It’s About Something Up in the Air: Measurement of Suspended Dust in Layer Facilities

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PIP Innovation Showcase

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Outline

- **A brief introduction on a few air pollutants in poultry facilities.**

- Project 1: Low-cost air quality sensors – towards a more affordable strategy for environmental monitoring in poultry facilities.

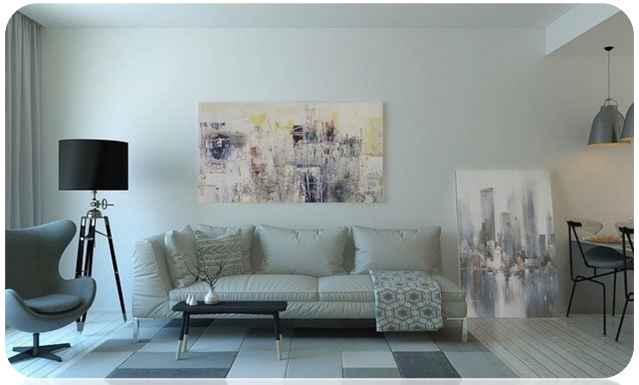
- Project 2: Exploring the origin of NH_3 – measurement of nitrogenous compounds in air and dust.

What is Atmospheric Chemistry

A discipline to study chemicals and chemical reactions happening in the air.
For example, research topics in my research group:

Chemistry in the air and cloudwater

Wildfire and air quality



Indoor quality and occupational health

Dust and air pollutants in poultry farms

Indoor Air Pollutants – A Brief Introduction

- Most Canadian farms are indoors.
- Indoor air pollutants can cumulate: particulate matter (PM), NH_3, volatile organic compounds, CO_2, etc.

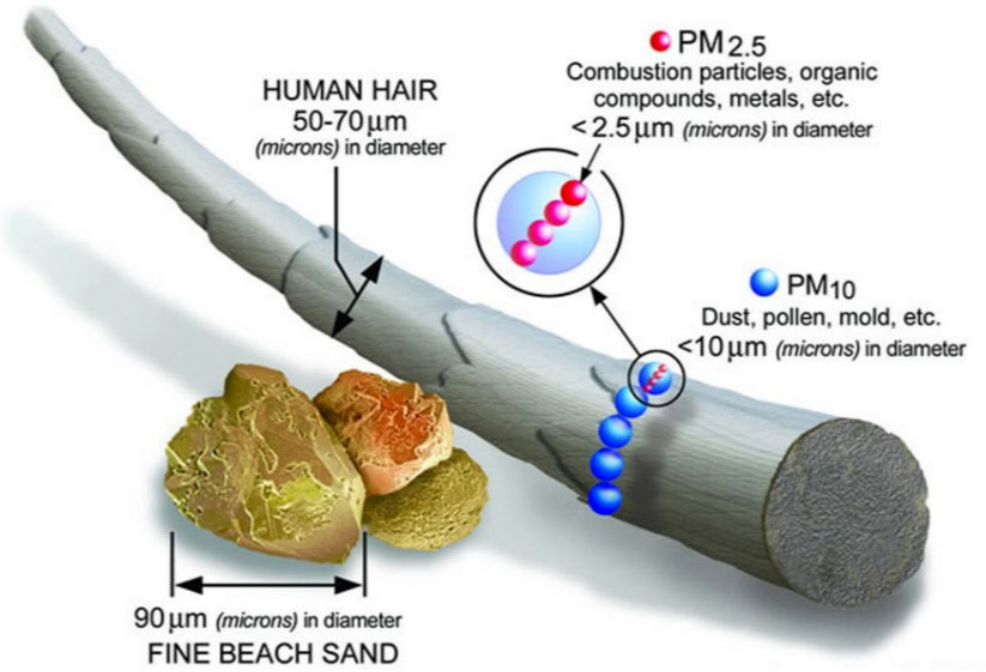
Dust in Poultry Farms

Dust, also called **particulate matter (PM)** or **aerosol** can:

- Be a carrier of disease potentially including Avian Influenza.[1,2]
- Affect the health of workers.[3]
- Affect the health and productivity of birds.

In the outside atmosphere, aerosol can

- Cause lung and heart diseases to humans.
- Affect the health of mothers and newborns.

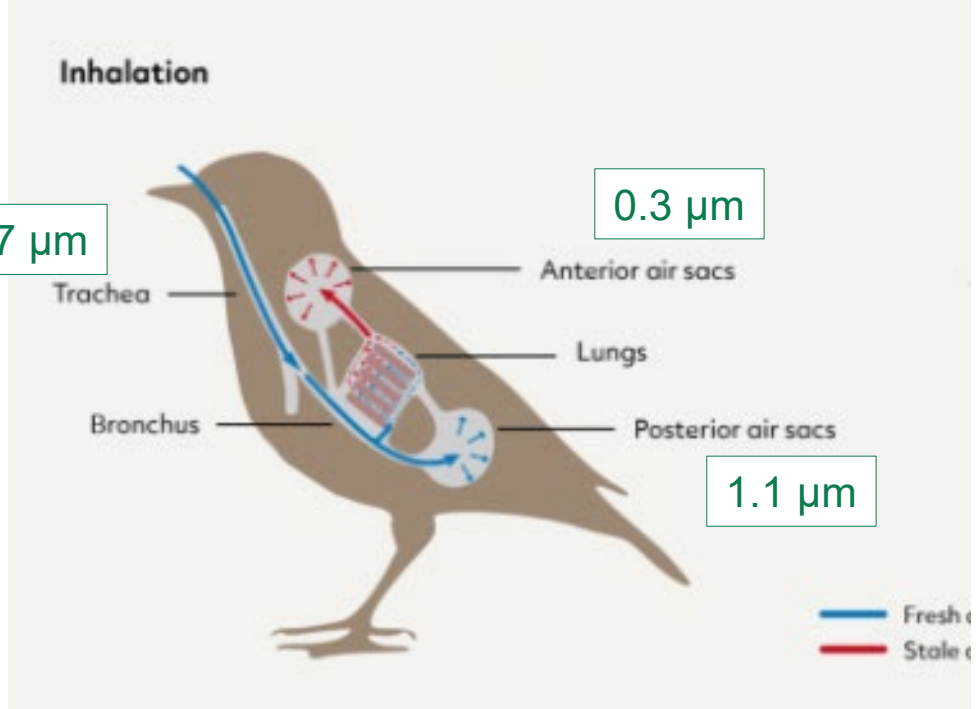


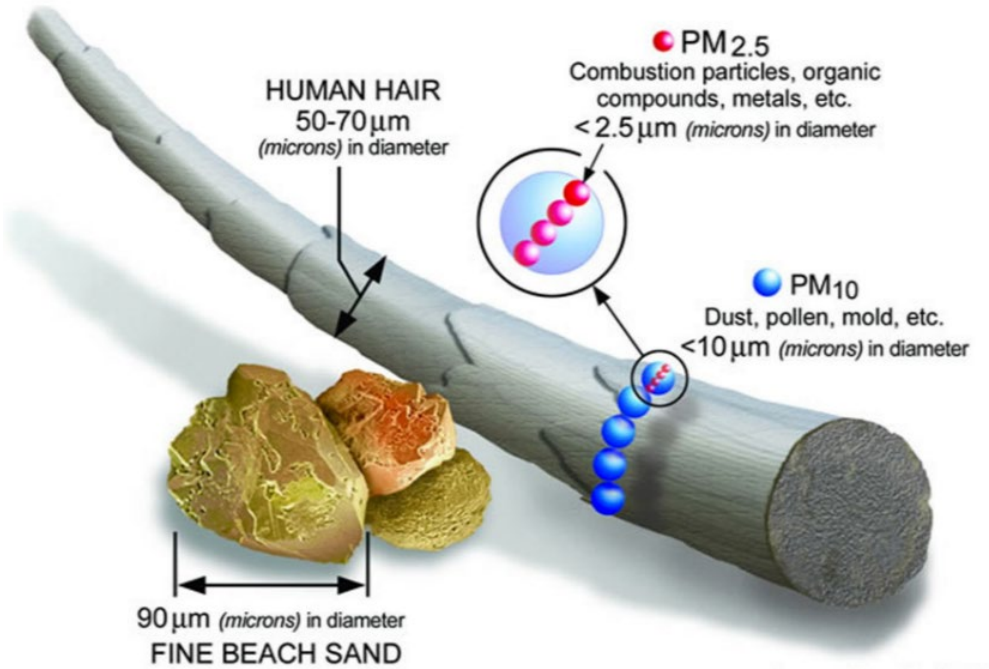
Source: US Environmental Protection Agency

[1] Chen et al. **2010**. *Environ. Health Perspec.* [2] Zhao et al. **2019** *Sci. Rep.*
[3] Viegas et al. **2013** *J. Toxicol. and Environ. Health*

Size Really Matters for PM

- A general air flow diagram in birds[1]





- Small particles penetrate deep into the respiratory system of birds [2]
- Specific impact of PM on birds is unclear.

Source: US Environmental Protection Agency

[1] https://asknature.org/strategy/respiratory-system-facilitates-efficient-gas-exchange/
[2] Hayter and Besch *Poult. Sci.* **1974** 53(4): 1507-1511

Ammonia (NH_3) in Poultry Facilities

- NH_3: odorous, irritating eyes and respiratory systems, causes respiratory diseases, reduce growth rate of chickens [1].
- National Farm Animal Care Council: NH_3 at 20~25 ppm is dangerous and must be reduced [3].

Where does NH_3 comes from?

