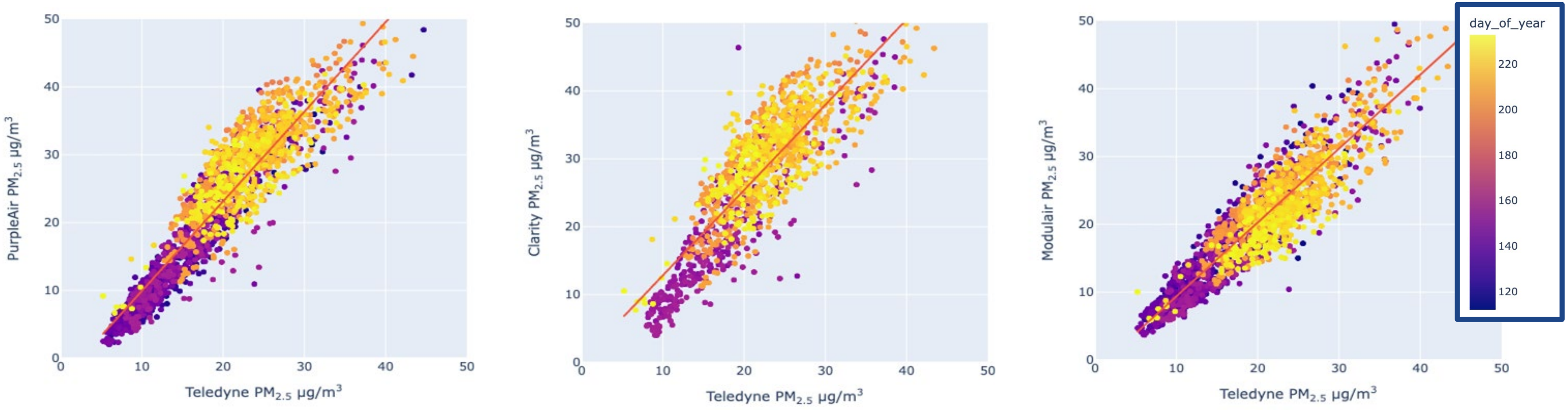


Key	
PA#c	PurpleAir
CL##	Clarity
TELE	Teledyne
MO	Modulair

Low-Cost Sensors Show Striking Accuracy

Modulair sensors show lowest mean absolute error; correlation for hourly comparison

PurpleAir	Clarity	Modulair
Y = 1.32x - 3.26	y = 1.25x + 0.27	y = 1.08x - 1.51
R^2 = 0.71 | MAE = 2.5 μg m^{-3}	R^2 = 0.64 | MAE = 2.7 μg m^{-3}	**R^2 = 0.75 | MAE = 2.3 μg m^{-3}**



Low-Cost Sensors Show Striking Accuracy

Modulair sensors show lowest mean absolute error; correlation affected by humidity

