THINGY:

Introduction to Thingy:AQ

Building for the EPA Wildland Fire Sensors Challenge

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Oct 4, 2018

Wildland Fire Sensors Challenge

Thing 1 and 2

bca Backcountry Access

K2 SPORTS

ASIC

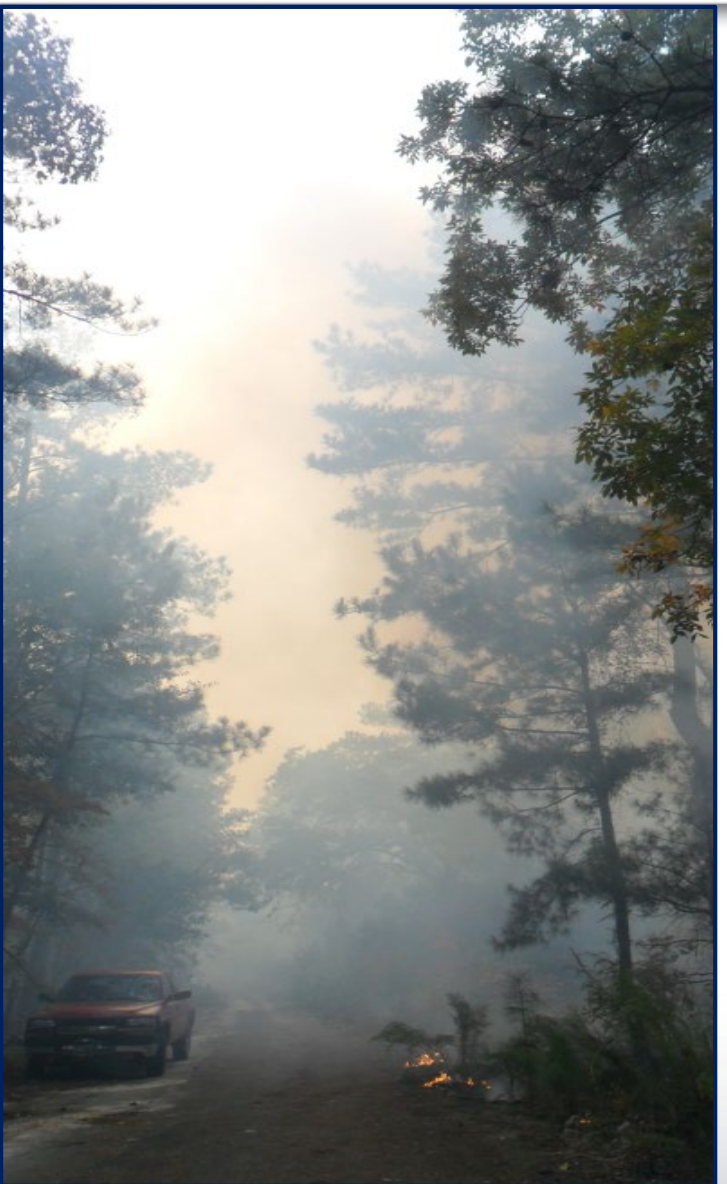
WASHINGTON STATE FIRE FIGHTERS' ASSOCIATION ™

ARE YOU BEEPING?

Microsoft®

Cisco Systems

Wildland Fire Sensor Challenge



Shared Vision by Partnering Organizations:

A desire to advance air measurement technology to be **easier to deploy**, suitable to use for **high concentrations observed during wildland fire events**, **durable** to withstand difficult field conditions, and report data **continuously and wirelessly**.

Desired Measurements:

$PM_{2.5}$, CO, CO_2, O_3.

Partnering Federal Organizations:

Our Solution

Utilize the latest in low-cost but pre-calibrated sensors that require no field calibration

SPEC SENSORS

SenseAir

Latest in LP-WAN and Narrowband LTE connectivity for the most difficult locations.

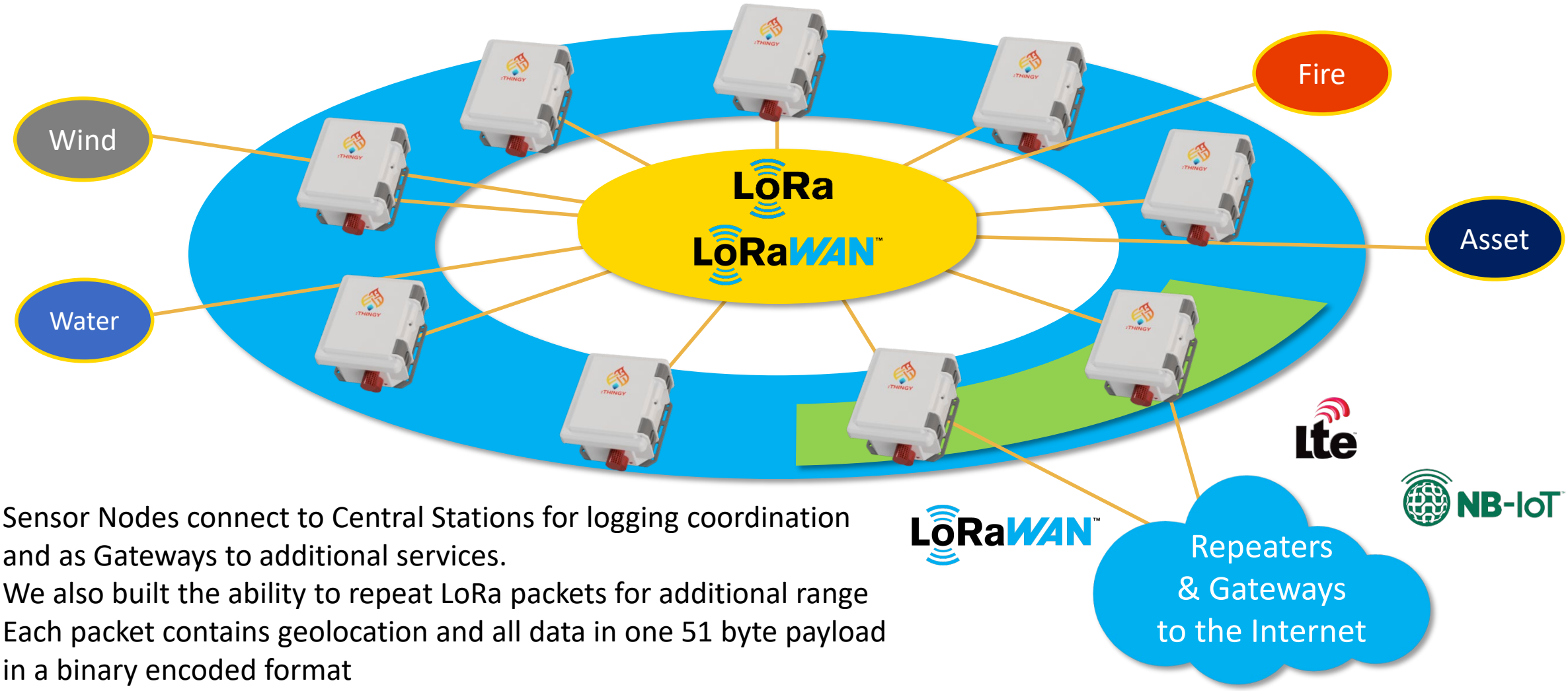
LoRaWAN

NB-IoT

Use our vast experiences in sensor networks, radio technologies, practical experiences in firefighting, and rapid innovation cycles.

Solving the Outdoor Telemetry Problem

We utilized LoRa operating in the unlicensed ISM band between 902MHz and 928MHz (915MHz center).



- Sensor Nodes connect to Central Stations for logging coordination and as Gateways to additional services.
- We also built the ability to repeat LoRa packets for additional range
- Each packet contains geolocation and all data in one 51 byte payload in a binary encoded format

Why LoRa?

Wildland Fires, aka Bush Fires, often occur in areas that lack communications infrastructure. There is little point in implementing a real-time monitoring and telemetry system solely dependent on a service providers GSM network if the service provider cannot guarantee ubiquitous coverage of the target area. The approach we have taken with Thingy:AQ uses LoRa (Long Range) telemetry from the sensor node to the central receiving site using LPWAN (Low Power Wide Area Network) protocols. LoRa is renowned for Long Range, Low Cost and Low Power consumption characteristics.

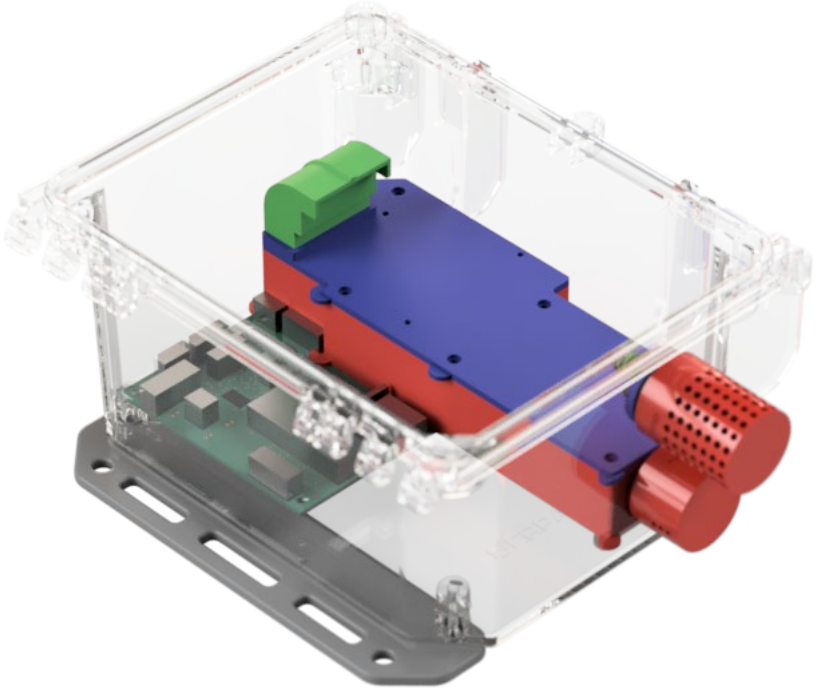
LoRa uses a spread spectrum modulation encoding data into chirps allowing signals to be recovered in extremely noisy RF environments. In the USA, LoRa operates in the unlicensed Industrial, Scientific and Medical (ISM) radio band between 902MHz and 928MHz. In remote areas, free from external noise sources, LoRa achieves line of sight distances with recorded cases of distances achieved of more than 200Km. Realistically however obstacles in the path will seriously attenuate and/or completely absorb / reflect the signal. More typical distances achieved are 15Km in the rural areas and 5Km in urban regions.

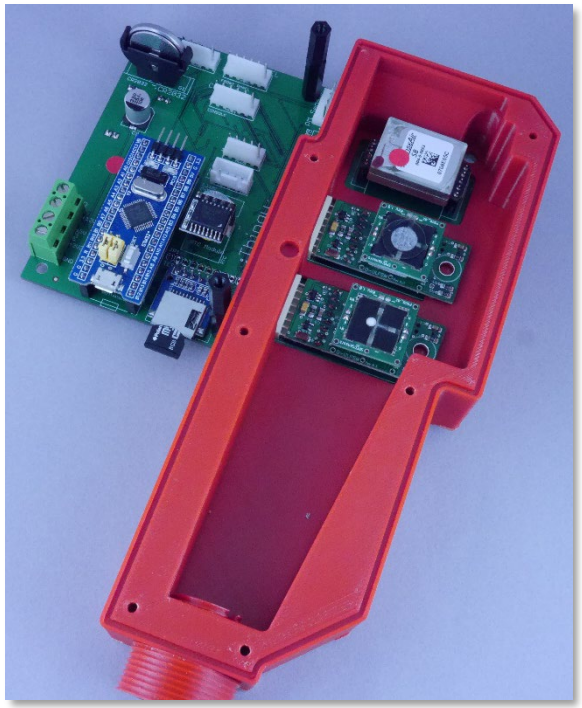
Significantly greater distances can be achieved by deploying strategically positioned LoRa radio repeaters. A single repeater on a hill top will greatly enhance the coverage area and range. By deploying repeaters on multiple hill tops, a single transmission from a sensor node can be received and repeated by multiple repeaters along the signal path. This architecture delivers a higher availability solution supporting multiple paths or even a meshed path between the sensor node and the central receiving station. The very low power consumption of this long range radio telemetry system means that very low cost, light weight, battery power repeaters can be readily and easily deployed. Thingy:AQ has been implemented using this architecture. When a packet is received by repeater node's radio and the central receiving site's radio, the packet is inspected to determine if this specific packet has already been received, if so this duplicate packet is discarded, otherwise it is forwarded or processed.

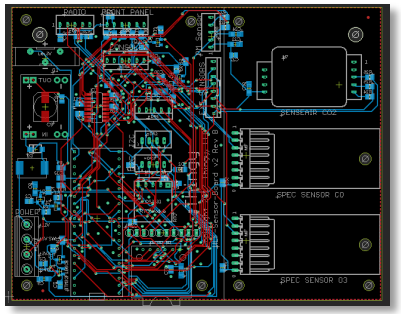
Building to our Requirements

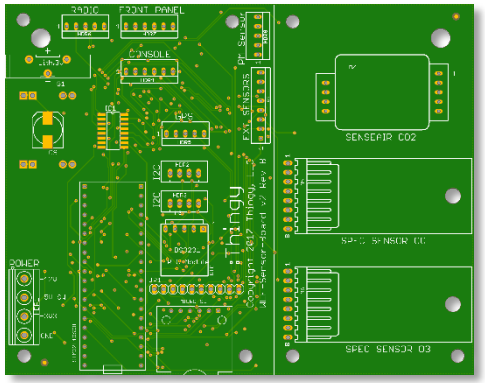
1. Lightweight and easily deployable air pollution monitoring solution that can be deployed permanently or during a fire event.
2. Utilize the latest in low-cost but pre-calibrated sensors that require no field calibration
3. Supports multiple sensor nodes and a central gateway + receiving unit
4. Communications between the Gateway and the Sensor utilize LoRa Technology
5. Easy to plug into an existing LoRa or LoRaWAN infrastructure and offers a network solution to serve other battery-operated IoT applications like weather stations.
6. Fully autonomous and solar powered.
7. Firefighter Proof

Rapid Design to Functional Prototype









“The Spider Filter”

Rapid changing of external filters in harsh conditions

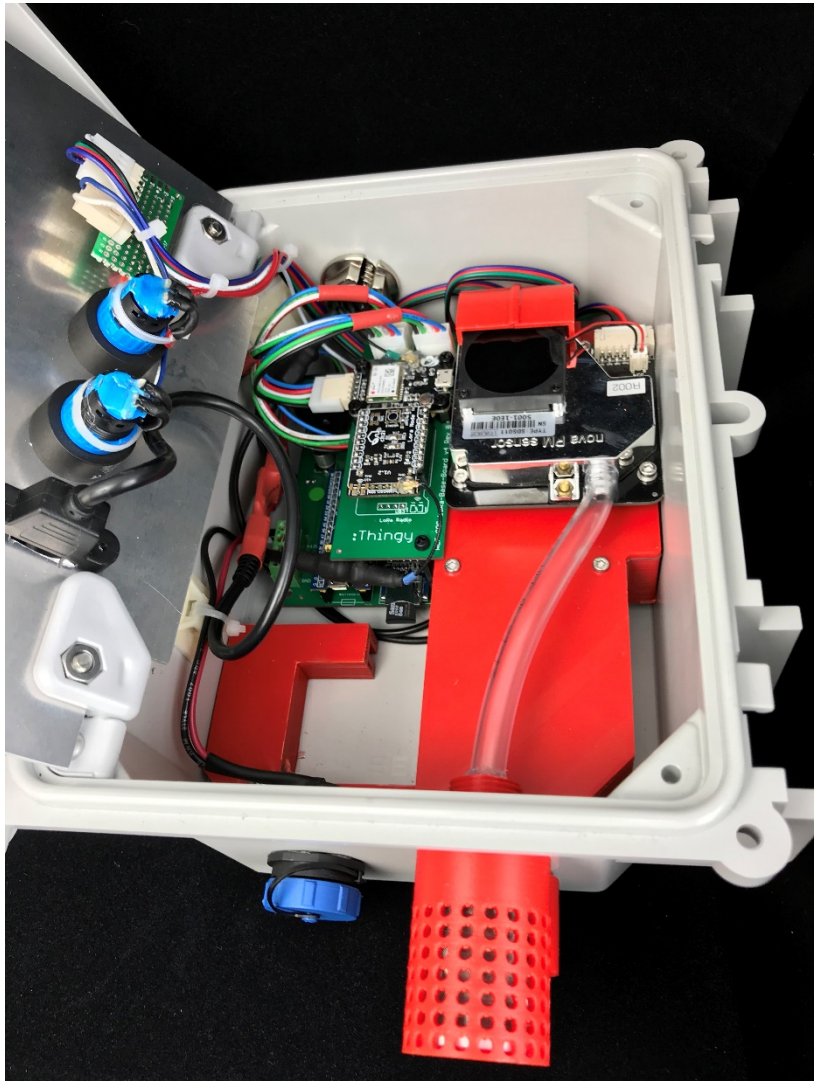
Inlet:

- 2.5MM outer housing
- 180um SS screen filter
- 80um inner filter

Exhaust

- 2.5MM outer housing
- 180um SS screen filter

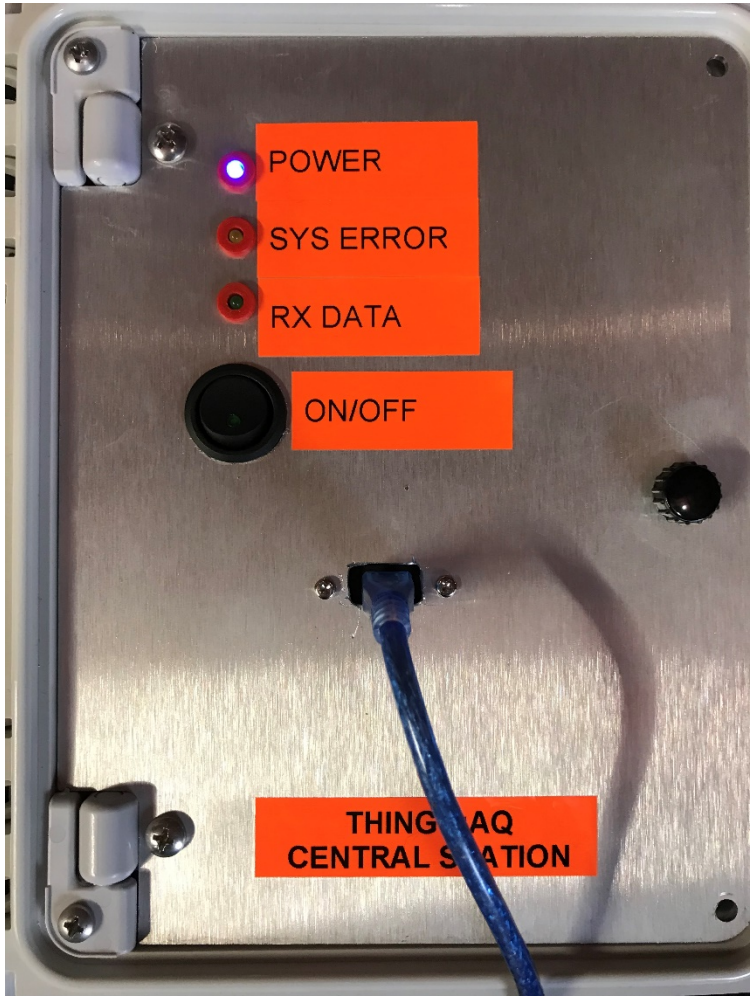
Finished Sensor Node Sent to EPA



Central Station / Gateway

Rapid 16’ Tripod Setup

Solar Options



Firefighter Proof

Thingy:AQ Specifications

Radio Options:

LoRa (915MHz)
LTE-M (Cat-M1)
NB-IoT (Cat-NB1)
GPRS/2G/3G

System:

ARM Cortex CPU
MicroSD for local storage
Active GPS
Dual Real-time Clocks + GPS time
I2C, Analog, Digital I/O
Bluetooth/Serial/USB for control/uploads

Sensor Packages:

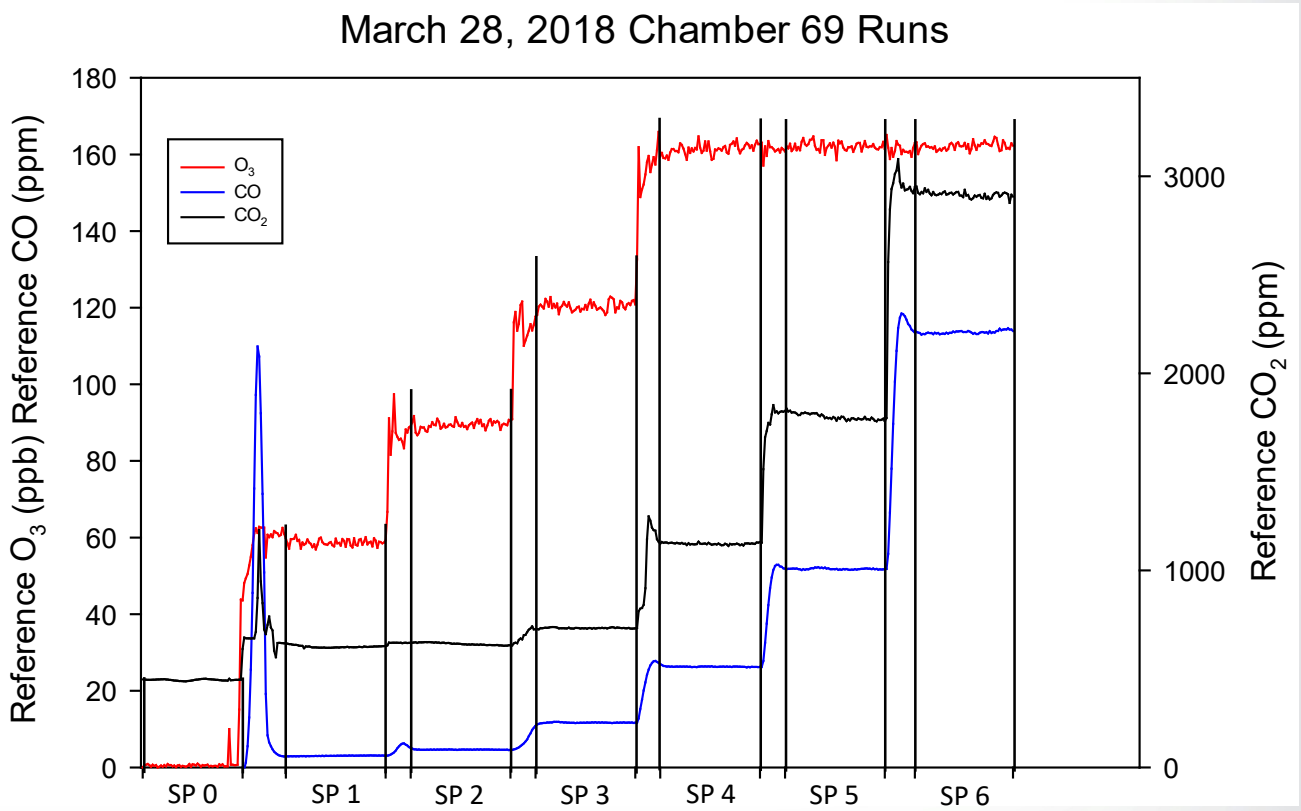
PM 2.5/10
CO/CO2
O3/NO2
Temp + RH (Per sensor)

Parameter	Technology	Range	Resolution	Accuracy
PM 2.5	Fan Aspirated, laser scattering, optical processing for particulate sizing and yield	0.0 to 999.9µg/m3	0.3µg/m3	Maximum of 15% or reading and ± 10µg/m3 (25DegC, 50%RH)
PM 10	Fan Aspirated, laser scattering, optical processing for particulate sizing and yield	0.0 to 999.9µg/m3	0.3µg/m3	Maximum of 15% or reading and ± 10µg/m3 (25DegC, 50%RH)
CO	ElectroChemical	0 to 1000ppm	0.1 ppm	15% of reading
CO2	Non-dispersive Infrared (NDIR)	400 to 5000ppm	1ppm	± 30ppm ± 3% of reading
O3	ElectroChemical	0 to 5 ppm	20ppb	15% of reading
Temp Deg C	Solid State sensor	-99 to +99	0.1	± 1 Deg C
Humidity RH	Solid State sensor	0 to 99%	0.1%	± 3% RH (max), 0–80% RH

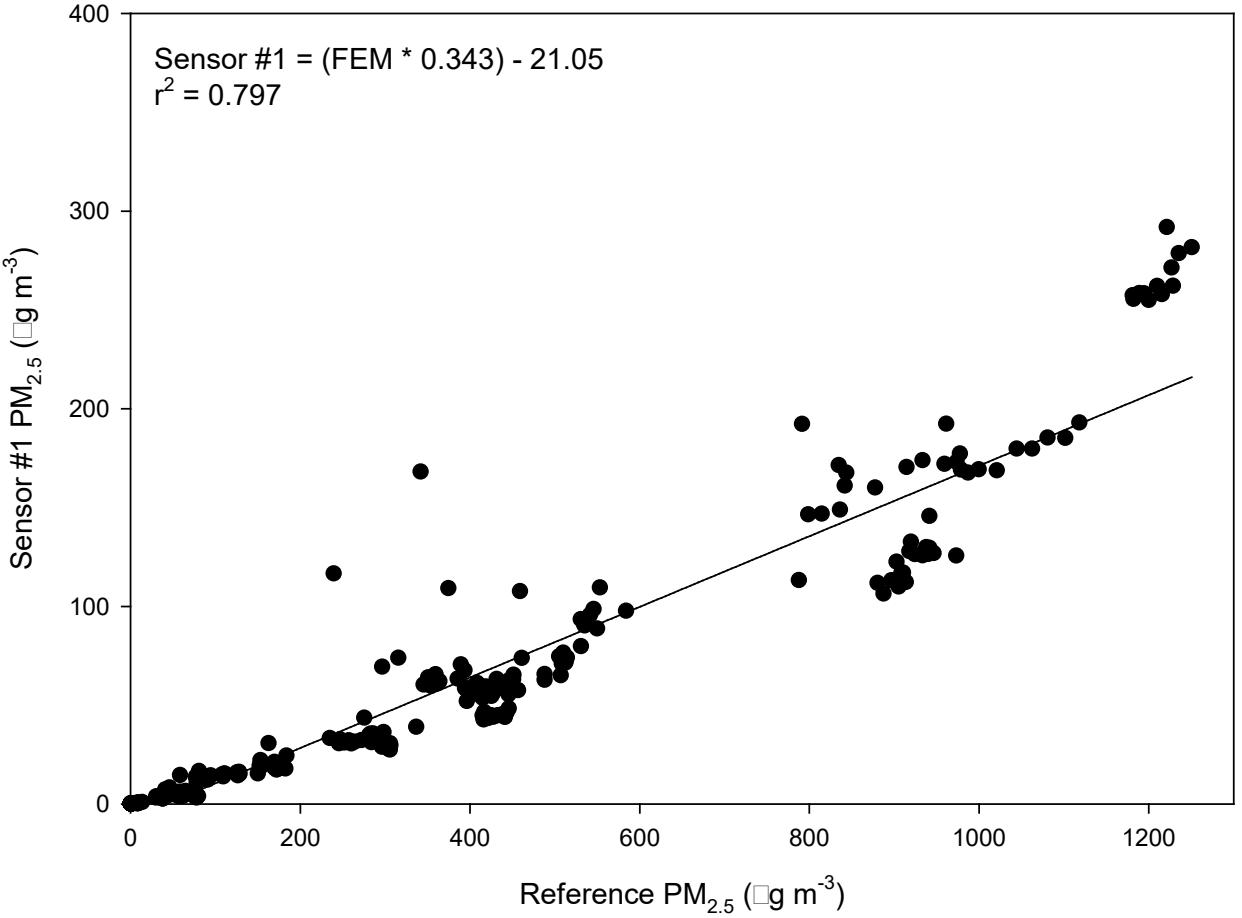
Phase I Testing – USEPA Chapel Hill Human Studies Facility

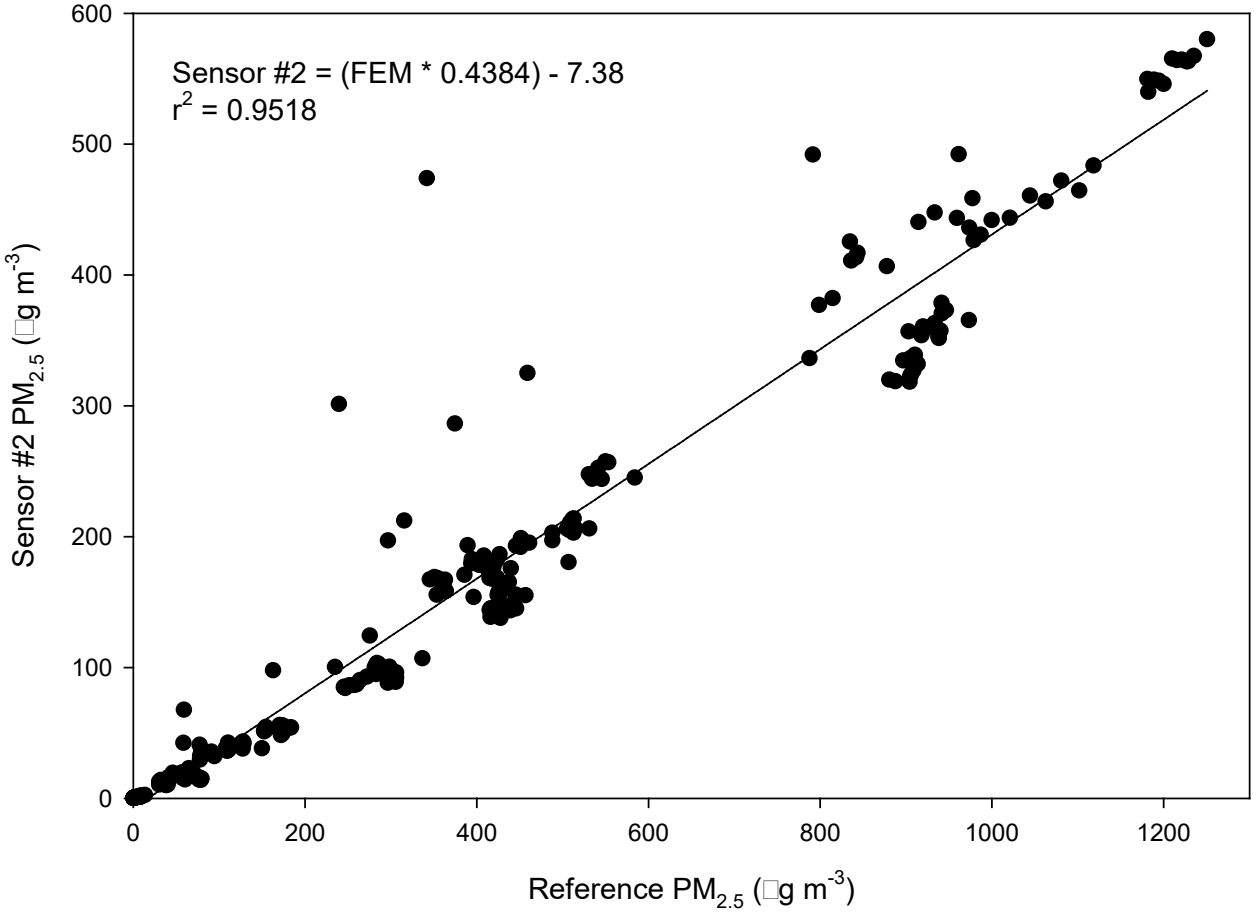
Phase I Sensor Testing Parameter Matrix

Parameter	Zero	Set Point 1	Set Point 2	Set Point 3	Set Point 4	Set Point 5	Set Point 6
$PM_{2.5}$ (µg m^{-3})	0	30	100	250	500	800	1200
CO (ppm)	0	3	5	10	25	50	100
CO_2 (ppm)	0	500	550	700	1100	1800	3000
O_3 (ppb)	0	60	90	120	160	160	160



Thingy:AQ Phase I $PM_{2.5}$ Testing Results – Scatter Plots





Roadmap and Plans

Q4 CY18 – *EPA Challenge Feedback and Applying Lessons Learned*

- Next Gen board design – focus on I2C, radios, air chamber re-design
- New modular air chamber for Gas sensors (SS-304)
- Adding NO2 sensor
- TSI conductive tubing for PM inlet path
- LTE radio enablement – GPRS, NB-IoT, LTE-M
- Testing Nova SDS and Plantower PM sensors in parallel
- Colocation testing with local FEM/FRM and eBAM at North Bend FTC
- User Offset and Span

Q1 CY19 – *Focus on Data Access and Production*

- LoraWAN connectivity to The Things Network
- AWS and Azure cloud connectivity
- Fireground data presentation/management tablet
- Sharing data (EPA Air Sensors Toolbox, AirSense, etc)

EPA and USFS Testing Results

(Provided by the EPA)

Challenge: Target Measurements

- Large measurement range targets were identified for all parameters due to the dynamic concentration levels that may be experienced
- Each node was required to provide geo-location (latitude and longitude) information along with measurement data
- Solvers were not be disqualified if these targets were not met – the target ranges were considered as goals

Pollutant	Target lower / upper detection limit
$PM_{2.5}$	10 / 1500 µg m^{-3}
CO	1 / 500 ppm
O_3	20 / 200 ppb
CO_2	350 / 10,000 ppm

Metric	Target
Accuracy	20%
Linearity	20%
Precision	20%
Calibration Error	10%
Operability / Durability	Qualitative

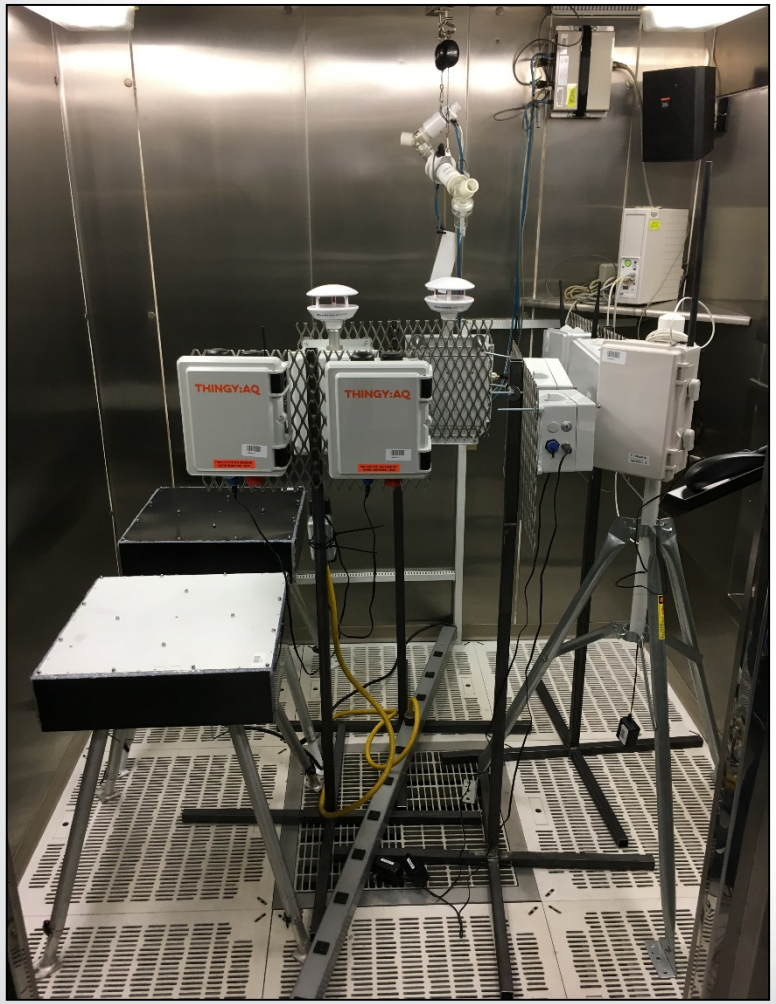
Thingy:AQ Submission

As Received

As Tested

Wildland Fire Sensor Challenge

Phase I Testing – USEPA Chapel Hill Human Studies Facility



- Well Characterized Human Exposure Research Chambers
  - Purified Conditioned Air (Purafil, Purocol, Hopcalite)
- Testing in Chamber 77 Conducted March 20 – 27, 2018
  - 4000 CFM Single Pass
  - Inject/Blend O_3 & NO_2 Interferent
- Testing in Chamber 69 Conducted March 28 – April 2, 2018
  - 550 CFM Single Pass
  - Inject/Blend $CO/CO_2/O_3/PM_{2.5}$ (Ammonium Sulfate)