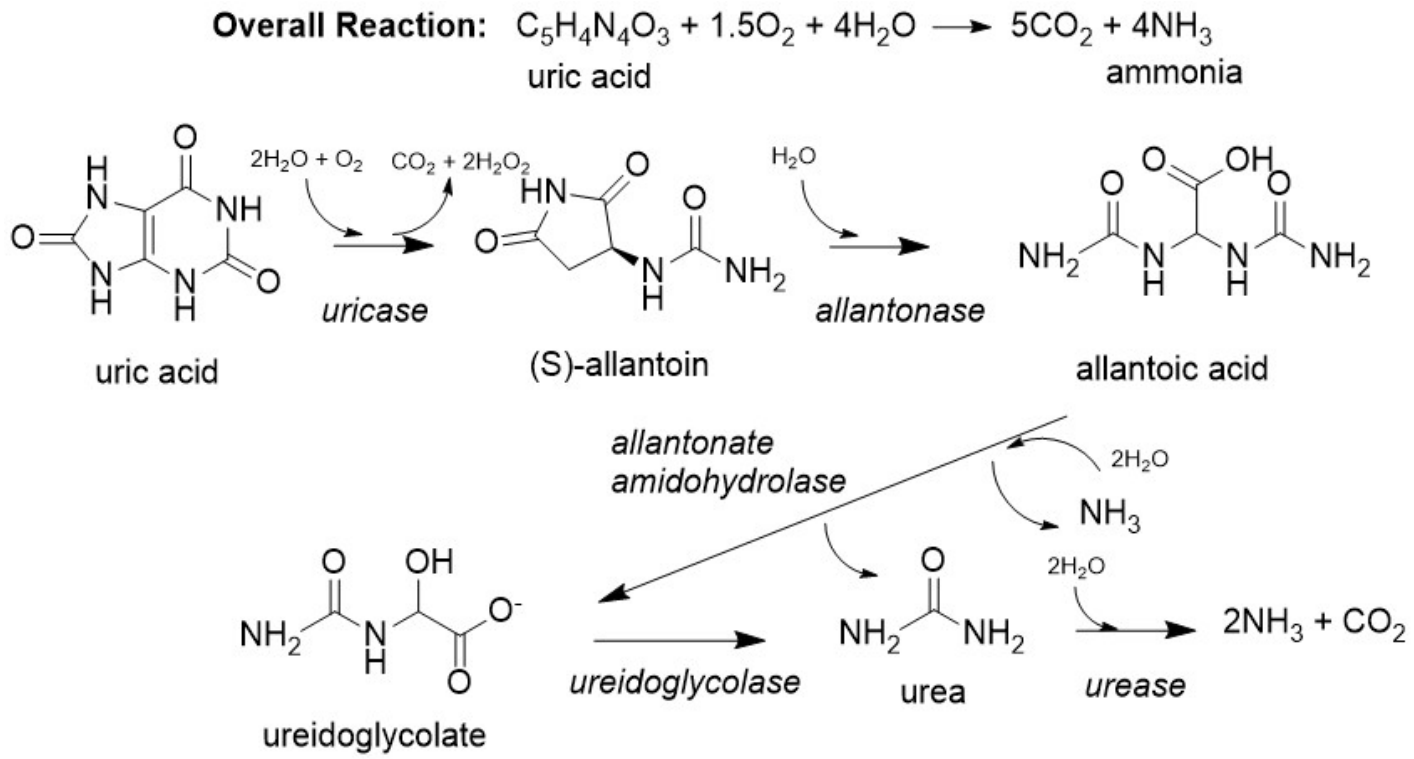
- From chicken waste, but the chemistry behind the scene is… very complicated.

[1] Kristensen and Wathes **2020** *Worlds Poult. Sci. J.* 1;56(3):235–45
[2] NFACC's Code of Practice (2016)

Formation of NH_3 in Poultry Facilities

- Up to 80% of excreted nitrogen (N) is in the form of uric acid, which decompose enzymatically in farms [1].
- Uric acid undergoes multi-step, complex chemical reactions mediated by both the environment and microbes (enzyme mediated) [2].
- Intermediate compounds:

  amines and amides



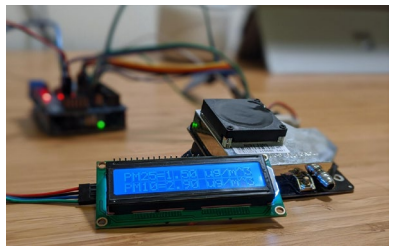
[1] O'dell et al. **1960** *Poult. Sci.* 39(2):426–32; [2] Sousa et al., 2017, *JABB* 5(2): 49-55

Generally, How Do We Measure Air Pollutants?

- Rule of thumb: you pay for what you get

Cost

Accuracy



Education and Information
Accuracy: ~ 30 %
Cost **~100 CAD**

Supplemental monitoring
Human exposure, citizen sicence
Accuracy: < 10~30 %
Cost: **> A few 100s to 1000s**

https://www.aeroqual.com/products/aqs-mini-air-quality-stations/aqs-urban-air-quality-monitor

Regulatory monitoring
Accuracy: < 10%
Cost: **10~50K CAD ea.** + Maintenance

Research grade
Accuracy: very good?
Cost: **100K to over 1 million CAD**

https://www.ionicon.com/products/details/ptr3

https://www.epa.gov/air-sensor-toolbox/how-use-air-sensors-air-sensor-guidebook

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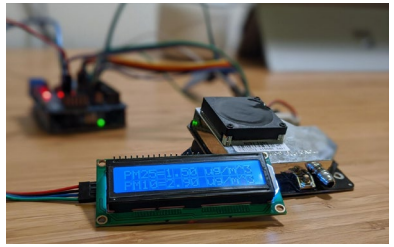


Affordable and sustainable options are now becoming available for air quality and enviornmental monitoring. Applicability and reliability in poultry facilities are yet to be confirmed.

New discoveries require expensive and research-grade instruments.
Method development for pollutants we have not been able to measure.

https://www.epa.gov/air-sensor-toolbox/how-use-air-sensors-air-sensor-guidebook

Quick Summary – Motivation and Gaps of Knowledge

Motivations

- Air pollutants harm both birds and workers.
- Indoor air pollution is a challenge facing the Canadian poultry industry.

Gaps of Knowledge and Challenges

- Need regular monitoring (e.g., for PM) to elucidate specific harms.
- Complex chemistry hinders the control of air pollutants (e.g., NH_3).
- Intermediate compounds towards NH_3 production are poorly understood.

Technical Challenges

- Need more affordable and accessible strategies for environmental monitoring in poultry facilities.
- Need to develop advanced chemical analyses for important chemicals currently overlooked (e.g., precursors of NH_3).

Outline - Revisited

- A brief introduction on air pollutants in poultry facilities.

- **Project 1: Low-cost air quality sensors – towards a more affordable strategy for environmental monitoring in poultry facilities.**

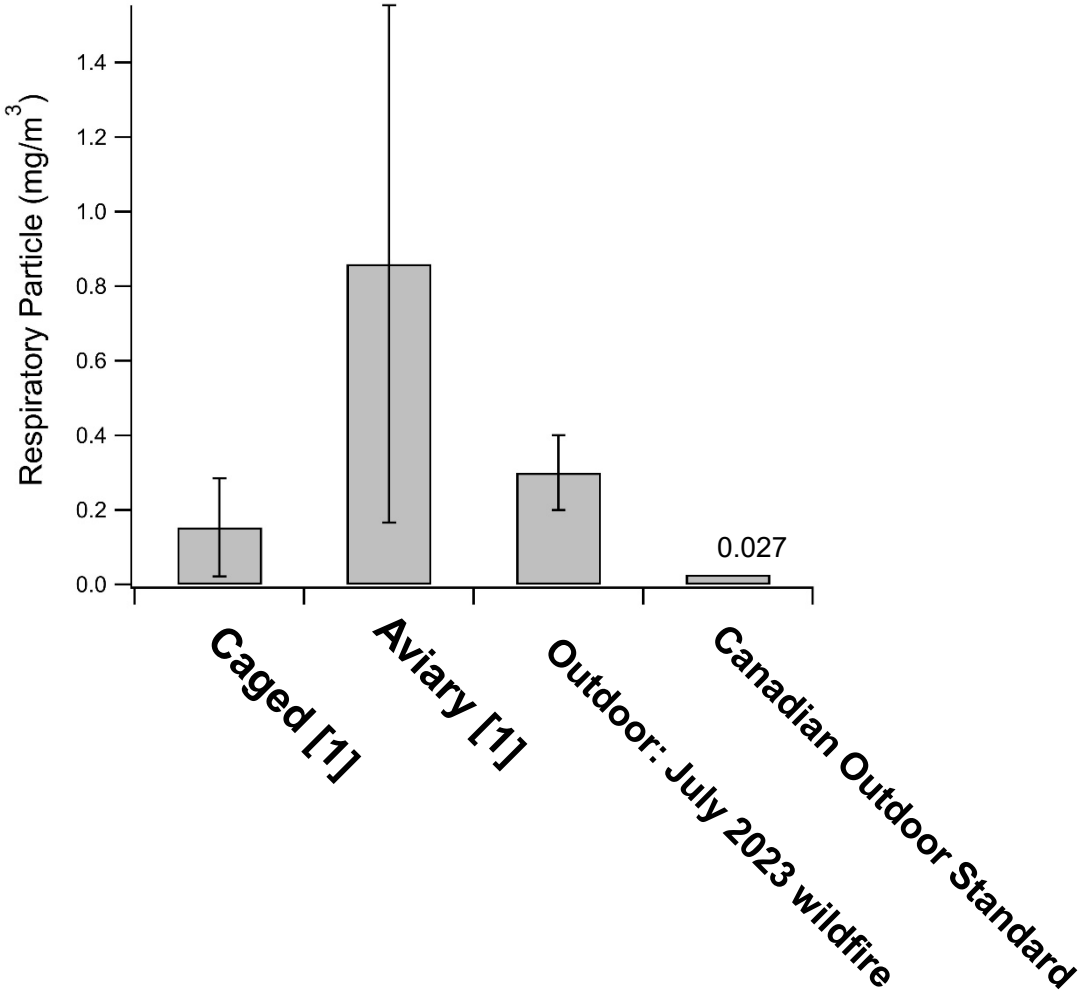
- **Project 2: Exploring the origin of NH_3 – measurement of nitrogen-containing pollutants in air and dust.**

Project 1: Low-cost air quality sensors – towards a more affordable strategy for environmental monitoring in poultry facilities.

Concentration of Dusts and PM in Poultry Facilities

- Concentration of dust in poultry farms can be much higher than outside.

- Challenges
- Longevity of sensors
- Concentration rage
- Accuracy of sensors



[1] David et al. **2015**. *Animals*

How Do We Measure Dust Particles?

esearch-grade instruments we have

Grimm Optical Particle Counter $20,000

Picture from Grimm website

Aerodynamic Particle Sizer
$60,000

Picture from TSI website

Pros:

- "You pay for what you get"
- Accurate
- Reliable

Cons:

- Expensive
- Requires specialized personnel
- Cannot have many of them – no spatial resolution. No concurrent measurements.

More affordable options?