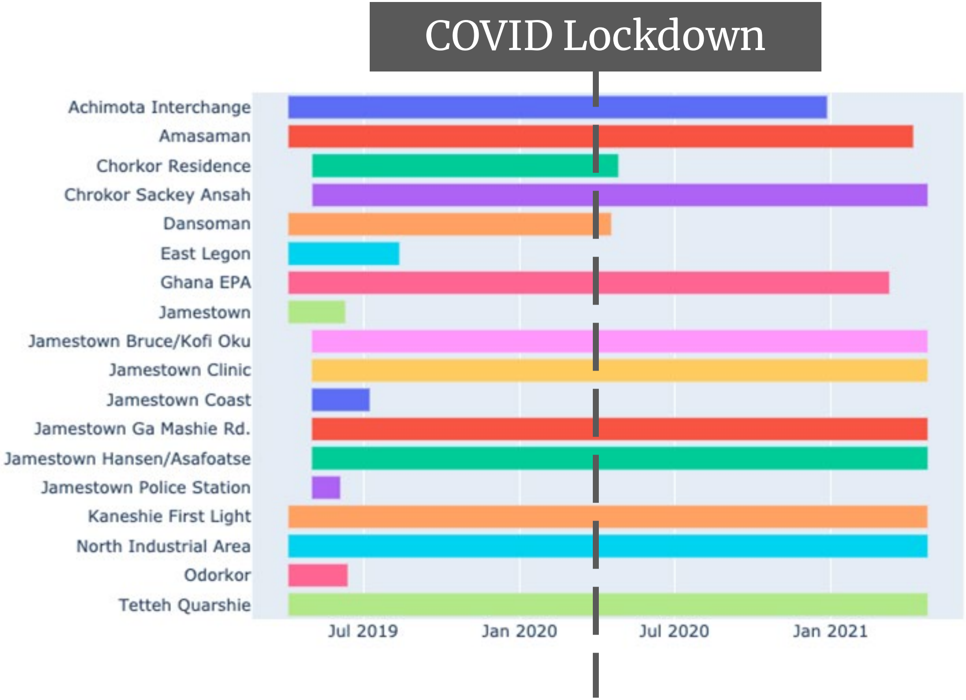
	PurpleAir		Clarity		Modulair	
Model	**R^2 (0 to 1)**	*MAE (µg/m³)*	**R^2 (0 to 1)**	*MAE (µg/m³)*	**R^2 (0 to 1)**	*MAE (µg/m³)*
Raw	**0.71**	5.95	**0.64**	7.51	**0.75**	2.87
RF	**0.68**	2.53	**0.62**	2.79	**0.70**	4.47
MLR	**0.78**	2.13	**0.79**	2.51	**0.81**	4.36
GMR	**0.78**	1.95	**0.79**	1.93	**0.78**	1.99

***Optimal Model** has highest correlation (R^2) and lowest mean absolute error (MAE)*

Accra, Ghana

Accra Deployment

18 Clarity sensors deployed around city for 3 years



29.0 $\frac{\mu g}{m^3}$ **Network-Wide Daily Mean**

15.0 $\frac{\mu g}{m^3}$ WHO Guideline Daily Mean

GMR-Corrected Data from Accra Deployment

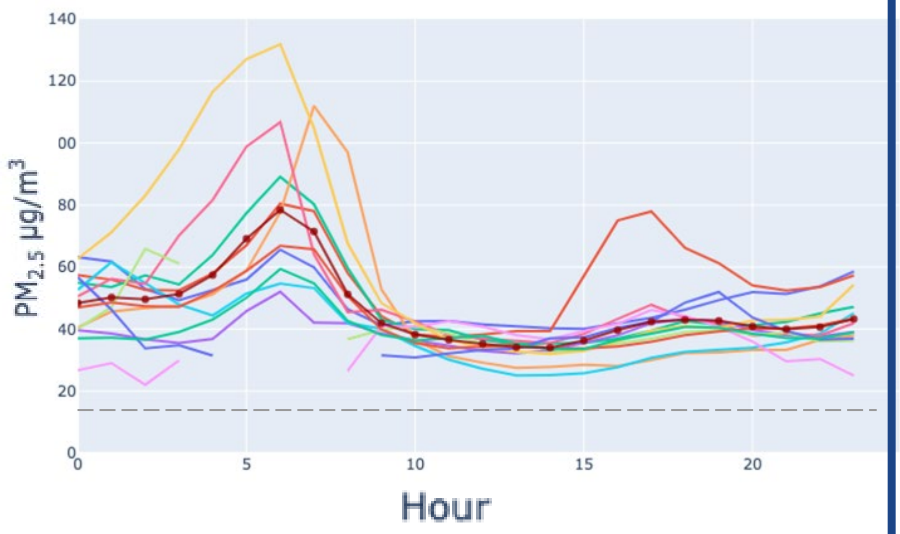
Deployed sensors show a wide spread that remains largely above WHO guidelines