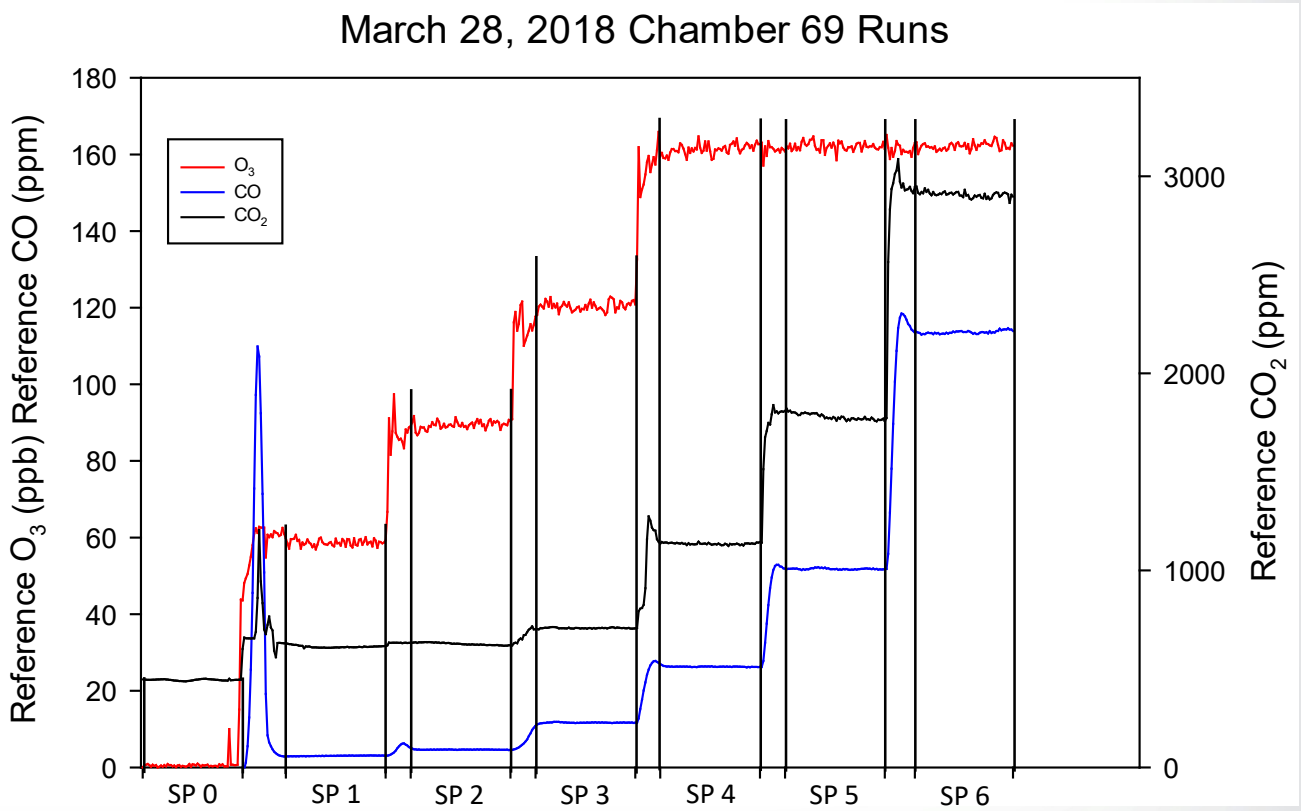
Phase I Sensor Testing Meteorological Parameter Matrix

Parameter	Set Point 1	Set Point 2	Set Point 3	Set Point 4
Temperature (°C)	15	15	30	30
Relative Humidity	20	40	20	40

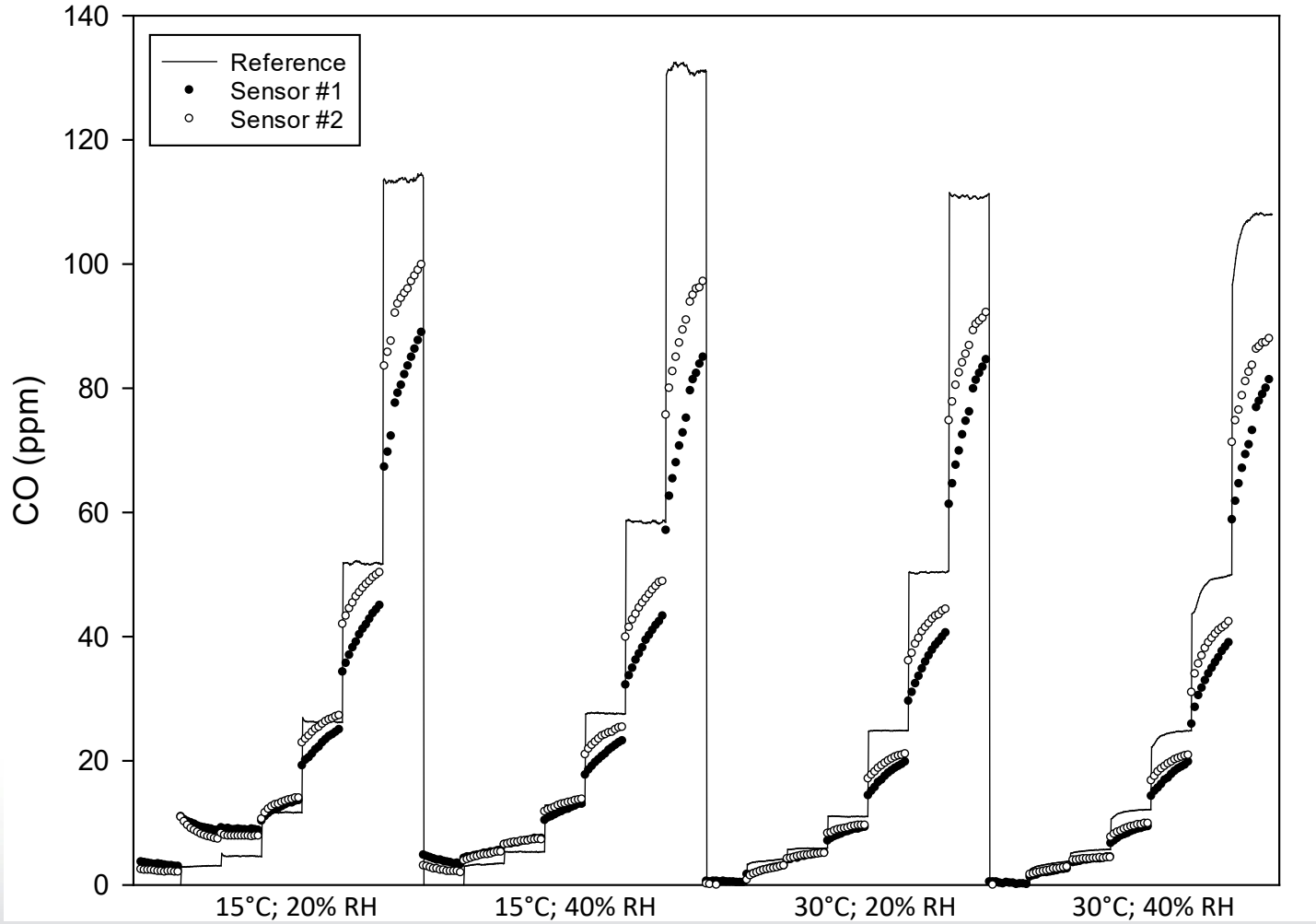
Phase I Testing – USEPA Chapel Hill Human Studies Facility

Phase I Sensor Testing Parameter Matrix

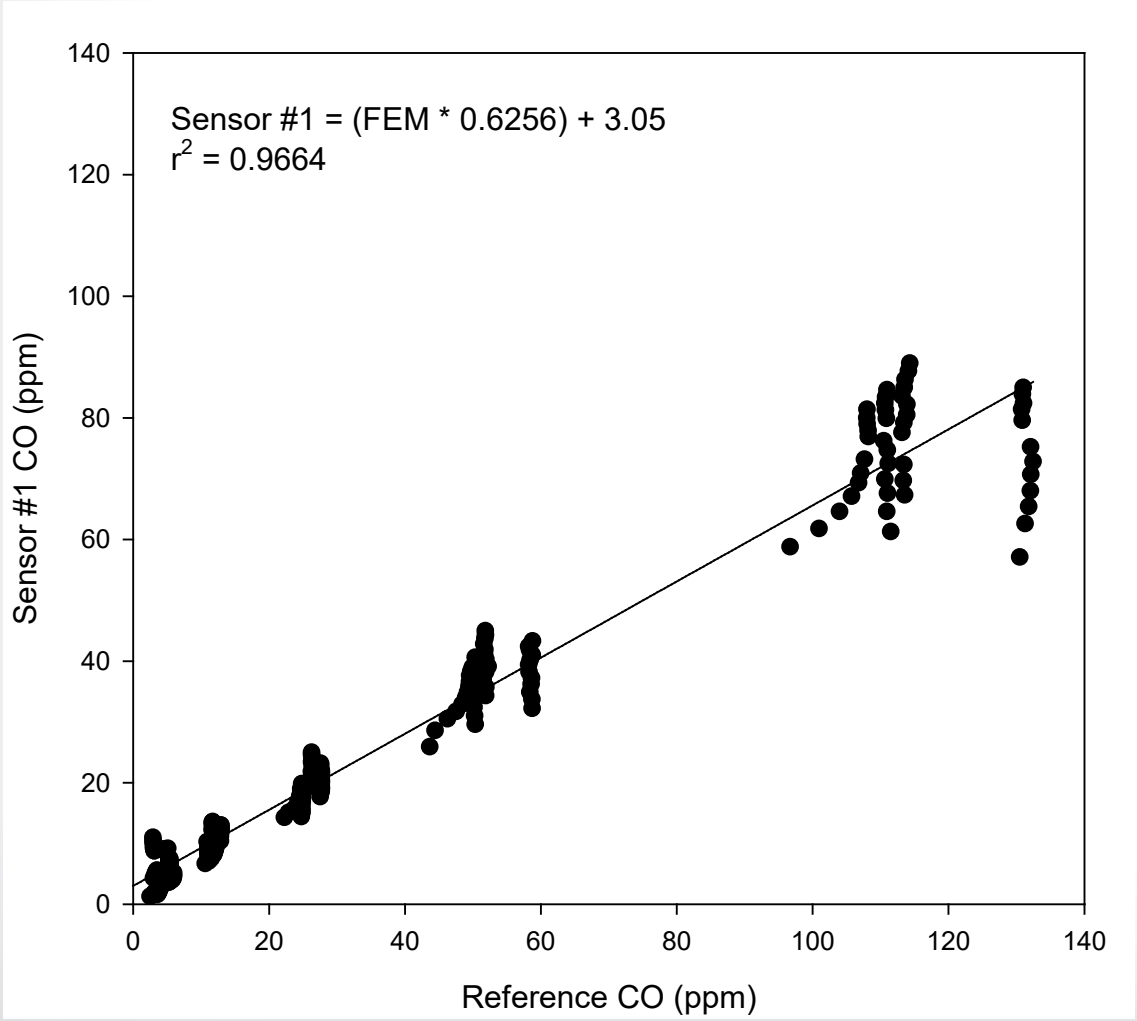
Parameter	Zero	Set Point 1	Set Point 2	Set Point 3	Set Point 4	Set Point 5	Set Point 6
$PM_{2.5}$ (µg m^{-3})	0	30	100	250	500	800	1200
CO (ppm)	0	3	5	10	25	50	100
CO_2 (ppm)	0	500	550	700	1100	1800	3000
O_3 (ppb)	0	60	90	120	160	160	160