More Affordable Alternatives

Alphasense Optical Particle Counter, $500

Picture from Alphasense website

Low-cost light scattering sensor, $180

Assembled by my team

Pros:

- Affordable
- Can set up more than one
- Easy to setup

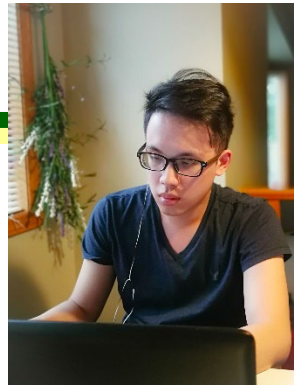
Cons:

- Never been verified in poultry facilities.

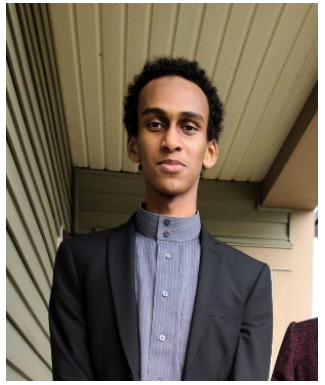
Home Built Sensor

Ryan Druisseau-Kuntz (RA)

Ariel Delorme (UG)

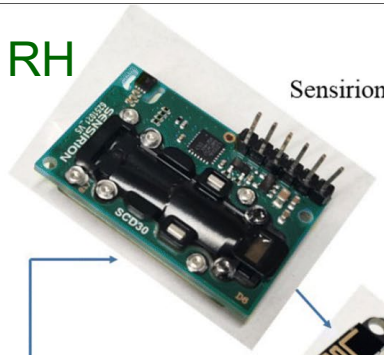


Wayne Cheng (RA)

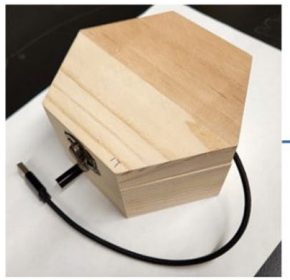


Sohaib Omar (UG)

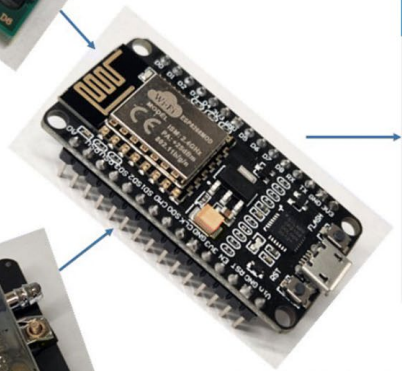
CO_2, Temp, RH



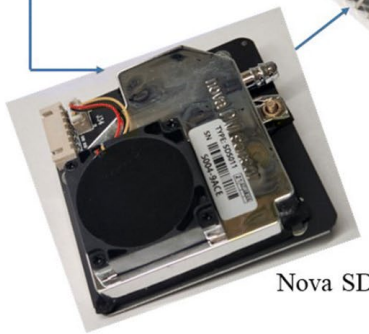
Sensirion SCD30



Low-cost sensor



ESP8266 NodeMcu



Nova SDS011

$PM_{2.5}$, PM_{10}

- Real-time IAQ data sent through Wifi.
- $PM_{2.5}$, CO_2, Temperature, and relative humidity

Applications

Wildfire smoke

Student residence

Children's health

Afroz et al. **2023**. *RSC Environ. Sci. Atmos.* 3, 347-362

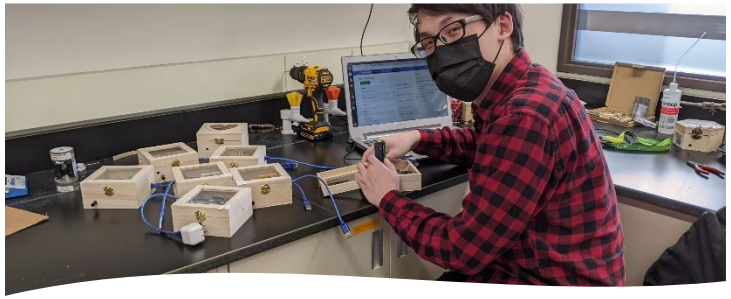
Objectives

- Development and verification of a low-cost air quality sensor applicable to layer facilities.
- Decay/degradation of sensors over time.
- Accuracy of sensors.

- Observation of the trends of PM in poultry facilities
- Relationship with bird activities.
- Daily (diurnal) trends.
- Variation of PM concentration at different locations.

Approach

Sensor Development in the Lab



Chuwen (Wayne) Cheng – technician

Deployment at a commercial table egg farm

Free-run housing, 8000 layers

Sensor Testing at Poultry Research Centre (PRC) at U of A

Small flock in an experimental farm

(the Heritage Flock)

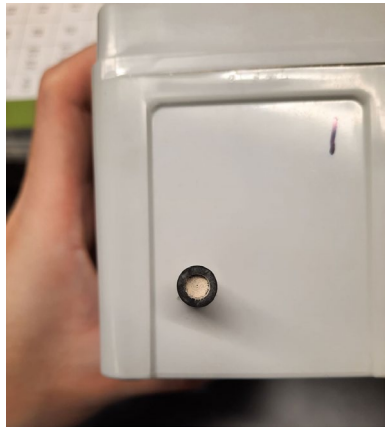
Floor pan style housings

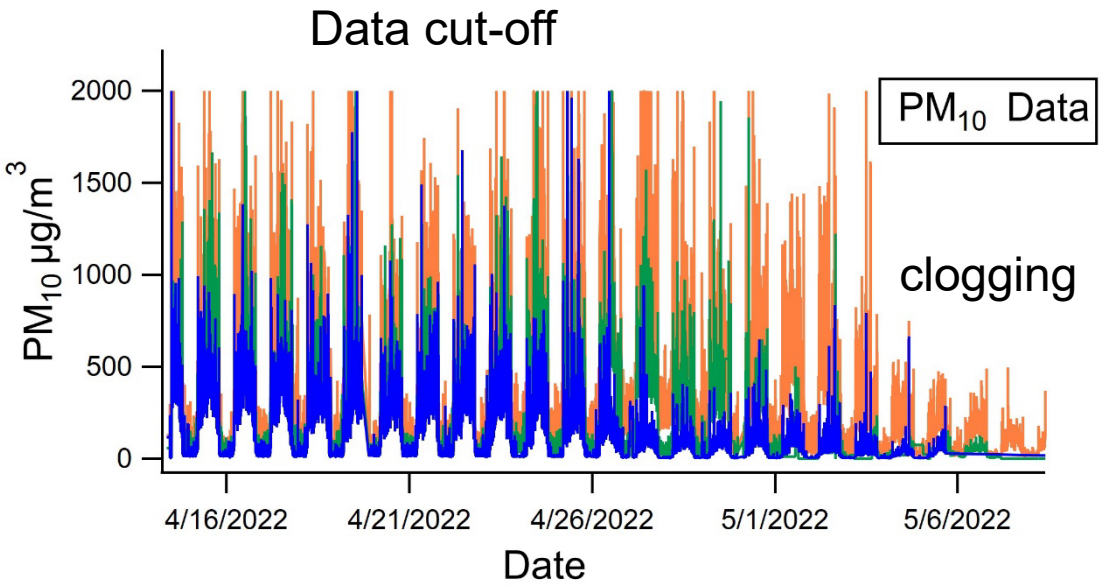
Xinyang (Timothy) Guo
PhD Candidate

Rowshon Afroz
PhD Student

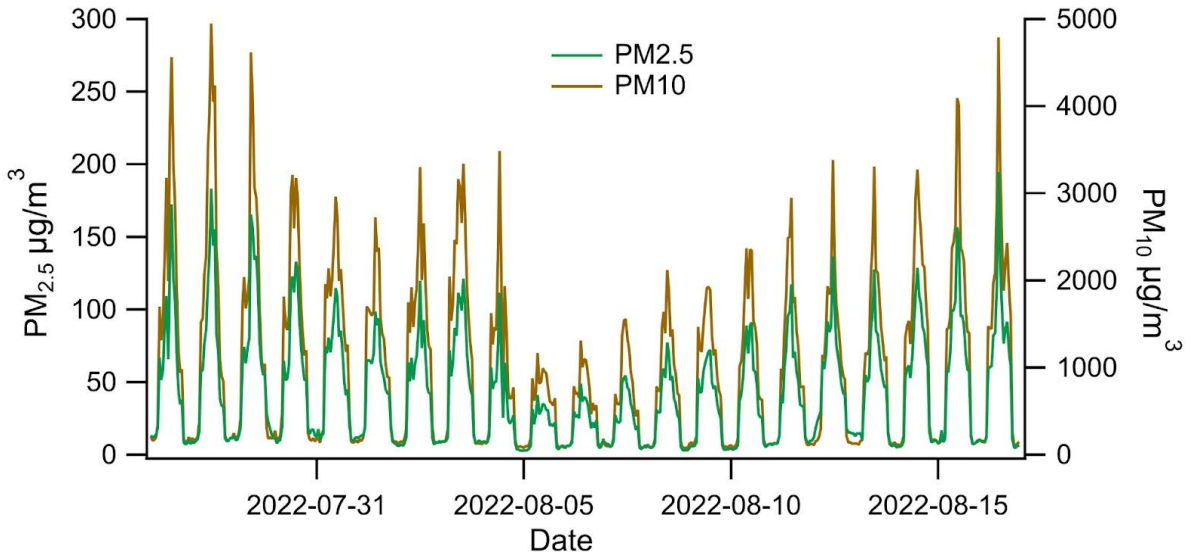
Sensor Development - Challenges Faced

- High dust load in the PRC farm resulted in reduced sensor lifetime, signal saturation (overshooting), and inaccuracy.