Accra Deployment - Daily Averaged GMR -Corrected $PM_{2.5}$

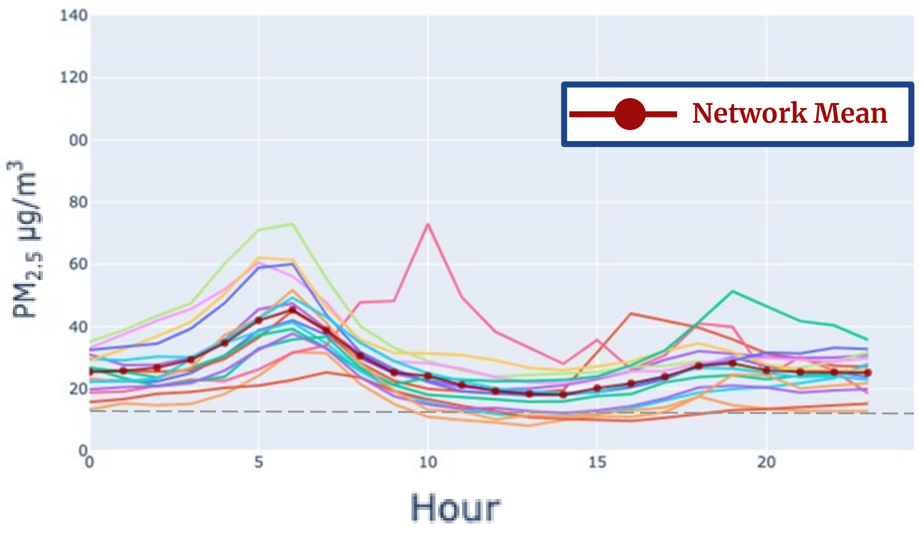
Harmattan Elevates Background Levels

Diurnal and weekly cycles largely governed by local activity

Diurnal Cycle - Harmattan



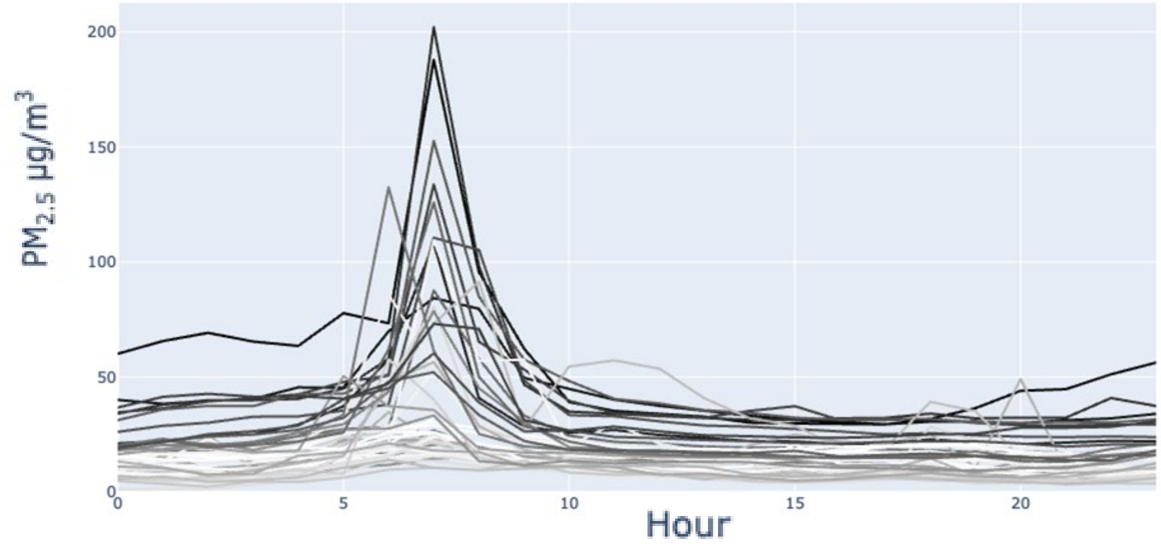
Diurnal Cycle - Non-Harmattan

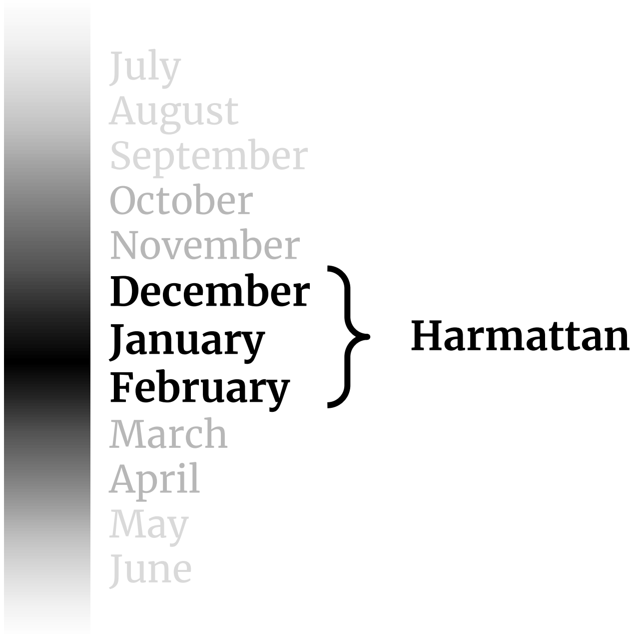