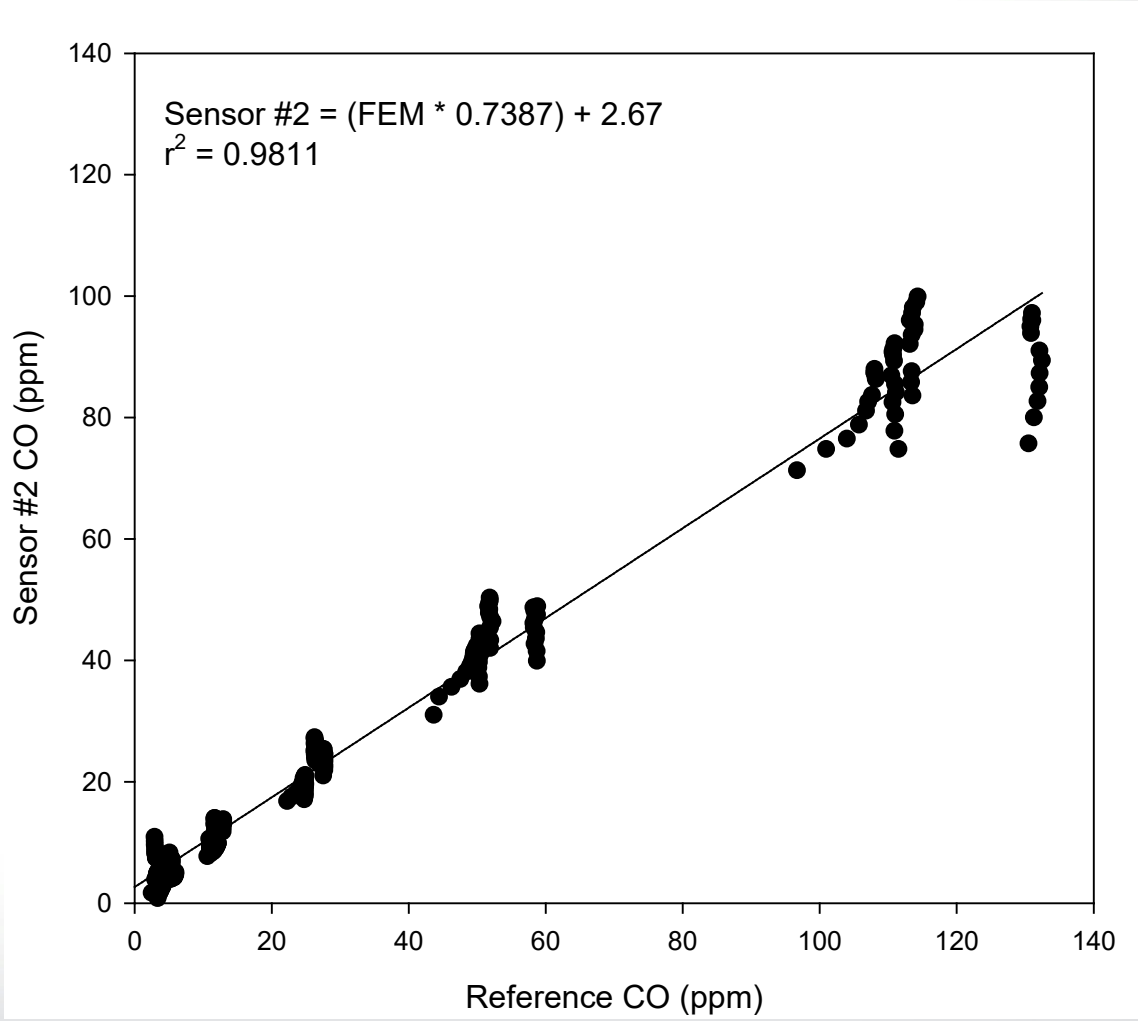


Thingy:AQ Phase I CO Testing Results – Time Series

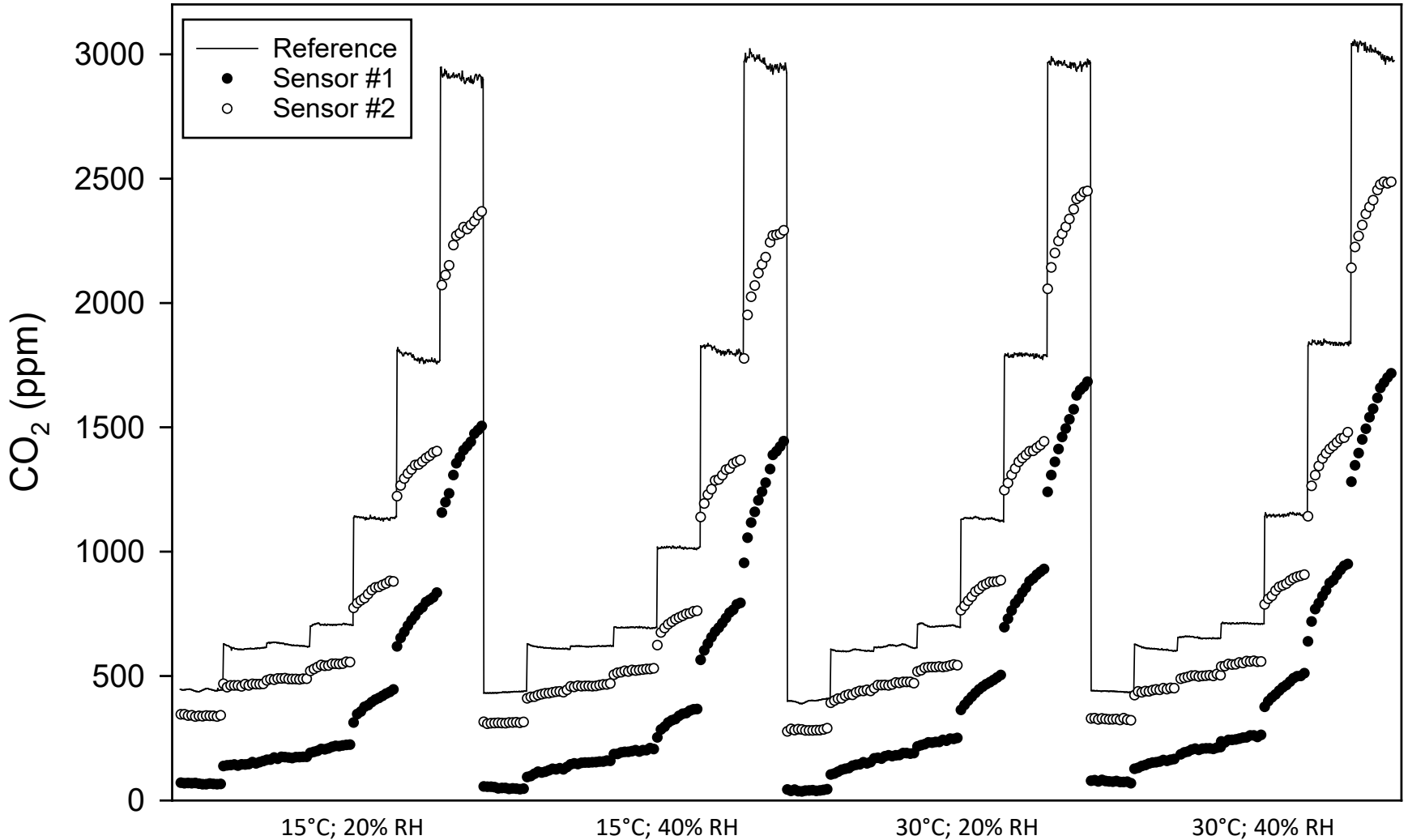


Thingy:AQ Phase I CO Testing Results – Scatter Plots

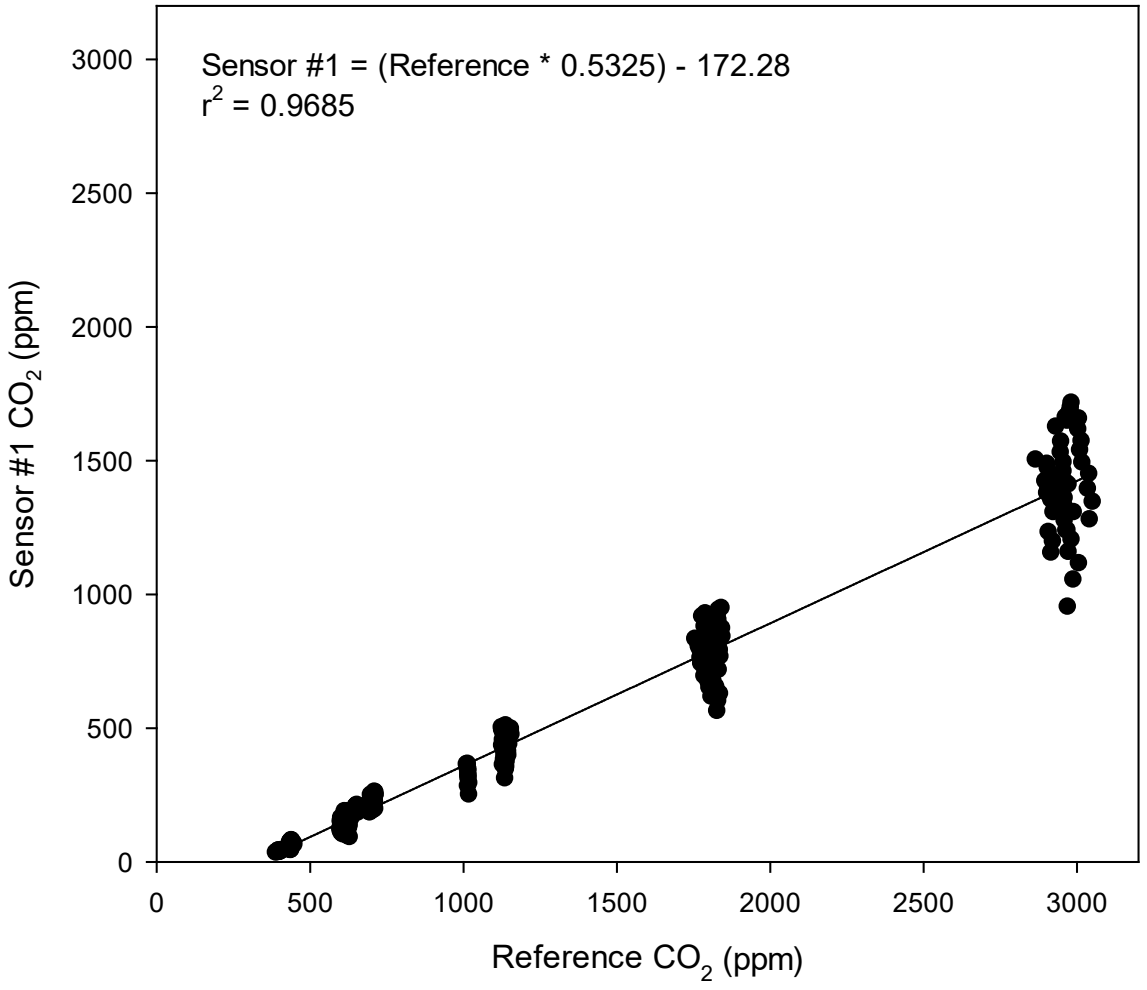


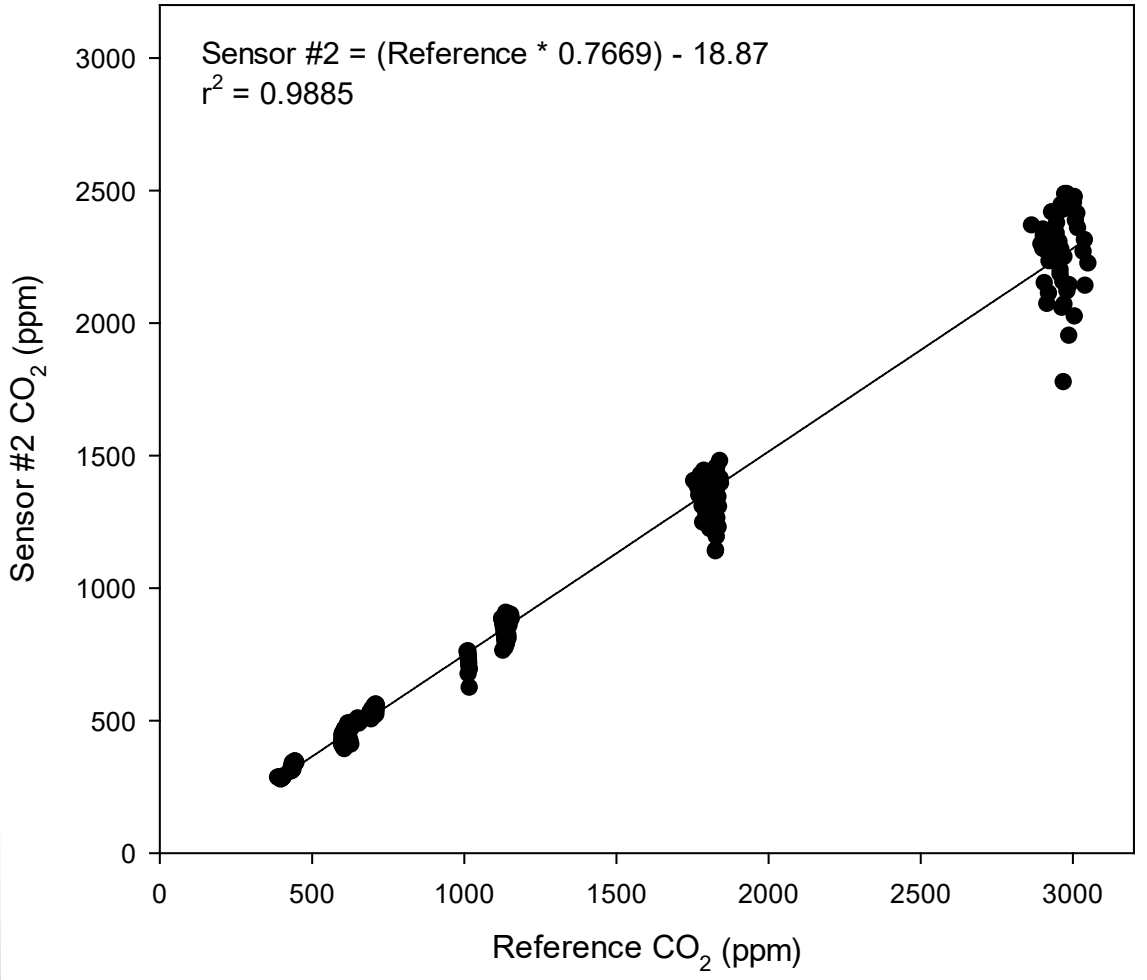


Thingy:AQ Phase I CO_2 Testing Results – Time Series



Thingy:AQ Phase I CO_2 Testing Results – Scatter Plots





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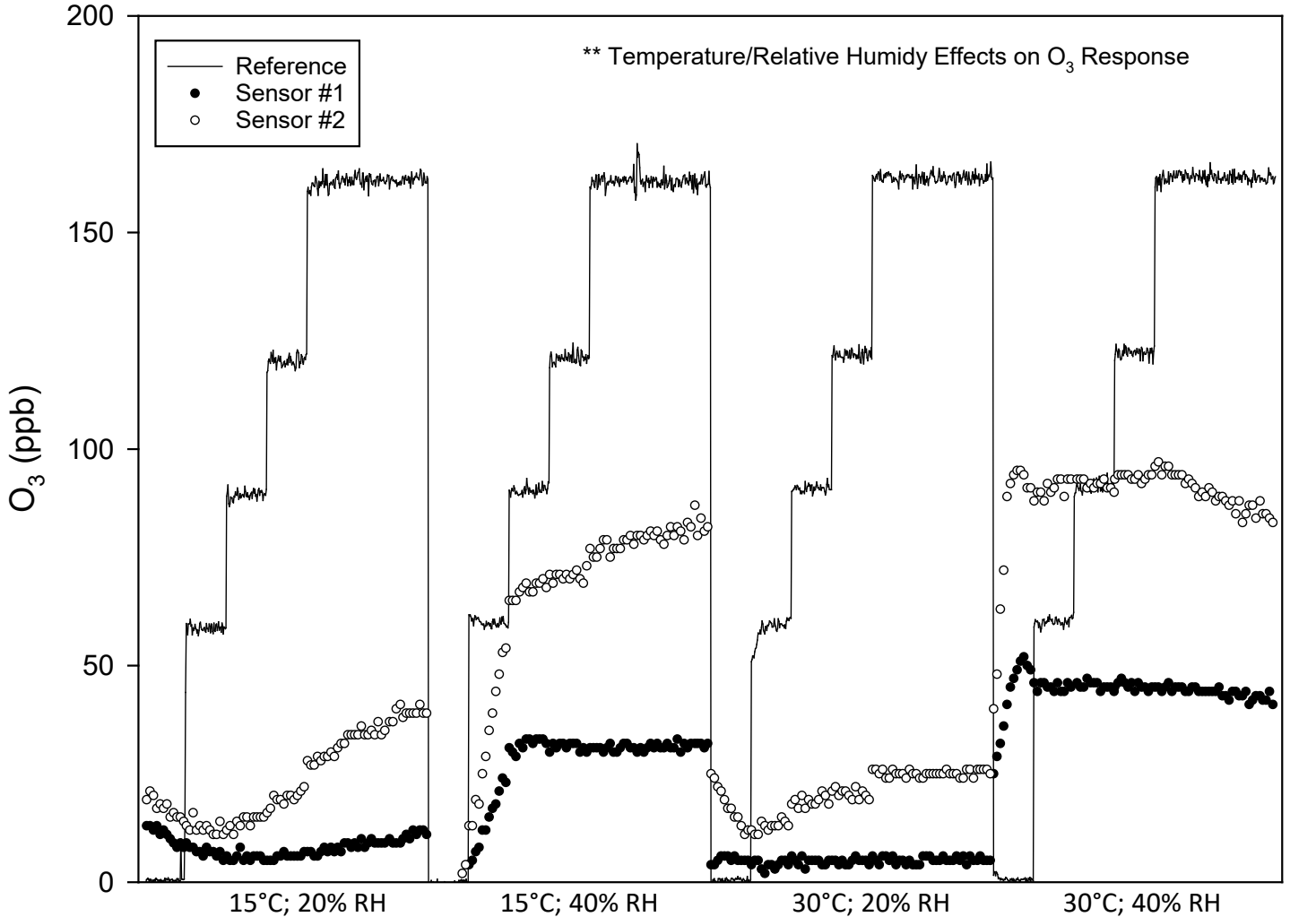

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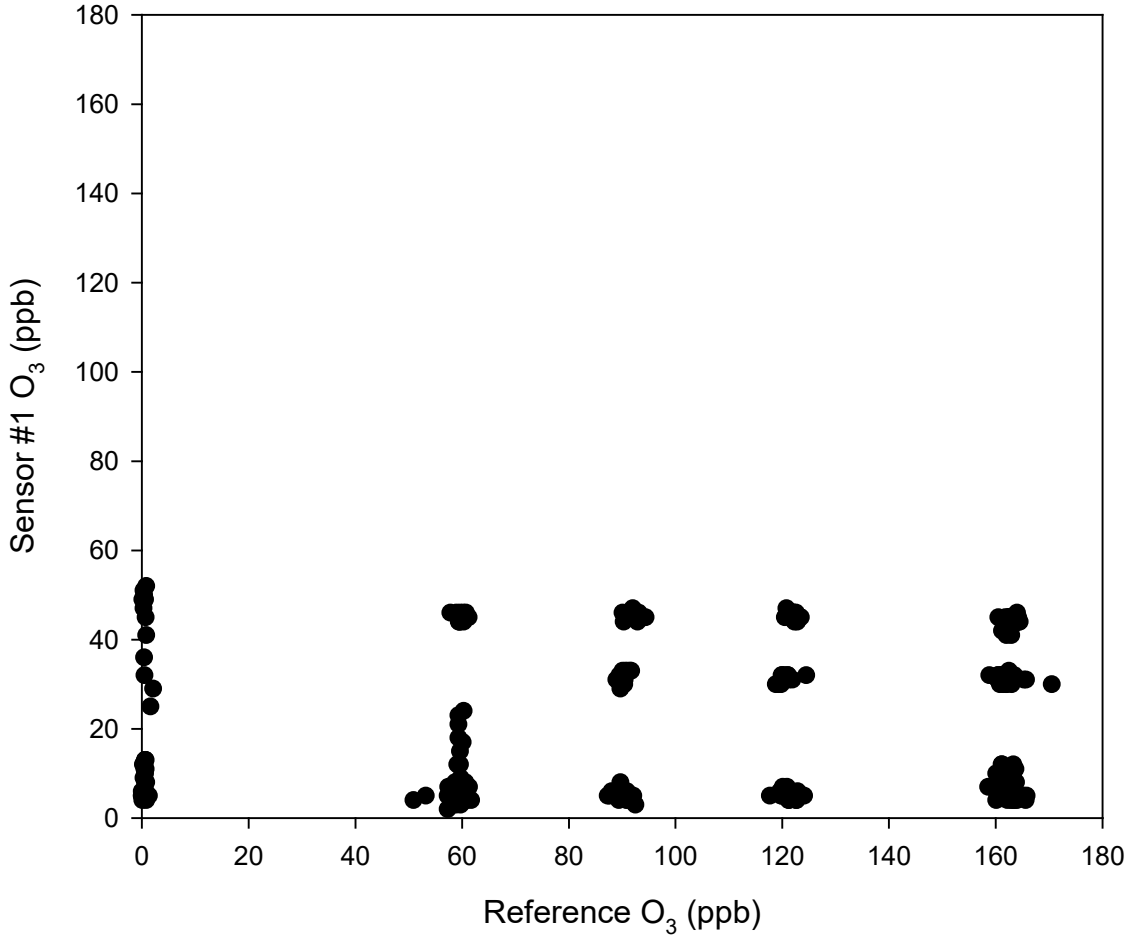
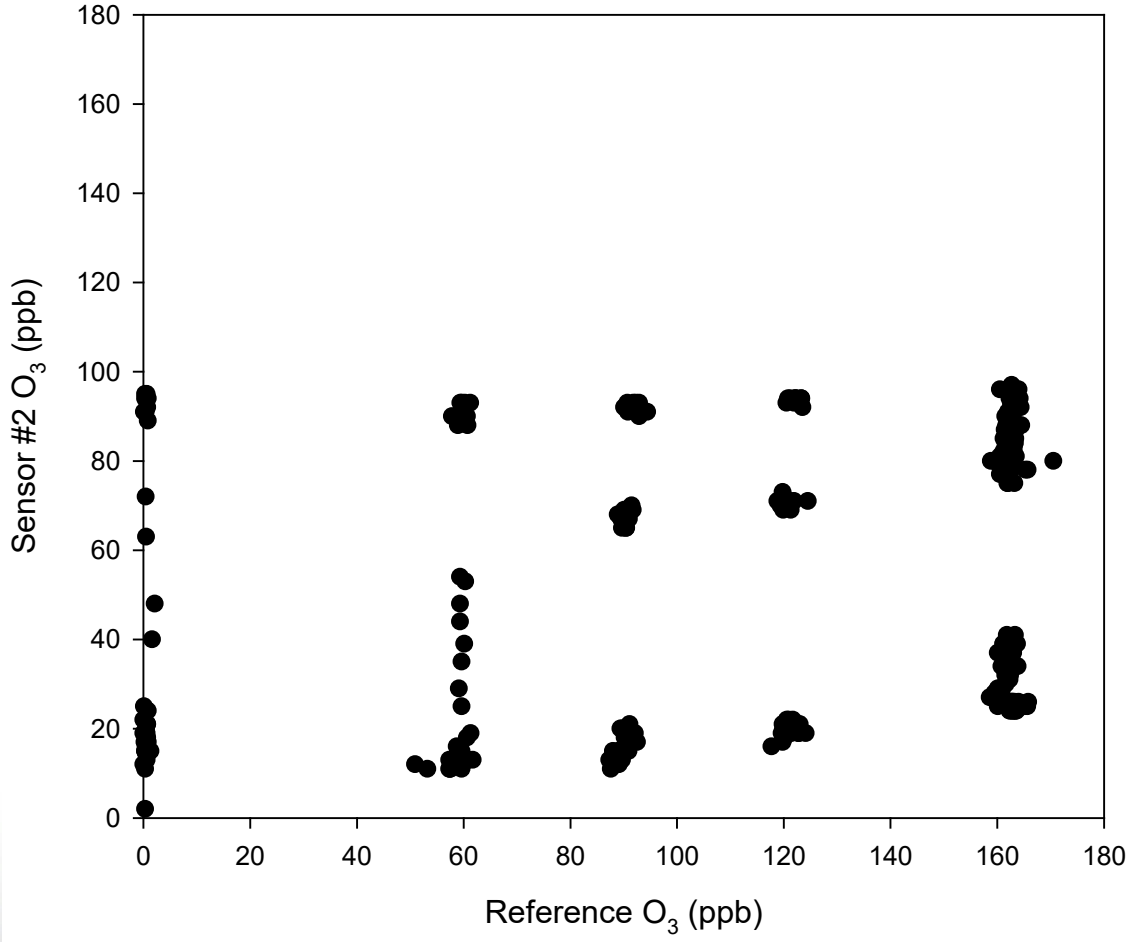
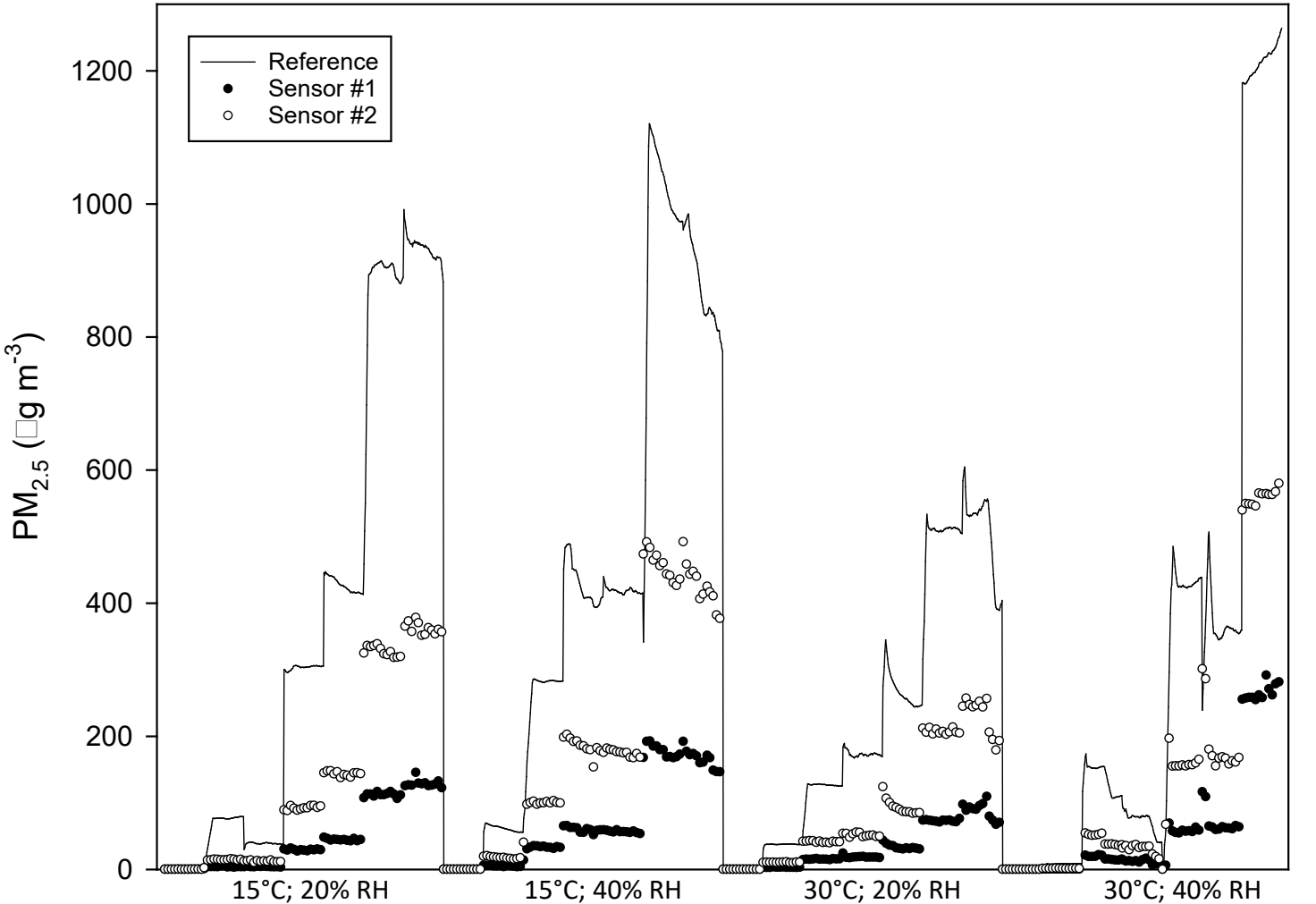
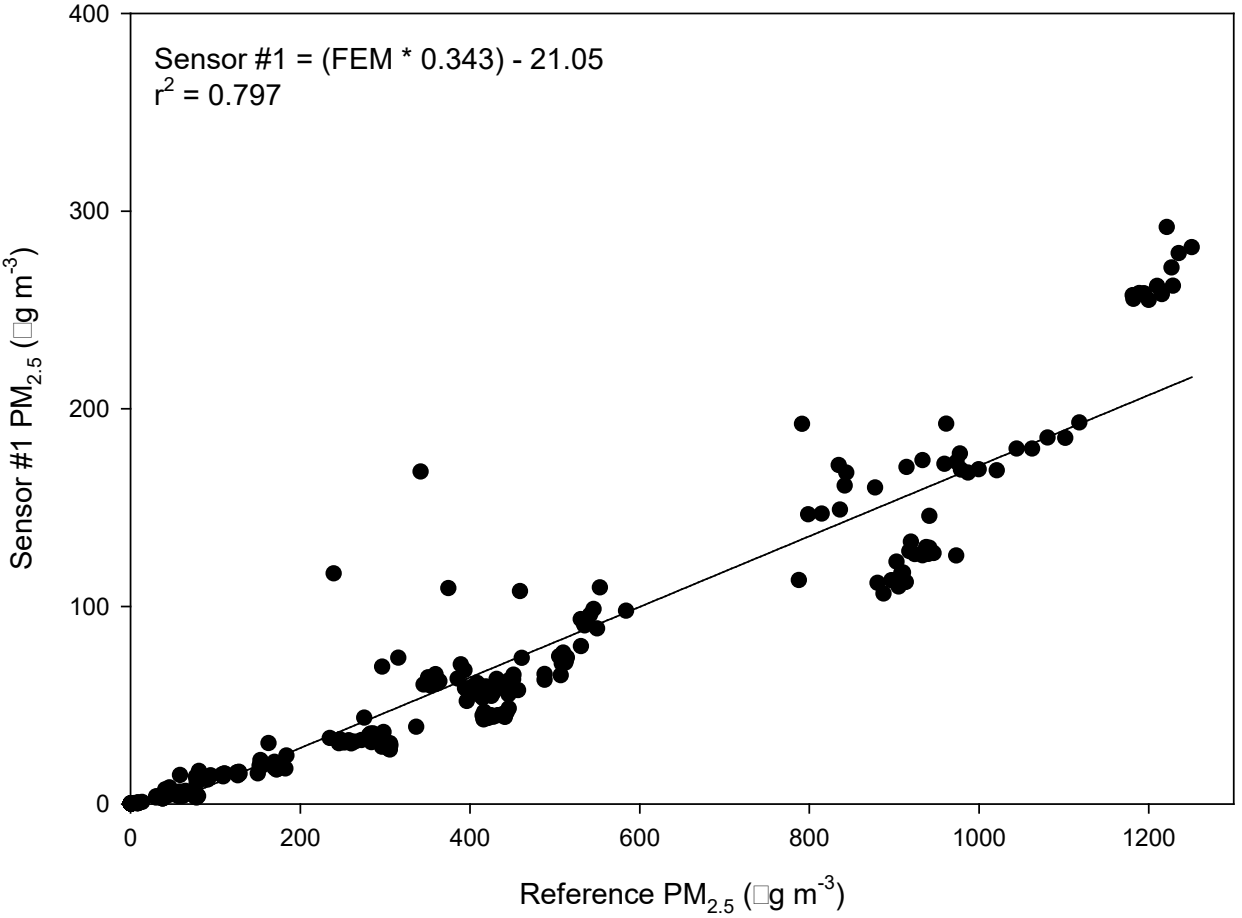