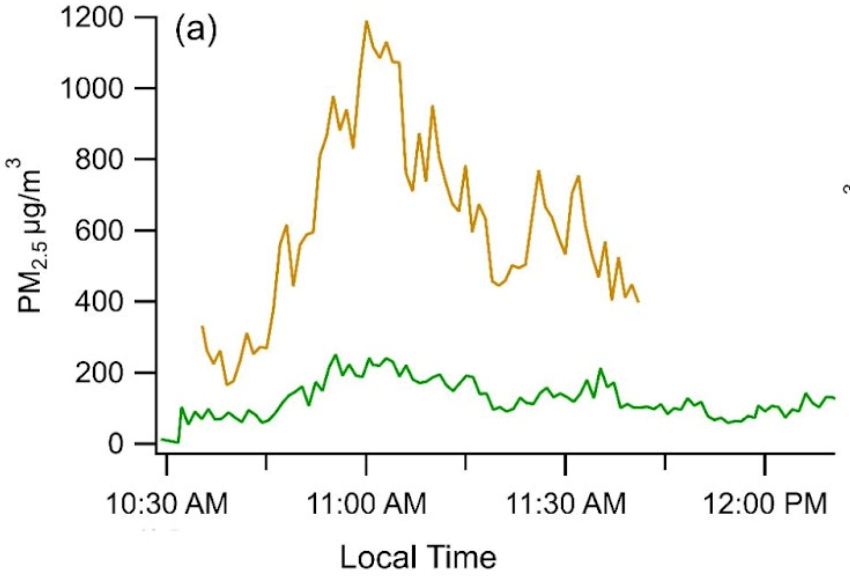
Sensor Development – Optimized Prototype

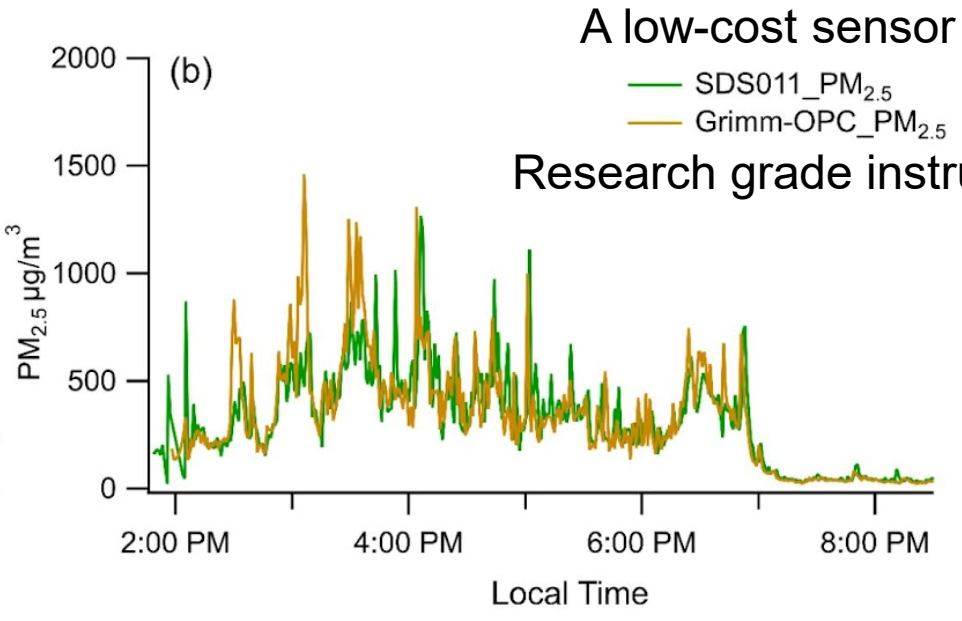


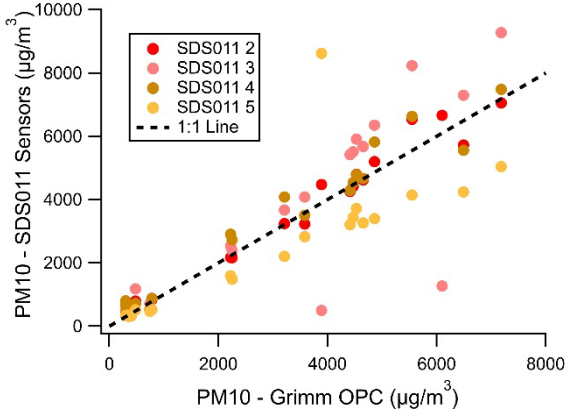
- A slower fan was used to avoid data saturation.
- The fan was re-programmed to turn on only for data acquisition.
- A much improved sensor longevity was achieved.

Sensor Development – Accuracy

- Because we changed the fan, low-cost sensor readings initially did not match the research-grade instrument.
- We co-located instrument and performed a single-factor correction.
- *Reasonable* accuracy compared to Grimm OPC was achieved.







Deployment at the Commercial Farm

- Six sensors were deployed a various locations inside the farm:
- 2’, 9’ and 10’ height from the floor
- Outside of the barn (prep room)

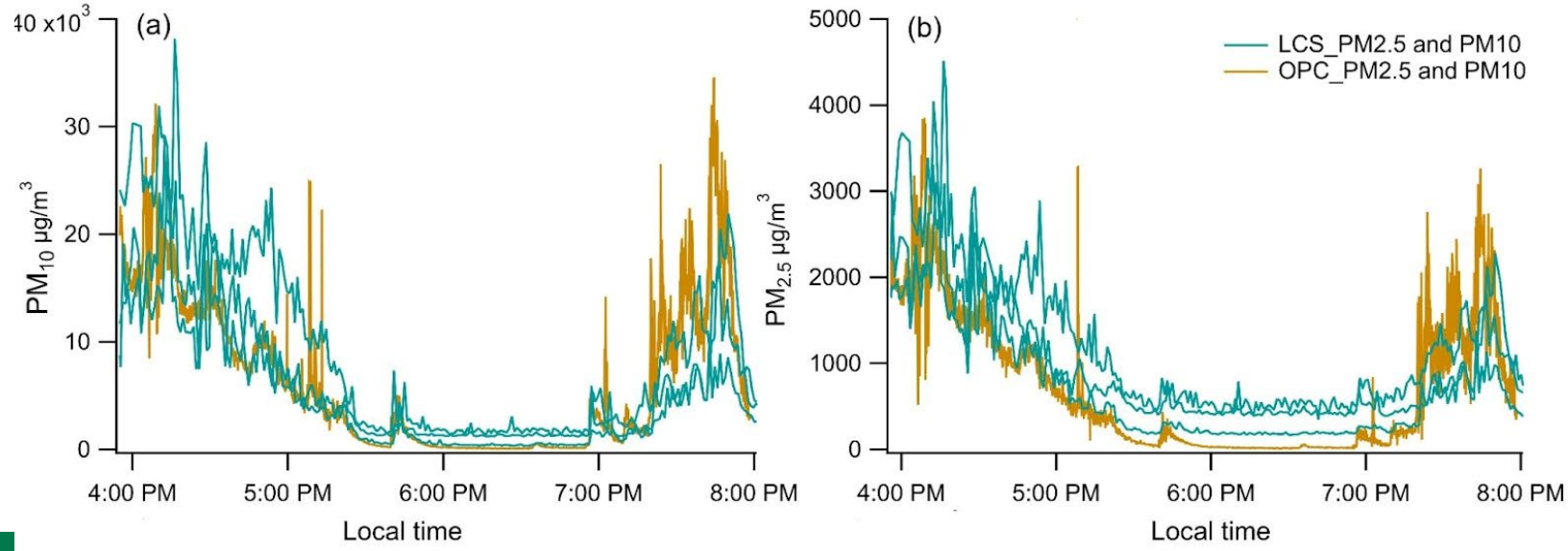
- Measurement continued from Nov 2022 to May 2023
- Visited the farm every few weeks for sensor maintenance and calibration – by colocation with the Grimm OPC.

- **A big thanks for producers at the farm for their assistance and welcoming!**

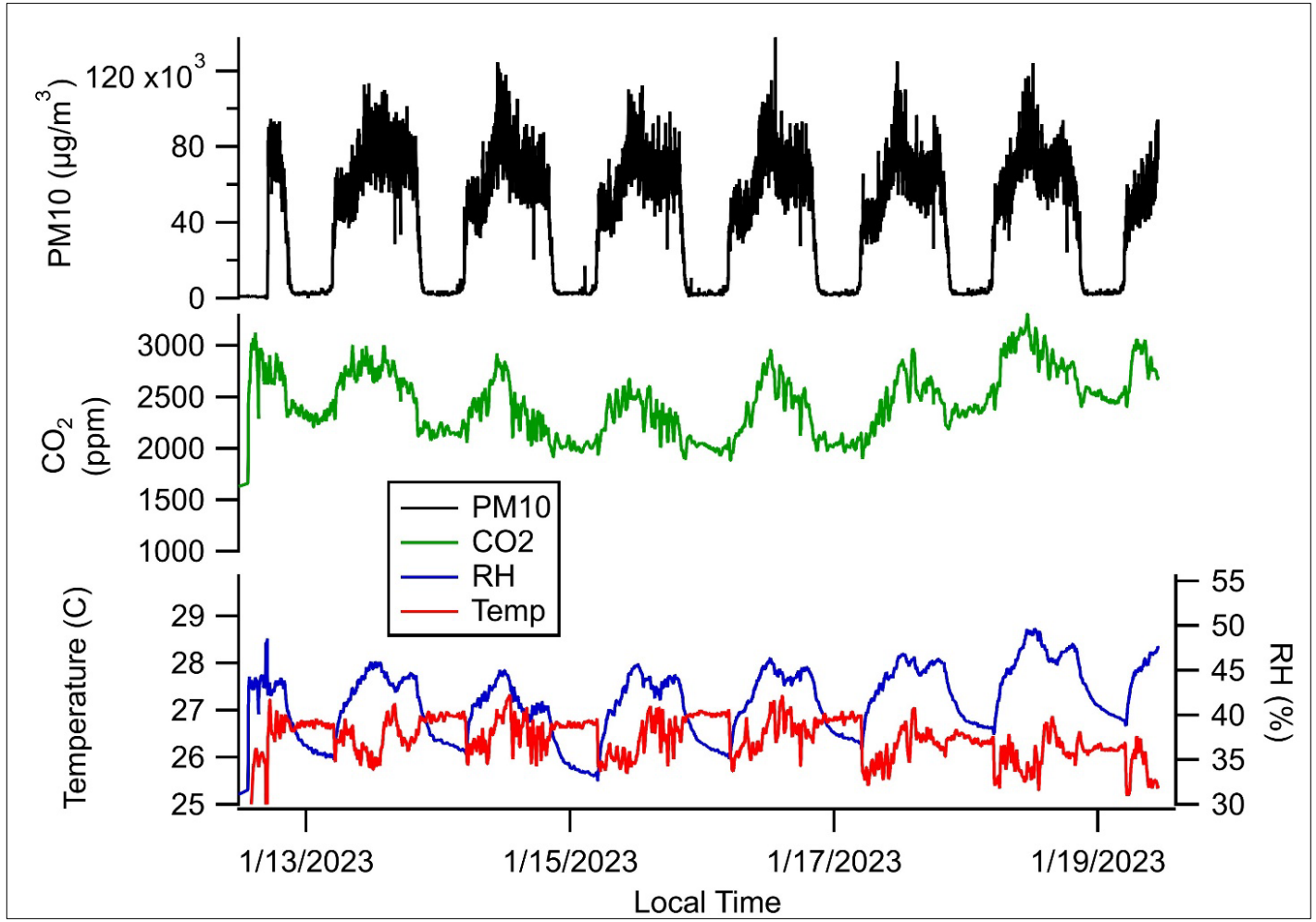
Calibration at the Commercial Farm

- The PM concentrations in the commercial farm was much higher than those in the PRC farm.
- Readings of the low cost sensors were more variable yet showed reasonable agreement with the Grimm OPC.
- Reading at the baseline – low concentration – is inaccurate.