Harmattan Elevates Background Levels

Diurnal and weekly cycles largely governed by local activity

Diurnal Cycle at Dansoman Site

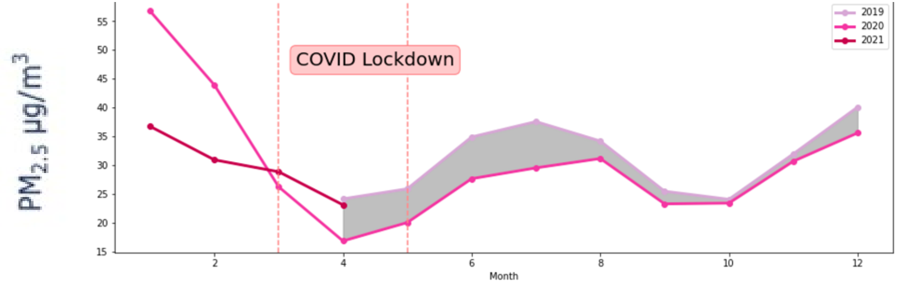




Understanding Regional Trends

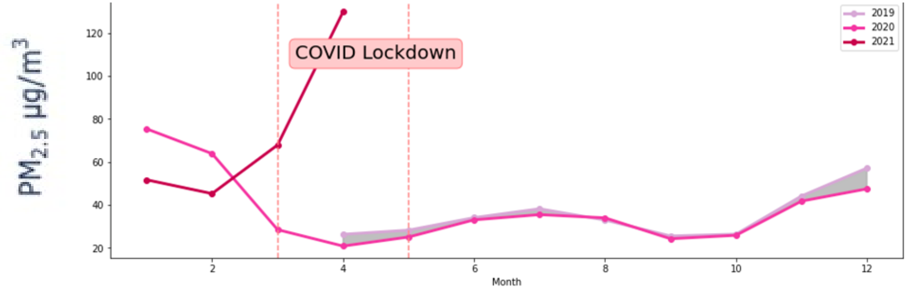
Varying correlations and differential reductions during major events show vitality of high-density network