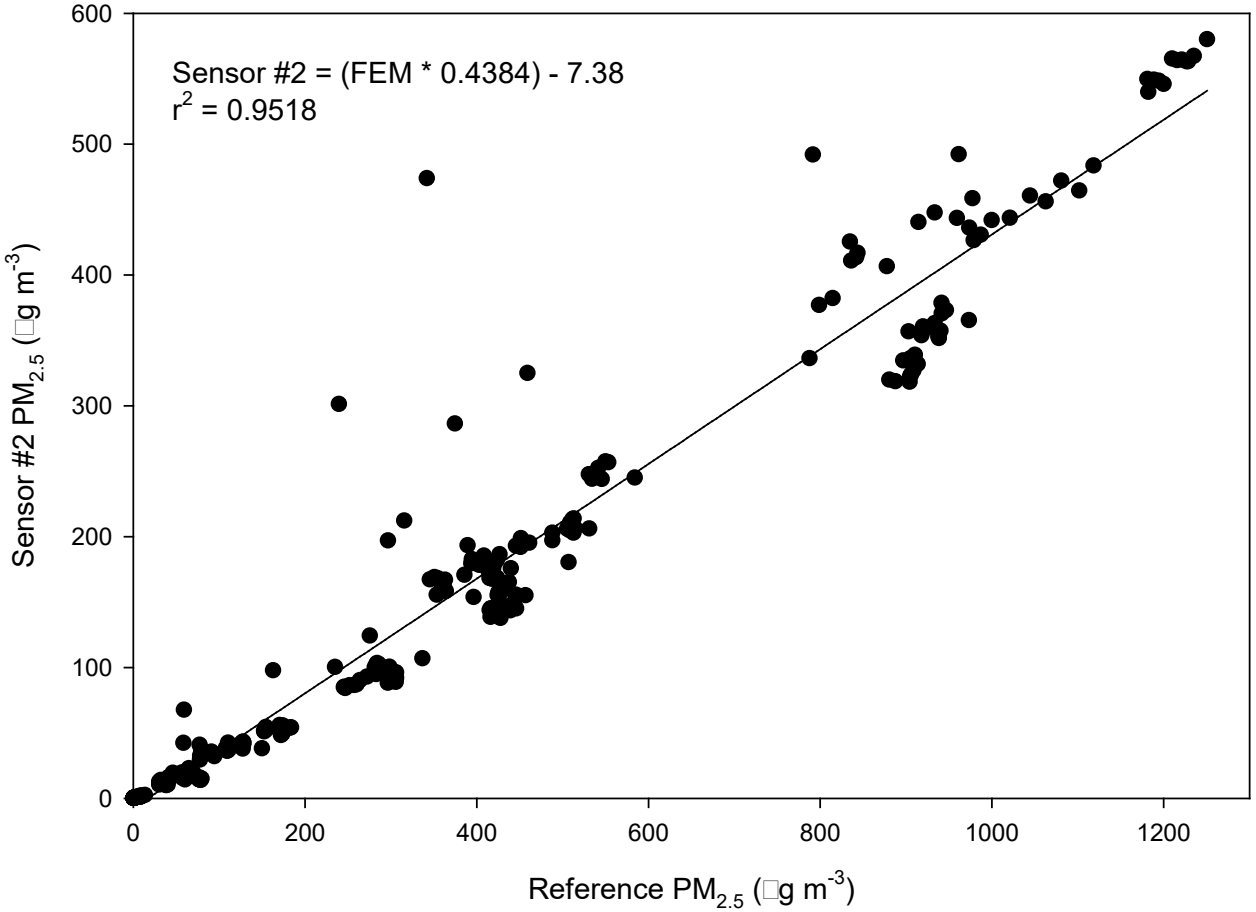


Thingy:AQ Phase I $PM_{2.5}$ Testing Results – Time Series



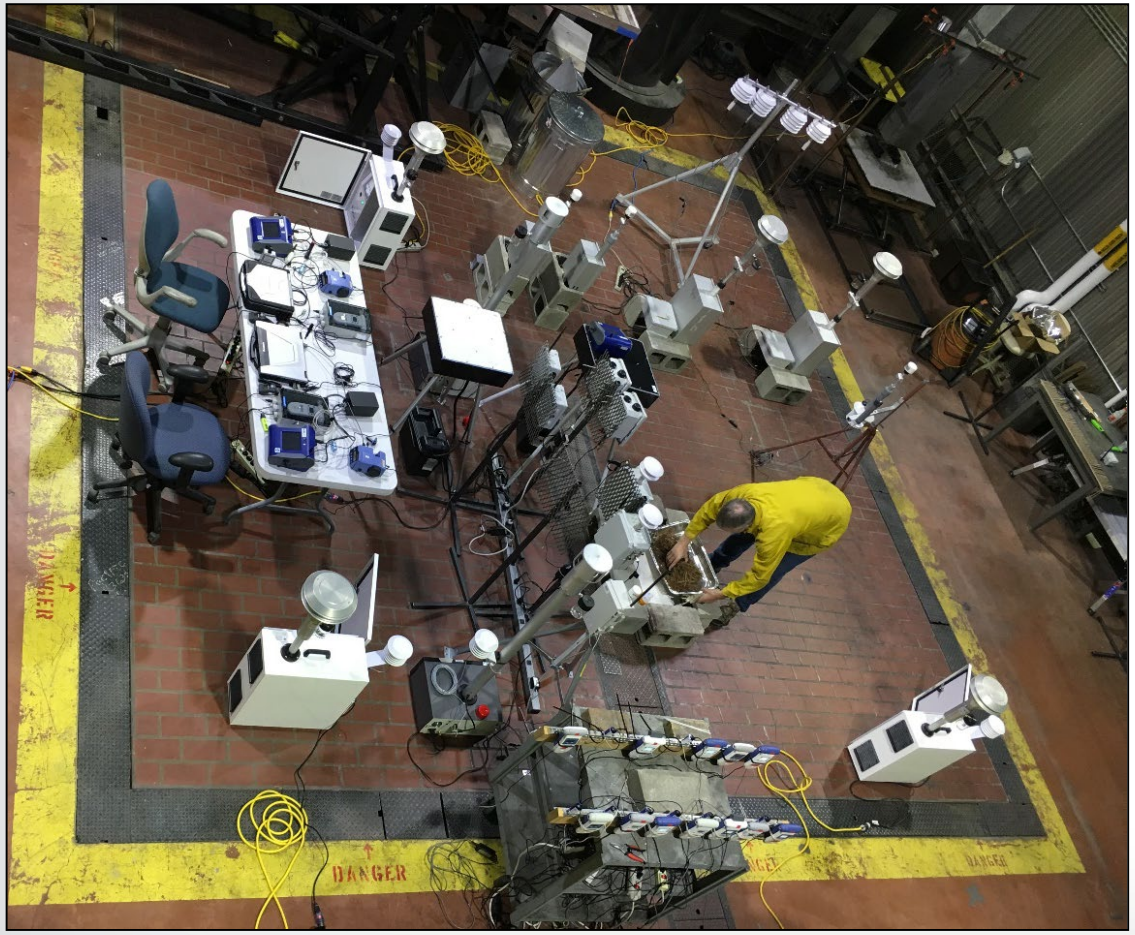
Thingy:AQ Phase I $PM_{2.5}$ Testing Results – Scatter Plots





Wildland Fire Sensor Challenge

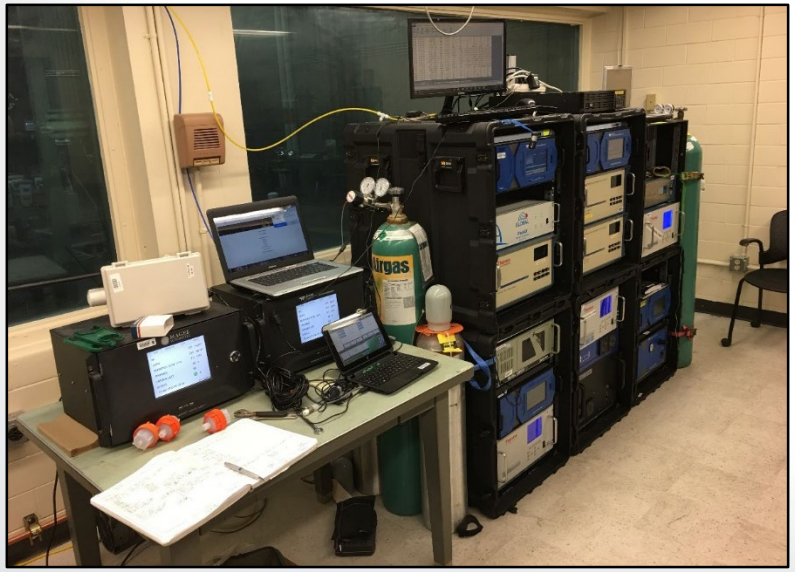
Phase II Testing – USFS Missoula Fire Science Lab

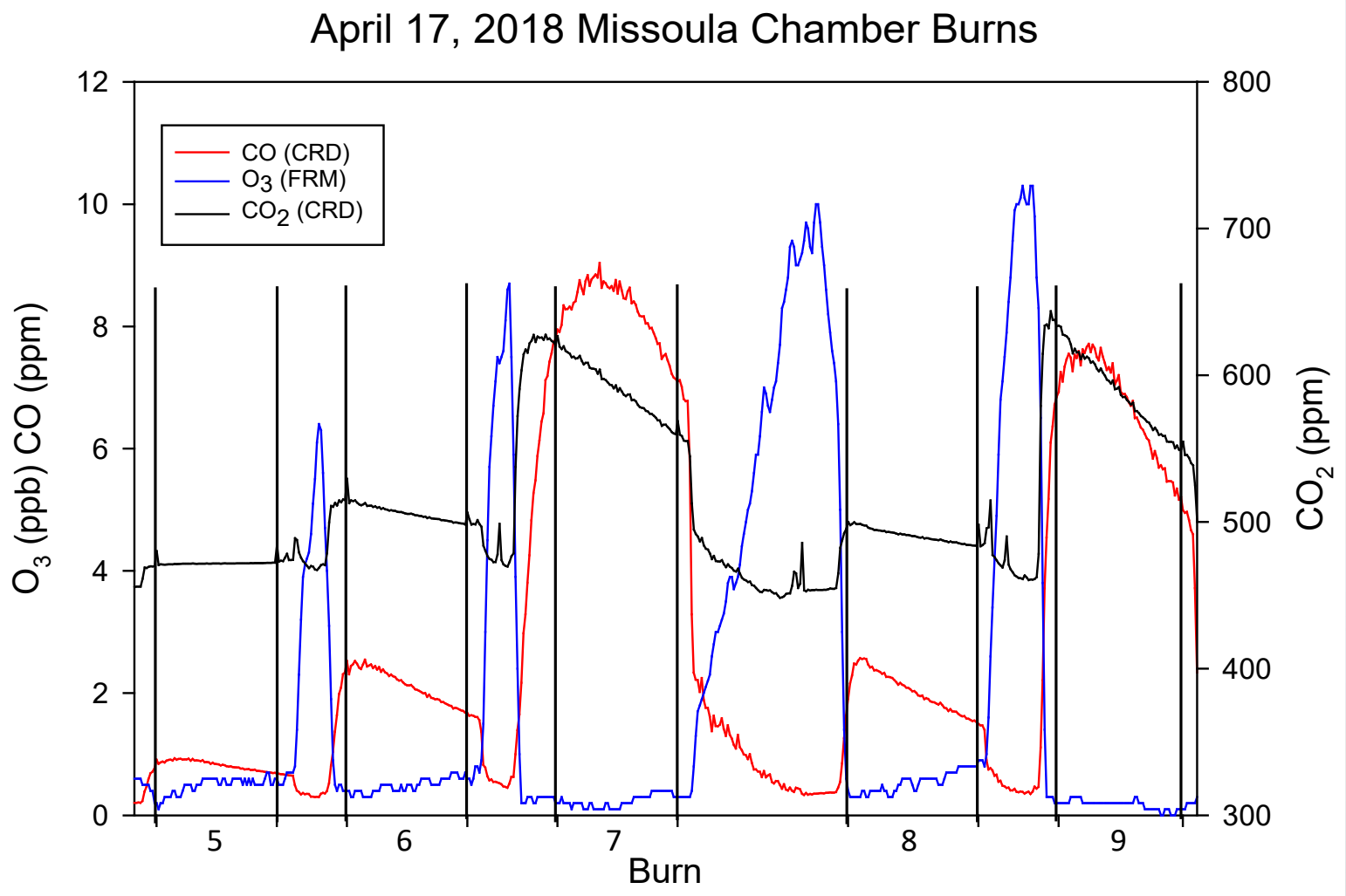


- Well Characterized Combustion Research Chamber
- Testing Conducted April 16 – 24, 2018
  - Fuel: Ponderosa Pine Needles & Mixed Woody Debris
  - Combustion: Flaming & Smoldering
  - Combustion Control Variables: Fuel Moisture & Load
- 33 One Hour Test Burns Were Conducted
  - Mean $PM_{2.5}$: Ranged from ~ 30 – 1800 $\mu g\ m^{-3}$
  - Mean CO: Ranged from ~ 0.4 – 15.8 ppm
  - Mean CO_2: Ranged from ~ 465 – 940 ppm
  - Mean O_3: Ranged from ~ 0 – 1 ppb
- FRM $PM_{2.5}$ APD Across Chamber = 5%
- Reference 1-Min $PM_{2.5}$: FRM Adjusted FEM (T640)