A comparison of low cost sensors (LCS) with the Grimm OPC

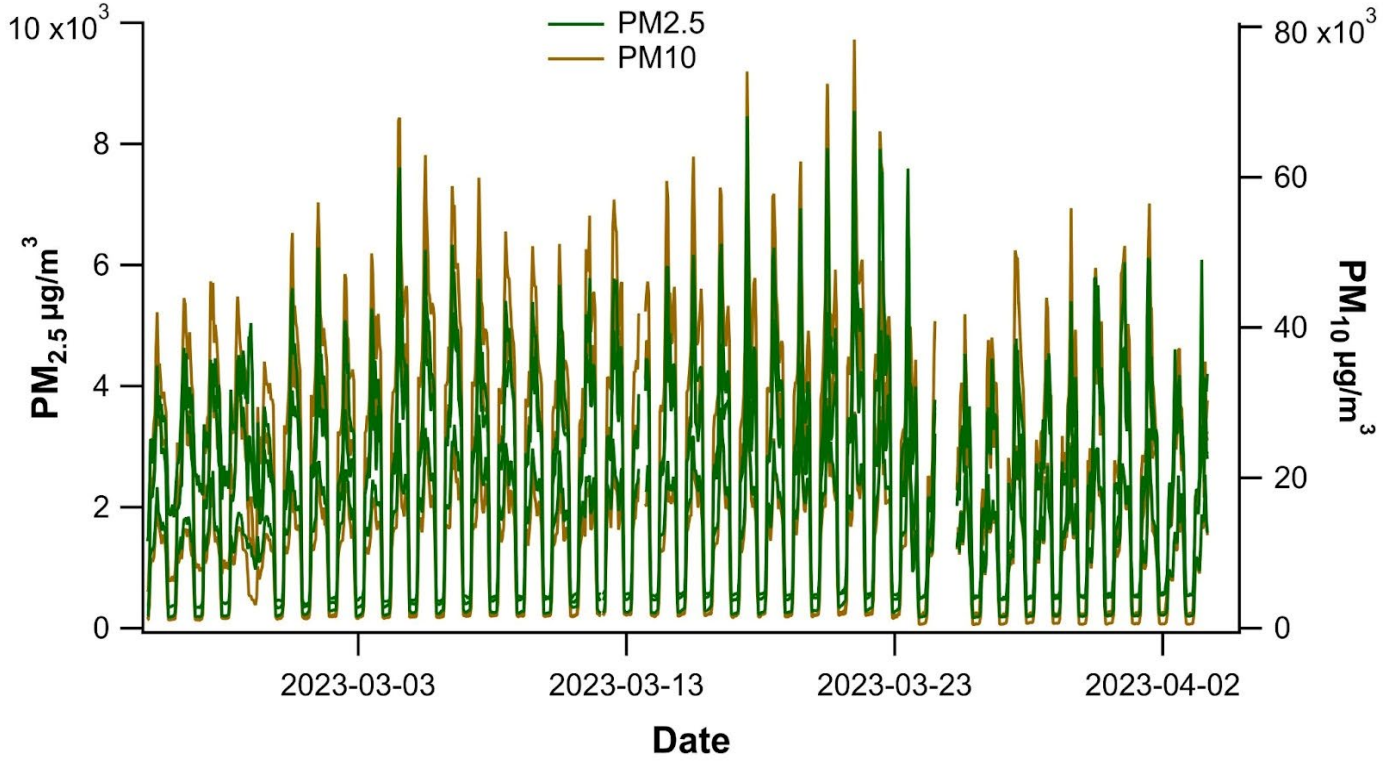


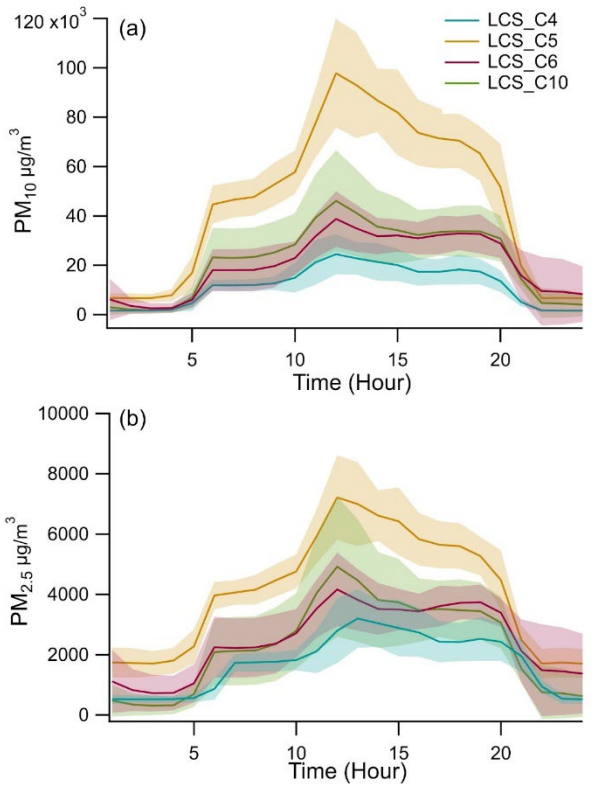
Results at the Commercial Farm



- Clear daily (diurnal) trends were observed.
- PM, RH, and CO_2 all exhibit increases during daytime, when birds were active.
- Note: our temperature and RH are not calibrated, but the trend is real.

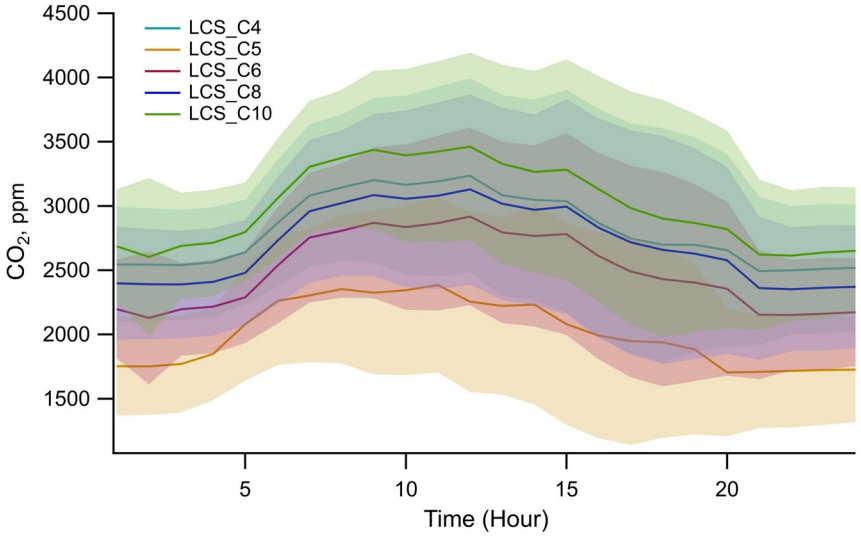
Results at the Commercial Farm

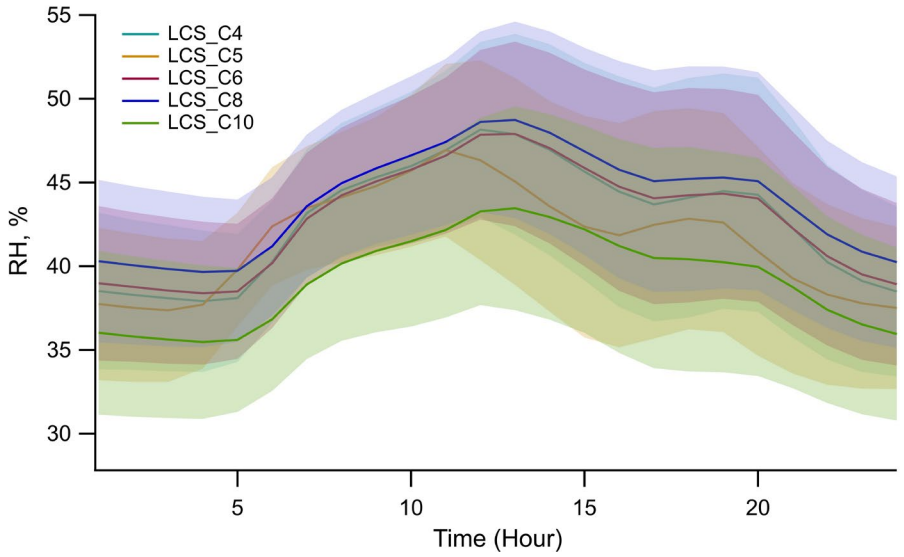




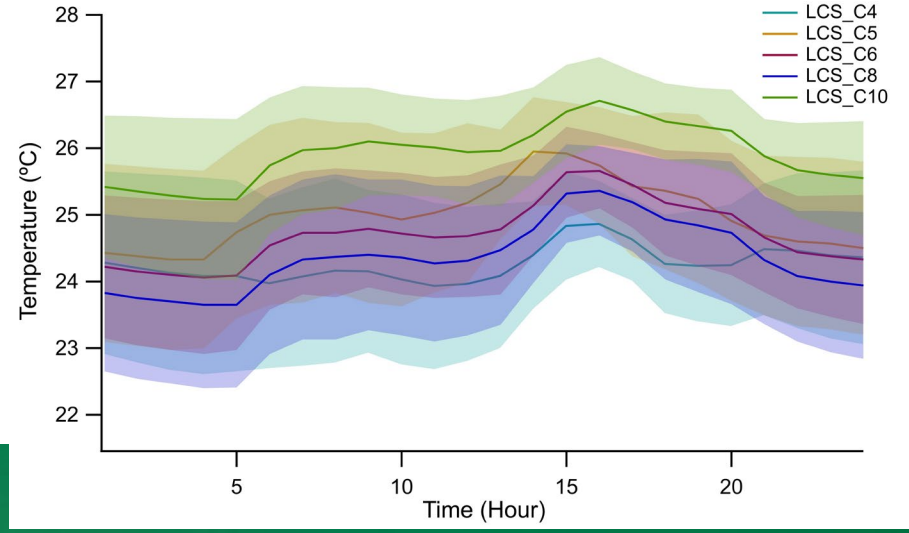
- Consistency among sensors were observed.
- C5 is at the chicken level (2’ above ground), thus highest in PM concentration?