Tetteh Quarshie *-23.7%*

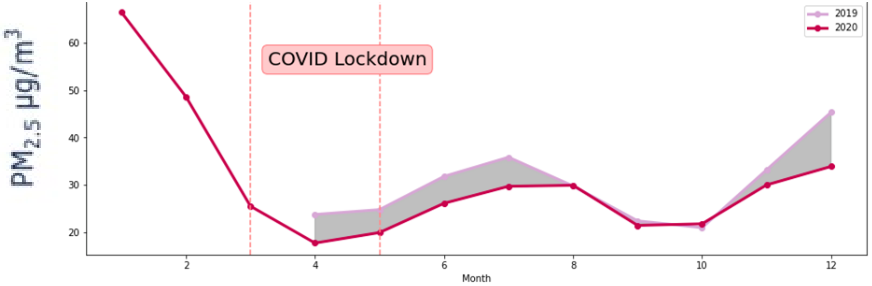


COVID-Related Reductions in $PM_{2.5}$

Amasaman *-15.7%*

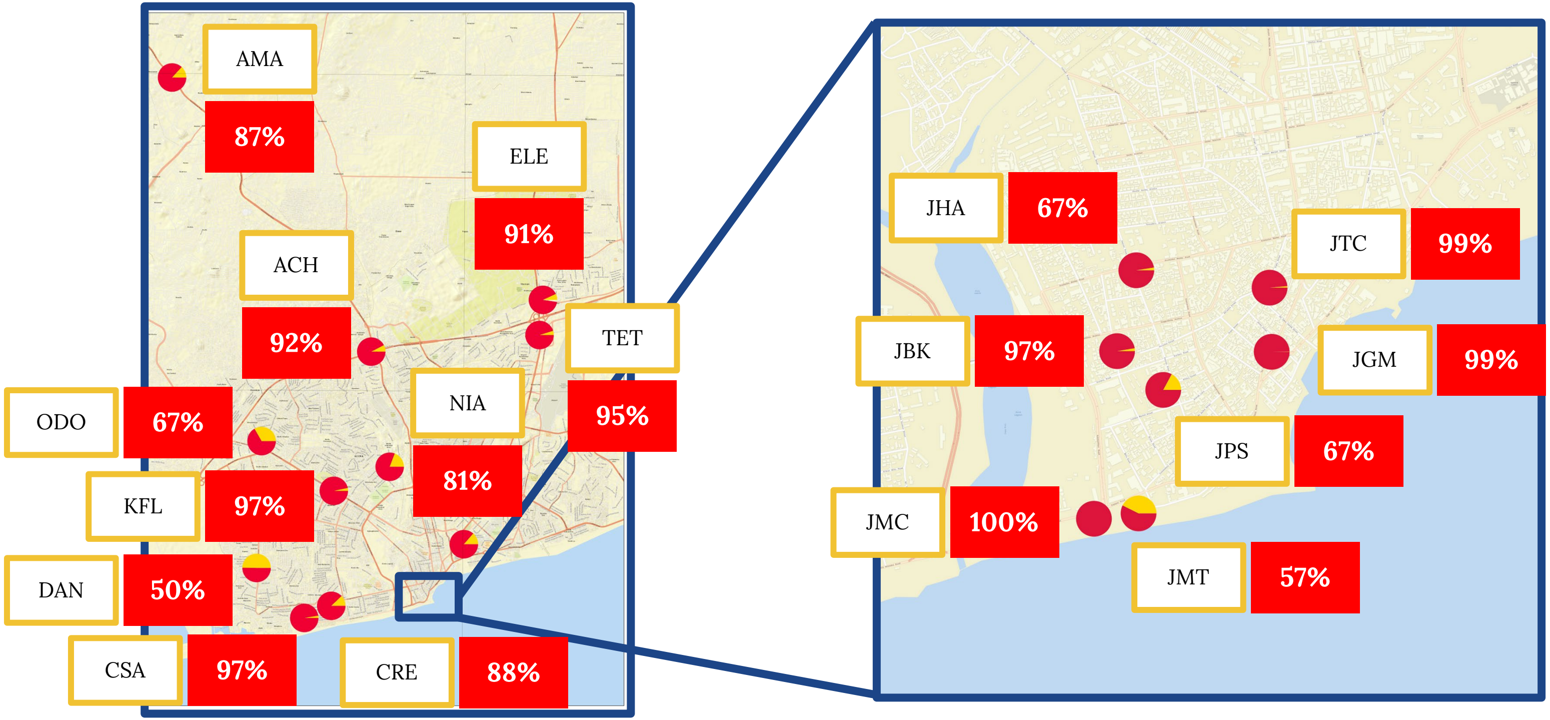


Achimota Interchange *-20.2%*



High $PM_{2.5}$ Levels Exceed WHO Standards

Pie charts show % of measured days above daily mean of 15 µg/m³

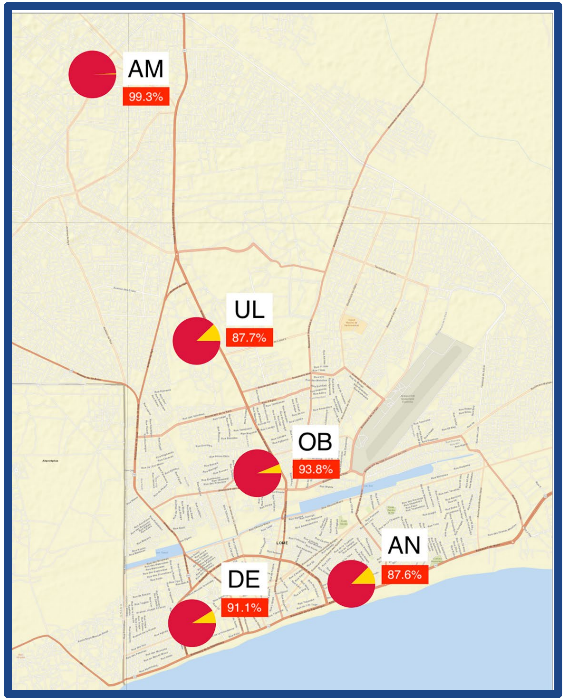


Lomé, Togo

5 Purple Airs deployed in Lomé

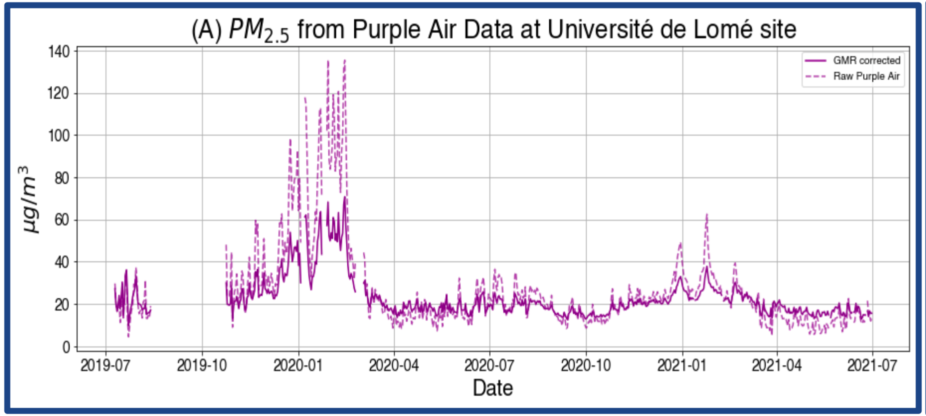
Applying Plantower correction factors to 2 years of data in previously unmonitored country

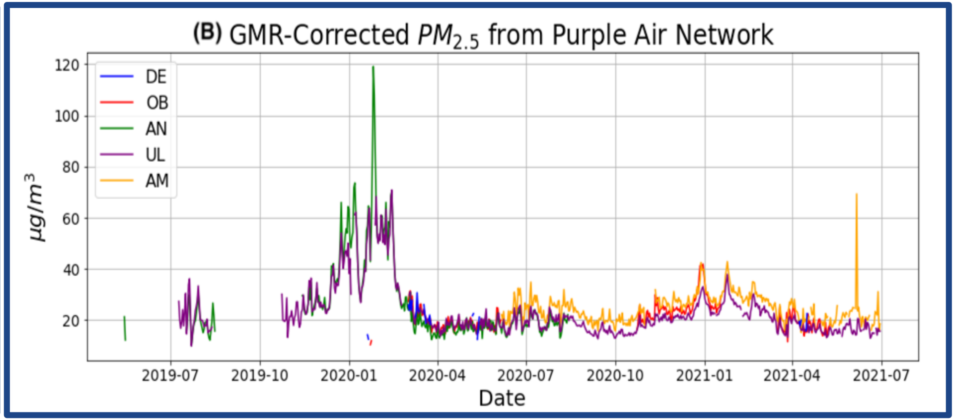
#	Site Name	Site Code	Location (Latitude, Longitude)	Duration	Number of Days of Data Retrieved
1	Office du Bac	OB	6.152, 1.224	01-23-2020 to 05-10-2021	241
2	Direction de l'Environnement	DE	6.125, 1.212	01-20-2020 to 04-19-2021	34
3	Université de Lomé	UL	6.177, 1.212	07-10-2019 to 06-30-2021	695
4	Agoe Minamadou	AM	6.227, 1.193	01-02-2018 to 06-30-2021	412
5	Agence Nationale de Gestion de l'Environnement	AN	6.132, 1.242	05-15-2019 to 08-13-2020	307



GMR-Corrected Data from Lomé Network

Correction factors help control for erratic events; daily and annual averages far above guidelines