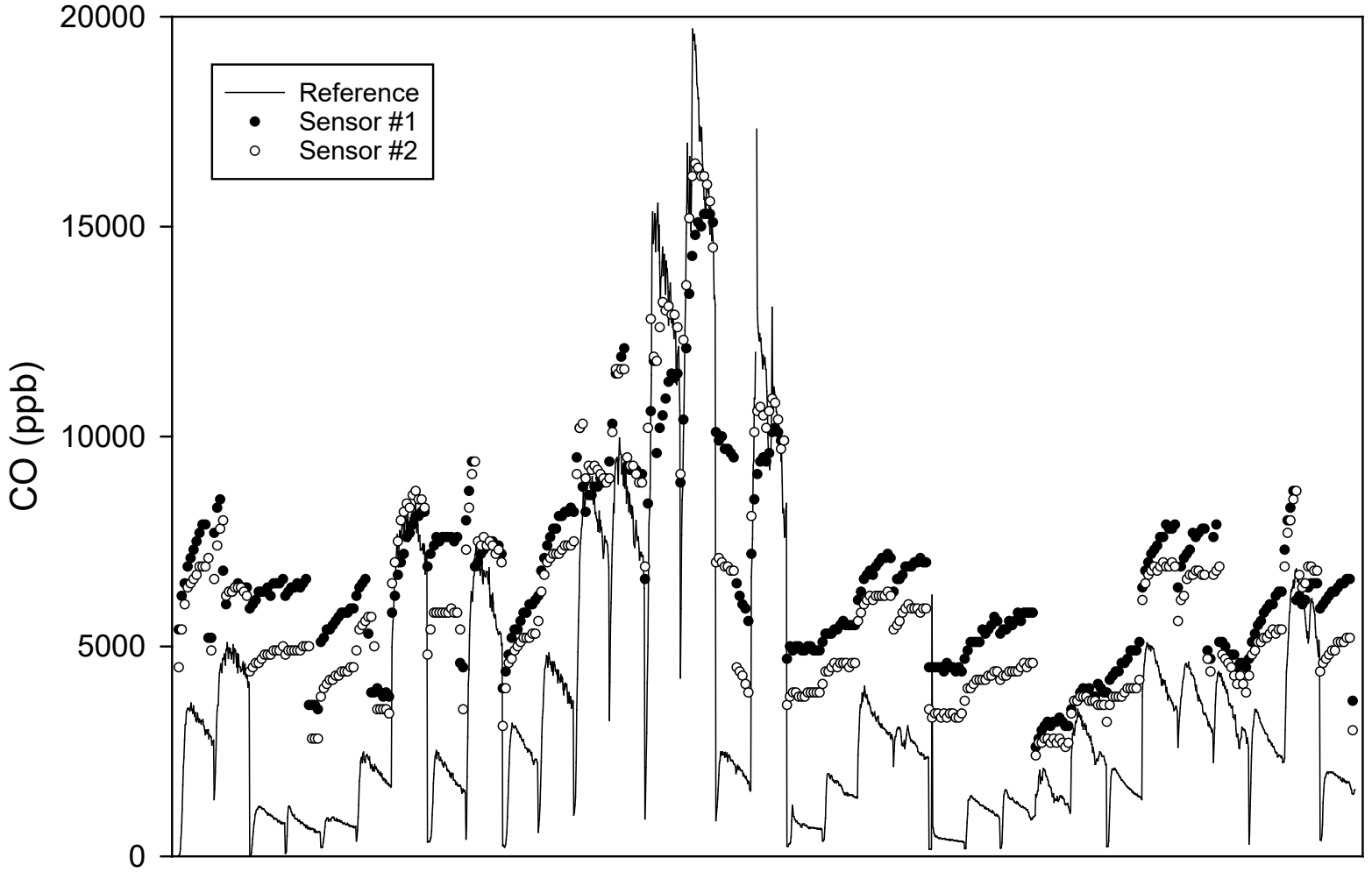
Wildland Fire Sensor Challenge

Phase II Testing – USFS Missoula Fire Science Lab

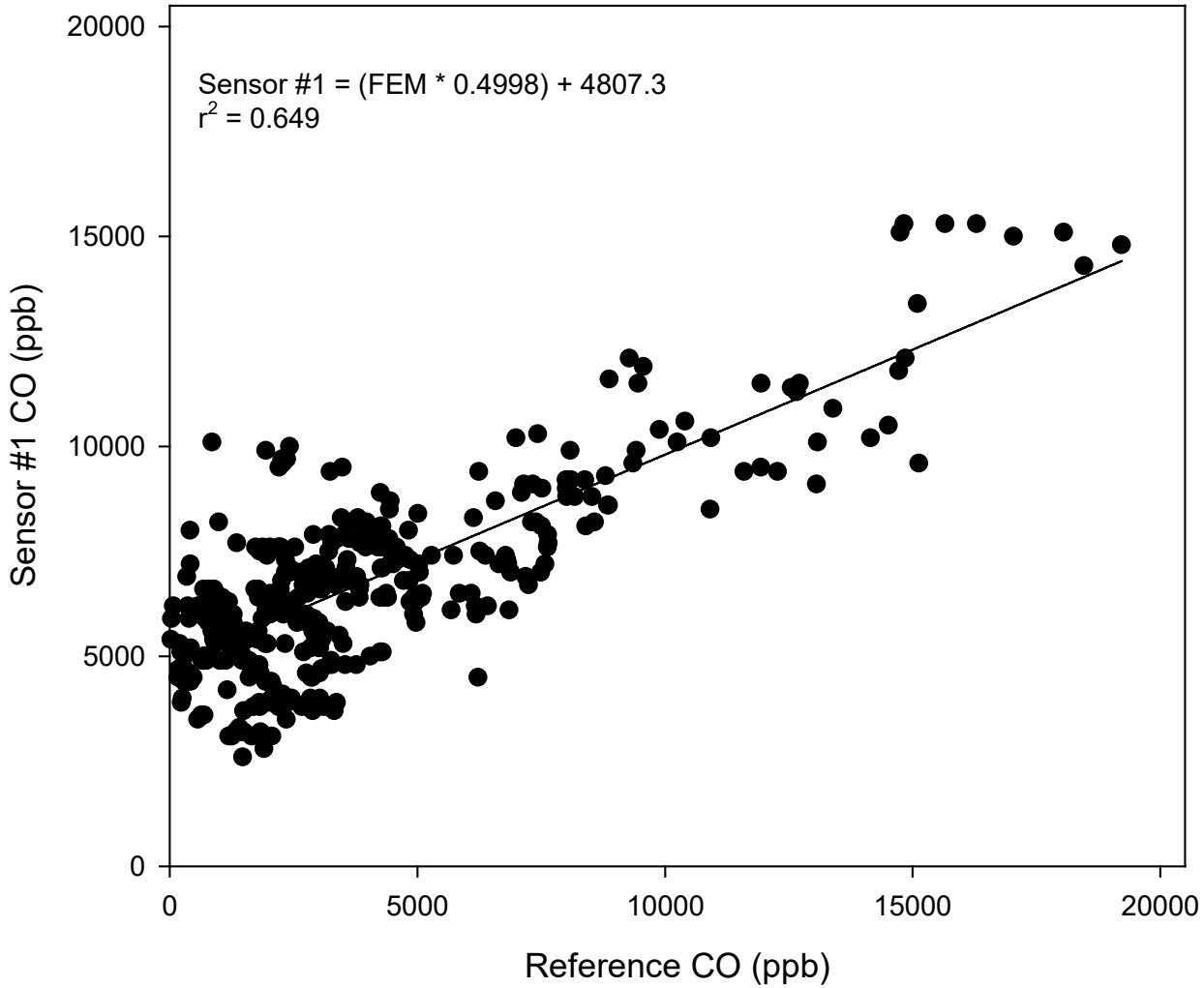


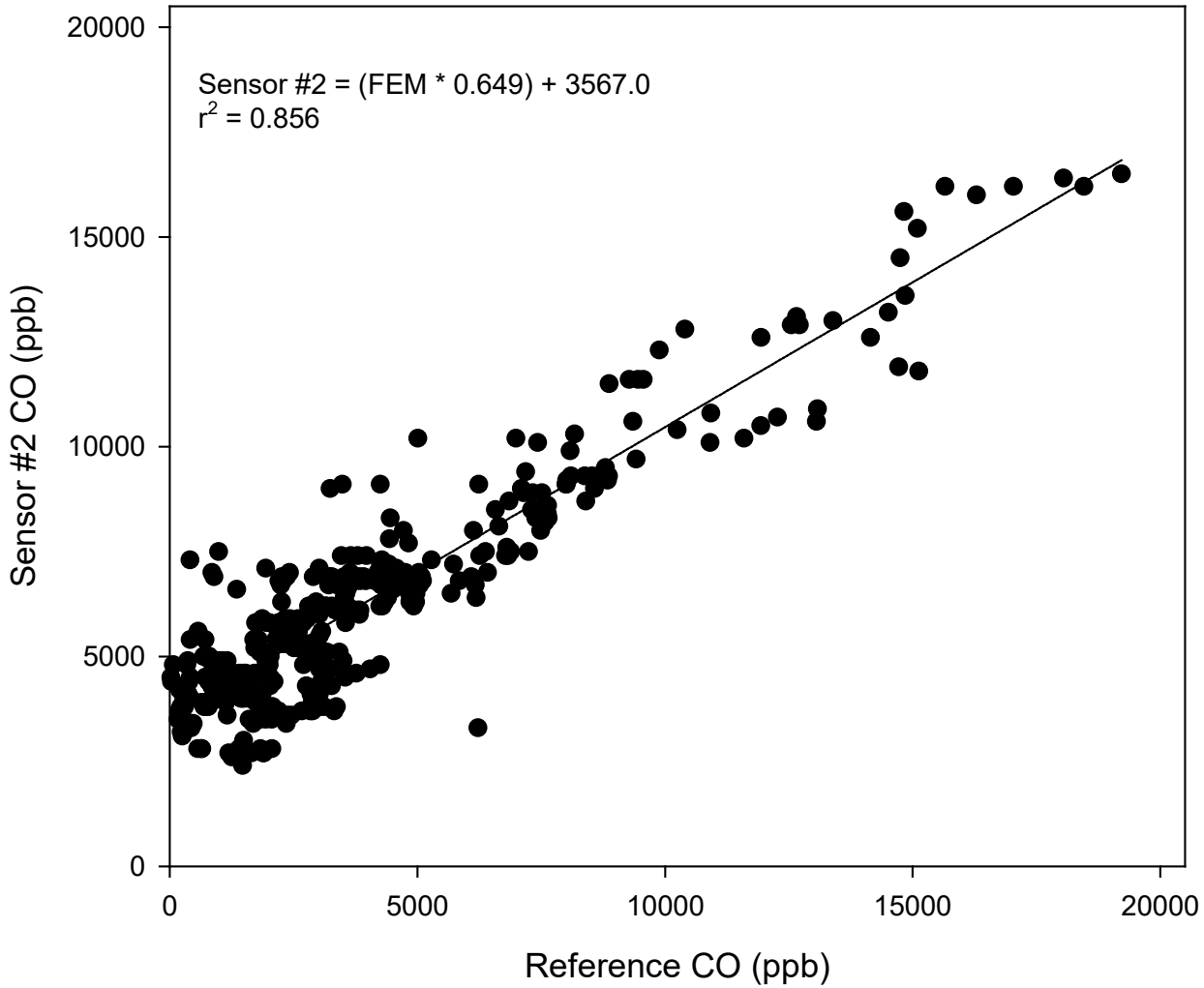


Thingy:AQ Phase II CO Testing Results – Time Series

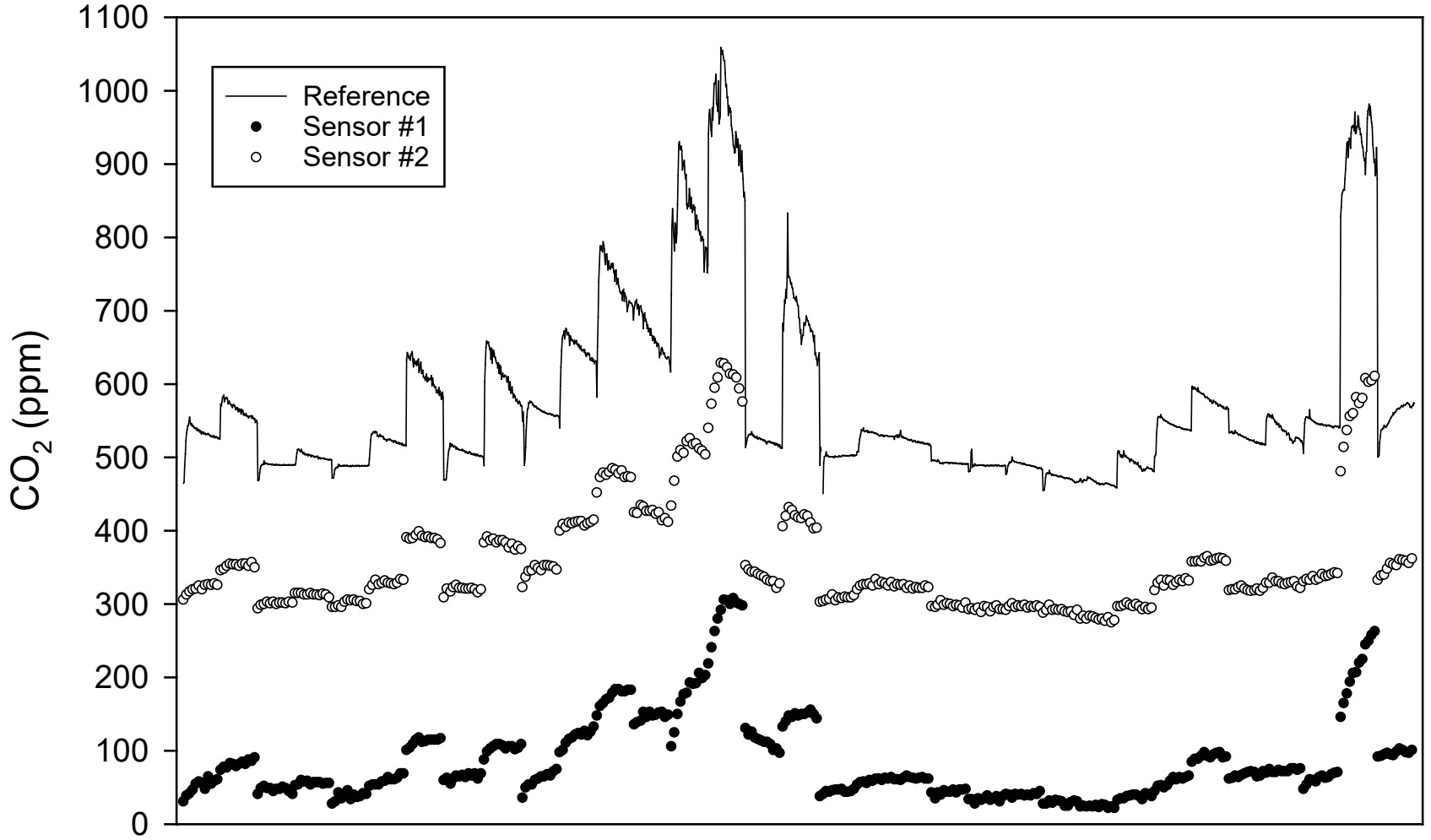


Thingy:AQ Phase II CO Testing Results – Scatter Plots

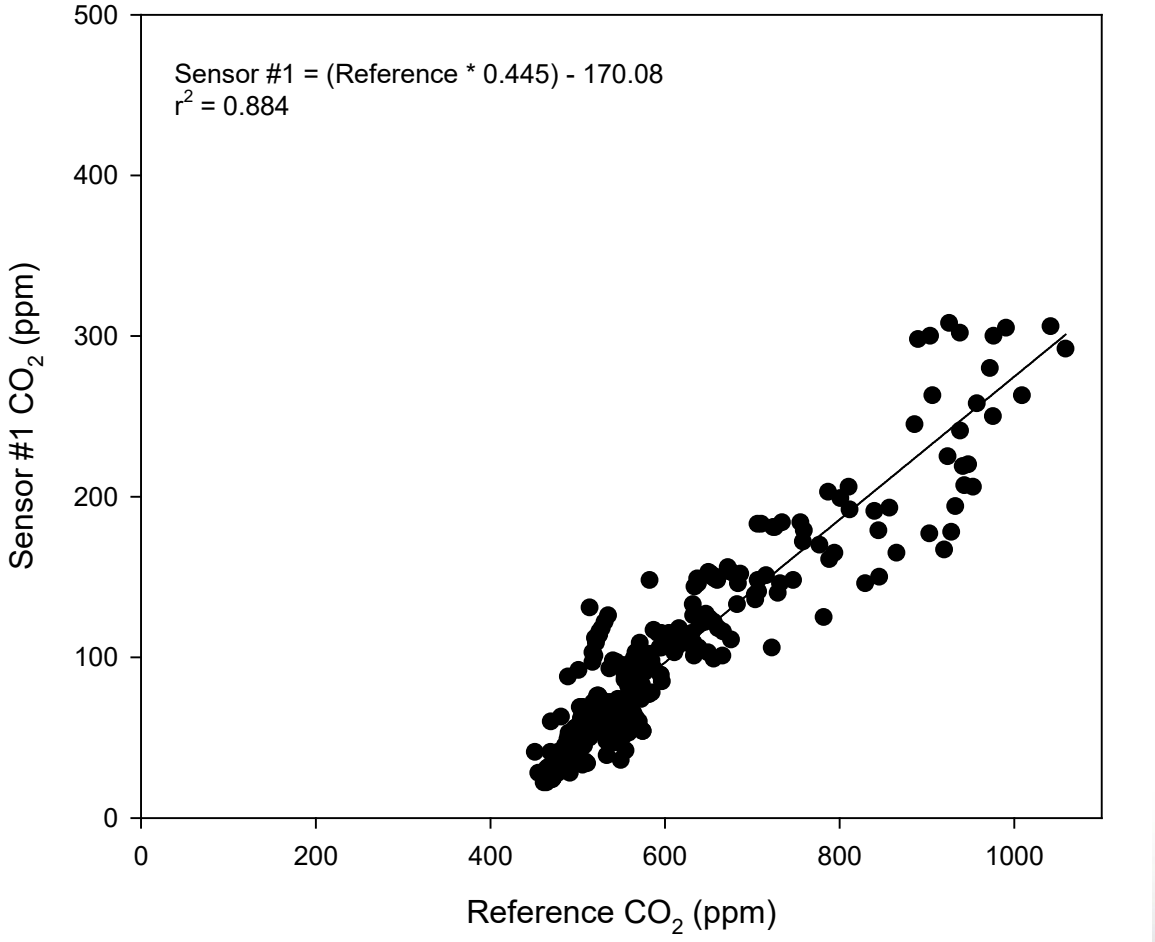