Diurnal Trend of Other Parameters

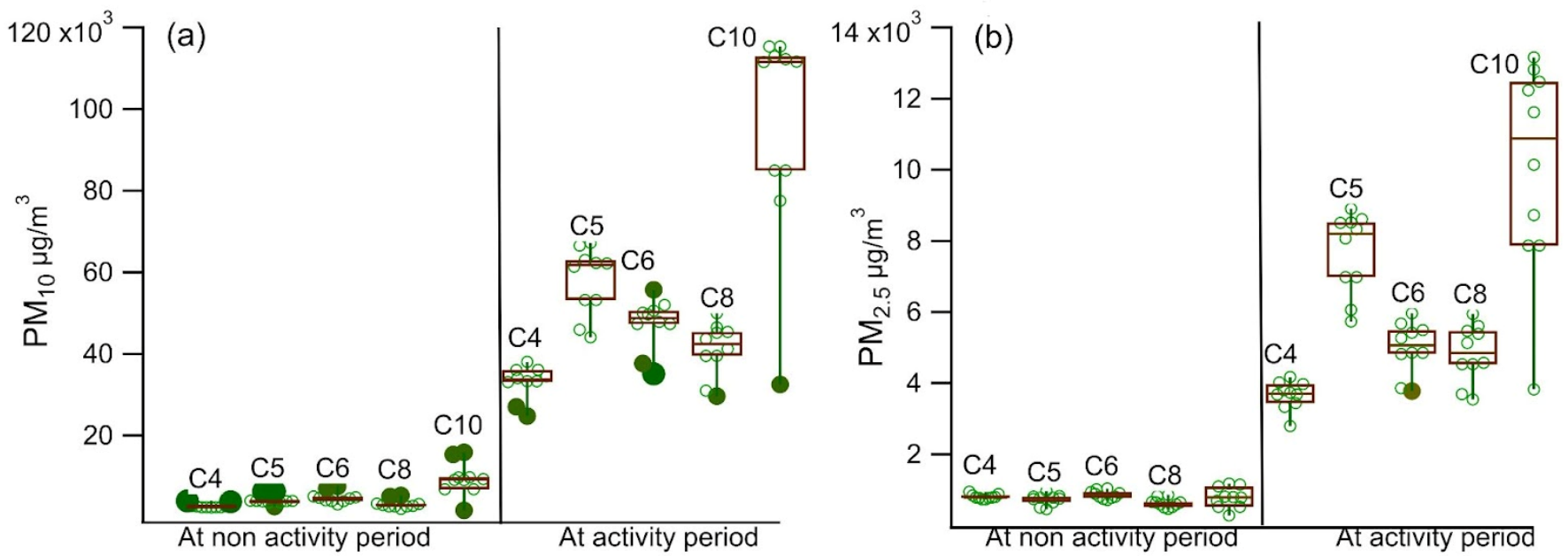




- The other parameters also exhibited similar diurnal trends.

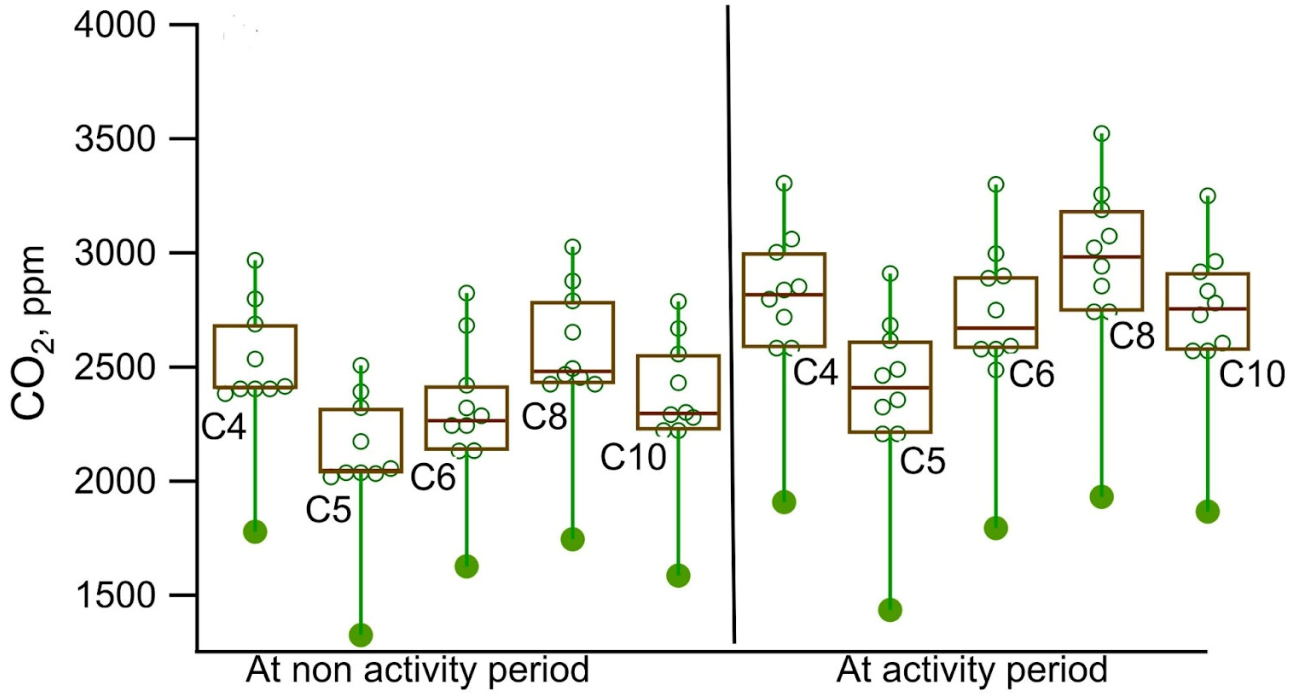


Impact of Birds' Activity – PM Concentration



- Taken from a 10 day period in January 2023.
- A huge difference between non-active periods (night) and active periods (daytime)

Impact of Birds' Activity – PM Concentration



- Minor differences observed between active and non-active periods.
- Birds continue exhaling CO_2 even during sleep.
- Highlights the need for different strategies to control PM vs CO_2.

Summary of Project 1 – Low Cost PM Sensor

- PM sensors currently on the market are not designed for application in poultry facilities.
- With adjustment we made to our sensor, we achieved *reasonable** results:
  - The sensors survived for ~6 months with minimal maintenance. Note: outdoor low-cost sensor's life expectancy is ~ 2 years.
  - General accuracy and consistency: ~30% was achieved.
  - For a price at $180, a device that reads reasonable PM concentration in farms is a good technological advancement.
  - Sensor requires individual calibration.
- PM concentrations in the commercial egg farm was very high and was correlated with bird activities.

Project 2: Exploring the origin of ammonia (NH_3)– measurement of nitrogenous compounds in air and dust.

Why NH_3 control in poultry facilities is so hard?

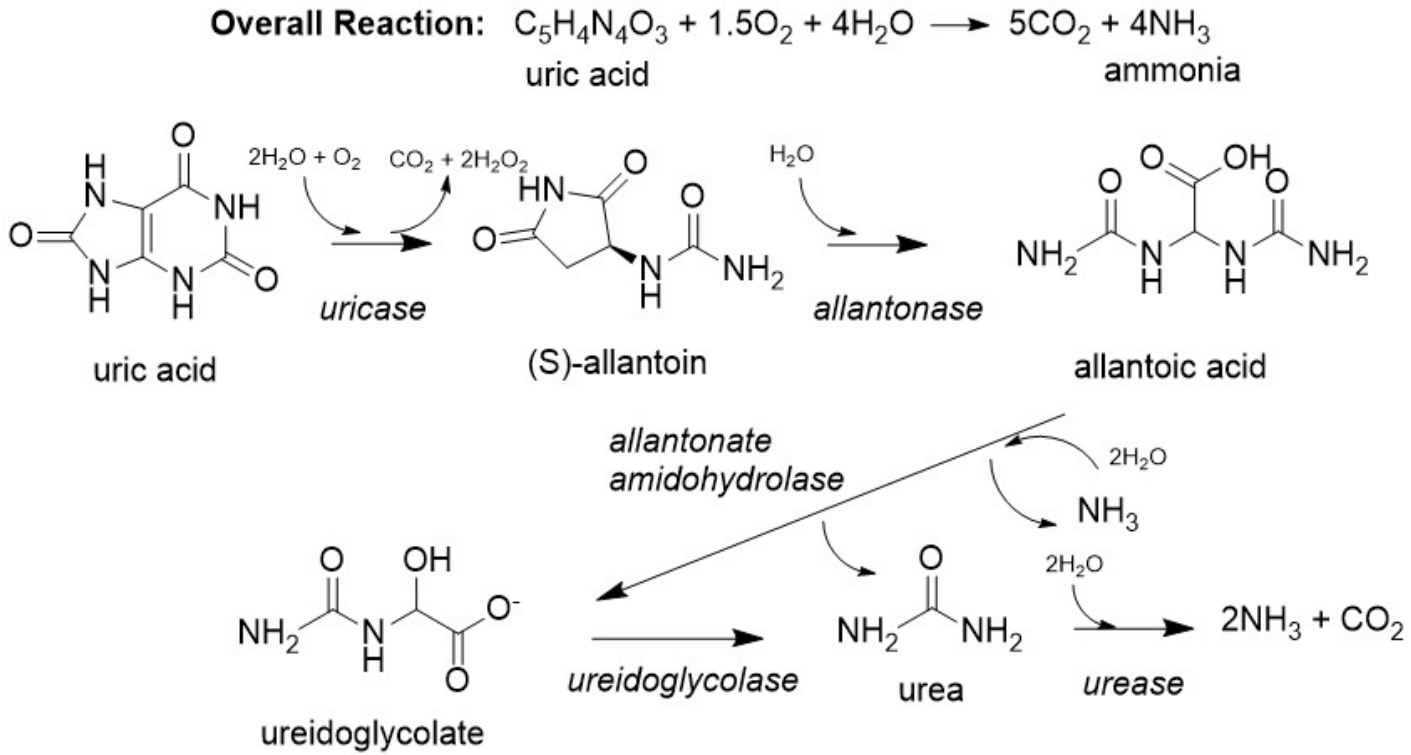
- Because the majority of NH_3 is produced through chemistry.
- Because NH_3 is 'sticky' to walls, floor materials, and dust/PM.
- Because its production depends on a lot of conditions (temperature, RH, acidity of waste, ventilation)
- Because every farm is different!