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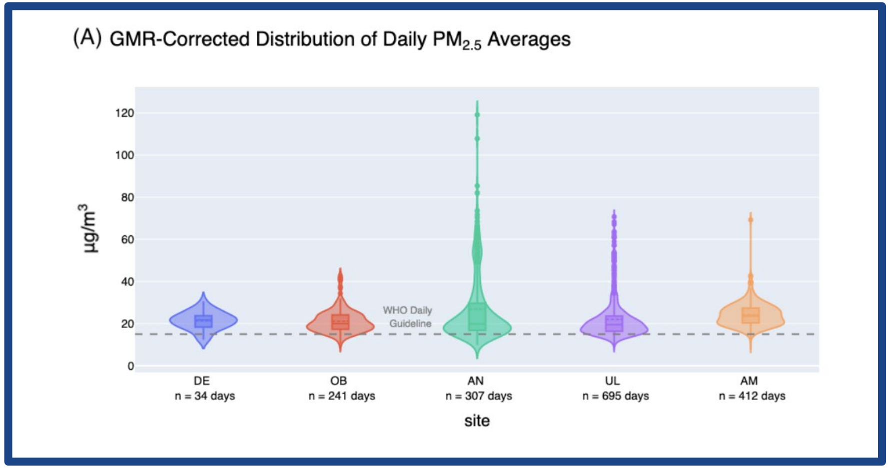
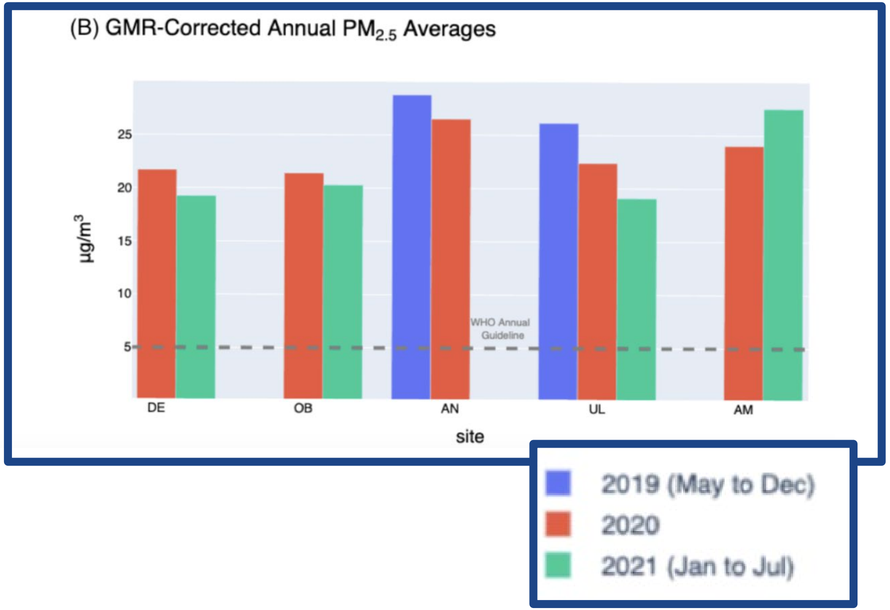
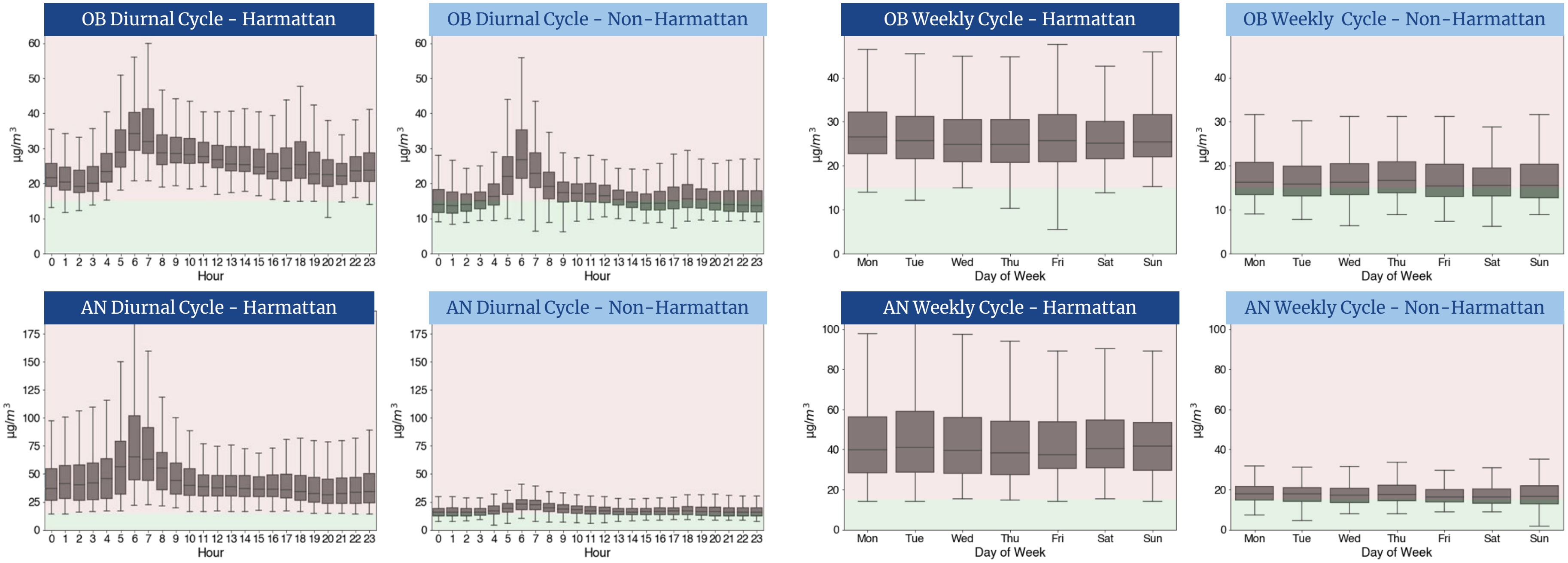