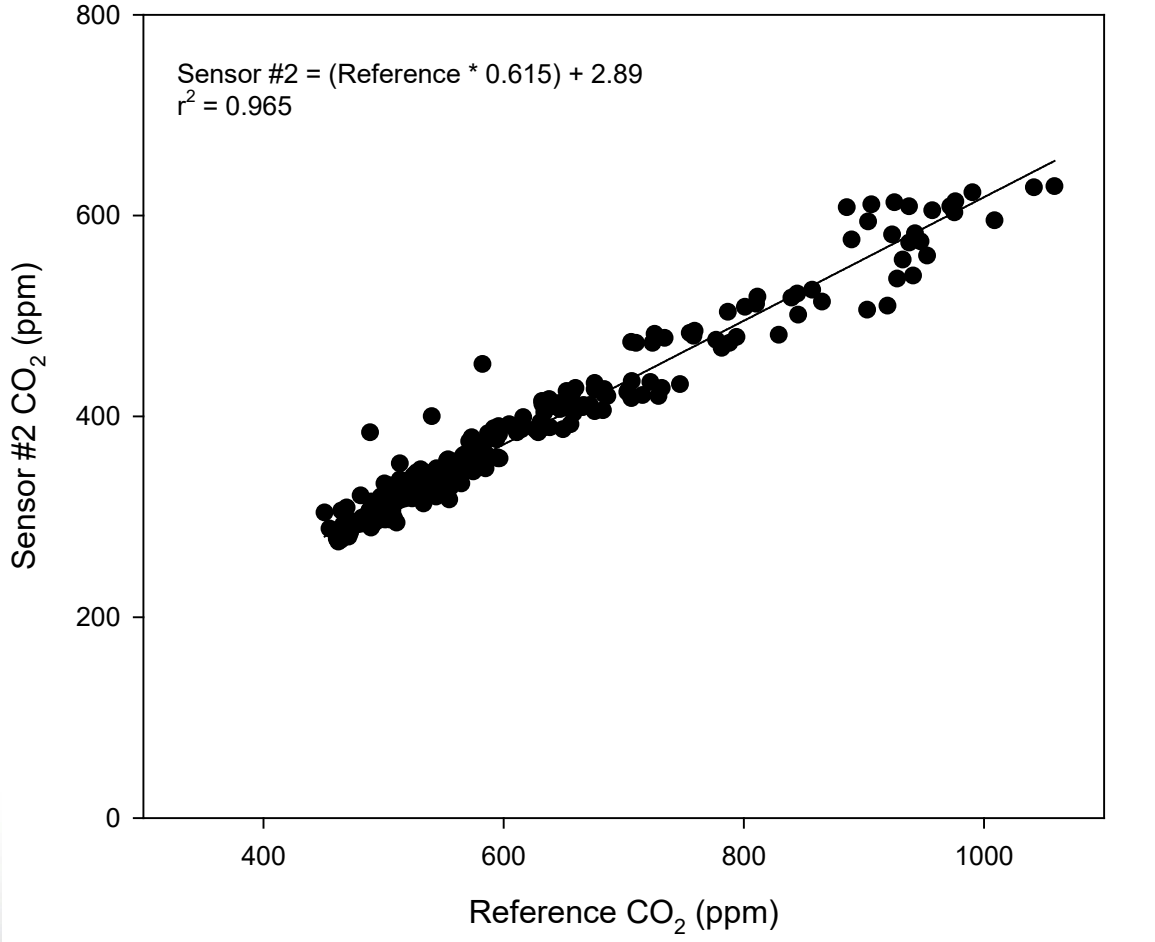


Thingy:AQ Phase II CO_2 Testing Results – Time Series

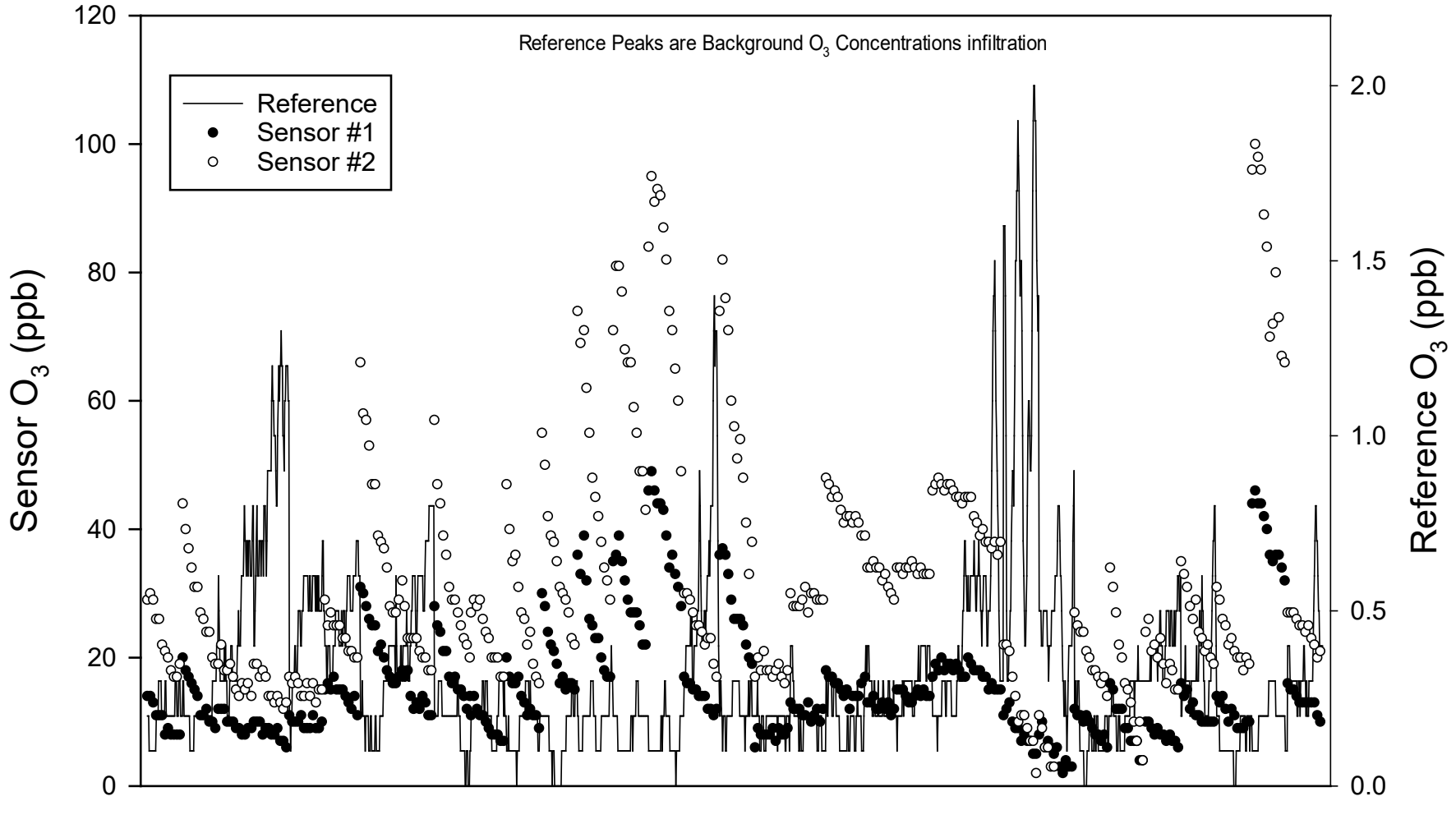


Thingy:AQ Phase II CO_2 Testing Results – Scatter Plots



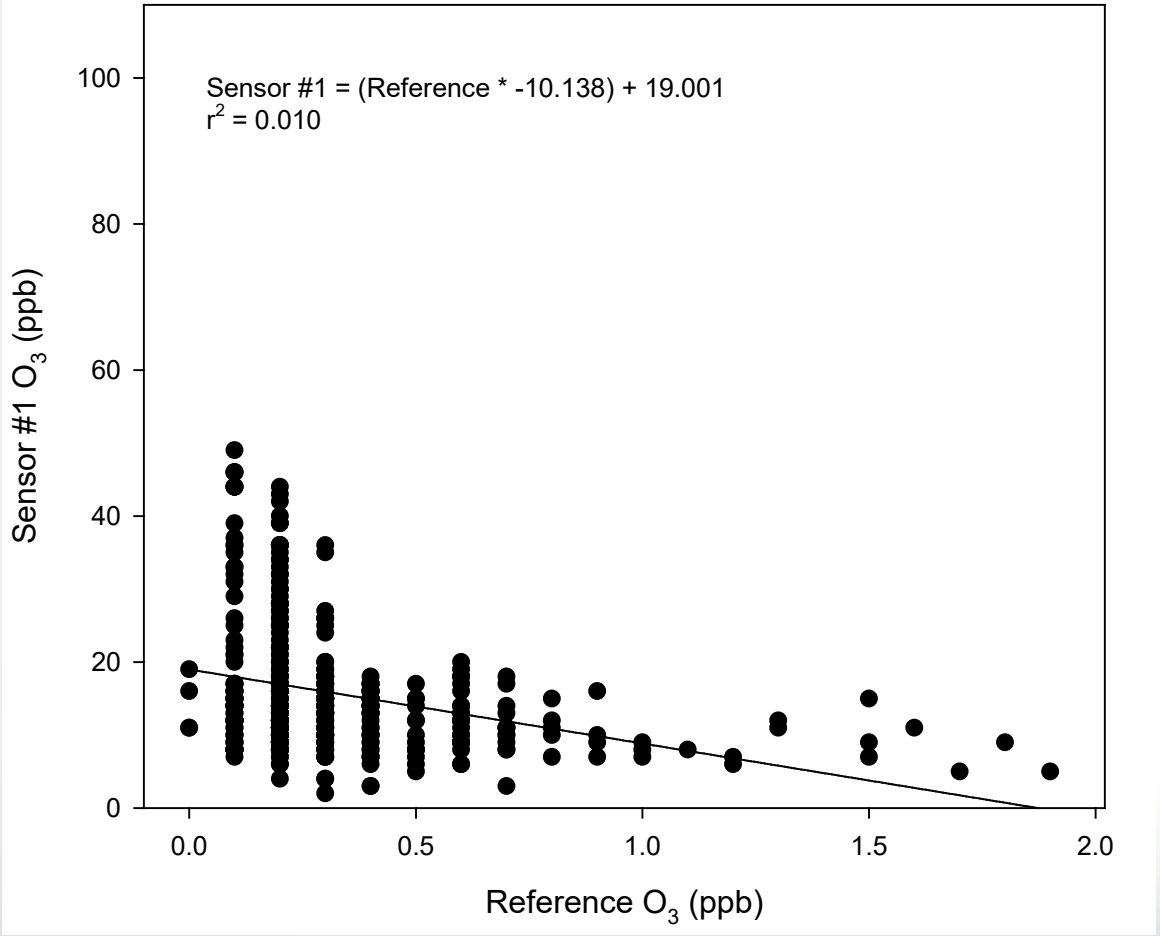


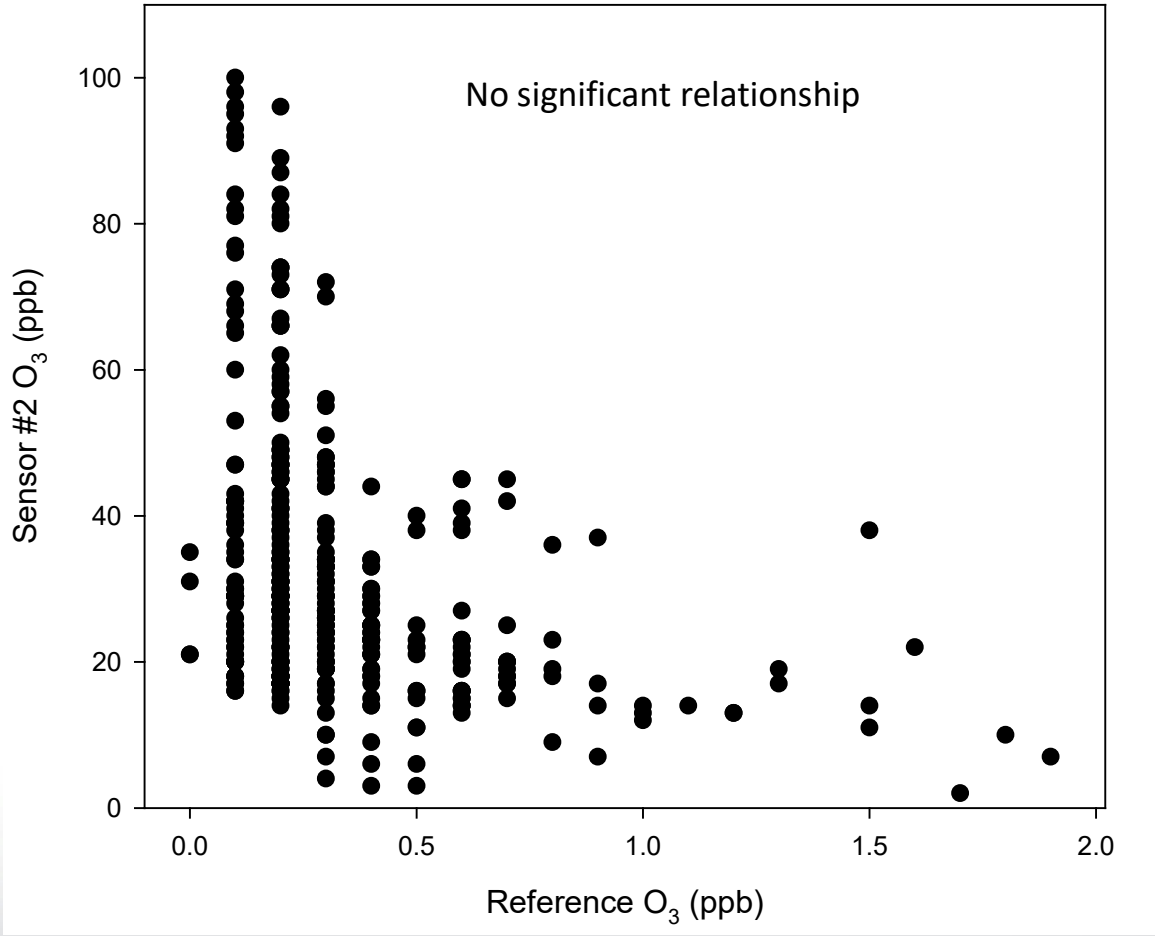
Thingy:AQ Phase II O_3 Testing Results – Time Series



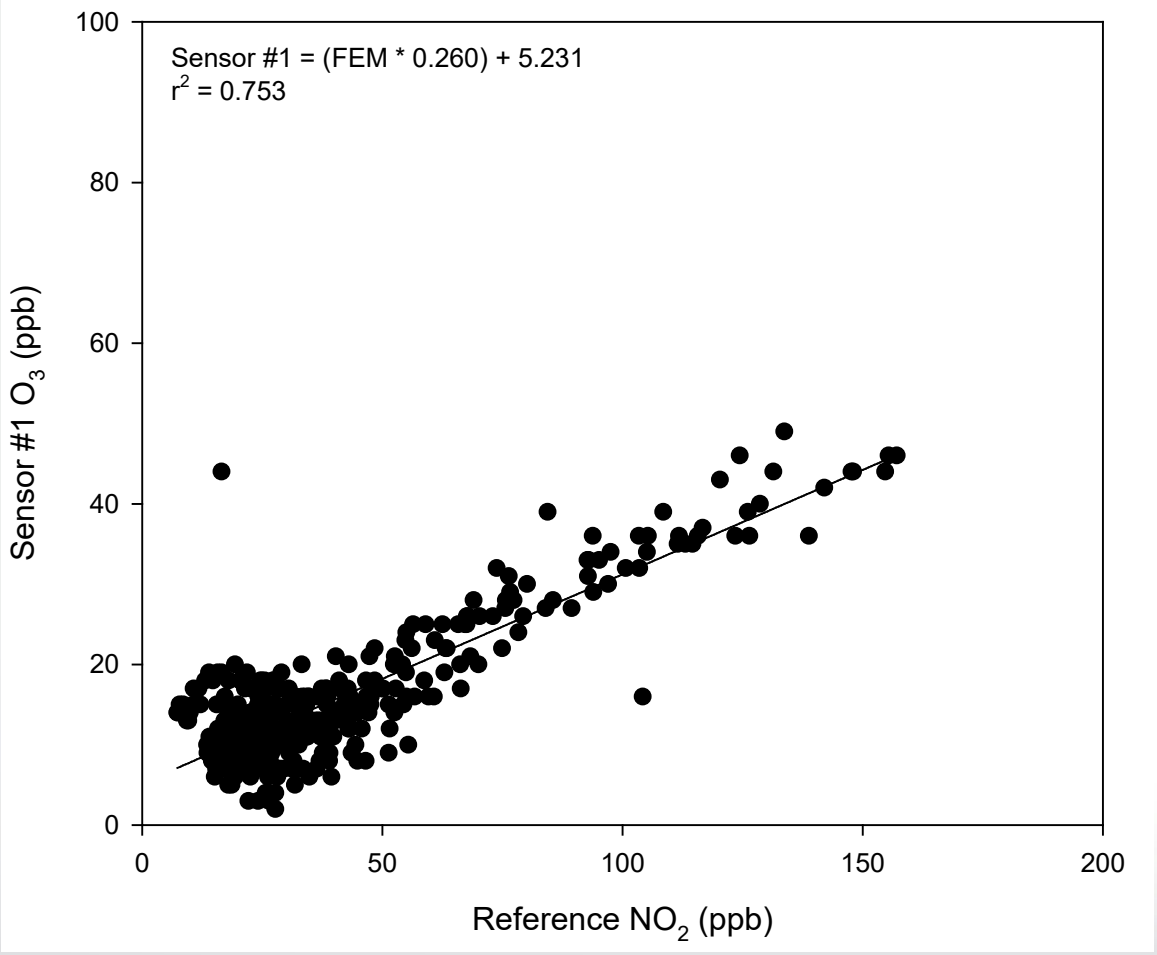
Thingy:AQ Phase II O_3 Testing Results – Scatter Plots