How do we approach?

- Understanding the fundamental chemistry becomes important.
- A few successful examples in the history of outdoor air quality control (e.g., acid rain).

Motivation of the Project

- It is known that NH_3 arises from uric acid degradation through complex chemistry.
- Many of the intermediate compounds - amines and amides – have not been measured.
- Many of them are sources of malodor as well.
- What are the largest pools of nitrogen? What are rate-limiting steps?
- Requires an analytical method specifically targeting these chemicals.



Sousa et al., 2017, *JABB* 5(2): 49-55

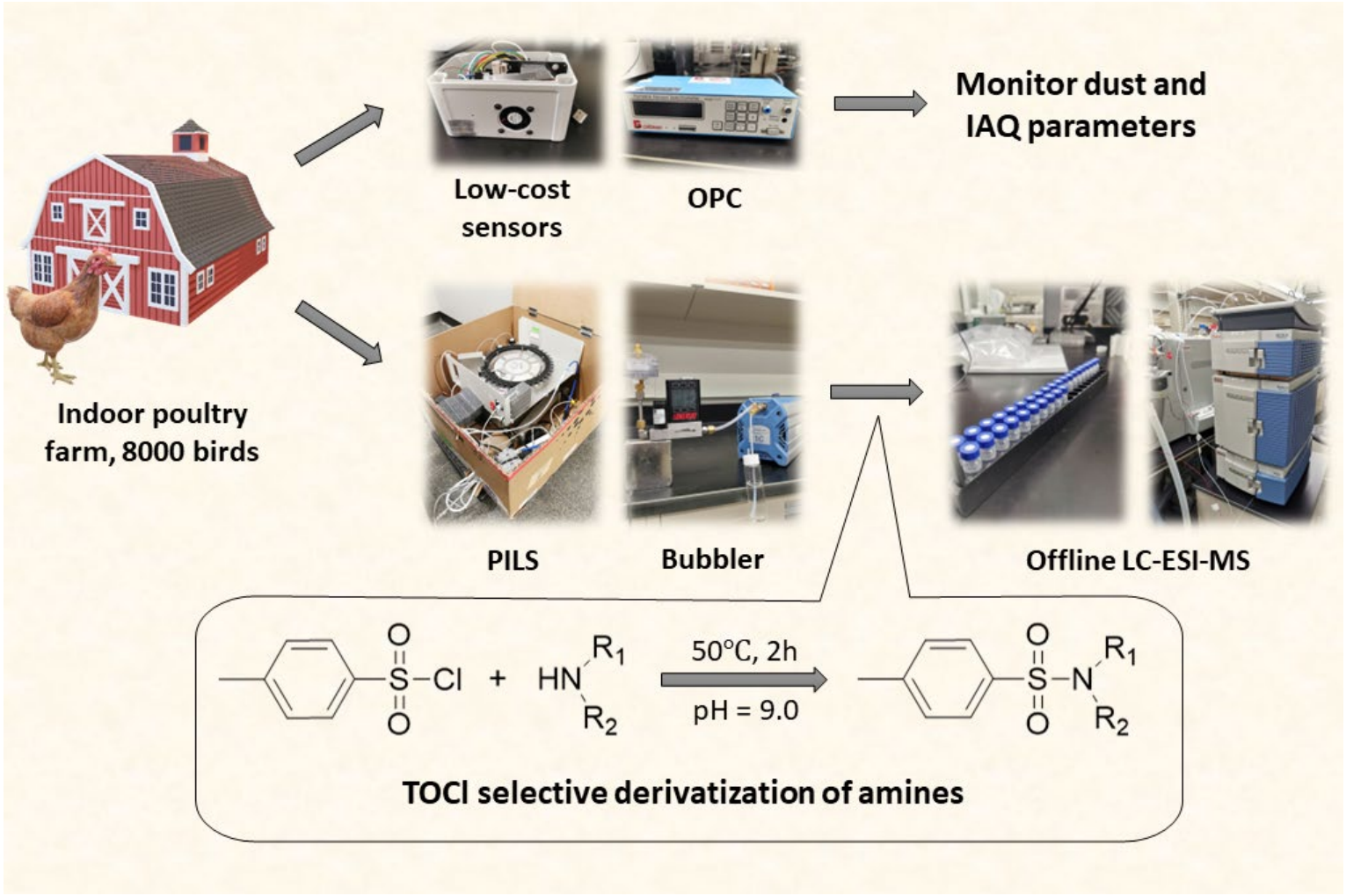
Objectives of Project 2

Overall: A better understanding of amines and amides in a layer facility (egg farm).

Specific:

- To develop a method to sample nitrogenous compounds in the gas, in PM, and in chicken litter.
- To develop a method to selectively detect nitrogenous compounds.
- Preliminary insights into their distribution in dust, air, and floor materials.

Sampling Method



Particle-into-liquid sampler (PILS)
Selectively collects particle-phase compounds.

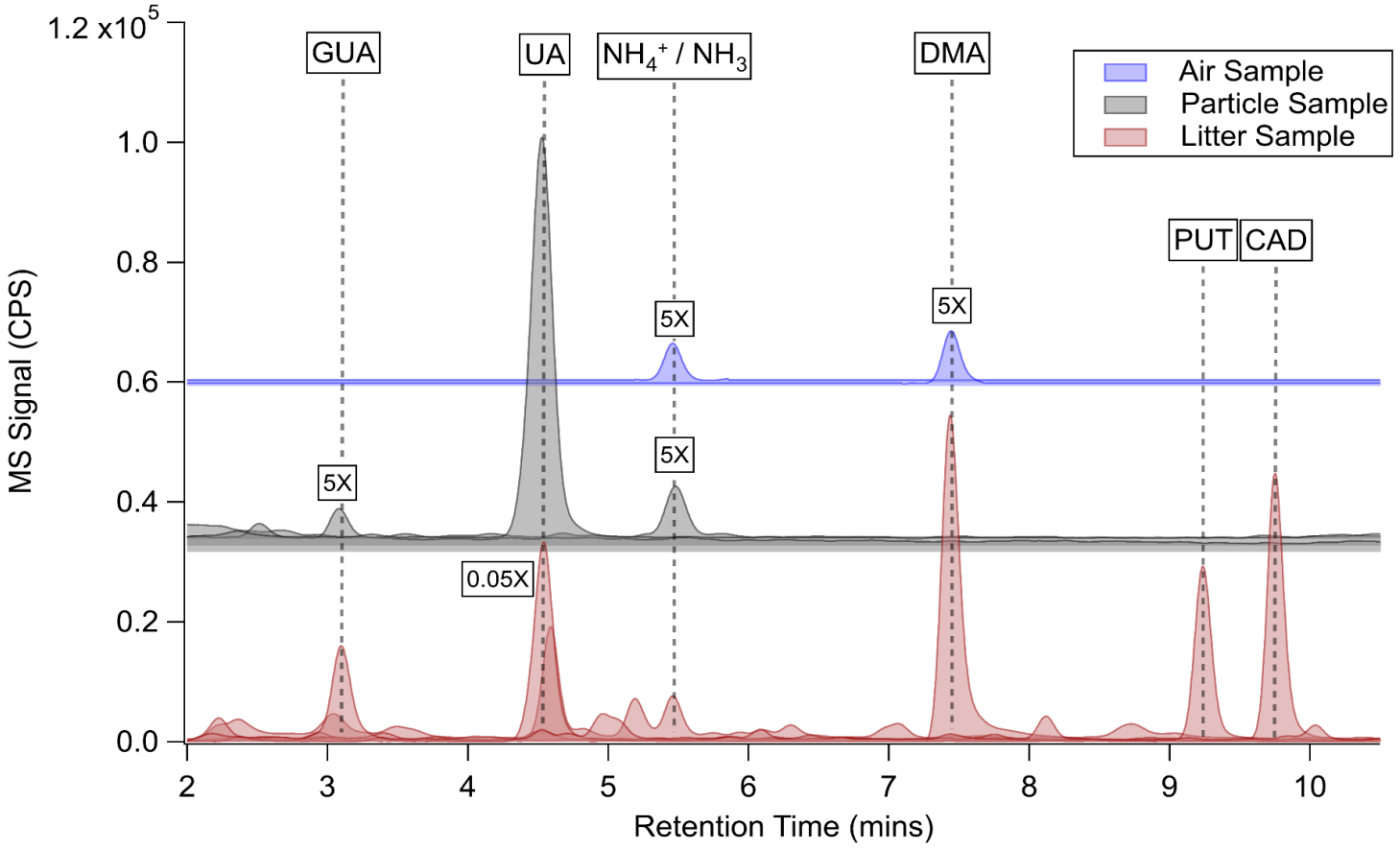
Bubbler, located downstream of a filter, collects gas-phase species.