Harmattan Elevates Background Levels

Diurnal and weekly cycles largely governed by local activities; baseline governed by regional



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    - **Low-cost sensors, especially when adequately calibrated and corrected, can provide very high quality data**

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  - Low-cost sensors, especially when adequately calibrated and corrected, can provide very high quality data
- **Deployed sensor networks demonstrate that the Harmattan drastically elevates baseline concentrations, but the trends are largely governed by local anthropogenic activity (such as traffic and waste burning)**
  - **Average concentrations in Accra and Lome are far above WHO daily guidelines, but the causes are not all anthropogenic**

Key Takeaways

- Sensor intercomparison builds towards a **deeper understanding of performance** and contributes to developing a **global calibration model**
    - Low-cost sensors, especially when adequately calibrated and corrected, can provide very high quality data
- Deployed sensor networks demonstrate that the **Harmattan drastically elevates baseline concentrations**, but the **trends are largely governed by local anthropogenic activity** (such as traffic and waste burning)
    - Average concentrations in Accra and Lome are far above WHO daily guidelines, but the causes are not all anthropogenic
- **More measurements, observations, analyses and interventions will further the study of air pollution in low- and middle- income countries**

Acknowledgements

Ebenezer Appah-Sampong Ghana Environmental Protection Agency
Emmanuel Appoh Ghana Environmental Protection Agency
Maxwell S Sunu Ghana Environmental Protection Agency
John K Nyante Ghana Environmental Protection Agency
Robert W Pinder US Environmental Protection Agency
Allison Felix Hughes University of Ghana, Accra
R Subramanian Carnegie Mellon University
Stefani L. Penn Industrial Economics, Inc.
Michael Giordano Drexel University
Levi Stanton Clarity Movement Co
Sabi Kokou Université de Lomé
Sonla Hèzouwè Université de Lomé
Eric Kokou Gbedjangni Université de Lomé
Collins Gameli Hodoli Clean Air One Atmosphere
Celeste McFarlane Columbia University Dept of Chemical Engineering
Daniel Westervelt Lamont-Doherty Earth Observatory of Columbia University

This work is funded by NSF Office of International Science and Engineering award number 2020677.

Questions?

CONTACT

garima.raheja@columbia.edu

@rahejagarima