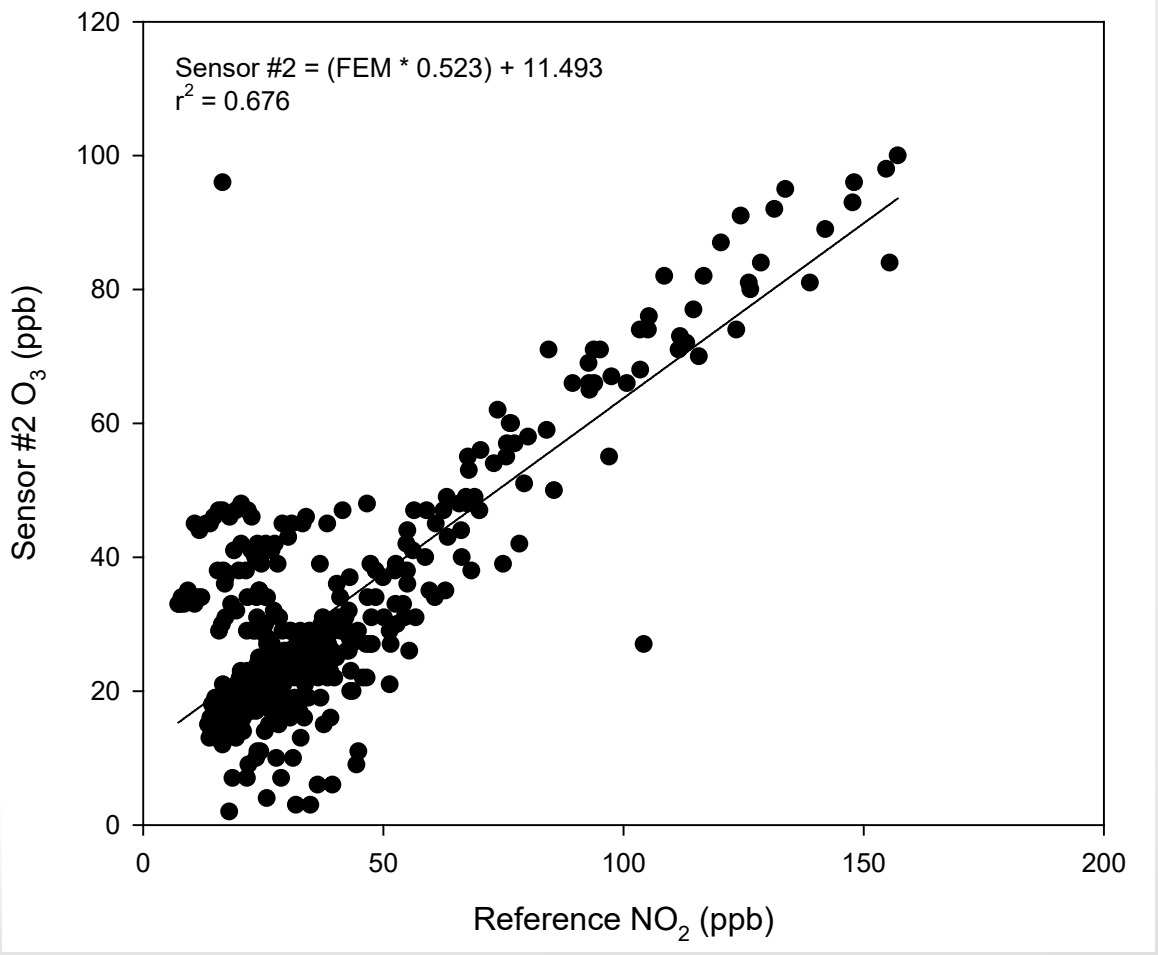
NO_2 artifact observed



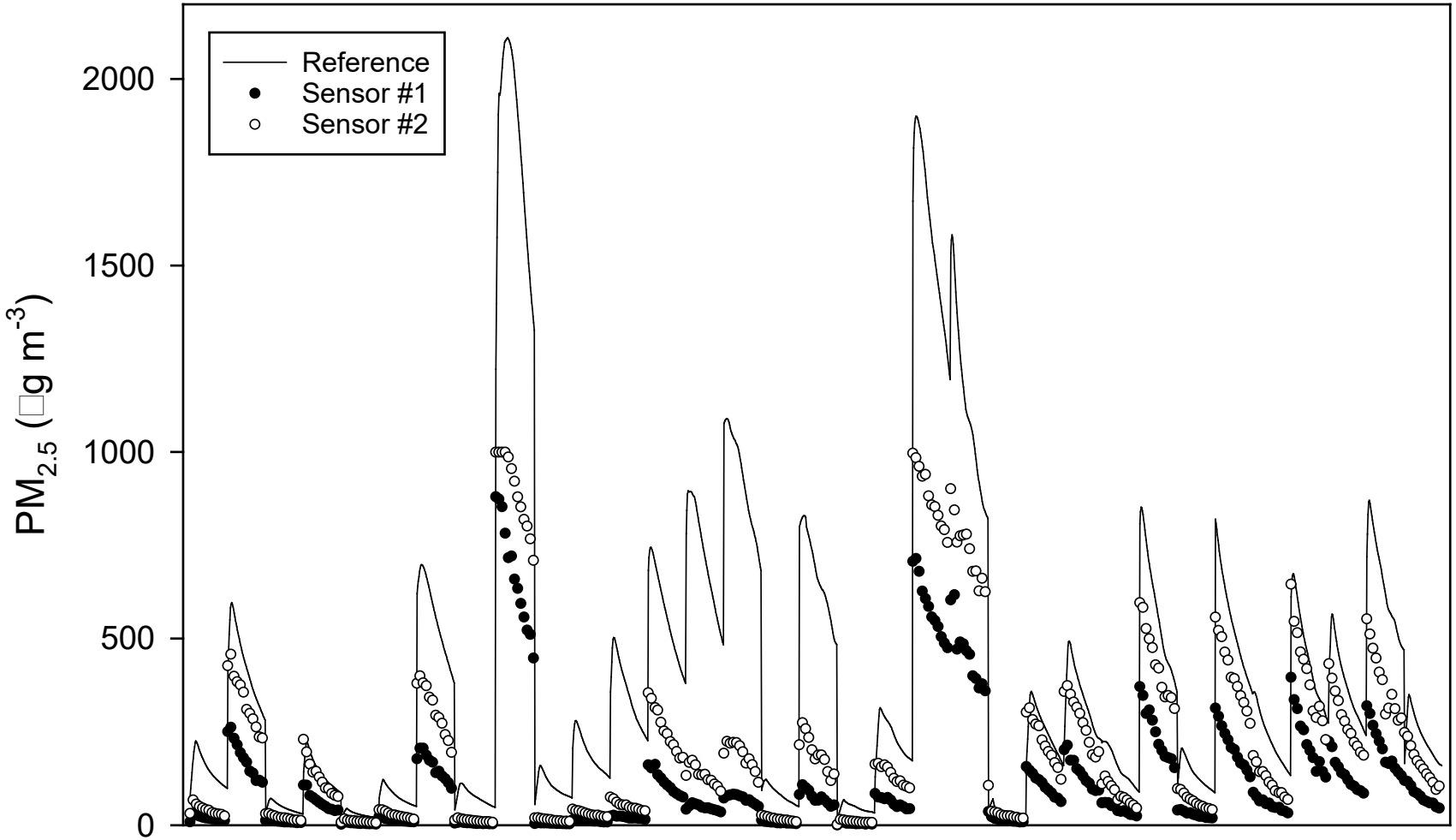


Thingy:AQ Phase II O_3 Testing Results – NO_2 Artifact

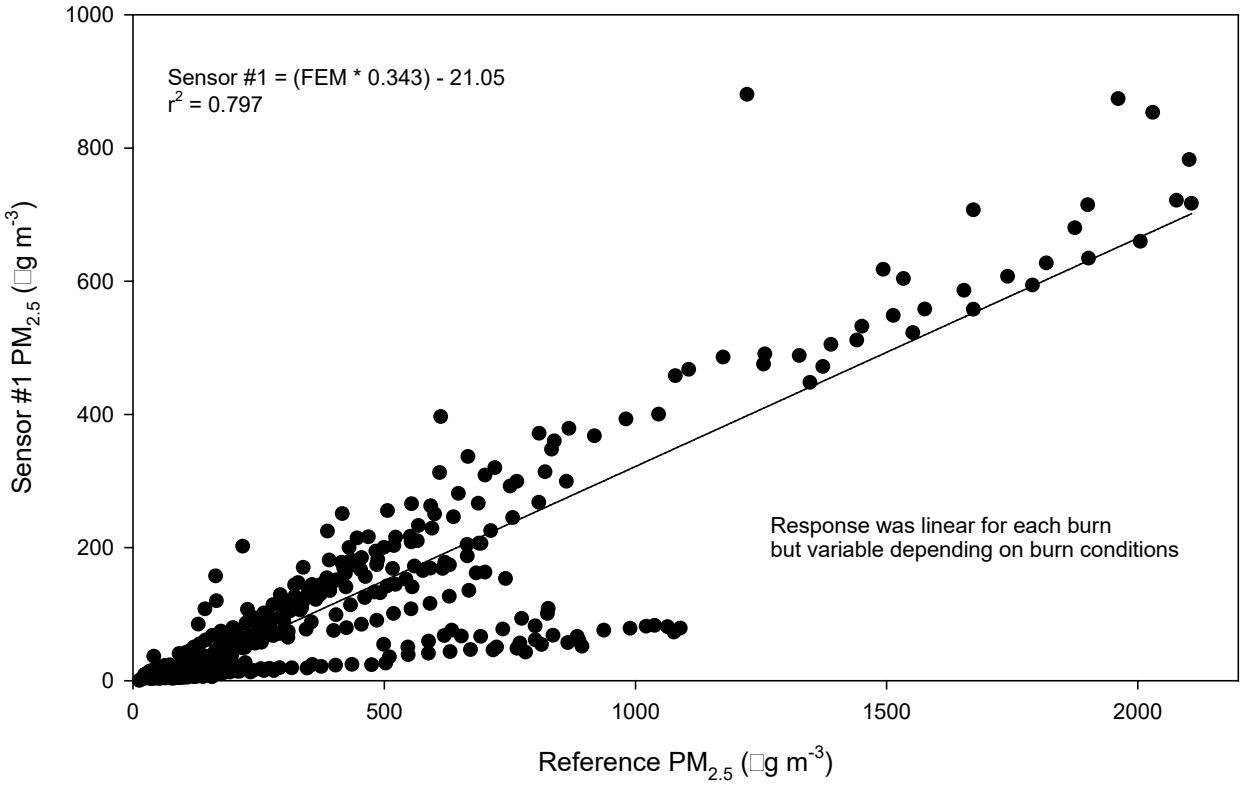


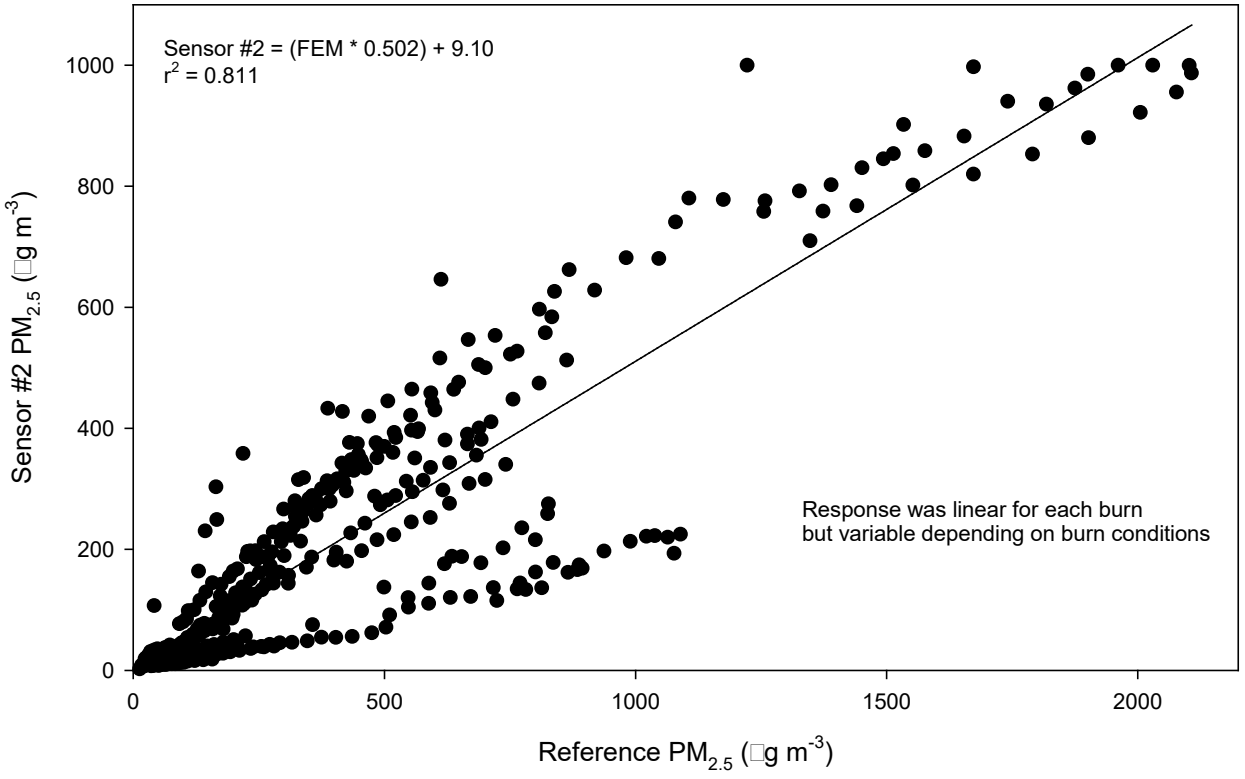


Thingy:AQ Phase II $PM_{2.5}$ Testing Results – Time Series



Thingy:AQ Phase II $PM_{2.5}$ Testing Results – Scatter Plots





Summary Testing Results – Accuracy* (Mean ± Std. Dev.)

Phase I Testing

	CO	CO_2	O_3	$PM_{2.5}$
Sensor #1	60.9 ± 41.7	34.8 ± 9.7	18.7 ± 17.5	13.5 ± 5.2
Sensor #2	69.7 ± 36.9	74.7 ± 4.0	39.4 ± 24.0	37.2 ± 10.1

Phase II Testing

	CO	CO_2	O_3**	$PM_{2.5}$
Sensor #1	-294.4 ± 1,545.9	14.0 ± 6.2	-7,883.4 ± 8,627.3	25.7 ± 15.5
Sensor #2	-205.3 ± 1,236.9	61.9 ± 2.2	-16,974 ± 18,145.7	48.4 ± 24.4

*$Accuracy = 100 - \frac{|\bar{X} - \bar{R}|}{\bar{R}} * 100$; where *X* is Sensor Value & *R* is Reference Value ** NO_2 Artifact Degraded Performance

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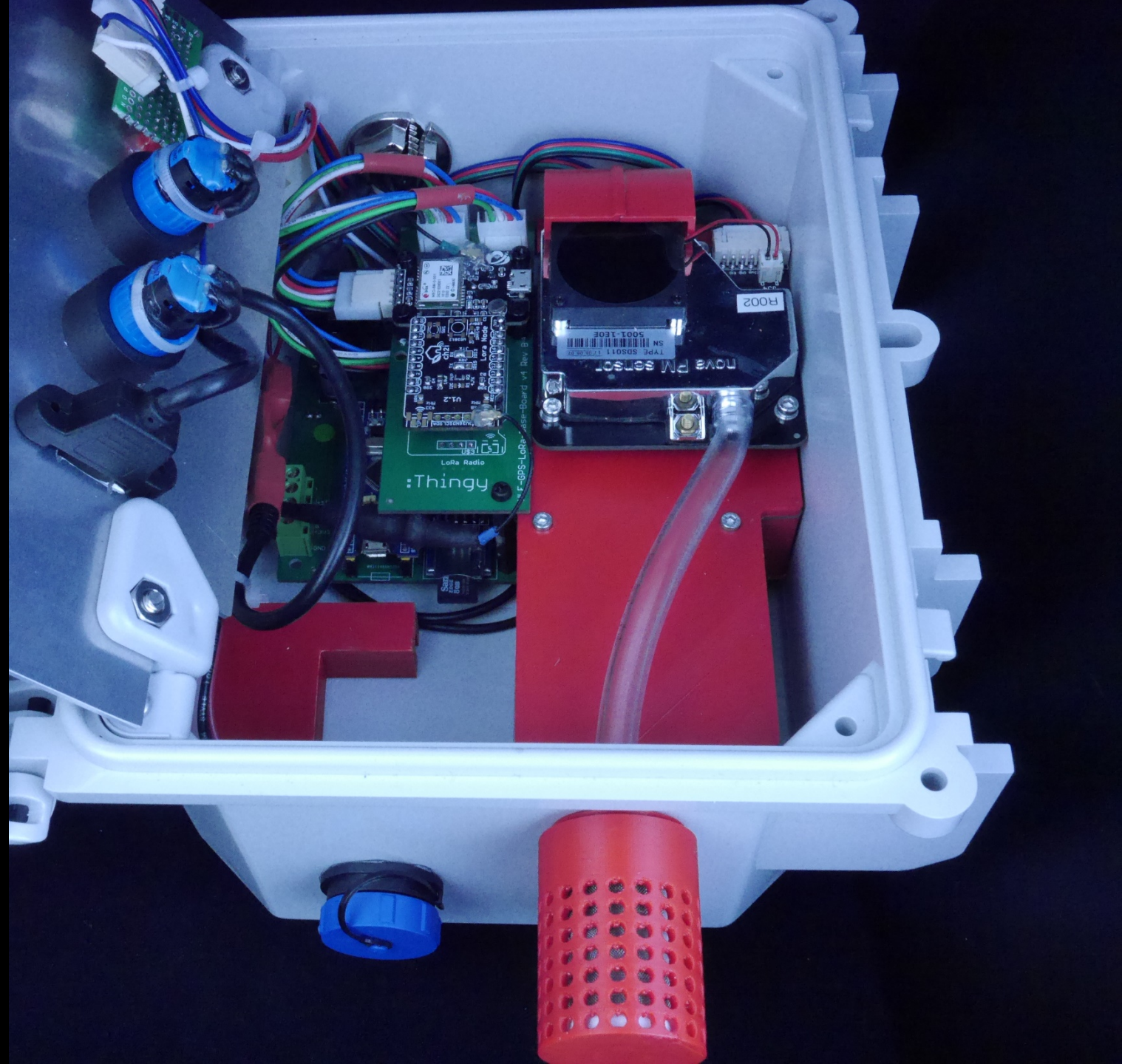

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