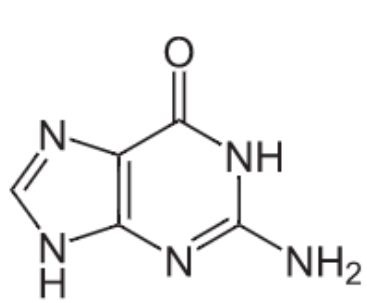
Chicken litter samples were collected on the farm floor.

p-Toluenesulfonyl chloride (TOCl)
Can selectively react with amines. [1]

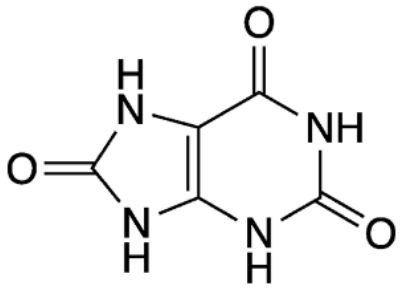
[1] Nalazek-Rudnicka, K., Wasik, A. *Monatsh Chem* **2017** 148, 1685–1696

Results - Distribution of Selected Species

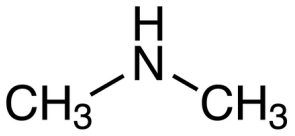




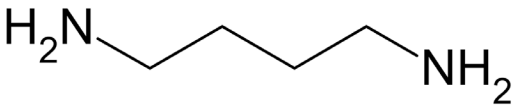
Guanine (GUA)



Uric acid (UA)



Dimethylamine (DMA)

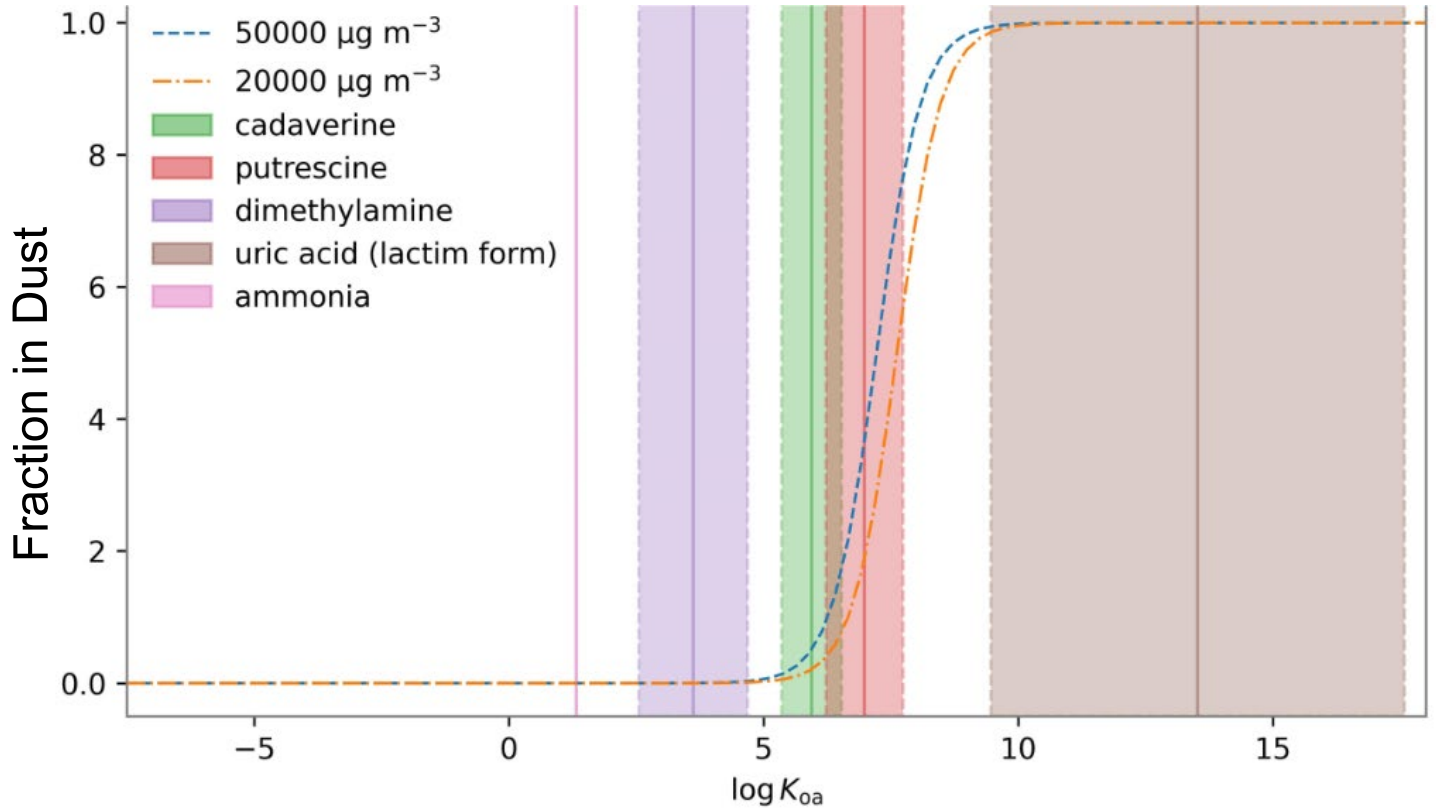


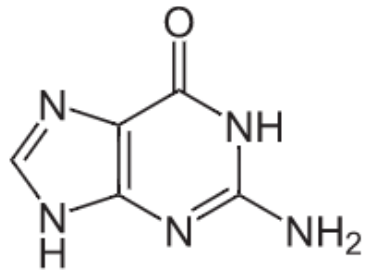
Putrescine (PUT)

Cadaverine (CAD)

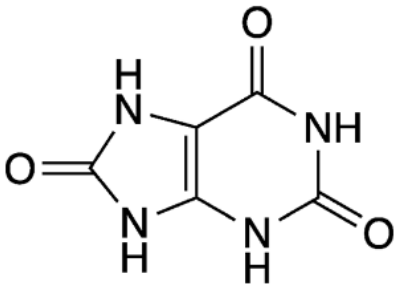
We observe distribution of chemicals between air and dust.
E.g. uric acid only present in dust; while dimethylamine only in air.

Why Some are in Air and Some are in Dust?

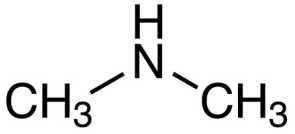




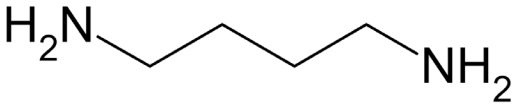
Guanine (GUA)



Uric acid (UA)



Dimethylamine (DMA)

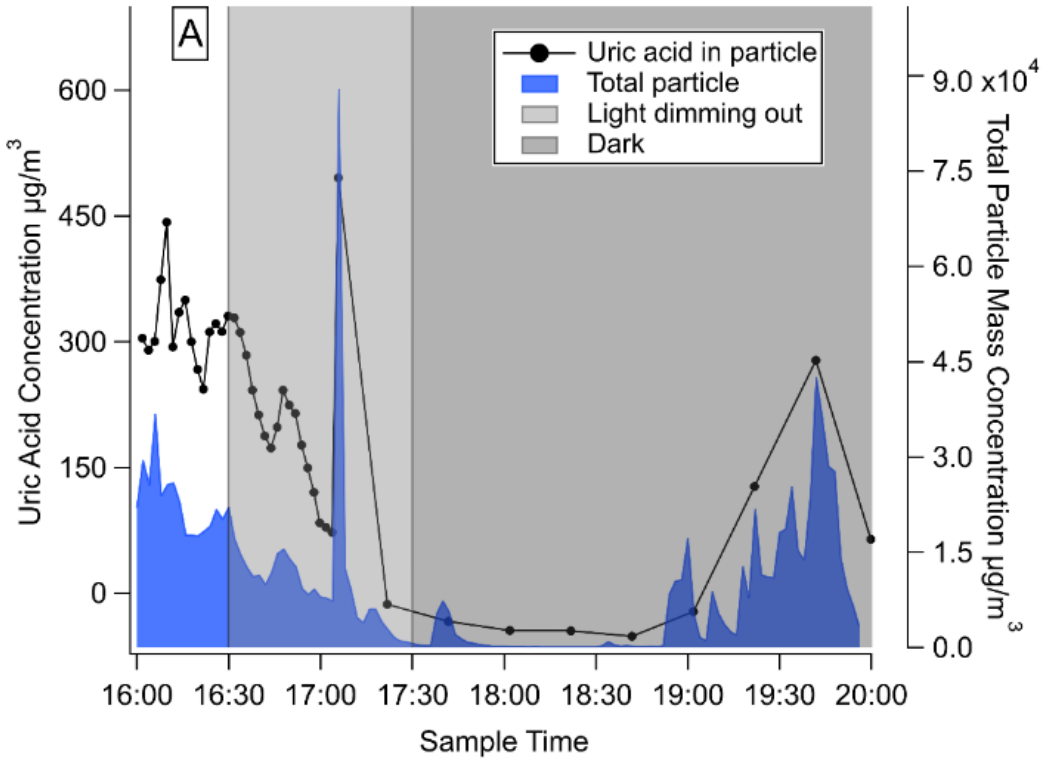


Putrescine (PUT)

Cadaverine (CAD)

- Using models, we confirmed that our observation is likely right.

Combining Project 1 and Project 2



- Bird activities and PM concentrations were affected by the lighting conditions.
- Particle-phase uric acid signal exhibited excellent correlation with PM concentration.
- ~1% of PM mass is comprised of uric acid.

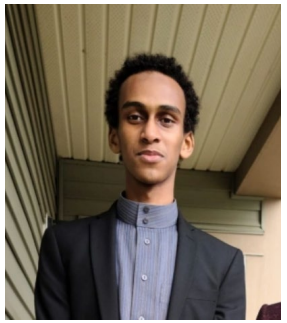
Preliminary Summary of Project 2 Thus Far

- Nitrogenous compounds are key part of nitrogen cycles in farms giving rise to NH_3 gas and malodors.
- My team has developed methods to monitor PM and its chemical compositions.
- Chemicals can re-distribute themselves between gas and PM.
- Those associated with PM will depend on bird activities.
- PM can be a carrier of NH_3 and other nitrogenous compounds.
- Certain chemicals can be controlled if we can control dust.

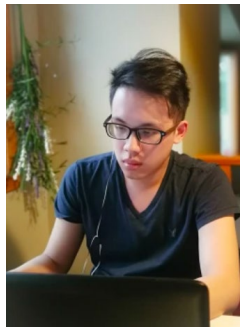
Acknowledgement

- Poultry Research Centre: Kerry Nadeau, Kim Thorsteinson, Chris Ouellette and others
- Poultry Innovation Partnership: Val Carney
- My Team
- **Producers**

Rowshon Afroz



Sohaib Omar



Wayne Cheng

Timothy Guo
Defending 2024

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